

STS-94 SPACE SHUTTLE MISSION REPORT

September 1997



**National Aeronautics and
Space Administration**

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

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STS-94
SPACE SHUTTLE
MISSION REPORT

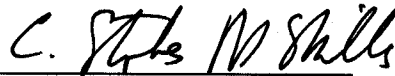
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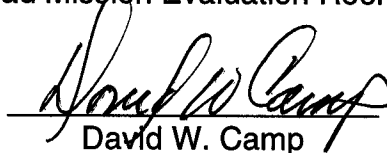
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INTRODUCTION

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-94 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 eighty-fifth mission of the Space Shuttle Program. STS-94 was the sixtieth flight since the return to flight, and the twenty-third flight of the OV-102 (Columbia) Orbiter vehicle.

The flight vehicle consisted of the OV-102 Orbiter; an ET that was designated ET-86; three SSMEs that were designated as serial numbers (S/N) 2041 (Block 1), 2034 (Phase II), and 2033 (Phase II) in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-088. The two RSRMs were designated RSRM 62 with one installed in each SRB. The individual RSRMs were designated 360T062A for the left SRB, and 360T062B for the right SRB.

The STS-94 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-94 flight was to successfully perform the planned operations of the First Microgravity Science Laboratory (MSL-1). The Orbital Acceleration Research Experiment (OARE) provided supplementary data for the MSL-1 microgravity experiments. Secondary objectives of this flight were to perform the operations of the Cryogenic Flexible Diode Experiment (CRYOFD); perform the requirements of the Shuttle Amateur Radio Experiment-II (SAREX-II); and as a payload of opportunity, perform the requirements of the Midcourse Space Experiment (MSX).

The STS-94 mission was a planned 16-day plus 2-contingency-day mission during which experiments were to be conducted in the MSL-1. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. The STS-94 sequence of events is shown in Table I, the Orbiter and Government Furnished Equipment/Flight Crew Equipment In-Flight Anomaly List in Table II, and the Kennedy Space Center In-Flight Anomaly List in Table III. 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-94 mission consisted of James Halsell, Jr., Lt. Col., United States Air Force, Commander; Susan Leigh Still, Lt. Cdr., United States Navy, Pilot; Janice Voss, Ph. D., Civilian, Payload Commander/Mission Specialist 1; Michael L. Gernhardt, Ph. D., Civilian, Mission Specialist 2; Donald A. Thomas, Ph. D., Civilian, Mission Specialist 3; Roger K. Crouch, Ph. D., Civilian, Payload Specialist 1; and Gregory T. Linteris, Ph. D., Civilian, Payload Specialist 2. STS-94 was the fourth space flight for the Commander, Mission Specialist 1 and Mission Specialist 2; the third space flight for Mission Specialist 3; and the second space flight for the Pilot, Payload Specialist 1 and Payload Specialist 2.

MISSION SUMMARY

During prelaunch operations following the start-up of fuel cell 1, a high pH indication was noted on the fuel cell 1 conductivity sensor for 17 minutes beginning at 182:04:16 G.m.t. No corresponding high pH indication was present from the common pH sensor. This indication on fuel cell 1 was not unusual considering that it was a new fuel cell. The high pH reading was caused by a trace of residual potassium hydroxide (KOH) solution or metallic ions being flushed out as the fuel cell began to produce water.

The STS-94 mission was launched on an inclination of 28.45 degrees at 182:18:01:59.993 G.m.t. (2:02 p.m. e.d.t.). The launch was delayed for 12 minutes because of unacceptable weather conditions in the launch area should a return-to-launch-site (RTLS) abort be required. The ascent was nominal. Performance of the SSMEs, ET, and main propulsion system (MPS) was normal. All SSME and RSRM start sequences occurred as expected, and the launch phase as well as first stage performance was nominal in all respects. SRB separation, entry, deceleration, and water impact occurred as anticipated. Both SRBs were successfully recovered and returned to Kennedy Space Center (KSC) for disassembly and refurbishment. During the disassembly process, a fastener was missing on the aft side to the right-hand ET attachment (ETA) ring bolt adjacent to the diagonal strut (Flight Problem KSC-94-01). The cause of this anomaly was still under investigation as this report was published.

A determination of the vehicle propulsive performance during ascent was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine I_{sp} determined for the time period between SRB separation and start of 3g throttling was 452.6 seconds as compared to the MPS tag value of 452.31 seconds.

The direct insertion ascent trajectory resulted in the orbital maneuvering subsystem (OMS) 1 maneuver not being required. The OMS 2 maneuver was satisfactorily performed at 182:18:41:52.9 G.m.t. (00:00:39:52.9 MET). The maneuver was 142.8 seconds in duration and the resulting differential velocity (ΔV) was 221.7 ft/sec.

Opening of the payload bay doors was completed normally at 182:19:38:44 G.m.t. (01:36:44 MET). Nominal dual-motor times were recorded for the door operation.

On two of the three previous flights (STS-78 and STS-83) of this Orbiter (OV-102), the flash evaporator system (FES) high-load duct temperatures dropped off sharply during ascent while using the system A high-load duct heater. As a result, STS-94 was launched with both the system A and B high-load duct heaters activated. During ascent, the inboard duct temperature dropped to 175 °F by 182:18:14 G.m.t. (00:00:12 MET) (Flight Problem

STS-94-V-01). The temperature normally remains above 190 °F with only one heater activated. Throughout the occurrence, the evaporator outlet temperatures were stable. It is suspected that excess water carryover was the cause of the duct-temperature drop. Postflight troubleshooting found no abnormality. Both primary A and B spray valves were replaced prior to STS-80, and the FES duct temperature response has been abnormal since that mission. A decision has been made for STS-87 to be flown using the primary B controller and spray valve since all previous ascents have been flown with the FES primary A controller and spray valve.

A review of postlaunch data showed that the fuel cell 3 substack 2 cell performance monitor (CPM) measurement increased 32 mV in 23 minutes, from 2 mV at 182:18:36 G.m.t. (00:00:34 MET) to 34 mV at 182:18:59 G.m.t. (00:00:57 MET) (Flight Problem STS-94-V-02). STS-94 is the fifth flight of this fuel cell. On the previous four flights, the substack 2 CPM measurement remained between 2 and 10 mV. The fuel-cell-contractor documentation shows that a failure in the CPM of resistor R115 would result in an output of approximately 37 mV. The increase to the 37 mV range after four flights in a lower range presented the possibility of a failed CPM resistor. The measurement appeared to have some sensitivity to purges, a response typical for a CPM measurement that was functioning properly. The potential still existed for this channel to be failed. The overall performance of all of the fuel cells remained nominal for the rest of the mission.

