

STS-90 SPACE SHUTTLE MISSION REPORT

June 1998



**National Aeronautics and
Space Administration**

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

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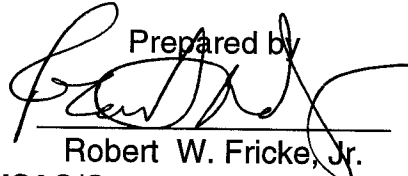
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SPACE SHUTTLE

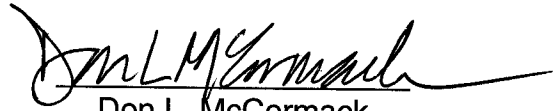
MISSION REPORT

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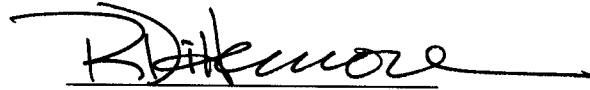
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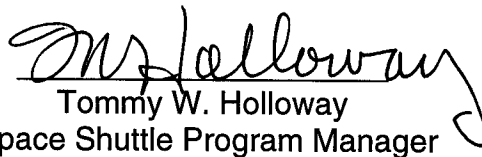
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INTRODUCTION

This Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified. The report also summarizes the activities of the STS-90 mission 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 ninetieth mission of the Space Shuttle Program. STS-90 was the sixty-fifth flight since the return to flight, and the twenty-fifth flight of the OV-102 (Columbia) Orbiter vehicle.

The flight vehicle consisted of the OV-102 Orbiter; an ET that was designated ET-90; three SSMEs that were designated as serial numbers (S/N) 2041 (Block IA), 2032 (Phase II), and 2012 (Phase II) in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-094. The two RSRMs were designated RSRM 65 with one installed in each SRB. The individual RSRMs were designated 360W065A for the left SRB, and 360W065B for the right SRB.

The STS-90 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirements as documented in NSTS 07700, Volume VII, Appendix E. The requirement is that each organizational element supporting the Program will report the results of their hardware and software evaluation and mission performance plus identify all related in-flight anomalies.

The primary objective of the STS-90 flight was to successfully perform the planned operations of the Neurolab. The secondary objectives of this flight were to perform the requirements of Shuttle Vibration Forces (SVF), Bioreactor Demonstration System-04 (BDS-04), and three Get-Away Specials (GAS).

The STS-90 mission was a planned 16-day plus 1-day plus 2-contingency-day mission during which neurological studies of the most complex and least understood part of the human body, the nervous system, were performed. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. The STS-90 sequence of events is shown in Table I and the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List in Table II. 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 using in this report. All times are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The seven-person crew of the STS-90 mission consisted of Richard A. Searfoss, Lt. Col., U. S. Air Force, Commander; Scott D. Altman, Lt. Comdr., U. S. Navy, Pilot; Richard M. Linnehan, D.V.M., Civilian, Payload Commander and Mission Specialist 1; Kathryn P. Hire, Commander, U. S. Naval Reserve, Mission Specialist 2; Dafydd Rhys Williams, M.D. Civilian, Mission Specialist 3; Jay Clark Buckley, Jr., M.D., Civilian, Dartmouth Medical School, Payload Specialist 1; and James A Pawelczyk, Ph.D., Civilian, Payload Specialist 2. STS-90 was the third space flight for the Commander; the second space flight for Mission Specialist 1 and Payload Commander; and the first space flight for the Pilot, Mission Specialist 2, Mission Specialist 3, Payload Specialist 1, and Payload Specialist 2.

MISSION SUMMARY

During the countdown for the STS-90 scheduled launch on April 16, 1998, network signal processor (NSP) 2 failed to acquire frame synchronization during the switch from NSP 1 to NSP 2 (Flight Problem STS-90-V-01). Downlink communications were not affected by the problem. The system was cycled from NSP 1 to NSP 2 nine times using several different modes. Each time, NSP 1 operated satisfactorily, but NSP 2 did not. No uplink communications could be established on NSP 2. As a result, the launch was delayed 24 hours, and NSP 2 was replaced and its checkout was completed satisfactorily.

The STS-90 mission was launched at 107:18:18:59.988 G.m.t. (2:19: p.m. e.d.t.) into a 39-degree inclination orbit. The first and second stage ascent phases were satisfactory and a nominal orbit of 147.2 by 41.3 nautical miles was achieved. All Orbiter subsystems performed nominally except water spray boiler (WSB) 3, which experienced an under-cooling condition that is discussed in a following paragraph.

During the second stage of ascent, an orbital maneuvering subsystem (OMS) assist-maneuver was performed for the first time during the Space Shuttle Program. Ignition for the OMS-assist-maneuver was 107:18:21:15 G.m.t. [00:00:02:15 Mission Elapsed Time (MET)], the maneuver was 102.4 seconds in duration, and the OMS engines performed satisfactorily.

WSB 3 experienced an under-cooling condition during ascent. The lubrication oil return temperature reached 334 °F, and the specification value for this temperature is no-greater-than 275 °F (Flight Problem STS-90-V-06). The WSB 3 controller was switched from A to B at 107:18:30:46 G.m.t. (00:00:11:46 MET) when the auxiliary power unit (APU) 3 lubrication oil return temperature was approximately 300 °F. No spray cooling was observed at that time. APU 3 was shut down about 2 minutes early at 107:18:32:12 G.m.t. (00:00:13:12 MET). Data review indicated no spraying was achieved during the operation with either WSB 3 controller.

The External Tank (ET)-liquid hydrogen (LH₂) 98-percent liquid-level sensor no. 2 failed wet at 107:18:20:06 G.m.t (00:00:01:06 MET). This sensor is only used during loading. There was no impact to the mission.

The LH₂ Space Shuttle main engine (SSME) 1 inlet pressure shifted upward approximately 3 to 4 psia at about 107:18:22:30 G.m.t. (00:00:03:30 MET) (Flight Problem STS-90-V-02). A similar signature was observed on previous flights of this and other Orbiter vehicles. There was no impact to the flight.

Data review also showed that the ET liquid oxygen (LO₂) 100-percent liquid-level sensor no. 2 flashed about a dozen times between wet and dry over a 15-second period beginning at approximately 107:18:23:56 G.m.t. (00:00:04:56 MET). The sensor read dry as expected at all other times during ascent. This sensor is only used during loading. There was no impact to the mission.

A determination of vehicle performance was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived specific

impulse (I_{sp}) that was determined for the period between SRB separation and start of 3g throttling was 452.9 seconds compared to the tag value of 452.66 seconds. All propulsive elements of the vehicle performed satisfactorily.

The OMS 2 maneuver was performed at 107:19:00:27.2 G.m.t. (00:00:41:34.2 MET). The maneuver was 110.3 seconds in duration and the differential velocity (ΔV) was 171.1 ft/sec. The resultant orbit was 154 by 138 nmi.

The starboard payload bay door was opened at 107:19:54:46 G.m.t. (00:01:35:46 MET), and the port payload bay door was opened at 107:19:56:07 G.m.t. (00:01:37:07 MET). The door operation was satisfactory in all respects with dual-motor times recorded.

The flash evaporator system (FES) shut down while operating on the primary A controller at approximately 111:02:06 G.m.t. (03:07:47 MET) (Flight Problem STS-90-V-04). The crew restarted the FES primary A controller 5 minutes after the shutdown occurred. The restart was successful, and the FES went into standby at 111:02:35 G.m.t. (03:08:16 MET); however, the FES failed to come out of the standby mode. At 111:03:13 G.m.t. (03:08:54 MET), the crew switched from the primary A to the primary B controller. The FES gained control for 10 minutes on the primary B controller and then shut down. The FES core flush procedure was implemented. After the flush procedure was completed, the FES primary B controller was successfully restarted. The FES topping duct heaters were placed on heater string A/B for the duration of the crew sleep period. Following the sleep period, the topping duct heaters were reconfigured from A/B to A as planned. It is believed that the most probable cause of the shut-down was a rapid FES heat-load transient that occurred while in the -ZLV +YVV (top-to-Earth local vertical, starboard wing on the velocity vector) water-dump attitude. This transient resulted in the formation of ice in the FES topper core and this eventually led to the shut-down. Note that the FES is certified to handle a transient of the magnitude seen. The Orbiter water-dump attitudes were changed from -ZLV +YVV to +ZLV +YVV (bottom to Earth local vertical, starboard wing on the velocity vector) to preclude the thermal condition that was believed to cause the FES shut down.

The reaction control subsystem (RCS) orbit adjust 1 maneuver was performed at 112:20:14:00 G.m.t. (05:01:55:00 MET). The duration of the maneuver was 15 seconds with a resultant ΔV of 3.34 ft/sec. All thrusters fired nominally.

At 115:03:49:46 G.m.t. (07:09:30:46 MET), the regenerative carbon dioxide removal system (RCRS) shut down while on controller 2. The crew reconfigured the RCRS to controller 1, but it too shut down (Flight Problem STS-90-V-03). The crew was told to use lithium hydroxide (LiOH) canisters for carbon dioxide removal during their sleep period. A fault tree was developed to investigate the cause of the shutdown and an in-flight maintenance (IFM) procedure was prepared to recover usage of the RCRS. The IFM procedure was performed and the RCRS was recovered. The IFM isolated a check valve which was leaking cabin air into the RCRS. The isolation was regained by disconnecting the outlet hose from the check valve and covering the fitting with aluminum tape. In addition, power was removed from the compressor since it is in the flow path blocked by the IFM procedure. Following the IFM, the RCRS was activated at 115:20:43 G.m.t. (08:02:24 MET) using controller 1 and it operated satisfactorily for the remainder of the mission.

At 114:18:07 G.m.t. (06:23:48 MET), the vernier driver power and logic power for the forward, left and right RCS went off. This resulted in two vernier thrusters failing off when they were subsequently commanded to fire. The vernier driver and logic switches were cycled and operation of all vernier thrusters was recovered. When operating on the vernier thrusters during the on-orbit phase of the mission, the logic power switches are positioned to off and depend on the logic latch to keep the logic power and vernier power on. Discussions with the crew indicated that the vernier driver power switch was probably bumped by one of the crewmembers. This bumping caused a momentary loss of power that resulted in the loss of driver power to all RCS thrusters. A momentary loss of contact in this switch, even though the switch was not completely thrown, would explain the loss of vernier driver and logic power. Therefore, it is believed that a switch bump was the most probable cause of this problem.

The APU 2 system B heater for the gas generator bed, and the system B heater for the gas generator valve module (GGVM), fuel pump and fuel lines did not operate when these heaters were initially reconfigured from system A to system B at 114:18:53 G.m.t. (07:34:00 MET). Both of these heaters are controlled by the same switch. At approximately 114:19:51 G.m.t. (07:01:32 MET), the crew cycled the GGVM/fuel pump system B heater switch to off and then back to B-automatic. Proper heater response followed, and the heaters cycled normally for the remainder of the mission. It is believed that the most probable cause of this failure was a condition referred to as switch tease, in which the switch is positioned so that all of the contacts of the switch are not made. Cycling the switch corrected the problem.

The RCS orbit adjust 2 maneuver was performed at 117:18:28:59 G.m.t. (10:00:09:59 MET). The duration of the maneuver was 7 seconds with a resultant ΔV of 1.51 ft/sec. All thrusters fired nominally.