At 189:15:54 G.m.t. (06:21:52 MET), the aerosurface servo amplifier (ASA) 4 power-on command-C switch-scan measurement and the associated remote power controller (RPC) output discrete measurement went from on to off, indicating loss of redundant power to ASA 4 (Flight Problem STS-94-V-03). Approximately two hours later, these discrete measurement values returned to the normal on-state. The measurements then again returned to the off-state approximately 3 ½ hours later.

Initial troubleshooting of the ASA 4 condition was performed by cycling the ascent thrust vector controller (ATVC) 4 power switch to on for about 15 seconds to determine if the flight control system (FCS) channel 4 switch contact was supplying power from control bus CA2 to ASA 4 and the ATVC 4 switch. When the ATVC 4 switch was placed to on, power was transferred properly. At the same time, the ASA 4 power-on command-C and RPC output discrete values both changed to on and remained on after the ATVC 4 switch was taken back to off. These indications continued to be correct for the remainder of the mission. Postflight troubleshooting the turnaround activity identified a loose solder particle within the ATVC 4 switch as the most probable cause of this condition.

The FCS checkout was performed using auxiliary power unit (APU) 1. The APU and hydraulics subsystems performed nominally during the checkout. APU 1 was started at 197:07:16 G.m.t. (013:13:14 MET) and ran for 6 minutes 20 seconds. The fuel consumption during this run was 19 lb. No water spray

boiler operation occurred due to the short APU run time. FCS performance was nominal.

The reaction control subsystem (RCS) hot-fire was initiated at 197:08:07 G.m.t. (014:14:05 MET) and was terminated seven minutes later with satisfactory results. During the hot-fire, all 38 primary thrusters were successfully fired for two pulses each.

In preparation for landing, the payload bay doors were closed and latched at 198:07:04:59 G.m.t. (15:13:02:59 MET). Nominal dual motor times were observed. The dual-engine deorbit maneuver for the landing at the Shuttle Landing Facility (SLF) runway 33 was performed on orbit 250 at 198:09:43:45.0 G.m.t. (15:15:41:45.0 MET). The maneuver was 180.6 seconds in duration with a ΔV of 298.6 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on KSC concrete runway 33 at 198:10:46:36 G.m.t. (15:16:44:36 MET) on July 16, 1997. The Orbiter drag chute was deployed at 198:10:46:37 G.m.t. and the nose gear touchdown occurred 8 seconds later. The drag chute was jettisoned at 198:10:47:12 G.m.t. with wheels stop occurring at 198:10:47:31 G.m.t. The rollout was normal in all respects. The flight duration was 15 days 10 hours 44 minutes 36 seconds. The APUs were shut down 16 minutes 42 seconds after landing.

PAYLOADS

The primary payload was the Microgravity Science Laboratory -1 (MSL-1), which was a collection of microgravity experiments housed in a European Spacelab long module. The MSL featured 19 materials science investigations in five major facilities. These facilities were the Large Isothermal Furnace, the Expedite the Processing of Experiments to the Space Station (EXPRESS) rack; the Electromagnetic Containerless Processing Facility (TEMPUS); the Coarsening in Solid-Liquid Mixtures (CSLM) facility; and the Combustion Module-1 facility. Additional technology experiments were also to be performed in the Middeck Glovebox (MGBX), using the High-Packed Digital Television (HI-PAC DTV) system for multi-channel real-time analog science video.

Experiments that measured microgravity included the Space Acceleration Measurement System (SAMS), the Microgravity Measurement Assembly (MMA), the Quasi-Steady Acceleration Measurement (QSAM) and the Orbital Acceleration Research Experiment (OARE).

The MGBX facility supported the Bubble and Drop Nonlinear Dynamics (BDND) Experiment, the Study of the Fundamental Operation of a Capillary-driven Heat Transfer (CHT) Device in the Microgravity Experiment, the Internal Flows in a Free Drop (IFFD) Experiment, and the Fiber Supported Droplet Combustion (FSDC) Experiment.

SPACELAB SYSTEMS OPERATION

Space Station EXPRESS Rack

The Space Station EXPRESS rack hardware operated nominally except for the communication/telemetry problem that was present for a period of time. Data collection was restored with the successful recycling of the rack interface controller and the re-establishment of commanding capabilities to Physics of Hard Spheres Experiment (PHaSE).

The EXPRESS rack facility experienced intermittent and erroneous data for subsystems housekeeping data, and the data and command interfaces for the PHaSE and ASTRO/Plant Generic Bioprocessing Apparatus (PGBA) experiments were not available. Malfunction procedures were performed by the crew to determine the cause of the rack interface controller (RIC) high temperature measurements. A power cycle of the RIC restored the command and data capability for the experiments, but housekeeping data could not be recovered and was transmitted to the ground by the crew.

In accordance with the nominal mission plan for approximately two days mission elapsed time, the crew removed the ASTRO/PGBA double-locker from the Orbiter middeck location (MF28K/M) and moved the double locker to the

Spacelab Express Rack. Two lockers that were removed from the Spacelab were then moved to the MF28K and MF28M positions on the Orbiter middeck. When installing one of the lockers in the MF28K position, the crew reported that the Spacelab locker installation/removal tool would turn in both directions but could not be removed from the lower port fastener. This was caused by the Spacelab tool being of a slightly different design than the Orbiter tool. When the crew tried to force the tool out of the retainer, the retainer housing broke off. The fastener is a Milson fastener that has a retainer that captures a spring-loaded sleeve bolt. By removing an adjacent locker, the crew was able to verify that the barrel nut on the wire tray at the lower-left fastener location of the locker in the MF28K position was not damaged.

At 196:14:30 G.m.t. (13:20:27 MET) the crew successfully transferred the ASTRO/PGBA payload from the Spacelab module back to the mid-deck locker position that the payload occupied for ascent. Using the Orbiter locker installation/removal tool, the crew reported no problems in engaging and torquing any of the fasteners on either the ASTRO/PGBA or the two middeck lockers that were transferred to the Spacelab module.

Spacelab Command and Data Management System

Three experiment computer operating system (ECOS) hang-ups were reported. Each had a quick recovery and minimal impact to the payload. Troubleshooting showed that a correlation existed between the ECOS hang-ups and heavy data flow from TEMPUS, Droplet Combustion Experiment (DCE), and CM-1 when running concurrently. An ECOS software patch was developed to correct a buffer allocation anomaly. The patch was successfully uplinked and installed; no subsequent recurrence of the anomaly was noted during the remainder of the mission.

Mission Peculiar Equipment

The Hi-PAC DTV system performed very well and provided downlink of up to six simultaneous video channels.