A simultaneous supply and waste water dump was initiated at 119:20:54:07 G.m.t. (12:02:35:07 MET) when the supply water dump valve was opened. The waste water dump valve was opened at 119:20:59:51 G.m.t. (12:02:40:51 MET). Both dumps proceeded nominally until 119:21:19:35 G.m.t. (12:03:00:35 MET) when the waste water dump rate decreased from 2.0 percent/minute to 0.3 percent/minute and the waste water dump valve was closed (Flight Problem STS-90-V-05). The dump nozzle temperature was allowed to increase to remove any ice that may have been blocking the nozzle. The dump was restarted at 119:21:29:25 G.m.t. (12:03:10:25 MET), but the dump rate continued to be reduced, and the dump was stopped again at 119:21:49:31 G.m.t. (12:03:30:31 MET). The waste water dump was started a final time at 119:21:53:55 G.m.t. (12:03:34:55 MET) to observe the spray pattern with the closed circuit television (CCTV). The crew reported that the spray pattern looked like previous dumps with both nozzles flowing; however, the dump rate appeared greatly reduced when the supply water dump was stopped during the observation period. The dump was again terminated at 119:21:55:19 G.m.t. (12:03:36:19 MET).

An IFM procedure was performed at 120:15:08 G.m.t. (12:20:49 MET) to bypass a potentially clogged urine solids filter located in the waste water dump line. The initial dump rates appeared normal (1.73 percent/minute); however, at 120:15:19 G.m.t. (12:21:00 MET) the dump rate decreased to near zero. The dump was stopped and the dump nozzle bake out was performed. A second cycle was attempted, with no corresponding change in tank quantity. A bake-out of the supply and waste water dump

nozzles was initiated to determine if ice was present on either nozzle assembly. No ice was indicated.

In an effort to further confirm the lack of ice on the supply and waste dump nozzles, the Orbiter was placed into a +ZLV, +YVV (bottom-to-Earth local vertical, starboard wing on the velocity vector) water-dump attitude for two orbits. The nozzle temperature profiles in response to environmental heating were then compared to those under similar conditions earlier in the flight and prior to the dump problems. Again no evidence of ice was indicated.

As a result of the problems with dumping waste water through the waste line, a decision was made that no more waste water overboard dumps would occur. An IFM procedure, which off-loaded the waste tank contents into a contingency water container (CWC), was performed satisfactorily. The waste tank quantity was reduced to approximately 5 percent, and this condition provided sufficient ullage to allow normal waste-tank operations for the nominal end-of-mission plus two contingency days.

Flight control system (FCS) checkout was performed with no anomalies in the flight control system. APU 3 was used because of the under-cooling of WSB 3 observed during ascent. APU 3 was started at 122:12:13:12 G.m.t. (14:17:54:12 MET). When no spray cooling was observed while on the WSB 3 controller A, the WSB 3 controller B was selected at 122:12:22:24 G.m.t. (14:18:03:24 MET). The APU 3 lubrication oil return temperature was 291 °F at the time of switch-over from controller A to B. When no cooling was observed on controller B, APU 3 was shut down at 122:12:23:33 G.m.t. (14:18:04:33 MET). The lubrication oil return temperature at the time of APU shutdown was 307 °F. APU 3 ran for 10 minutes and 21 seconds, and consumed 24 lb of fuel.

At 122:13:22 G.m.t. (14:19:03 MET), the RCS hot fire procedure was initiated. It was completed at 122:13:40 G.m.t. (14:19:21:00 MET). All primary thrusters were pulsed successfully, with no problems noted.

Because of the FES shut down, a FES primary A controller water dump test was began at 122:15:33 G.m.t. (14:21:14 MET). The test lasted 2 hours 7 minutes. There was no indication of water carryover from the core or core icing during the dump. However, a FES core flush procedure was performed, being completed at 122:18:50 G.m.t. (15:00:31 MET), and there was no indication of icing during the core flushing procedure.

The payload bay doors were closed and latched for landing at 123:12:35:35 G.m.t. (15:18:16:35 MET). The dual-engine deorbit maneuver for the first landing opportunity at the Shuttle Landing Facility (SLF) was performed on orbit 255 at 123:15:10:09 G.m.t. (15:20:51:09 MET). The maneuver was 139 seconds in duration with a ΔV of 213 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on Kennedy Space Center (KSC) SLF concrete runway 33 at 123:16:08:58 G.m.t. (15:21:49:58 MET) on May 3, 1998. The Orbiter drag chute was deployed at 123:16:09:06.2 G.m.t. and the nose gear touchdown occurred 4 seconds later. The drag chute was jettisoned at 123:16:09:39 G.m.t. with wheels stop occurring at 123:16:09:57 G.m.t. The rollout was normal in all respects. The flight duration was 15 days 21 hours 49 minutes 58 seconds.

As a result of the loss of WSB 3 that was discussed earlier in this section, the start of APU 3 for entry was delayed until terminal area energy management (TAEM) was reached. WSB 3 controller B was used for entry and APU 3 was run until the APU 3 lubrication oil return fault detection and annunciation limit of 290 °F was reached approximately 2 minutes 28 seconds after landing.

APU 3 was shut down 2 minutes 28 seconds after landing. The remaining two APUs were shut down by 16 minutes 58 seconds after landing.

PAYLOADS AND EXPERIMENTS

Neurolab, a NASA research mission that was dedicated to the study of life sciences, focused on the most complex and least understood part of the human body, the nervous system. On the flight, the Neurolab crew served both as experiment subjects and operators. The experiments were grouped into eight teams. Four teams (11 experiments) used crewmembers as subjects, and four teams (15 experiments) used animals (rats, mice, fish, snails and crickets) as subjects. The eight teams were as follows:

- a. Autonomic Nervous System - human;
- b. Sensory Motor and Performance - human;
- c. Vestibular - human;
- d. Sleep - human;
- e. Neuronal Plasticity - animal;
- f. Mammalian Development - animal;
- g. Aquatic - animal; and
- h. Neurobiology - animal.

In addition to the Neurolab experiments, several non-neurological experiments were performed during the mission. These experiments are discussed in the latter paragraphs of this section.

Spacelab activation was delayed about 40 minutes because of a high carbon dioxide level in the Spacelab. However, the activation was completed satisfactorily.

NEUROLAB EXPERIMENTS

All scheduled activities for each flight day of the mission were completed as planned or completed as re-scheduled activities later in the mission. Overall, 96 percent of the data collections sessions were completed.

Autonomic Nervous System

The four experiments that were conducted by the autonomic nervous system team were as follows:

- a. Artificial Neural Networks and Cardiovascular Regulation;
- b. Integration of Neural Cardiovascular Control in Space;
- c. Autonomic Neuroplasticity in Weightlessness; and
- d. Autonomic Neurophysiology in Microgravity.

Science data for early autonomic subjects were collected as planned and data were collected on an additional subject. All autonomic mid-mission and late-mission sessions were completed on four crewmembers.

Sensory Motor Performance

The three experiments that were conducted by the sensory motor performance team were as follows:

- a. Frames of Reference and Internal Models;
- b. Visuo-Motor Coordination during Space Flight; and
- c. Role of Visual Clues in Spatial Orientation.

On flight day 1, the Visuo-Motor Coordination Facility (VCF) was set up, and the SITE experiment was performed on all four payload crewmembers as scheduled. On flight day 7, all four payload crewmembers again completed the SITE testing as planned. The Commander also completed SITE sessions as an additional subject. On flight day 10, two additional subjects completed SITE sessions. On flight day 14, all SITE protocols were completed as planned.

On flight day 3 and 4, all Virtual Environment Generator (VEG) object recognition sessions were completed successfully. On flight day 16, an additional VEG reserve protocol was completed in accordance with the nominal timeline.

The Kinelite Ball Catch activities were completed on flight day 3, including an additional subject. On flight day 9, all four payload crewmembers and two additional subjects completed ball-catch sessions. All subjects completed an additional 10 ball-catch reserve trials on flight day 9. On flight day 15, all four payload crewmembers completed the ball-catch protocol as planned.

Vestibular

The two experiments that were conducted by the vestibular team were as follows:

- a. Visual-Otolithic Interactions in Microgravity; and
- b. Spatial Orientation of the Vestibulo-Ocular Reflex.

On flight day 1, the Body Rotating Device (BRD) was set up by all four payload crewmembers per the timeline. On flight day 2, Visual and Vestibular Investigation System (VVIS) activities were completed on three of the four subjects scheduled. Data were not collected on one subject because of time constraints.

On flight day 5, the full VVIS protocol was completed by all four payload crewmembers and one additional crewmember. On flight day 7, the VVIS sessions were completed as planned. On flight day 10 and 11, again all VVIS protocols were completed as planned, as well as on flight days 12 and 16.

Sleep

The two experiments that were conducted by the sleep team were as follows:

- a. Sleep and Respiration in Microgravity; and
- b. Clinical Trial of Melatonin as Hypnotic for Neurolab Crew:

On flight day 1, the Gas Analyzer System for Metabolic Analysis Physiology (GASMAP), Actilum, and Chromatograph were set up. Melatonin and placebo ingestion was completed during the pre-sleep activity. On flight day 4 and 5, the planned cognitive performance testing (COG) and Core Body Temperature (CORE) activities were performed on the four payload crewmembers. On flight day 6 and 7, COG sessions and sleep de-instrumentation were completed as planned. The crew did not go to sleep on time on flight day 8 because of the RCRS malfunction. However, there was no impact to the circadian rhythm because the crew went to sleep at the scheduled time on flight day 9. On flight day 13, COG sessions were completed as planned, as well as sleep instrumentation and de-instrumentation activities. On flight day 14, all four payload crewmembers completed CORE instrumentation as planned. On flight day 15 and 16, COG sessions were completed in accordance with the schedule timeline.

All four payload crewmembers completed the Pulmonary Function Test (PFT) protocol on flight day 4 and an additional PFT session was also performed that same day. On flight day 6, 11, and 15, the payload crewmembers again completed the PFT protocol. In addition, an additional PFT protocol was completed on flight day 11, and an additional reserve protocol was completed on flight day 15.

Mammalian Development

The five experiments that were conducted by the mammalian development team were as follows:

- a. Neuro-Thyroid Interaction on Skeletal Isomyosin Expression in Zero Gravity;
- b. Neuronal Development Under Conditions of Space Flight;
- c. Reduced Gravity: Effects in the Developing Nervous System;
- d. Microgravity and Development of Vestibular Circuits; and
- e. Effects of Microgravity on Neuromuscular Development.

Early mission mouse injections and dissections were performed as planned. All tissues were successfully collected. Mid-mission mouse injections and dissections were also completed.

Neonate dexterity sessions were performed on flight day 6 using animal enclosure module (AEM) animals. Flight day 11 neonate dexterity sessions were completed using AEM and research animal holding facility (RAHF) animals. New tissue-sharing plans were developed during the mission because of the loss of the neonates. These alternate plans enabled all principal investigators (PIs) to accomplish their prime objectives.

Neuronal Plasticity

The three experiments that were conducted by the neuronal plasticity team were as follows:

- a. CNS Control of Rhythms and Homeostasis During Spaceflight;
- b. Anatomical Studies of Central Vestibular Adaptation; and
- c. Multidisciplinary Studies of Neural Plasticity in Space.

On flight day 4, the Escher rodent sessions were performed and complete data were collected on rodents 1, 2, and 3. On flight day 9, the remaining rodent sessions were completed.