Spacelab Electrical Power Distribution

The Spacelab electrical power distribution system performed satisfactorily throughout the mission.

Spacelab Environmental Control

The Orbiter flow proportioning valves were configured to the payload/payload orientation at 184:08:49:00 G.m.t. (01:14:47 MET). This reconfiguration occurred later than normal for a Spacelab mission; however, it was necessary so that more cooling could be provided to the warm cabin that resulted from a day-time summer launch.

COMBUSTION SCIENCE RESULTS

Two investigations were conducted using the combustion module in the Spacelab. The investigations were the Laminar Soot Processes (LSP), and the Structure of Flame Balls at Low Lewis-number (SOFBALL). These investigations provided data for use in the theoretical models of combustion. In addition, a Droplet Combustion Apparatus was flown for the conduct of one experiment - Droplet Combustion Experiment. The experiment results will have a direct impact on spacecraft fire safety, and the theories predicting the formation of soot, which is a major factor as a pollutant as well as in the spread of unwanted fires.

Laminar Soot Processes

The principle investigators received data from the onboard LSP experiment on the properties of soot and its production process, important factors in diffusion flames. Experiment investigators were "amazed and surprised" by the flame height and reported that these results were unlike anything achieved in aircraft or drop-tower tests.

A new mechanism of flame extinction caused by radiation from soot was discovered. In addition, the non-buoyant flames were about twice as large as ground-based flames under similar conditions, and the flames emitted soot sooner than expected. A total of 19 LSP test points were completed and only 14 were planned.

Structure of Flame Balls at Low Lewis-Number

The SOFBALL experiment showed that many flame-balls were formed providing the weakest flames ever burned either in space or on the ground, as well as the longest burning flames ever in space (500 seconds). Flame-ball powers were as low as one watt. Test results will provide new data for models of weak combustion processes needed to develop cleaner, more efficient internal combustion engines. A total of 16 SOFBALL test points and 10 reburns were completed with only 15 test points planned.

Droplet Combustion Experiment

The DCE experiment results are expected to improve the fundamental understanding of the behavior of fuel droplet combustion, which may help make the combustion of fossil fuels cleaner and more efficient. All 25 cartridges were processed as planned. The DCE investigators reported that the boundary line between extinction of larger droplets and diffusive extinction for smaller droplets has been more clearly defined as a result of this experiment.

Investigators completed a test matrix of heptane droplet burns over a range of pressures from one atmosphere to 0.25 atmosphere of helium and oxygen

mixtures in the chamber, and this was the objective of the experiment. In addition, a series of tests were performed with air in the chamber, and the results will be compared with the results of the MGBX Fiber Supported Droplet Combustion-2 (FSDC-2) experiment.

A DCE high-speed camera failure occurred and a film change-out procedure was modified to tighten the screw necessary for proper camera operation.

MATERIALS SCIENCE RESULTS

Physics of Hard Spheres Experiment

The Physics of Hard Spheres Experiment (PHaSE) was used to examine changes to obtain an improved fundamental understanding of the transition of substances from liquids to solids. A total of 85 of the planned 86 measurements were completed. The initial data have shown that these model crystals nucleate and grow faster in space than in the 1-g environment. Also, the time scale for particle movement (diffusion) is considerably different in 1-g than in the low-g environment. Dynamic light-scattering measurements revealed the motions of the individual atoms and spheres that make up the hard spheres. Results show that the spheres vibrate about their equilibrium positions but are constrained within the crystal lattice.

Data gathering was placed on hold for a period of time as a result of the EXPRESS rack communications/telemetry problems. Power to the rack interface controller was recycled and optimal science was regained.

Large Isothermal Furnace

The Large Isothermal Furnace (LIF), sponsored by the Japanese Space Agency, was used to heat large samples of lead-tin-telluride alloys to a temperature of 2912 °F (1,600 °C) and then rapidly cool the samples using a flow of helium. Also processes were to determine self diffusion in tin, silver-chloride in eutectic salts, and dopants in semiconductors. Samples of liquid-phase sintering, a process by which turbine blades are formed, were also processed. The planned processing was completed for all 25 samples, which were divided between six individual experiments. One minor helium leak was corrected by tightening cartridge fittings that interfaced with the LIF helium supply.

a. **Liquid Phase Sintering II:** Data from this experiment were used to test theories about liquid-phase sintering, to examine coarsening and/or coalescence during liquid-phase sintering in the microgravity environment. Experiment runs were processed at temperatures as high as 1500 °F.

b. **Measurement of Diffusion Coefficient by Shear Cell Method:** The

Shear Cell method is an important tool in determining the rate of diffusion in a variety of materials. This test of the shear cell method used tin as its sample material.

c. **Diffusion of Liquid Metals and Alloys:** Data from these samples will help clarify the diffusion mechanism and the atomic transport mechanism in liquid materials, based on the hard-sphere model and other kinetics theories of liquids. This, in turn, will help in the design of metallic alloys and processing techniques.

d. **Diffusion in Liquid Lead-Tin Telluride:** The purpose of this experiment was to determine precisely the liquid diffusion coefficient of lead-tin-telluride, a potential material for infrared detectors and lasers.

e. **Diffusion Process in Molten Semiconductors:** This experiment was designed to determine the samples' diffusion coefficients and their dependence on variables such as temperature, drop size, and impurity type. One of the sample cartridge thermocouple readings was off-nominal and corrected by an in-flight maintenance (IFM) procedure to correctly wire the thermocouple. The processing of the second sample cartridge was eliminated after it caused an early shut-off of the furnace.

f. **Measurement of Impurity Coefficients in Ionic Melts:** Diffusion coefficients provided by this experiment will help investigators improve diffusion theory.

ELECTROMAGNETIC CONTAINERLESS PROCESSING FACILITY

The Electromagnetic Containerless Processing Facility, referred to by its German acronym of TEMPUS, was developed by the German Space Agency. STS-94 was the third flight of the TEMPUS hardware. Eleven individual experiments were performed in this facility during the mission. TEMPUS completed more than 150 hours of containerless processing and this had never been done in previous missions. This mission has demonstrated the great potential of this novel method and facility.

The first measurements were obtained of specific heat and thermal expansion of glass-forming metallic alloys; these measurements have never been done before and are not possible on Earth. More than 120 melting cycles with zirconium were accomplished with a maximum temperature of 2000 °C and under-cooling to -340 °C. The first measurements of viscosity of palladium-silicon alloys were made in the under-cooled liquid alloy and these measurements are not possible on Earth. Investigators completed 21 experiments out of 20 planned. An IFM procedure was successful after several updates to restore a malfunctioning top-view TEMPUS video camera, which developed a problem at the beginning of the mission.

a. **Bayuzick, Zirconium (FO10):** This experiment was designed to determine quantitatively the temperatures of solid nucleation's from melts of pure zirconium, and the number of nucleations at each temperature as the melts are cooled below their equilibrium freezing points.

b. **Johnson, ZrCuNiNbAl (FO4):** This study, using ZrCuNiNbAl was completed during flight day 5. With this experiment, investigators sought to measure thermophysical properties of good glass-forming metallic alloys to allow improvement of process technologies for such materials.

c. **Fecht, ZrA;CuNi (FO6)/ZrAlCuCo (FO8):** The thermophysical properties of Advanced Materials in the Undercooled State experiments were completed, and the purpose of these experiments was to measure the specific heat of under-cooled metallic melts to further the current understanding of how metallic glass forms in zirconium-based alloys.

d. **Johnson, ZrTiNiCu (FO7):** With this experiment, investigators measured thermophysical properties of good glass-forming metallic alloys to allow improvement of process techniques for such materials.

e. **Egry, Pd-Cu-Si (FO24):** This experiment was designed to measure surface tension, viscosity, and electrical conductivity of liquid and under-cooled alloys.

f. **Szekely (FO15):** This experiment was designed to demonstrate a containerless technique for measuring the viscosity and surface tension of reactive and under-cooled liquid metals.

g. **Szekely (FO12):** Sample processing for this experiment was stopped when it was discovered that the sample was contaminated. The (FO15) PdSi sample was substituted.

h. **Flemings (FO13 and FO16):** Measurements of the solidification velocity in steel alloys were completed, thereby helping scientists to understand how welding may be conducted in space.

i. **Herlach, NiC (FO17):** This study of the Morphological Stability of Growing Dendrites experiment sought to verify theoretical predictions of dendritic growth behavior and to study the influence of melt convection on crystal growth velocities of pure nickel and dilute nickel-carbon alloy melts.

j. **Zirconium (FO99):** Zirconium sample processing is expected to provide more data on contamination and facility operations for this unique furnace.

k. **Holland-Moritz, AlCuCo (FO11):** This experiment was intended to investigate the maximum undercoolability and temperature dependence of the specific heat of melts of certain quasicrystal-forming alloys.

BIOTECHNOLOGY RESULTS

Four crystal and plant growth experiments, all of which were unattended, operated satisfactorily throughout the mission. The experiments were:

a. **Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity; Protein Crystal Growth Using the Second Generation Vapor Diffusion Apparatus; and Protein Crystal Growth Using the Hand-Held Diffusion Test Cells:** Status checks and videos indicated that the 742 individual crystal-growth cells in the three experiments were growing nominally. The single locker thermal enclosure system used for the Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity (PCAM) and the commercial refrigerator/incubator module operated nominally.

b. **ASTRO/Plant Generic Bioprocessing Apparatus:** The ASTRO/PGBA experiment supports commercial research into how higher plants adapt to space flight. The research focuses on the production of lignin-based structural elements, the production of secondary metabolites used as pharmaceuticals, and alterations in sugar and starches in vegetable plants. Experiment data could be applied to the lumber industry for production of trees with low lignin content that would reduce waste in the production of paper.

Downlinked video images indicated nominal plant growth. An anomaly with the humidity control loop flow-rate readings was determined to be caused by a faulty sensor instead of actual variations in the water-loop flow. Transfer operations between the middeck and the EXPRESS rack were completed, and the unit operated well in both locations.

An EXPRESS rack structural anomaly resulted in the ASTRO-PGBA being held in place by only 5 of 8 fasteners. A detailed discussion of this anomaly is provided under the Space Station EXPRESS Rack section of this report.

At 196:14:30 G.m.t. (13:20:27 MET) the crew successfully transferred the ASTRO/PGBA payload from the Spacelab module back to the mid-deck locker position that the payload occupied for ascent. Using the Orbiter locker installation/removal tool, the crew reported no problems in engaging and torquing any of the fasteners on either the ASTRO/PGBA or the two mid-deck lockers that were transferred to the Spacelab module. When the reverse procedure was performed earlier, a fastener cover on one of the mid-deck lockers was broken when the Spacelab locker tool became stuck in the fastener bolt.

MIDDECK GLOVEBOX EXPERIMENT RESULTS

The Middeck Glovebox facility supported five experiments during this flight. The Glovebox facility was installed in rack 12 of the Spacelab module. This location provided a sealed facility for experiment processing. The capabilities of the glovebox included cooling, video systems, and air circulation.

Fiber Supported Droplet Combustion

The primary goal of the FSDC-2 experiments was to test the technique of droplet deployment and ignition using thin fibers. The crew performed the first microgravity experiment in which droplet arrays were burned. These consisted of pairs of drops positioned on fiber and ignited simultaneously. Science return was estimated at 240 percent with 125 FSDC-2 runs out of the planned 52 runs.

Coarsening of Solid-Liquid Mixtures

Experiment runs were designed to test the validity of existing coarsening theories. Nine of the planned nine runs were completed.

Bubble and Drop Nonlinear Dynamics

The Bubble and Drop Nonlinear Dynamics (BDND) experiment will allow scientists to understand the shape and behavior of bubble changes in response to ultrasonic radiation pressure. These data could allow the development of techniques that eliminate or counteract the complications that bubbles cause during materials processing. Experiments were designed to measure the dependence of the resonant mode on shape-oscillation amplitude. Driven and free oscillation experiments were completed using single drops deployed in an ultrasonic resonant chamber. Their shape was deformed by radiation pressure, and their oscillatory response was recorded through an optical detection method. Non-linear oscillation-characterization experiments were also performed.

The first data for the nonlinear free-decay frequency for a totally free drop and the first accurate data for drop deformation as a function of acoustic pressure were obtained. An effective method for bubble positioning and manipulation in microgravity was discovered. Four BDND runs and seven partial BDND runs out of the 12 planned runs were completed, and one run was deleted.

A Study of Fundamental Operation of a Capillary-Driven Heat Transfer Device in Microgravity

The Study of the Fundamental Operation of a Capillary Heat Transfer (CHT) Device in Microgravity experiment will provide information about the mechanisms leading to the unstable operation and failure of capillary-pumped phase-change heat-transfer devices in low gravity. The objectives of this experiment are to observe the low gravity behavior of a capillary-driven meniscus washing over a

hot dry surface, and to observe the final low gravity configuration of the rewetted system. Capillary-pumped loops are used in many spacecraft but have proven to be unreliable. Physics phenomena is thought to be responsible for the failure of these pumps in low gravity.

The expected failure mode for capillary-pumped, heat-transfer loops was observed as well as a failure mode which had not even been considered previously. Eight CHT runs including two partials were completed out of the seven planned.