Aquatic

The two experiments that were conducted by the aquatic team were as follow:

- a. Chronic Recording of Otolith Nerves in Microgravity; and
- b. Development of Vestibular Organs in Microgravity:

All Closed Equilibrium Biological Aquatic System (CEBAS) tape changes were performed as planned. All Vestibular Function Experiment Unit (VFEU) accelerations were performed and three additional accelerations were completed.

Neurobiology

The Development of an Insect Gravity Sensory System experiment was conducted by the neurobiology team. On flight day 1, the Botany Experiment (BOTEX) transfer to the Spacelab was performed. Air exchange activities were completed as scheduled. Late on flight day 16, the BOTEX was transferred back to the middeck as part of the payload deactivation.

GET-AWAY SPECIAL PAYLOADS

The Get-Away Special (GAS) payloads were all activated on flight day 2.

G-197 - Pulse Tube Cooling Technology: The G-197 payload was automatically shut down sometime between flight day 2 and flight day 3 because of either a high internal temperature or a battery under-voltage condition. An attempt was made to repower the payload at 109:18:29 G.m.t. (02:00:10 MET); however, the attempt was unsuccessful. A successful attempt was made to repower the G-197 payload at 111:15:50 G.m.t. (03:21:31 MET). Approximately four hours later, the crew reported that the power status relay was off again. The decision was made by the experiment personnel to leave the remainder of the relays on as thermal and accelerometer data were still being gathered. The payload functioned in this manner until it was shut down as planned on flight day 15. Data may be obtained on this payload from the GAS Payloads Representative at the Goddard Space Flight Center (GSFC).

G-744 - Ozone Measurements: The G-744 payload [Ozone Measurements (OM)], which was activated as planned on flight day 2, functioned nominally throughout the mission. The payload was shut down as planned on flight day 15. Data may be obtained on this payload from the GAS Payloads Representative at the GSFC.

G-772 - Collisions in Dust Experiment: The G-772 payload [Collisions in Dust Experiment (CDE)], which was activated on flight day 2, functioned nominally until it was shut down as planned on flight day 15. Data may be obtained on this payload from the GAS Payloads Representative at the GSFC.

HITCHHIKER EXPERIMENT

Shuttle Vibration Forces: The Shuttle Vibration Forces (SVF) experiment data were collected during ascent as planned. These data will be evaluated during the postflight period, and the results of this experiment may be obtained from the Experiment Sponsor.

BIOREACTOR DEMONSTRATION SYSTEM - 04

The Bioreactor Demonstration System - 04 (BDS-04) biotechnology specimen temperature controller (BSTC), located on the middeck, housed two experiments on this mission. These were the Human Renal Cell experiment and the Microgravity Induced Differentiation of HL-60 Promyelocytic Leukemia Cells. The BDS-04 experiment was powered-on at the planned time (approximately 2 hours 30 minutes after liftoff). The crew performed all planned activities with the BDS-04 after completing the power-up of the experiment. The experiments performed satisfactorily throughout the mission.

Daily crew status checks were performed and the data were provided verbally to the Principal Investigator. These status checks revealed that the BDS-04 operated as expected with the exception of some bubbles in the G6+ cartridges on flight day 5 and some bubbles in the Portable Clinical Blood Analyzer (PCBA) cartridges during chamber 1 operations on flight day 9. The data and hardware have been given to the sponsor for the BDS-04 for evaluation. The results of that evaluation will be reported in separate documentation.

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTERS

Analysis of the data from the Solid Rocket Booster (SRB) systems showed nominal performance as expected. The SRB prelaunch countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operational Maintenance Requirements and Specification Document (OMRSD) violations occurred, nor were any SRB in-flight anomalies identified.

Both SRBs were successfully separated from the External Tank (ET) approximately 121 seconds after liftoff. The SRB recovery forces reported that all deceleration and recovery systems performed satisfactorily. The SRBs were recovered and returned to KSC for disassembly and refurbishment.

The post-retrieval inspection of the SRBs revealed that the boosters were overall in excellent condition with no anomalous conditions noted. Both frustums were in excellent condition with no thermal protection system (TPS) missing and no debonded areas noted. The forward skirts exhibited no debonded areas or missing TPS. The range safety system (RSS) antennae covers/phenolic base plates were intact; however, one phenolic layer on both +Z side base plates was delaminated. The field-joint protection system close-outs were generally in good condition.

REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motors (RSRM) performed satisfactorily, and no RSRM LCC or OMRSD violations occurred nor were any in-flight anomalies identified.

Power-up and operation of all igniter and field joint heaters was accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. The heated ground purge of the SRB aft skirts was used to maintain the case/nozzle joint temperatures within the required LCC ranges.

Data indicate that the flight performance of both RSRMs was well within the allowable contract end item (CEI) specification limits, and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was 68 °F at liftoff. The maximum trace-shape variation of pressure versus time during the 62 to 80 second time frame was calculated to be -0.45 percent at 67 seconds on the left motor, and +0.87 percent at 73.5 seconds on the right motor. Both of these values were well within the 3.2 percent allowable limits. The table on the following page delineates the RSRM propulsion systems performance during ascent.

Field joint heaters operated for a total time of 10 hours 19 minutes during the launch countdown. Power was applied to the heating elements approximately 22 percent of the LCC time frame to maintain the field joints in the normal heating range.

Igniter joint heaters operated for 10 hours 9 minutes during the launch countdown. Power was applied to the heating elements 53 percent of the time to maintain the igniter joints within the normal temperature range.

RSSRM PROPULSION PERFORMANCE

Parameter	Left motor, 68 °F		Right motor, 68 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	64.80	64.87	65.05	64.89
I-60, 10 ⁶ lbf-sec	173.11	173.86	173.65	174.03
I-AT, 10 ⁶ lbf-sec	296.78	296.60	296.75	296.64
Vacuum Isp, lbf-sec/lbm	268.5	268.3	268.5	268.4
Burn rate, in/sec @ 60 °F at 625 psia	0.3663	0.3674	0.3672	0.3676
Event times, seconds ^a				
Ignition interval	0.232	N/A	0.232	N/A
Web time ^b	111.1	110.3	110.6	110.1
50 psia cue time	120.9	120.4	120.4	120.0
Action time ^b	123.0	122.8	122.5	122.6
Separation command	125.8	125.1	125.8	125.3
PMBT, °F	68	68	68	68
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	3.3	2.8	3.3
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		156.7	

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

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

^bReferenced to liftoff time (ignition interval).

The aft skirt purge operated for a total of 13 hours 7 minutes. During the countdown, the aft skirt purge was activated to maintain the nozzle/case joint temperatures above the minimum LCC temperature. The calculated flex bearing mean bulk temperature was 79 °F.

Postflight observations indicated a gas path through the left-hand nozzle joint 1 room temperature vulcanizing (RTV) material. Also, a fiber was observed on the right-hand aft field joint capture feature O-ring and on the left-hand forward field joint capture feature O-ring. Excessive grease was also observed on the left-hand igniter outer gasket leak-check groove. None of these conditions impacted the flight in any way.

EXTERNAL TANK

All objectives and requirements associated with the ET propellant loading and flight operations were met satisfactorily. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operations were monitored and all performed properly. No ET LCC or OMRSD violations occurred nor were any in-flight anomalies identified in the data review and analysis.

No unexpected ice/frost formations were observed on the ET during the countdown, and there was no observed frost or ice on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen (LO₂) and liquid hydrogen (LH₂) feed-lines, the pressurization-line brackets, and along the LH₂ protuberance air load (PAL) ramps. These observations were all acceptable based on NSTS-08303. Likewise, the Ice/Frost Red Team reported that there were not anomalous thermal protection system (TPS) conditions.

Propellant loading was acceptable with both tank pressures maintained within acceptable limits throughout the loading sequence. The ET ullage pressurization system functioned properly throughout engine start and the flight. The minimum LO₂ ullage pressure experienced during the period of the ullage pressure slump was 13.6 psid.

The ET separation occurred as planned with ET entry and breakup within the predicted footprint. The postflight predicted ET intact impact point was approximately 77 nmi. uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) parameters appeared to be normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine ready was achieved at the proper time; all LCC were met; and engine start and thrust build-up were normal.

Flight data indicate that the SSME performance during main-stage, throttling, shutdown and propellant dump operations was normal with no in-flight anomalies identified. The high-pressure oxidizer turbopump (HPOTP) and high-pressure fuel turbopump (HPFTP) temperatures appeared to be well within specification throughout engine operation. The specific impulse (I_{sp}) was rated as 452.81 seconds based on trajectory data. The Space Shuttle main engine cutoff (MECO) occurred 508.01 seconds after liftoff. Cutoff times were 514.32, 514.45, and 514.56 seconds for SSMEs 1, 2, and 3, respectively.

SHUTTLE RANGE SAFETY SYSTEM

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

The right-hand SRB SRSS signal strength B exceeded the range safety minimum requirement of -85 dBm when tracking from the Cape command site. This condition did not affect system operation as the combined signal strength of all four SRB SRSS detectors was always sufficiently high to maintain proper system operation through SRB separation. The observed low signal strength B was caused by the vehicle roll maneuver and right-hand SRB shading.

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion System

The overall performance of the main propulsion system (MPS) was satisfactory. The LO₂ and LH₂ loading was performed with no stop flows or reverts. There were no LCC or OMRSD violations. Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment (occurred shortly after start of fast-fill) was approximately 146 ppm, which compares favorably with previous data for this vehicle.

The LH₂ loading operations were normal throughout the entire sequence of the activity. Based on an analysis of loading system data, the load at the end of replenish was 231,223 lbm. Compared to the inventory (predicted) load of 231,235 lbm, the load was well within the required accuracy of ± 0.37 percent.

The LO₂ loading operations were normal throughout the entire sequence of the activity. Based on an analysis of loading system data, the load at the end of replenish was 1,381,517 lbm. Compared to the inventory (predicted) load of 1,382,754 lbm, the load was well within the required accuracy of ± 0.43 percent.

Ascent MPS performance was completely nominal. Data indicate that the LO₂ and LH₂ pressurization systems performed as planned, and all net positive suction pressure (NPSP) requirements were met throughout the flight. The minimum LO₂ ullage pressure experienced during the period of ullage pressure slump was 13.6 psid.

At approximately 1 minutes 6 seconds after liftoff, the ET LH₂ 98-percent liquid-level sensor 2 failed wet. Based on the failure signature, it is highly probable that the failure occurred in the sensor. This sensor is only used during loading and the loss was no impact to the mission. Postflight testing of the associated circuits in the Orbiter will be performed.

The SSME 1 LH₂ inlet pressure shifted upward approximately 3 to 4 psia at about 107:18:22:30 G.m.t. (00:00:03:30 MET) (Flight Problem STS-90-V-02). A similar signature has been observed on previous flights of this and other Orbiter vehicles. This measurement is used primarily for engineering data during loading. However, it is also used during ascent in the event of a premature engine shutdown to determine if an LH₂ dump can be performed through that engine. There was no impact to the remainder of the flight. Troubleshooting of the transducer and measurement circuitry will be performed during turnaround operations.

The data analysis has shown that ET LO₂ liquid-level sensor 2 flashed about a dozen times between wet and dry over a 15-second period that began at approximately 107:18:23:56 G.m.t. (00:00:04:56 MET). The sensor read dry at all other times during ascent as expected. This problem had no impact on the flight as the sensor is only used during loading. Postflight testing of the multiplexer/demultiplexer (MDM) and associated wiring will be performed during the postflight turnaround operations.

The overall GH_2 system in-flight performance was nominal. Also, the GO_2 fixed-orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely matched the actual ET ullage pressure measurements.