Internal Flows in a Free Drop

The Internal Flows in a Free Drop (IFFD) experiment demonstrated quiescent positioning and control of the rotation of a liquid drop can be achieved using acoustic levitation microgravity, and this phenomena provided data on the dependence of acoustic torque pressure and internal flows in a liquid drop. The experiment was designed to assess the capability of current non-contact and remote manipulation techniques for controlling the position and motion of free liquids in microgravity. The goal of this experiment was to perform the first measurement of thermocapillary flows in a totally free drop. Four investigations and two partial investigations out of the six planned were completed.

ACCELEROMETER RESULTS

Microgravity Measurement Assembly

The Microgravity Measurement Assembly (MMA) monitored the microgravity environment in the range of 0.1 to 100 Hertz inside the Spacelab. The MMA heads were deployed in the Spacelab racks where gravity-sensitive investigations were located. Investigators were particularly interesting in looking at the effect of crew exercise on measurements. With live video downlinks and a fairly quiet module, investigators were able to assess the affect of crew motion, such as using the hand rails and tools, on acceleration. The MMA detected significant disturbances in the Spacelab during the ASTRO/PGBA installation situation, and the problem with the middeck locker extension tool. A large part of the data and graphics produced by the MMA was made available on the World Wide Web.

Space Acceleration Measurement System

The SAMS sensor heads were placed in three locations in the Spacelab and the Orbiter middeck. The SAMS measured accelerations from 0.1 to 25 Hertz.

Quasi-Steady Acceleration Measurement

The QSAM was located in rack 3 of the Spacelab and was used to measure accelerations between 0 and 0.02 Hertz.

Orbital Acceleration Research Experiment

The OARE measured very-low-frequency accelerations in the payload bay of the Orbiter. The OARE had a real-time data interface with the Spacelab high-rate multiplexer (HRM), which was used to downlink OARE data to the science community using the Ku-band along with MSL-1 high-rate data. The data were processed by Lewis Research Center-provided equipment.

MIDCOURSE SPACE EXPERIMENT

No MSX activities were performed during the mission because of the lack of opportunities.

CRYOGENIC FLEXIBLE DIODE EXPERIMENT

The Cryogenic Flexible Diode Experiment (CRYOFD) heat pipe experiment was flown as a Hitchhiker payload, and was being flown to gain advances in passive thermal control technology. The CRYOFD consisted of two heat-pipe experiments: the Cryogenic Flexible Diode Heat Pipe (CFDHP) and the American Loop Heat Pipe with Ammonia (ALPHA).

The CRYOFD/ALPHA portion of the experiment exceeded the nominal requirements for all the experiments. The CRYOFD completed six cycles each for the Oxygen and the Methane Flexible Diodes (OFD and MFD), and this was 120 percent of the nominal mission objectives. Five ALPHA test cycles were completed accomplishing 100 percent of the mission objectives. The ALPHA accomplishments demonstrated the first American-made loop heat pipe and the highest capacity cryogenic heat pipes (65 to 150 °K range) ever developed.

A total of 32 OFD and 27 MFD steady-state calibrations were completed and these provided cooler performance and heat-load parasitic estimations. These data will enable accurate calculation of the heat pipe capabilities. A total of 22 OFD and 14 MFD dry-out calibrations established the maximum transport capacities of the OFD and the MFD heat pipes between 88 and 135 °K and 120 and 175 °K, respectively. This exceeded OFD predictions by 2 watts and established the OFD as the highest capacity oxygen heat pipe ever developed. MFD capacity was 5 watts less than predicted, however, the MFD recorded the highest heat pipe capacity ever for the noted temperature range.

The ALPLHA operated for 52.5 hours, and all test cycles and new test procedures, which stressed the heat pipes to extremes, were successfully completed. High-power, rapid-cycling, and low-power tests demonstrated excellent performance. The ALPHA demonstrated a high resistance to intentional de-priming efforts and when deprimed, recovery was easy and instantaneous. High heat transport capacity (320 watts) and operational ease made this an ideal candidate for thermal management of future spacecraft.

SHUTTLE AMATEUR RADIO EXPERIMENT

The Shuttle Amateur Radio Experiment (SAREX) -II provided the capability for the three licensed amateur (ham) radio operators to make scheduled contacts with school students as well as unscheduled contacts with other ham radio operators throughout the world. This was the twenty-fourth mission for this experiment which has been flying on Space Shuttle since 1983. Ham radio operators on the ground were also able to make contact with the Space Shuttle.

The SAREX-II was used to make nine personal contacts (eight prescheduled) and 17 school contacts. This translates to 100 percent completion rate with over 194 questions being addressed. There were over 2,100 people who witnessed the contacts and over 52 media organizations who were represented. There were also two Mir/STS-94 air-to-air contacts. Random contacts with the crew averaged about 20 per day.

RISK MITIGATION EXPERIMENT

Wireless Data Acquisition System

The Wireless Data Acquisition System (WDAS) Risk Mitigation Experiment (RME) 1330 was activated and warmed up in accordance with the planned timeline.

On-orbit operations included three downloads of data from 24 temperature sensors on the Spacelab module, Extended Orbiter Duration (EDO) pallet, and the cargo bay via the Orbiter Communications Adapter (OCA). Additionally, a test was performed to determine the communication signal strength of WDAS RF transmissions in twelve flight deck and middeck locations. This test will enable more flexibility in positioning the network communications unit (NCU) on future flights; the NCU receives data from the temperature sensors and interfaces with a portable onboard computer (PGSC).

An anomaly occurred during the first data download when PGSC-to-NCU communications were interrupted and resulted in the creation of a corrupt data file that prevented PGSC display of WDAS data to the crew. The corrupt files were downlinked and corrected. A good data file was uplinked, installed, and normal operations were restored. The RME data continued to be recorded during entry, and data continued to be recorded until the scheduled data download approximately two weeks after landing.

VEHICLE PERFORMANCE

The STS-94 mission was launched at 182:18:01:59.993 G.m.t. after a 12 minute launch delay because of weather conditions at the RTLS landing site. The overall performance of the vehicle was excellent during the mission.

SOLID ROCKET BOOSTERS

All Solid Rocket Booster (SRB) systems performed as expected. The SRB prelaunch countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operational Maintenance Requirements and Specifications Document (OMRSD) violations occurred.

One SRB in-flight anomaly was identified during the postflight inspection of the SRB. A fastener was determined to be missing from the aft side of the right SRB External Tank attachment (ETA) ring (Flight Problem KSC-94-01). The investigation of this anomaly revealed that the fastener had not been installed preflight. Subsequent analysis demonstrated that a positive factor of safety (+0.8) existed with the fastener missing from this location.

Both SRBs were successfully separated from the External Tank (ET) at approximately liftoff plus 123.443 seconds, and the deceleration systems performed nominally. The SRBs were recovered and returned to KSC for disassembly and refurbishment.

REUSABLE SOLID ROCKET MOTORS

All Reusable Solid Rocket Motor (RSRM) systems performed as designed. No LCC or OMRSD violations occurred. 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. For this flight, the heated ground purge in the SRB aft skirts, which is used to maintain the case/nozzle joint temperatures within required LCC ranges, was not activated until T-15 minutes in the countdown when it was turned on in the high-flow-rate mode.

The calculated propellant mean bulk temperature (PMBT) at liftoff was 79 °F. Flight data indicate that the performance of both RSRMs was well within the allowable performance envelopes and was typical of the performance observed on previous flights. The maximum trace-shape variation of pressure versus time during the 62- to 80-second time period was calculated to be 0.49 percent at 80 seconds for the left RSRM, and 0.93 percent at 79.5 seconds for the right RSRM. Both of these values were well within the 3.2-percent allowable limits.

The field joint heaters and igniter joint heaters operated satisfactorily throughout the countdown maintaining the joint temperatures within normal operating limits.

The aft-skirt purge was activated to maintain the nozzle/case joint temperatures above the minimum LCC temperature requirements. The calculated flex bearing mean bulk temperature was 83 °F.

The following table shows the propulsion system performance for the RSRMs.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 79 °F		Right motor, 79 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	66.02	65.64	66.06	65.78
I-60, 10 ⁶ lbf-sec	175.78	175.80	175.88	176.19
I-AT, 10 ⁶ lbf-sec	296.50	296.77	296.54	296.62
Vacuum lsp, lbf-sec/lbm	268.6	268.9	268.6	269.62
Burn rate, in/sec @ 60 °F at 625 psia	0.3682	0.3682	0.3683	0.3692
Event times, seconds ^a				
Ignition interval	0.232	N/A	0.232	N/A
Web time ^b	109.0	108.7	108.9	108.0
50 psia cue time	118.7	118.5	118.6	118.2
Action time ^b	120.7	120.6	120.7	120.2
Separation command	123.6	123.5	123.6	123.5
PMBT, °F	79	79	79	79
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	2.9	2.8	2.7
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		717.3	

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

^b Referenced to liftoff time (ignition interval).

EXTERNAL TANK

All objectives and requirements associated with the ET propellant loading and flight operations were met in an excellent manner. All electrical equipment and instrumentation operated satisfactorily. ET purge and heater operations were monitored and performed properly. No ET LCC or OMRSD violations occurred. All flight objectives were satisfied, and no in-flight anomalies were identified.

As expected, no out-of-family ice/frost formations were observed on the ET during the countdown. No ice or frost was observed on the acreage areas of the ET. Normal quantities of ice or frost were present on the LO₂ and LH₂ feed-lines, the pressurization-line brackets, and along the LH₂ protuberance air load (PAL)

ramps. The observations were acceptable per NSTS 08303. The Ice/Frost Red Team reported that no anomalous thermal protection system (TPS) conditions were observed.

The intertank temperatures were maintained within acceptable limits, all components within the intertank performed satisfactorily, and there were no hazardous gas violations. There was an increase in the area of insulation coverage on the aft dome of the LO₂ tank, and as a result, the demand on the heater output decreased. The heater outlet temperatures were about 28 °F lower than the previous maximum yet the intertank compartment temperatures were in the normal range.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO₂ ullage pressure experienced during the ullage pressure slump was 14.3 psid.

ET separation occurred approximately 18 seconds after main engine cutoff (MECO), which was within expected tolerances. ET entry and breakup occurred within the preflight predicted footprint, and the ET intact impact point was approximately 49 nmi. uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine ready was achieved at the proper time, and engine start and thrust buildup were normal. No OMRSD or LCC violations occurred.

Flight data indicate that SSME performance during main-stage, throttling, shutdown, and propellant dump operations was normal. There were no in-flight anomalies identified from the data. The high pressure oxidizer turbopump (HPOTP) and the high pressure fuel turbopump (HPFTP) temperatures were well within specification throughout engine operation. Space Shuttle MECO occurred at liftoff plus 508.7 seconds. The SSME cutoff times for engine 1, 2, and 3 were 515.06, 515.22, and 515.33 seconds, respectively. This was the first flight of the continuous fuel system purge, and all operations were nominal.

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 designed throughout the countdown and flight.

As planned, the SRB S&A devices were safed, and the SRB system power was turned off prior to SRB separation. The ET system has been deleted.

Postflight analysis revealed one condition that exceeded the countdown experience base. The left-hand range safety system battery A current read 0.03 ampere and that is 0.01 ampere above the experience base of 0.02 ampere. This OMRS upper limit is 0.04 ampere, and therefore, this condition is not a problem or concern.

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion Subsystem

The overall performance of the main propulsion system (MPS) was as expected. The LO₂ and LH₂ loading was performed with no stop-flows or reverts. There were no OMRSD or LCC violations. Data indicate that the LO₂ and LH₂ pressurization systems performed as planned, and that all net positive suction pressure (NPSP) requirements were met throughout the flight. The gaseous oxygen (GO₂) fixed-orifice pressurization system performed as predicted. Reconstructed data from the engine and MPS parameters closely matched the actual ET ullage pressure measurements. The minimum LO₂ ullage pressure experienced during the ullage pressure slump was 14.3 psid. Performance analyses of the propulsion systems during start, mainstage, and shutdown operations indicated that performance was nominal and all requirements were satisfied. No in-flight anomalies occurred during the mission.

Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level, which occurred after the start of fast-fill, in the Orbiter aft compartment was approximately 188 ppm. This level compares favorably with previous data from this vehicle.

Liquid hydrogen (LH₂) loading operations were normal during chilldown, slow fill, fast fill, topping, and replenish. The analysis of the loading system data showed that the LH₂ load at the end of replenish was 231,375 lbm. Compared to the inventory (predicted) load of 231,332 lbm, this assessment yields a difference of +0.02 percent, which is well within the required MPS loading accuracy of ±0.37 percent.

The liquid oxygen (LO₂) loading operations were normal throughout the entire prelaunch period. Based on an analysis of the loading data, the LO₂ load at the end of replenish was 1,389,158 lbm. Compared to the inventory (predicted) load of 1,388,728 lbm, this assessment yields a difference of +0.03 percent, which is well within the required MPS loading accuracy of ±0.43 percent.