All three flow control valves performed nominally. Likewise, the helium system performance was also nominal. Entry helium usage was 58.8 lbm, which is within the requirements. All other MPS parameters were nominal.

Reaction Control Subsystem

The RCS performed satisfactorily throughout the mission. Minor problems were encountered that are discussed in the following paragraphs; however, neither of the problems impacted the mission or its successful completion.

The total propellants consumed by the RCS during the mission was 4207.6 lbm. All of the propellants were fed by the RCS as no OMS interconnect operations were performed on this flight. The primary RCS had a total of 2321 firings, and a total firing time of 761.36 seconds. The vernier RCS had a total of 22,828 firings, and a total firing time of 20,901.6 seconds. A four-thruster forward dump of 48 seconds was performed near the end of the flight. Two maneuvers were performed with the RCS and data from these maneuvers is shown in the following table.

RCS MANEUVERS

Maneuver	Time, G.m.t./MET	ΔV , ft/sec	Duration, seconds
Orbit Adjust 1	112:20:14:00 G.m.t. 05:01:55:00 MET	3.34	15
Orbit Adjust 2	117:18:28:59 G.m.t. 10:00:09:59 MET	1.51	7

During the first sleep period, the RCS thruster F5L injector temperature approached the 130 °F redundancy management (RM) limit because of the limited number of thruster firings. Thruster R5R was deselected in an effort to cause thruster F5L to fire more frequently. Also, during the second sleep period, the -Z pitch attitude was changed to have a 5-degree pitch bias. As a result of the attitude change and deselection of thruster R5R, thruster F5L fired more often and the injector temperatures were maintained well above the minimum RM limit. Thruster R5R was deselected for the majority of the mission to force firings of F5L.

At 114:18:07 G.m.t. (06:23:48 MET), the RCS vernier driver power and logic power for the forward, left and right RCS went off. This resulted in two vernier thrusters failing off when they were subsequently commanded to fire. The vernier driver and logic switches were cycled and operation of all vernier thrusters was recovered. The problem would have to involve the path from the control bus through the vernier driver power switch contact to the terminal board where it splits to go to the forward, left and right drivers. There are two contacts in the switch, and either leg could be the source of the problem. Another possibility is that the vernier driver power switch may have been bumped by one of the crewmembers. The crew has indicated that they probably bumped the switch, which would explain the event. No postflight troubleshooting or testing will be required.

A more complete discussion of this problem is contained in the Flight Control System section of this report.

At 122:13:22 G.m.t. (14:19:03 MET), the RCS hot fire procedure was initiated. It was completed at 122:13:40 G.m.t. (14:19:21:00 MET). All primary thrusters were pulsed successfully, with no problems noted.

Orbital Maneuvering Subsystem

The orbital maneuvering subsystem (OMS) performed satisfactorily during the three required maneuvers. No LCC or OMRSD deviations occurred prior to launch, and no in-flight anomalies occurred during the mission. A total of 13634 lbm of OMS propellants were consumed during the mission, none of which was used by the RCS. The following table provides the pertinent data for each of the maneuvers.

OMS MANEUVERS

Maneuver/Engines	Time, G.m.t./MET	ΔV , ft/sec	Duration, seconds
OMS Assist/2	107:18:21:15 G.m.t. 00:00:02:15 MET	a	102.4
OMS 2/ 2	107:19:00:27.2 G.m.t. 00:00:41:34.2 MET	171.1	110.2
Deorbit/2	123:15:10:09.6 G.m.t. 15:20:51:09.6 MET	228	139

Note a: The use of the OMS engines during ascent provides an additional payload-to-orbit capability of approximately 250 lb for each 4000 lbm of fuel used. The thrust from the OMS is very small when compared with the SSME thrust and therefore cannot be accurately determined.

During the second stage of ascent, an OMS assist-maneuver was performed for the first time during the Space Shuttle Program. The OMS-2 maneuver was performed satisfactorily, and the resultant orbit was 154 by 138 nmi. The deorbit maneuver for the first landing opportunity at the SLF was performed satisfactorily on orbit 255.

A leak in the right OMS engine low-pressure side of the GN₂ system caused the pressure to drop, which in turn required repressurizations to be performed. The initial calculated leak rate was 40 scch. The table on the following page shows that the leak rate decreased following each repressurization until the rate was below 10 scch. This leak has been seen on previous missions; however, it has not been observed during ground operations.

Repressurization	Leak Rate After Repressurization, scch	Time of Repressurization, G.m.t./MET
1	40	108:04:13/00:09:54
2	31	109:03:35/01:09:16
3	28	110:03:25/02:09:06
4	2	112:00:45/04:06:26
5	4	121:22:03/14:03:44

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution subsystem (PRSD) performed nominally throughout the mission, and no in-flight anomalies were noted during the mission and postmission data review. The subsystem provided the fuel cells with 4830 lbm of oxygen and 608 lbm of hydrogen for the production of electricity. In addition, the environmental control and life support system (ECLSS) was supplied 276 lbm of oxygen. A 102-hour mission-extension capability existed at touchdown at the average mission power level, and at an extension-day power level of 13.2 kW, a 143-hour mission extension was available.

Fuel Cell Powerplant Subsystem

The fuel cell powerplant (FCP) subsystem performance was nominal during the mission with no in-flight anomalies identified from the data. The average electrical power level and load for the mission was 18.0 kW and 600 amperes. The fuel cells produced 6889 kWh of electrical energy and 5438 lbm of by-product potable water, using 4830 lbm of oxygen and 608 lbm of hydrogen. Eight purges of the fuel cells using both the automatic and manual systems were performed satisfactorily during the mission. The actual fuel cell voltages at the end of the mission were 0.15 Vdc above the predicted level for fuel cell 1, as predicted for fuel cell 2, and 0.10 Vdc above the predicted level for fuel cell 3.

STS-90 was the second flight of the fuel cell performance monitor system (FCMS) on this vehicle (OV-102). The FCMS was activated and on-orbit fuel cell individual-cell-voltage data were recorded for 12 minutes, from 109:19:13:54 G.m.t. (02:00:54:54 MET) to 109:19:25:54 G.m.t. (02:01:06:54 MET). A review of the data showed that all of the cell voltages were nominal.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performance was nominal throughout the mission. No in-flight anomalies were noted in the review of the mission data. The APU run times and propellant consumption are shown in the table on the following page.

The APU 2 system B heater for the gas generator bed, and the system B heater for the gas generator valve module (GGVM), fuel pump and fuel lines did not operate when these heaters were initially reconfigured from system A to system B at 114:18:42 G.m.t. (07:00:23 MET). Both of these heaters are controlled by the same switch. At approximately 114:19:51 G.m.t. (07:01:32 MET), the crew cycled the GGVM/fuel pump system B heater switch to off and then back to B-automatic. Proper heater response

followed, and the heaters cycled normally for the remainder of the mission. It is believed that the most probable cause of this failure was a condition referred to as switch tease, in which the switch is positioned so that all of the contacts of the switch are not made. Cycling the switch corrected the problem.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 401)		APU 2 (S/N 410)		APU 3 (S/N 304)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	20:20	55	20:27	55	17:54	49
FCS checkout					10:09	24
Entry ^a	60:16	134	80:45	156	08:54	23
Total	80:36	189	101:12	211	36:57	96

^a APUs 1 and 2 were shut down 16 minutes 58 seconds after landing.

^b APU 3 was used for the FCS checkout.

^c APU 3 was shut down early after ascent because of the lack of WSB cooling. APU 3 was also started at TAEM and shut down approximately 2 minutes 28 seconds after landing because of the lack of WSB cooling.

APU 3 was shut down early after ascent because of the lack of WSB cooling of the APU lubrication oil as indicated by the outlet temperature. APU 3 was started at 122:12:13:12 G.m.t. (14:17:54:12 MET) for the FCS checkout. When no spray cooling was observed while on the WSB 3 controller A, the WSB 3 controller B was selected at 122:12:22:24 G.m.t. (14:18:03:24 MET). The APU 3 lubrication oil return temperature was 291 °F at the time of switch-over from controller A to B. When no cooling was observed on controller B, APU 3 was shut down at 122:12:23:33 G.m.t. (14:18:04:33 MET). The lubrication oil return temperature at the time of APU shutdown was 307 °F. During entry, APU 3 was started at the terminal area energy management (TAEM) point, and the APU was shut down 2 minutes 28 seconds after landing when the lubrication oil outlet temperature reached 290 °F, the fault detection and annunciation (FDA) system limit. This problem is discussed in greater detail in the Hydraulics/Water Spray Boiler paragraphs of this report.

The APU 1 exhaust gas temperature (EGT) sensor 2 and APU 3 EGT sensor 2 operated erratically during entry. This condition did not affect the entry operations. The sensors will be replaced during postflight turnaround operations.

Hydraulics/Water Spray Boiler Subsystem

Overall performance of the hydraulics/water spray boiler (WSB) subsystem was acceptable. No APU 3 lubrication oil spray cooling was observed during ascent, FCS checkout, or entry. As a result of the lack of cooling, APU 3 was not started until TAEM, whereas it would normally be started at entry interface (EI) minus 13 minutes.

WSB 3 experienced an under-cooling condition during ascent. The WSB 3 controller was switched from A to B at 107:18:30:46 G.m.t. (00:00:11:46 MET) when the APU 3 lubrication oil return temperature was approximately 300 °F. No spray cooling was observed at that time. The lubrication oil return temperature reached 334 °F when APU 3 was shut down. The specification value for this temperature is no-greater-than 275 °F (Flight Problem STS-90-V-06). APU 3 was shut down at 107:18:32:12 G.m.t. (00:00:13:12 MET), which was approximately 2 minutes earlier than planned. Data review indicates no spraying was achieved during the operation of either WSB 3 controller.

The lack of cooling as well as under-cooling conditions have occurred previously during ascent on this and other WSBs. This behavior is believed to be caused by ice forming on the WSB spray bars. As a result, APU 3 was run for FCS checkout to verify satisfactory WSB 3 operation. Spraying was not seen on either the WSB A or B controllers. During entry, APU 3 was started at the TAEM point and was configured to operate on the B controller. No spraying was seen during entry, and APU 3 was shut down 2 minutes 28 seconds after landing when the lubrication oil return temperature reached the FDA limit of 290 °F. Troubleshooting will include a visual inspection plus checkout of the WSB components.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed nominally throughout the mission. No abnormal conditions or in-flight anomalies were identified from the review of the data, and all in-flight checkout requirements were satisfied.

Atmospheric Revitalization Pressure Control Subsystem

The atmospheric revitalization pressure control subsystem (ARPCS) performed normally throughout the duration of the flight with the exception of a loss of the PCS system 2 GN₂ flow indication. The flow rate sensor had a bias which resulted in an indicated flow rate of 0.18 lb/hr. At the time of this indication, the PCS was configured to system 1 and the PCS 2 GN₂ should have indicated 0.0 lb/hr. The indicated system 2 flow rate bias decreased to 0.0 lb/hr by 110:21:45 G.m.t. (03:03:26 MET). When the PCS was configured to system 2 at 114:16:41 G.m.t. (06:22:22 MET), the PCS GN₂ flow sensor correctly indicated flow for several days. However, during the GN₂ flow cycle at 117:19:29 G.m.t. (10:01:10 MET), the flow sensor failed to indicate GN₂ flow (indicated 0.0 lb/hr). The failure to indicate GN₂ flow persisted throughout the remainder of the mission.

Atmospheric Revitalization System

At 115:03:49:46 G.m.t. (07:09:30:46 MET), the regenerative carbon dioxide removal system (RCRS) shut down while on controller 2. The crew reconfigured the RCRS to controller 1, but it too shut down (Flight Problem STS-90-V-03). The crew was told to use lithium hydroxide (LiOH) canisters for carbon dioxide removal during their sleep period. Flight data were reviewed, and a fault tree was developed to investigate the cause of the shutdown. An IFM procedure was prepared and performed to recover usage of the RCRS. The IFM isolated a check valve which was leaking cabin air into the RCRS, and the RCRS was successfully recovered. The isolation was regained by

disconnecting the outlet hose from the check valve and covering the fitting with aluminum tape. In addition, power was removed from the compressor since it is in the flow path blocked by the IFM procedure. Following the IFM, the RCRS was activated at 115:20:43 G.m.t. (08:02:24 MET) using controller 1 and it operated as expected in light of the IFM modifications for the remainder of the mission. The loss of the RCRS ullage save operation resulting from the compressor being unpowered had no mission impact. The RCRS will be removed from the vehicle and shipped to the vendor for troubleshooting and repair. The RCRS will not be flown on the STS-93 mission, the next mission of this Orbiter.

Active Thermal Control Subsystem

The active thermal control subsystem (ATCS) operation was satisfactory throughout the mission. There was an on-orbit problem with the FES that had no significant mission impact.

The FES shut down while operating on the primary A controller at approximately 111:02:06 G.m.t. (03:07:47 MET) (Flight Problem STS-90-V-04). The crew restarted the FES primary A controller 4 minutes after the shutdown occurred. The restart was successful, and the FES went into standby at 111:02:35 G.m.t. (03:08:16 MET); however, the FES failed to come out of the standby mode. At 111:03:13 G.m.t. (03:08:54 MET), the crew switched from the primary A to the primary B controller. The FES gained control for 10 minutes on the primary B controller and then shut down. The FES core flush procedure was implemented and it indicated that there had been ice in the core. After the flush procedure was completed, the FES primary B controller was successfully restarted. The FES topping duct heaters were placed on heater string A/B for the duration of the crew sleep period. Following the sleep period, the topping duct heaters were reconfigured from A/B to A as planned.

About 1 hour 27 minutes prior (one orbit cycle) to the initial shutdown, the FES heat load approached 30,000 Btu/hr, the on-orbit Shuttle Operational Data Book (SODB) limit, and dropped off rapidly. It is believed that this transient resulted in the formation of ice in the FES topper core, and this eventually led to the shut-down. Note that the FES is certified to handle a transient of the magnitude seen. The transient occurred while in the -ZLV +YVV (top-to-Earth local vertical, starboard wing on the velocity vector) water-dump attitude. The Orbiter water-dump attitudes were changed from -ZLV +YVV to +ZLV +YVV (bottom to Earth local vertical, starboard wing on the velocity vector) to preclude the thermal condition that was believed to cause the FES shut down. Also, a planned 14-hour period of -ZLV +YVV attitude near the end of the mission was modified to preclude further FES problems.

A FES primary A controller water dump test was begun at 122:15:33 G.m.t. (14:21:14 MET), and the dump lasted for 2 hours 7 minutes during which the FES operated properly. There was no indication of water carry-over from the core or icing during the dump. A FES core-flush procedure was performed as a safeguard following the completion of the dump. Again, there were no indications of icing. Visual inspection of the topper core and checks of the water will be performed during the postflight turnaround operations.

The flow proportioning valve (FPV) on Freon coolant loop (FCL) 2 was taken to the payload position at 107:20:25 G.m.t. (00:02:06 MET) to support the Spacelab cooling. The FPV on FCL 1 was not taken to the payload position until approximately 108:16:14 G.m.t. (00:21:55 MET) to provide more cooling to the Orbiter cabin during the first day of flight. The Orbiter provided satisfactory cooling to the Spacelab throughout the flight. Deployment of the port radiator was required during the flight to support payload operations.

The radiator cold-soak provided cooling during entry through landing plus 5 minutes at which time the ammonia boiler system primary B was activated. System B provided cooling for 37 minutes at which time the tank pressure blow-down occurred, indicating an empty tank. The crew switched to primary A system which operated for 3 minutes after which it was disconnected in preparation for ground cooling.

Supply and Waste Water Subsystem

The supply water system performed nominally. However, an anomaly occurred in the waste water system. This anomaly is discussed in a following paragraph.

Supply water was managed through the use of supply water dumps. Nine supply water dumps were performed at an average flow rate of 1.70 percent/minute (2.81 lb/min). The supply water-dump-line temperature was maintained between 76.1 °F and 108.3 °F throughout the mission with the operation of the line heater.

Waste water was gathered at about the predicted rate. The waste water dump line temperature was maintained between 54.3 °F and 80.0 °F throughout the mission. The waste line heater 2 thermostat dithered after the mid-mission heater reconfiguration, and this condition continued throughout the remainder of the mission. The vacuum vent line temperature was maintained between 59.3 °F and 74.9 °F.

Three nominal waste water dumps were performed. The fourth waste water dump was a simultaneous supply and waste water dump and it was initiated at 119:20:54:07 G.m.t. (12:02:35:07 MET) when the supply water dump valve was opened. The waste water dump valve was opened at 119:20:59:51 G.m.t. (12:02:40:51 MET). Both dumps proceeded nominally until 119:21:19:35 G.m.t. (12:03:00:35 MET) when the waste water dump rate decreased from 2.0 percent/minute to 0.5 percent/minute and the waste water dump valve was closed (Flight Problem STS-90-V-05). The nozzle temperatures remained relatively constant (approximately 75 °F) throughout the dump. During the bakeout following the dump, the temperature signature did not appear to indicate ice on the nozzle. The dump was restarted at 119:21:29:25 G.m.t. (12:03:10:25 MET), but the dump rate continued to be reduced, and the dump was stopped again at 119:21:49:31 G.m.t. (12:03:30:31 MET). Video of the waste water dump stream showed that some water was coming out of the nozzle. The waste water dump was started a final time at 119:21:53:55 G.m.t. (12:03:34:55 MET) to observe the spray pattern with the closed circuit television (CCTV). The crew reported that the spray pattern looked like previous dumps with both nozzles flowing; however, the dump rate appeared greatly reduced when the supply water dump was stopped during the observation period. The waste water dump was again terminated at 119:21:55:19 G.m.t. (12:03:36:19 MET).

It was suspected that the urine solids filter was blocked. An IFM procedure was performed at 120:15:08 G.m.t. (12:20:49 MET) to bypass the potentially clogged urine

solids filter located in the waste water dump line. The initial dump rates appeared normal (1.73 percent/minute); however, at 120:15:19 G.m.t. (12:21:00 MET) the dump rate decreased to near zero. The dump was stopped and the dump nozzle bake out was performed. An additional 17 percent of the waste water was dumped before the dump was stopped. A second cycle was attempted, with no corresponding change in tank quantity. A bake-out of the supply and waste water dump nozzles was initiated to determine if ice was present on either nozzle assembly. No ice was indicated.

In an effort to further confirm the lack of ice on the supply and waste dump nozzles, the Orbiter was placed into a +ZLV, +YVV (bottom-to-Earth local vertical, starboard wing on the velocity vector) water-dump attitude for two orbits. The nozzle temperature profiles in response to environmental heating were then compared to those under similar conditions earlier in the flight and prior to the dump problems. Again no evidence of ice was indicated.

As a result of the problems with dumping waste water through the waste line, a decision was made that no more waste water overboard dumps would occur. An IFM procedure, which off-loaded the waste tank contents into a contingency water container (CWC), was performed satisfactorily. The waste tank quantity was reduced to approximately 5 percent, and this condition provided sufficient ullage to allow normal waste-tank operations for the nominal end-of-mission plus two contingency days. Postflight troubleshooting will be performed to determine the cause of the blockage.

Waste Collection Subsystem

The waste collection subsystem (WCS) performed its primary functions nominally throughout the mission. However, the crew reported during postflight discussions that the WCS floodlight had failed a few days into the mission. Troubleshooting of the light circuit and the bulb will be performed during postflight turnaround operations.

Airlock Support System

Use of the airlock support system components was not required because there was no extravehicular activity (EVA). The active system monitor parameters indicated normal outputs throughout the duration of the flight.

Smoke Detection and Fire Suppression Subsystem

The smoke detection performed nominally throughout the mission. The smoke detection system showed no indications of smoke generation. Use of the fire suppression system was not required.

Flight Data System

The flight data systems performed satisfactorily. Ascent and descent navigation was nominal with no hardware failures or significant problems. The external sensor [drag, tactical air navigation (TACAN), air data transducer assembly (ADTA), and microwave scanning beam landing system (MSBLS)] data were incorporated into the onboard navigation state vectors in the expected regions of operation. Drag measurement processing started at approximately 232,500 ft and ended at approximately 85,200 ft. The TACAN acquisition occurred at approximately 151,300 ft, and except for the cone of

confusion from 68,800 ft to 31,700 ft, TACAN bearing data were used throughout entry. The ADTA data incorporation began at 81,800 ft and continued to approximately 16,500 ft. The processing of MSBLS data by the navigation filter was initiated at 16,400 ft. All external sensor measurement residuals and residual ratio values were normal with no navigation measurement data editing observed. The backup flight system (BFS) navigation data also exhibited similar characteristics to the primary flight system, and postflight error analyses showed a good comparison between the Primary Avionics Software System (PASS) and Backup Flight System (BFS) state vectors.

The inertial measurement units (IMUs) performed satisfactorily throughout the mission. Only one IMU accelerometer compensation was required during the flight, and only one gyro drift compensation was required on IMU 1 and 3. All of these compensations were expected.

Flight Software

The flight software performed satisfactorily throughout the mission with no in-flight anomalies identified from the data.

Flight Control Subsystem

The flight control system (FCS) performed nominally throughout the mission with one minor exception. This exception is discussed in a following paragraph.

The first use of the OMS ascent enhancement firing during second stage operations occurred on this flight. The engines remained in the stow position throughout the firing with the actuators unpowered. The actuators allowed no movement during this firing.

The forward, left and right vernier driver remote power controllers (RPCs) and logic RPCs went off and this resulted in two vernier thrusters being declared failed off when commanded to fire for attitude control. During vernier thruster control, the logic power switches are placed to the off position, and thus depend on the latching circuit to maintain logic power in the on condition while vernier driver power is on. The rationale used for this is that it is easier to turn off the eight logic switches than to turn off five of the switches and leave the three switches that power the vernier thrusters (manifold 5) on. However, in this configuration, a momentary break of 4 or 5 milliseconds in either one of the two switch contacts will result in the unlatching of the circuit which in turn powers down the vernier thrusters. The crew believes that the dropout may have been caused by bumping the vernier manifold 5 driver switch. Note that the switch would not have to be moved to the off position to cause this condition to occur. A bump which would cause the switch to move in the on-direction could tease the switch for a dropout of the 4 to 5 milliseconds. Turning on the logic power and reselecting the failed thrusters re-established vernier attitude control of the Orbiter. Following the reactivation of the thrusters, the logic switches were again taken to the off position. No other dropouts were experienced during the remaining nine days of the mission.

FCS checkout was performed with no anomalies in the flight control system.