The loading program predicted a significant underload (approximately 1,000 lbm) of LO₂. Further investigation revealed that an erroneous input had been made to the program. The amount of propellants in the SSME lines had not been taken into account.

After the pneumatic Helium system was isolated following the on-orbit vacuum inerting procedure, the regulator outlet pressure decay exceeded the File IX maximum allowable limit of 2.4 psi/min by 0.6 psi/min. This leak rate equated to approximately 35 standard cubic inches per minute (scim). The decay test was rerun in the Orbiter Processing Facility (OPF) after landing, and the leak rate had decreased to 1.7 psi/min. While this level meets the maximum allowable leak rate, a decision was made to perform individual solenoid valve leak checks. One valve was found to be leaking at a rate of 10.4 scim, which violates the specification allowable for three-way solenoid valves de-energized leakage of 7.4 scim. Current traces for the valve showed no binding was present, and therefore, the valve is acceptable for flight use with up to 100 scim leakage, provided the valve passes subsequent current-signature tests.

An LH₂ manifold repressurization test was initiated at 195:17:10 G.m.t. (012:23:08 MET). The LH₂ manifold pressure rose to 17 psia at which time the 20-psig regulator lock-up occurred. The LH₂ manifold pressure decayed at about 0.25 psi/hr after the repressurization. This compares favorably with the 4 psi/hr seen following OMS-2. It is believed that the higher starting pressure that occurred for this test helped to seal the disconnects. Helium usage during the test was about 2 lbm. The LH₂ manifold pressure decay was monitored throughout the remainder of the flight to determine if an in-flight leak check could be used to replace a ground check. This test will probably be requested on each Orbiter to verify the capability of holding pressure well enough to satisfy the current ground check requirements.

The LH₂ and LO₂ propellant dump operations were initiated at MECO + 122 seconds as planned. Postflight analyses indicated that the performance was nominal. The MPS vacuum inerting of the hydrogen and oxygen feed systems was performed as planned. Performance was nominal.

Reaction Control Subsystem

The reaction control subsystem performed satisfactorily throughout the STS-94 mission. No in-flight anomalies or significant problems were noted during the flight. A total of 4684.7 lbm of propellants were consumed by the RCS during the mission. Of this total, 489 lbm of propellants were provided by the orbital maneuvering subsystem (OMS) during left- and right-pod interconnect operations. The primary RCS had a total of 2157 firings, and a total firing time of 753.2 seconds. The vernier RCS had a total of 27,085 firings, and a total firing time of 27,774.4 seconds.

RCS thruster F5L's oxidizer valve temperature dropped to a point near its leak-detection limit of 130 °F due to a lack of firing. Vernier aft-yaw thrusters R5R and L5L were temporarily deselected, and the attitude deadband was tightened to increase the firing time on both forward vernier thrusters, F5L and F5R. The total time for the six deselections was 2 hours 1½ minutes. Later in the mission,

after thrusters F5L and F5R oxidizer valve temperatures continued to be low, thrusters R5R and L5L were deselected for six days and one hour on the final deselection. Vehicle control proved to be adequate in this mode, and thrusters F5L and F5R remained warmer due to more frequent firings. The total time the two thrusters were deselected was 8 hours 2 ½ minutes.

The RCS hot-fire was initiated at 197:08:07 G.m.t. (014:14:05 MET) and was terminated seven minutes later with satisfactory results. During the hot-fire, all 38 primary thrusters were successfully fired for two pulses each.

Development Test Objective (DTO) 255 - Wraparound Digital Autopilot (DAP) Flight Test Verification was performed during entry, and it has proven to be a successful Space Shuttle performance enhancement. The results are discussed in more detail in the Development Test Objective section of this report.

Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the mission. No in-flight anomalies or significant problems occurred during the mission. A total of 13,027 lbm of OMS propellants were consumed, and of this total, 489 lbm was consumed by the RCS during interconnect operations. The direct insertion ascent trajectory resulted in the OMS 1 maneuver not being required. The following table provides pertinent data about the two OMS maneuvers performed during the mission.

OMS FIRINGS

OMS firing	Engine	Ignition time, G.m.t./MET	Firing duration, seconds	ΔV, ft/sec
OMS-2	Both	182:18:41:52.9 G.m.t. 00:00:39:52.9 MET	142.8	221.7
Deorbit	Both	198:09:43:45.0 G.m.t. 15:15:41:45.0 MET	180.6	298.6

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) performed satisfactorily on the STS-94 mission, which was also the eleventh flight of the Extended Duration Orbiter (EDO) pallet. The PRSD subsystem supplied 5300 lbm of oxygen and 667 lbm of hydrogen to the fuel cells for the production of 7611 kWh of electrical energy. In addition, 193 lbm of oxygen was supplied to the environmental control and life support system (ECLSS) for life support to the crew. A 111-hour mission extension was possible at extension-day power levels. During the mission, tank sets 4 through 9 were depleted to residual quantities. Both oxygen and hydrogen manifold isolation valves were successfully cycled during the mission. There were no PRSD in-flight anomalies or significant problems noted.

The PRSD subsystem O₂ and H₂ tank sets 4 and 5 were depleted. Usually on long-duration missions, after tank sets 4 and 5 are depleted, cryogenic tank heater control was switched to the pallet tanks. However, due to center-of-gravity concerns for this mission, tank sets 1, 2, and 3 were used for the next two days before control was switched to the pallet tanks.

The PRSD subsystem O₂ tank 2 cryogenic check valve required a slightly higher than normal differential pressure (ΔP) of 12 psid across the poppet before it opened at 191:23:50 G.m.t. (09:05:48 MET). At that time, the O₂ tank 3 was in use and controlling the manifold pressure, and the O₂ tank 2 check valve was closed and its heater was idle. As pressure built-up due to heat leak in O₂ tank 2, the tank-to-manifold ΔP reached 12 psid before the valve cracked. The specification cracking value is 3-5 psid. Slightly sticky check valves like this have been seen on previous flights, but this was the first occurrence for this particular valve. The OMRSD File IX requirement allows a 40-psid cracking pressure before a failure can be declared.

Hydrogen tanks 8 and 9 diverged in quantity because of the higher on-orbit heat leak into tank 8, which is normal for EDO pallet flights. This condition led to a higher on-orbit reactant boil-off rate in tank 8, thereby depleting that tank faster than tank 9. The maximum divergence observed between these two tanks was 15 percent. Since tanks 8 and 9 have independent heater control, tank 9 can be depleted to residual quantities, if required; however, the tank 8 and 9 quantities typically converge without independent heater control.