During the secondary actuator check portion of the STS-87 FCS checkout, the speedbrake channel 3 secondary differential pressure initially responded to

approximately 1100 psid, where it then hesitated for approximately 1.43 seconds before reaching the 2800 to 2900 psid expected pressure. As a result, a request was made to repeat the secondary actuator check for a second run with this stimuli for this mission. There was no secondary differential pressure hesitation of the servovalve during either the first or second performance of the test procedure.

Displays and Control Subsystem

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

During the performance of the Ku-band antenna stowage procedure, the crew reported that the hundreds digit on the range rate/azimuth display on panel A2 was not showing the value 1. A lamp test verified that the hundreds digit was not working. Troubleshooting will be performed during the turnaround operations for the next flight.

During ET umbilical door opening following the landing, the crew reported that the right door uplock latch release talkback indicated barberpole after telemetry indicated that the latches were open. The crew was able to proceed with ET door opening with no other anomalies. Postlanding, KSC personnel reported the talkback was in the proper state. Troubleshooting of this condition will be performed during postflight turnaround operations.

The loss of the floodlight in the WCS is discussed in the Waste Collection Subsystem section of the report.

Communications and Tracking Subsystem

The communications and tracking subsystem performed satisfactorily throughout the mission with no in-flight anomalies documented from the review of the data. The preflight anomaly that occurred in the network signal processor is discussed in the following paragraph.

During the countdown for the STS-90 scheduled launch on April 16, 1998, network signal processor (NSP) 2 failed to acquire frame synchronization during the switch from NSP 1 to NSP 2 (Flight Problem STS-90-V-01). Downlink communications were not affected by the problem. The system was cycled from NSP 1 to NSP 2 nine times using several different modes. Each time, NSP 1 operated satisfactorily, but NSP 2 did not. No uplink communications could be established on NSP 2. As a result, the launch was delayed 24 hours, and NSP 2 was replaced and the checkout was completed satisfactorily. Failure analysis of the NSP is being performed by the manufacturer.

At 114:02:08 G.m.t. (006:07:49 MET), the Ku-band radio frequency (RF) power output measurement became erratic for approximately six minutes. The downlink signal-strength was not affected, and there were no additional occurrences. A similar signature occurred on this deployment assembly during STS-43 and STS-45. The repairs were made to a broken shield on a coaxial cable as well as removing excessive conformal coating that was in a connector. The assembly was flown on STS-83 and STS-94 and no problems were noted. However, this condition recurred during STS-87 on three separate occasions. The problem could not be duplicated during ground

testing, and the decision was made to fly the deployment assembly in the as-is condition until a more significant problem occurs.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation and modular auxiliary data system (MADS) performed satisfactorily throughout the mission. No in-flight anomalies were documented in the review and analysis of the data.

The left-hand nose landing gear pressure sensor 2 exhibited erratic behavior prior to launch and throughout ascent. Prior to launch, the sensor was reading low compared to sensor 1. During ascent, the sensor 2 output alternately recovered and dropped out several times. The sensor output was increasingly erratic during the first two days of the mission and failed off-scale-low (231 psia) at 109:20:47 G.m.t. (02:02:28 MET). This problem was first found during the flow, and was accepted based on the presence of the redundant measurement and the successful wheel/tire leak checks performed previously.

Structures and Mechanical Subsystems

All structures and mechanical subsystems performed nominally during the STS-90 mission. No in-flight anomalies were noted in the review of the data and inspection of the hardware. The landing and braking parameters for the mission are shown in the table on the following page.

The starboard payload bay door was opened at 107:19:54:46 G.m.t. (00:01:35:46 MET), and the port payload bay door was opened at 107:19:56:07 G.m.t. (00:01:37:07 MET). The door operation was satisfactory in all respects with dual-motor times recorded.

The payload bay doors were closed and latched for landing at 123:12:35:35 G.m.t. (15:18:16:35 MET).

The postlanding inspection of the tires revealed some ply undercutting on the left-hand inboard and right-hand outboard (downwind) tires. The tires were in average condition for a landing on the KSC concrete runway.

The ET/Orbiter separation devices (EO-1, -2, and -3) functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. The EO-2 fitting retainer springs were in nominal configuration. One of the three retainer springs in the EO-3 fitting was dislodged. No clips were missing from the salad bowls. A significant amount of umbilical closeout foam had adhered to the umbilical plate near the LH₂ recirculation line disconnect.

All of the drag chute hardware was recovered during the postlanding walk-down of runway 33. It was noted that the two pyrotechnic devices on the reefing line cutters had been expended.

The potential identification of debris damage sources for this mission will be based on laboratory analysis of Orbiter postlanding microchemical samples, inspection of the

recovered SRB components, and film analysis. The results will be documented in the STS-90 Debris/Ice/TPS Assessment and Integrated Photographic Analysis Report.

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2796.3	196.2	-3.18	N/A
Nose gear touchdown	6108.8	148.6	N/A	-5.04
Brake initiation speed		88.3 knots		
Brake-on time		26.74 seconds		
Rollout distance		9769.3 feet		
Rollout time		71.1 seconds		
Runway		15 (Concrete) KSC		
Orbiter weight at landing		216635 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	717.9	Left-hand inboard	14.99	
Left-hand inboard 3	717.9			
Left-hand outboard 2	652.5	Left-hand outboard	10.78	
Left-hand outboard 4	652.5			
Right-hand inboard 1	671.4	Right-hand inboard	11.68	
Right-hand inboard 3	671.4			
Right-hand outboard 2	572.1	Right-hand outboard	8.93	
Right-hand outboard 4	572.1			

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 higher with metal bluing evident. Material hardness tests will be performed prior to flying these engines again.

Thermal Control Subsystem

The OV-102 thermal control subsystem (TCS) performance was nominal during all phases of the STS-90 mission. All Orbiter subsystem temperatures were maintained within acceptable limits. There were no major TCS failures or anomalies during the STS-90 mission which had significant impact to the mission.

The F5L and F5R forward vernier thrusters both got cold. Due to the high degree of stability of the pure -ZLV -XVV attitude and the bias -ZLV -XVV with a 25-degree starboard roll bias, the forward vernier thruster F5L firings were infrequent. The F5L thruster injector temperatures approached the leak detection lower limit of 130 °F. The

planned primary Neurolab attitude (bias -ZLV -XVV, 25-degree roll bias) was changed to a less-stable attitude (bias -ZLV -XVV, 5-degree negative pitch bias), only during crew sleep periods to promote more frequent firings. The F5R vernier thruster injector temperatures dropped to 130°F during a period of less frequent thruster firing toward the end of the mission, setting off a FDA alarm before the thruster deadband could be collapsed. The thruster was subsequently re-selected and there was no mission impact.

The tire-temperature program calculation indicated that the port tire pressure-inferred temperature (calculated) was approximately 7 °F less than the brake-line temperature sensor used to monitor the main landing gear (MLG) tires on-orbit. It was recommended to add an additional 10 hours of bottom-sun thermal conditioning for the MLG tires to achieve a positive margin at landing on the port MLG tire based on the pressure-inferred (calculated) temperature. The port and starboard MLG brake-line temperatures were approximately 34 °F and 35 °F, respectively, at entry interface, corresponding to pressure-inferred temperatures of approximately 28°F and 35°F, respectively.

Aerothermodynamics

The boundary layer transition was asymmetrical and MADS data showed boundary layer transition from laminar to turbulent flow occurred early with a large transition zone. Data indicate that the transition occurred at Mach 15 and 1047 seconds after entry interface on the fuselage, and between Mach 8 and 11 on the left wing, which also appears to be early. The early transition may have been caused by protruding gap filler in two locations. Acreage heating was higher than normal, and the aft structural temperature was high as well as the aft structural temperature rise data. Also, local heating was normal overall. A slight slumping of the left-hand elevon gap ablator tiles was noted, and one tile will be replaced.

Thermal Protection Subsystem and Windows

The thermal protection subsystem (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was higher than normal based on structural temperature rise data that was almost identical to STS-83. MADS data showed nominal transition occurred 1185 seconds after entry interface and it was asymmetric.

The Orbiter TPS sustained a total of 131 hits (damage sites) of which 20 had a major dimension of 1 inch or larger. The total number of hits and their distribution, shown in the table on the following page, does not include the numerous hits on the base heat shield that are attributed to the SSME vibration/acoustics, exhaust plume recirculation, and the flame arrestment sparkler system.

Based on data from the postflight debris inspection team reports as well as the comparison with statistics from 71 previous flights of similar configuration, the total number of damage sites was slightly greater than average, and the number of damage sites that was 1 inch or larger was average.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	11	76
Upper Surface	3	12
Right Side	0	0
Left Side	1	8
Right OMS Pod	0	5
Left OMS Pod	2	8
Window Area	3	22
Total	20	131

Most of the 76 damage sites on the lower surface was concentrated aft of the nose to the main landing gear wheel wells on both left and right chines with most of the damage occurring on the left side. Virtually no damage occurred on the Orbiter centerline, although there was evidence of flow path on the leading edge tiles of the nose landing gear door and over-temperature of the centerline primary thermal barriers. The damage location pattern follows the same pattern that was observed on STS-86, STS-87, and STS-89. This ET was sanded to a greater degree than previous ETs and this may be the cause of the reduced number of damage sites on the lower surface. The size and depth of the damage sites were comparable to STS-89. The following table presents a comparison of the damage data from the previous four flights.

COMPARISON OF DAMAGE SITE DATA FROM PREVIOUS FOUR FLIGHTS

Parameter	STS-86	STS-87	STS-89	STS-90	Fleet Average
Lower surface total hits	100	244	95	76	83
Lower surface hits > 1 in.	27	109	38	11	13
Longest damage site, in.	7	15	2.8	3.0	N/A
Deepest damage site, in.	0.4	1.5	0.2	0.25	N/A

The largest lower surface tile damage site was located aft of the right-hand main landing gear wheel well. The site measured 4-inches long by 1.25-inches wide by 0.1-inch deep. The deepest lower surface tile damage sites (0.25 inch) were located on the left chine and could have been caused by an impact from the umbilical purge barrier material or by tape flapping in the airstream. At this time, no lower surface tiles will be scrapped due to debris damage.

Tile damage sites around and aft of the LH₂ and LO₂ ET/Orbiter umbilicals were less than usual. The damage that was present was probably caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The usual amounts of tile damage occurred on the base heat shield. The SSME 3 dome mounted heat shield (DMHS) closeout blankets were in excellent condition. However, the blanket panels on SSME 1 were torn or frayed with batting material missing at the 7:00 o'clock position. Also, the SSME 2 blankets were frayed at the 2:00 to 3:00 o'clock location, but no material was missing.

No unusual tile damage was detected on the leading edges of the OMS pods. Several shallow damage sites were observed on the leading edge of the vertical stabilizer. A 1-inch by 1-inch corner down to the substrate was missing from a tile on the right side of the speed brake, but its loss did not appear to be the result of debris impact.

The window 3 and 4 carrier-plate tiles had minor damages. Hazing and streaking of forward-facing Orbiter windows was moderate to heavy. Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The overall performance of the Government furnished equipment/flight crew equipment (GFE/FCE) was satisfactory. Three minor problems are discussed in the following paragraphs.

During the set-up of a camcorder in preparation for a Public Affairs event, the camera failed to power up while connected to a video interface unit (VIU) by a standard camcorder video/power cable. The camcorder was then powered by a battery, and the event was completed nominally. The crew reported that they had isolated the failure to the VIU. The failed VIU was identified and stowed. Postflight testing will be performed to determine the cause of the failure.

The crew reported that the video routed from monitor 2 to the TEAC recorder was poor in quality. The video quality improved when the crew manipulated the blue cable connector on the recorder. When the video problem occurred, the crew used a camcorder in the Spacelab as a recording device for a data take. The original configuration was restored and used with the camcorder configuration remaining as a backup, should future problems have occurred. A postflight inspection of the cable will be performed during the turnaround operations.

The crew reported that monitor 1 on the aft flight deck was exhibiting jittering video. The crew checked the cable and pulled on the blue cable. The crew reported that the cable pulled out about one inch, and the video returned to normal. A postflight inspection of the cable will be performed during turnaround operations.

CARGO INTEGRATION

Integration hardware performance was nominal throughout the mission with no anomalies or other issues identified.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

DEVELOPMENT TEST OBJECTIVES

DTO 623 - Cabin Air Monitoring - All of the scheduled activities were performed with no problems noted. The data have been given to the sponsor of the Development Test Objective (DTO). The results of the analysis will be reported in separate documentation.

DTO 667 - Portable In-Flight Landing Operations Trainer - The Portable In-Flight Landing Operations Trainer (PILOT) was used during the mission by both the Commander and Pilot. No problems were noted.

DTO 700-16 - S-Band Sequential Still Video Demonstration - Downlink data were recorded in both the high-data-rate mode and the low-data-rate mode. The operations in both modes required a flight rule change, which was made so that more data than planned were recorded.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 331 - The Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion - The launch and entry suits as well as the associated instrumentation were donned and data were recorded during the mission. These data have been given to the sponsor for evaluation. The results of the evaluation will be published in separate documentation

DSO 497 - Effects of Microgravity on Cell Mediated Immunity and Reaction of Latent Viral Infections - The activities required in support of the DSO were performed as scheduled. These data have been given to the primary investigator for evaluation. The results of the evaluation will be reported in separate documentation.

DSO 904 - Assessment of Human Factors (Configuration A) - The activities required in support of the DSO were performed as scheduled. These data have been given to the primary investigator for evaluation. The results of the evaluation will be reported in separate documentation.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Launch Pad Cameras

A total of 43 films and 38 videos of the launch phase were reviewed and evaluated for anomalous conditions that might have an effect on landing. None of the photography or video revealed any anomalous conditions.

Vibration from the SRB exhaust plume caused a white 4-ft by 4-ft board to become dislodged from the top of the hammerhead crane machine room of the pad. The board slid down a curved wall, landed temporarily on the top level of the fixed service structure (FSS), and then fell farther into the microwave antenna area before being obscured by the smoke. The vehicle was well clear of the tower, and the loose board was not a threat to the flight hardware.

A small 4-inch bat was noted clinging to the ET foam on the -Z side of the ET, and it was still present and attached after the vehicle had cleared the tower and begun its roll maneuver.

Umbilical Well Cameras

The umbilical well cameras provided the expected coverage of the SRB and ET; however, the focus on the 16 mm camera with the 5 mm lens was somewhat soft. The lighting was very good once the Orbiter shadow had passed. No damage was noted on either ET/Orbiter umbilical. The SRB separation appeared nominal. The wide-angle LH₂ umbilical well camera provided a view of both SRB forward skirts/frustums/nose caps during separation. The nose caps, which are not recovered, were intact and in good condition.

The ET separation was nominal. No venting from the ground umbilical carrier plate (GUCP)/intertank area was observed in the two films. No divots were detected in the LO₂ and LH₂ tank acreage.

The +Z side of the intertank was in good condition. Heating from the shock waves left black marks on the intertank acreage. These marks have not been so pronounced on previous tanks and may have been more visible because of the sanded foam acreage.

A 6-inch diameter divot was centered between the bipods in the LH₂ tank-to-intertank flange closeout. Also, three divots (two that were 4 to 6 inches in diameter and one that was 10 inches in diameter) were visible in the flange closeout -Y+Z quadrant along with one 3-inch diameter divot in the +Y+Z quadrant. None of the divots were deep enough to show the primed substrate.

The 35 mm camera images were very well focused and the lighting was excellent. The evaluation of those images showed the ET nose cone and ogive had experienced ascent heating. Thin layers of foam from the machined area between the top-coated area of the nose cone to the as-sprayed area on the LO₂ tank ogive (on both the +Y and

-Y sides of the pressurization line/cable tray) had charred and flaked off in a pattern that was similar to that typically observed on the aft surfaces of the vertical struts. The charred foam loss left bright areas of underlying foam exposed. However, in two or three cases, the thin layers of lost foam appeared to be deeper almost to the point of being very small divots. Signs of ascent heating on the ogive were visible as scorch marks and wide-spread small divots close to the +Z axis in the area from the nose cone aft to approximately the XT-480 point on the tank.

Two divots in the -Y+Z quadrant of the LH₂ tank-to-intertank flange closeout were deep enough to expose substrate. A small portion of the +Y thrust panel was visible and very small shallow areas of thermal protection system (TPS) were missing from stringer heads.

Both the +Y and -Y thrust struts exhibited typical ascent erosion and very small divoting. A divot that was 4 inches in diameter was noted on the aft surface of the -Y vertical strut and it was deep enough to show the underlying super light ablator (SLA).

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

The crew operated the hand-held video camera to provide coverage of the ET after separation. The down-linked video, which had good resolution and lighting, did not reveal any anomalous conditions. Aside from the dark discoloration caused by shock wave heating effects and booster separation motor (BSM) burn scars, of which both were expected, no divots were detected on the -Y thrust panel. Two shallow divots (4 to 6-inch diameter) could be seen where the +Y thrust panel interfaces with the first +Z side intertank stringer.

Thirty-eight good quality hand-held camera images of the STS-90 ET were acquired after vehicle separation using a 35 mm Nikon camera and a 400 mm lens. The views of the ET were of excellent quality and showed the entire tank surface. No obvious damage to the ET, including the thrust panels, was noted during the review of the images. The most significant findings from the photographs are as follows:

- a. The "pencil-sharpened" just aft of the nose cone had a mottled appearance, most probably the result of a combination of shedding of charred TPS and topcoat material and some surface "popcorning".
- b. No evidence was noted of widespread material loss from the thrust panels as experienced on STS-87. However, small areas of material loss could not be ruled out and probably did occur on the +Y thrust panel.
- c. There were four or five locations on the intertank-to-LH₂ splice closeout where divots were visible. One of the locations was centered between the bipods, of which three or four were in the -Y/+Z quadrant and one was on the +Y/+Z areas just forward of the closeout.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Twelve videos and ten films of the early afternoon landing at the KSC Shuttle Landing Facility were taken. The landing appeared harder than normal. A sink-rate analysis of the main landing gear was performed and it showed a sink-rate of 6.7 ft/sec. The drag chute deployment also appeared to be normal.

TABLE I.- STS-90 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	107:18:14:08.736 107:18:14:10.430 107:18:14:12.026
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	107:18:18:32.108 107:18:18:32.268 107:18:18:32.428 107:18:18:32.588
Main Propulsion System Start ^a	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	107:18:18:53.435 107:18:18:53.554 107:18:18:53.669
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	107:18:18:59.988
Throttle up to 104 Percent Thrust ^a	ME-1 Command accepted ME-3 Command accepted ME-2 Command accepted	107:18:19:04.229 107:18:19:04.235 107:18:19:04.235
Throttle down to 69 Percent Thrust ^a	ME-1 Command accepted ME-2 Command accepted ME-3 Command accepted	107:18:19:29.190 107:18:19:29.195 107:18:19:29.196
Throttle up to 104 Percent ^a	ME-1 Command accepted ME-3 Command accepted ME-2 Command accepted	107:18:19:55.430 107:18:19:55.436 107:18:19:55.436
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	107:18:20:05
Both RSRM's Chamber Pressure at 50 psi ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	107:18:20:59.908 107:18:21:00.508
End RSRM ^a Action ^a Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	107:18:21:02.818 107:18:21:03.008
SRB Physical Separation ^a	LH rate APU B turbine speed - LOS	107:18 21:05.108
SRB Separation Command	SRB separation command flag	107:18:21:05
OMS Assist Maneuver Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	107:18:21:15.3 107:18:21:15.4
OMS Assist Maneuver Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	107:18:22:57.8 107:18:22:57.9
Throttle Down for 3g Acceleration ^a	ME-1 command accepted ME-3 command accepted ME-2 command accepted	107:18:26:27.917 107:18:26:27.923 107:18:26:27.926
3g Acceleration	Total load factor	107:18:26:33.7
Throttle Down to 67 Percent Thrust ^a	ME-1 command accepted ME-3 command accepted ME-2 command accepted	107:18:27:21.678 107:18:27:21.684 107:18:27:21.687
SSME Shutdown ^a	ME-1 command accepted ME-3 command accepted ME-2 command accepted	107:18:27:27.998 107:18:27:28.004 107:18:27:28.007
MECO	MECO command flag MECO confirm flag	107:18:27:28 107:18:27:29

^aMSFC supplied data

**TABLE I.- STS-90 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
ET Separation	ET separation command flag	107:18:27:48
APU Deactivation	APU-3 GG chamber pressure APU 1 GG chamber pressure APU 3 GG chamber pressure	107:18:32:05.093 107:18:34:28.476 107:18:34:36.721
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	107:19:00:27.4 107:19:00:27.5
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	107:19:02:18.0 107:19:02:18.1
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	107:19:54:46 107:19:56:07
Flight Control System Checkout APU 3 Start APU 3 Stop	APU 3 GG chamber pressure APU 3 GG chamber pressure	122:12:13:12.363 122:12:23:20.843
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	123:12:30:53 123:12:34:36
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	123:15:05:13.748 123:15:25:31.904 123:16:02:35.502
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	123:15:10:10.2 123:15:10:10.2
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	123:15:12:29.4 123:15:12:29:6
Entry Interface (400K feet)	Current orbital altitude above	123:15:37:14
Terminal Area Energy Mgmt.	Major mode change (305)	123:16:02:42
Main Landing Gear Contact	LH main landing gear tire pressure 2 RH main landing gear tire pressure 2	123:16:08:59 123:16:08:59
Main Landing Gear Weight on Wheels	RH main landing gear weight on wheels LH main landing gear weight on wheels	123:16:08:59 123:16:08:59
Drag Chute Deployment	Drag chute deploy 1 CP volts	123:16:09:06.2
Nose Landing Gear Contact	NLG LH tire pressure 1	123:16:09:12
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	123:16:09:13
Drag Chute Jettison	Drag chute jettison 1 CP Volts	123:16:09:37.0
Wheel Stop	Velocity with respect to runway	123:16:09:57
APU Deactivation	APU-3 GG chamber pressure APU-1 GG chamber pressure APU-2 GG chamber pressure	123:16:11:28.822 123:16:25:47.746 123:16:25:58.111

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

No.	Title	Reference	Comments
STS-90-V-01	Network Signal Processor (NSP) 2 Failure	106:06:19 G.m.t. CAR KB3991 Prelaunch IPR 90V-0002	During the countdown on April 16, 1998, shortly before ET tanking, NSP 2 failed to acquire frame synchronization during the switch from NSP 1 to NSP 2. The downlink was not impacted by this problem. The system was cycled from NSP 1 to NSP 2 nine times through several modes. Each time NSP 1 operated correctly, but NSP 2 did not. Uplink communications with NSP 2 could not be established. NSP 2 was removed and replaced with NSP 2 from the OV-105 vehicle. OMRSD File III retest requirements, which could not be performed following the NSP 2 replacement on the pad, will be performed during the STS-93 flow. Failure analysis of the NSP was performed at the manufacturer.
STS-90-V-02	Space Shuttle Main Engine (SSME) 1 LH ₂ Inlet Pressure Shifted Up.	107:18:22:30 G.m.t. 00:00:03:30 MET CAR 90RF01 IPR 93V-0004	The SSME 1 liquid hydrogen (LH ₂) inlet pressure shifted upward about 3 to 4 psia at approximately 107:18:22:30 G.m.t. (00:00:03:30 MET). Similar signatures have been observed on previous flights of other Orbiter vehicles. This measurement is primarily used for engineering data during loading of liquid hydrogen. However, it is also used during ascent in the event of a premature engine shutdown to determine if an LH ₂ dump can be performed through that engine. As a result, this measurement is listed as criticality 1R2 for aborts. There was no impact to the remainder of the flight. KSC: Troubleshooting and replacement of the transducer.
STS-90-V-03	RCRS Shutdown	115:03:49:46 G.m.t. 07:09:30:46 MET CAR 90RF03 IPR 93V-0013	At approximately 115:03:49:46 G.m.t. (07:09:30:46 MET), the RCRS shut down while on controller 2. The crew reconfigured the RCRS to controller 1, but it too shut down. The crew was told to use LiOH canisters for carbon dioxide removal during their upcoming sleep period. Flight data were reviewed and a fault tree was developed to investigate the cause of the shutdown. An in-flight maintenance (IFM) procedure was subsequently developed to recover usage of the RCRS. The IFM isolated a check valve which was believed to be leaking cabin air into the RCRS. The isolation was regained by disconnecting the outlet hose from the check valve and covering the fitting with aluminum tape. In addition, power was removed from the compressor since it is in the flow path blocked by the procedure. Following the IFM, the RCRS was activated at 115:20:43 G.m.t. (08:02:24 MET) using controller 1. The RCRS performance was as expected in light of the IFM modifications. The loss of the RCRS ullage-save operation that resulted from the compressor being unpowered had no mission impact. KSC: The RCRS will be removed from the vehicle and shipped to the vendor for repair. The RCRS is not flown on STS-93, the next flight of this vehicle.
STS-90-V-04	Flash Evaporator System (FES) Shutdowns	111:02:06 G.m.t. 03:04:47 MET CAR 90RF04 IPR 93V-0012	The FES primary A controller shut down at approximately 111:02:06 G.m.t. At that time, the FES inlet temperatures were averaging approximately 48 °F. The crew restarted the FES primary A controller four minutes after the shut down occurred. The restart was successful, and the FES went into standby at 111:02:35 G.m.t. (03:08:16 MET); however, the FES failed to come out of the standby mode. At 111:03:13 G.m.t. (03:08:54 MET), the crew switched from the primary A controller to the primary B controller.

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

No.	Title	Reference	Comments
STS-90-V-05	Waste Water Dump Failure	119:21:21 G.m.t 012:03:02 MET CAR 90RF05 IPR 93V-0010	<p>The FES gained control for nine minutes on the primary B controller and then shut down. The FES core flush procedure was implemented. After the flush procedure was completed, the FES primary B controller successfully restarted. The FES topping duct heaters were placed on heater string A/B for the duration of the upcoming sleep period, after which the heaters were reconfigured to string A. The FES operated normally on the A controller, and also on the primary B controller during entry.</p> <p>It is believed that the most probable cause of the shut-down was a rapid FES heat-load transient that occurred while in the -ZLV +YVV (top-to-Earth local vertical, starboard wing on the velocity vector) water-dump attitude. The FES heat load approached 30,000 Btu/hr, the on-orbit Shuttle Operational Data Book (SODB) limit, and dropped off rapidly. This transient resulted in the formation of ice in the FES topper core, and this eventually lead to the shut-down. Note that the FES is certified to handle a transient of the magnitude seen. The Orbiter water-dump attitudes were changed from -ZLV +YVV to +ZLV +YVV (bottom to Earth local vertical, starboard wing on the velocity vector) to preclude the thermal condition that was believed to cause the FES shut down. Also, a planned 14-hour period of -ZLV +YVV attitude near the end of the mission was modified to preclude further FES problems.</p> <p>A FES primary A controller water dump test was begun at 122:15:33 G.m.t. (14:21:14 MET), and the dump lasted for 2 hours 7 minutes. There was no indication of water carry-over in the core or icing during the dump. A FES core-flush procedure was performed as a safeguard following the completion of the dump. Again, there was no indications of icing. Postflight testing and checks of the water will be performed during the postflight turnaround operations</p> <p>During a waste water dump, the dump rate declined from about 2-percent/minute (normal) to about 0.5 percent/minute, while the nozzle temperatures remained relatively constant (about 75 °F). The dump was stopped and a nozzle bake-out was performed. During the bake-out, the temperature signature did not appear to indicate ice on the nozzle. The dump was re-initiated and the dump rate remained at about 0.5 percent/minute.</p> <p>An IFM procedure was performed at 120:15:08 G.m.t. (12:20:49 MET) to bypass a potentially clogged urine solids filter located in the waste water dump line. The initial dump rates appeared normal (1.73 percent/minute; however, at 120:15:19 G.m.t. (12:21:00 MET), the dump rate decreased to near zero. The dump was stopped and the dump nozzle bake out was performed. An additional 17 percent of quantity was dumped before the dump was stopped. A second cycle was attempted with no corresponding change in tank quantity. A bake out of the supply and waste water dump nozzles was initiated to determine if ice was present on either of the dump problems. No ice was indicated.</p> <p>In an effort to further confirm the lack of ice on the supply and waste dump nozzles, the Orbiter was placed into a +ZLV, +YVV water-dump attitude for two orbits. The nozzle temperature profiles in response to</p>

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

No.	Title	Reference	Comments
STS-90-V-05 (Continued)	Waste Water Dump Failure	119:21:21 G.m.t 012:03:02 MET CAR 90RF05 IPR 93V-0010	<p>environmental heating were then compared to those under similar conditions earlier in the flight and prior to the dump problems. Again, no evidence of ice was indicated.</p> <p>At approximately 122:10:40 G.m.t. (014:16:21 MET), waste water was transferred from the waste tank to a contingency water container (CWC) to create enough ullage in the tank to support the end-of-mission plus two contingency day requirements. The transfer was nominal.</p> <p>A troubleshooting plan for the contingency dump/collection hardware and the vehicle hardware was prepared. The plan includes visual inspections, the taking of samples for chemical and particulate analysis, flow testing, and a leak test.</p>
STS-90-V-06	Water Spray Boiler (WSB) 3 Failed to Cool	107:18:30 G.m.t. 00:00:11 MET 90RF02 IPR 93V-0009	<p>Water spray boiler (WSB) 3 experienced an under-cooling condition during ascent.</p> <p>The WSB 3 controller was switched from A to B at 107:18:30:46 G.m.t. (00:00:11:46 MET) when the auxiliary power unit (APU) 3 lubrication oil return temperature was approximately 300 °F. No spray cooling was observed at that time. The lubrication oil return temperature reached 334 °F when APU 3 was shut down. The specification value for this temperature is no-greater-than 275 °F (Flight Problem STS-90-V-06). APU 3 was shut down at 107:18:32:12 G.m.t. (00:00:13:12 MET), which was approximately 2 minutes earlier than planned. Data review indicates no spraying was achieved during the operation of either WSB 3 controller.</p> <p>The lack of cooling as well as under-cooling conditions have occurred previously during ascent on this and other WSBs. This behavior is believed to be caused by ice forming on the WSB spray bars. As a result, APU 3 was run for FCS checkout to verify satisfactory WSB 3 operation. Spraying was not seen on either the WSB A or B controllers. During entry, APU 3 was started at the terminal area energy management (TAEM) point and was configured to operate on the B controller. No spraying was seen during entry, and APU 3 was shut down 2 minutes 28 seconds after landing when the lubrication oil return temperature reached the FDA limit of 290 °F. Troubleshooting will include a visual inspection plus checkout of the WSB components.</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-90 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.

ADTA	air data transducer assembly
AEM	animal enclosure module
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
BDS-04	Bioreactor Demonstration System -04
BFS	backup flight system
BOTEX	Botany Experiment
BRD	Body Rotating Device
BSM	booster separation motor
BSTC	biotechnology specimen temperature controller
CCTV	closed circuit television
CDE	Collisions in Dust Experiment
CEBAS	Closed Equilibrium Biological Aquatic System
CEI	contract end item
CNS	central nervous system
COG	cognitive performance testing
CORE	core body temperature
CPM	cell performance monitor
CWC	contingency water container
dBm	decibel per meter
DMHS	dome-mounted heat shield
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔV	differential velocity
ECLSS	Environmental Control and Life Support System
e.d.t.	eastern daylight time
EGT	exhaust gas temperature
EI	entry interface
EO	ET/Orbiter
EPDC	electrical power distribution and control
ET	External Tank
EVA	extravehicular activity
FCE	flight crew equipment
FCL	Freon coolant loop
FCMS	fuel cell performance monitoring system
FCP	fuel cell powerplant
FCS	flight control system
FDA	fault detection and annunciation
FES	flash evaporator system
FPV	flow proportioning valve
FSS	fixed service structure
ft/sec	feet per second

g	gravity
GAS	Get-Away Special
GASMAP	Gas Analyzer System for Metabolic Analysis Physiology
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
GSFC	Goddard Space Flight Center
GUCP	ground umbilical carrier plate
H ₂	hydrogen
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
IFM	in-flight maintenance
I _{sp}	specific impulse
JSC	Lyndon B. Johnson Space Center
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lb	pound
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LH ₂	liquid hydrogen
LiOH	lithium hydroxide
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO ₂	liquid oxygen
MADS	modular auxiliary data system
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MET	mission elapsed time
MLG	main landing gear
MOD	Mission Operations Directorate
MPS	main propulsion system
MSBLS	microwave scanning beam landing system
MSFC	Marshall Space Flight Center
mV	millivolts
NASA	National Aeronautics and Space Administration
NEUROLAB	Neurological Laboratory
nmi.	nautical mile
NPSP	net positive suction pressure
NSP	network signal processor
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O ₂	oxygen
OM	ozone measurements
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
PAL	protuberance air load

PASS	primary avionics software system
PCAM	Protein Crystallization Apparatus for Microgravity
PCBA	Portable Clinical Blood Analyzer
PFT	Pulmonary Function Test
PGSC	payload general support computer
PI	Principal Investigator
PILOT	Portable In-flight Landing Operations Trainer
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution
psia	pound per square inch absolute
RAHS	research animal holding facility
RCRS	regenerative carbon dioxide removal system
RCS	reaction control subsystem
RF	radio frequency
RM	redundancy management
RPC	remote power controller
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTV	room temperature vulcanizing (material)
S&A	safe and arm
scch	standard cubic centimeters per hour
SITE	
SLA	super lightweight ablator
SLF	Shuttle Landing Facility
S/N	serial number
SODB	Shuttle Operational Data Book
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
SVF	Shuttle Vibration Forces
TACAN	Tactical Air Navigation
TAEM	terminal area energy management
TCS	thermal control subsystem
TPS	thermal protection system/subsystem
VCF	Visuo-Motor Coordination Facility
Vdc	Volts direct current
VEG	Virtual Environment Generator
VFEU	Vestibular Function Experiment Unit
VIU	video interface unit
VVIS	Visual and Vestibular Investigation System
WCS	Waste Collection System
WSB	water spray boiler