Fuel Cell Powerplant Subsystem

Performance of the fuel cell powerplant (FCP) subsystem was nominal during the mission. The average power level for the mission was 20.2 kW and 668 amperes. The fuel cells produced 5,967 lbm of potable water during the production of 7,611 kWh of electrical energy. The oxygen consumption was 5300 lbm, and the hydrogen consumption was 667 lbm. One in-flight anomaly was noted and it is discussed in a following paragraph.

Eight on-orbit fuel cell purges were performed during the mission. The actual fuel cell voltages at the end of the mission were 0.1 volt above predicted for fuel cell 1, 0.2 volt below predicted for fuel cell 2, and as predicted for fuel cell 3.

During prelaunch operations following the start-up of fuel cell 1, a high pH indication was noted on the fuel cell 1 conductivity sensor for 17 minutes beginning at 182:04:16 G.m.t. No corresponding high pH indication was present from the common pH sensor. This indication on fuel cell 1 was not unusual considering that it was a new fuel cell. The high pH reading was caused by a trace of residual potassium hydroxide (KOH) solution or metallic ions being flushed out as the fuel cell began to produce water.

The fuel cell 1 and 3 alternate water line temperatures were erratic in the 100 to 125 °F and 85 to 120 °F ranges, respectively, indicating slight internal leakage of warm fuel cell product water through the check valve into the alternate water line. All three alternate water line check valves on this vehicle (OV-102) have shown leakage in the past; however, only the fuel cell 3 leakage is a repeat from the previous flight, STS-83. Temperatures as high as 124 °F were observed. The normal temperature range of this line with the heater cycling is 70 to 90 °F. This condition did not impact the mission.

A review of postlaunch data showed that the fuel cell 3 substack 2 cell performance monitor (CPM) measurement increased 32 mV in 23 minutes, from 2 mV at 182:18:36:38 G.m.t. (00:00:34:38 MET) to 34 mV at 182:19:00 G.m.t. (00:00:58 MET) (Flight Problem STS-94-V-02). This CPM generally trended upward throughout the mission to a maximum value of 46 mV. The fuel cell contractor expressed a concern that a failure in the CPM of resistor R115 would result in an output in the range of $37 \text{ mV} \pm 6 \text{ mV}$. The potential existed for this channel to be failed. However, the measurement appeared to have some sensitivity to purges as the value decreased slightly during purges, decreasing 2-4 mV during a purge, which is not unusual for a healthy CPM.

STS-94 is the fifth flight of fuel cell 3. On the previous four flights, the substack 2 CPM measurement remained between 2 and 10 mV. A failure mode may exist in the CPM circuitry that could cause incorrect CPM output signals and not be detectable by the self-tests. The Flight Rules for a failed CPM require bus-tying the affected fuel cell to another fuel cell. As part of the pre-planned Orbiter configuration for STS-94, main busses B and C were tied together to support Spacelab payload operations. The overall performance of all of the fuel cells remained nominal for the mission. The CPM value began decreasing during the normal end-of-mission power-down procedures and reached a steady-state value of 18 mV after landing. The standard postflight checkout activities confirmed that the CPM was anomalous, and the CPM was replaced.

Normally, when hydraulic circulation pump 2 operation was required, the busses were untied to minimize voltage transients to the Spacelab payloads. Therefore, each operation of circulation pump 2 required that the busses be untied for the duration of the activity and then re-tied. Since repeated untying and retying the busses adversely affected and complicated the fuel cell health monitoring required because of the suspect fuel cell 3 CPM, an analysis was performed that showed the voltage transients would not affect Spacelab. Therefore, the busses remained tied during numerous hydraulic circulation pump 2 runs for the remainder of the mission, and no problems were noted.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission. No in-flight anomalies or significant problems were noted during the

course of the mission. The APU run times and fuel consumption are shown in the following table.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 407)		APU 2 (S/N 402)		APU 3 (S/N 308)	
	(a) (b) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	19:54	51	20:11	55	20:27	55
FCS checkout	06:18	19				
Entry ^a	61:08	116	84:11	178	61:32	128
Total	87:20	186	104:22	233	81:59	183

^a APUs were shut down 17 minutes 36 seconds after landing.

^b APU 1 was used for the FCS checkout.

Following APU 3 shut down, the crew reported three master alarms. Two of the three were normal and resulted from the hydraulic pump 3 outlet pressure dropping below 2400 psia after APU 3 was shut down. The unexplained caution and warning message was attributed to the rise in the APU 3 gearbox lubrication-oil return temperature. Telemetry indicated that this temperature reached the hardware fault detection and annunciation (FDA) limit. The data show that the lubrication oil temperature increase was caused by the 45-second delay between the shut down of the WSB and the APU. The procedures require the WSB to be shut down before the APU is shut down. With the APU running without cooling from the WSB, the gearbox lubrication oil return temperature continued to increase to slightly above the FDA limit, which caused the additional master alarm.

To verify that the APU B heaters were cycling properly (File IX requirement), the reconfiguration from the A heaters to the B heaters was performed at 191:09:32 G.m.t. (08:15:30 MET). At that time, the APU isolation valve and service line temperatures began to decrease. On heater system A, the isolation valve minimum temperature was approximately 53 °F. Following the switch to heater system B, the minimum temperature was approximately 46 °F, only 1 °F above the 45 °F lower fault detection annunciator (FDA) limit. The data review and analysis showed that the isolation valve and service line temperatures have been consistently lower when on heater system B since the heater strings were disturbed and the heater system B controlling thermostat was replaced following the fuel line freeze-up on STS-62. This reconfiguration had been performed following the FCS checkout on previous missions, and in one case the File IX requirement had not been satisfied because of lack of time for heater cycling prior to landing.

The APU 1 drain line pressure steadily decreased following the thermal soak-back pressure increase after APU shutdown following ascent. The pressure initially decreased from 19 psia at a rate of 2.5 psia per day. The pressure continued to decay, though at a decreasing rate, until it reached 12.5 psia at the time of APU prestart for entry. The total average mission leakage did not exceed the 0.5 psi/day, which is acceptable in meeting the File IX requirements.

The flight control system (FCS) checkout was performed using APU 1. The APU subsystem performed nominally during the checkout. APU 1 was started at 197:07:16 G.m.t. (013:13:14 MET) and ran for 6 minutes 18 seconds. The fuel consumption during this run was 19 lb.

Hydraulics/Water Spray Boiler Subsystem

Overall hydraulics and water spray boiler (WSB) system performance was nominal with no in-flight anomalies identified. Minor problems were noted and these are discussed in the following paragraphs.

The WSB 2 vent temperature was low during the prelaunch operations. The WSB 2 vent heater remained on continuously throughout the prelaunch operations with the vent temperature reaching a maximum of 154 °F just prior to ET loading. The heater normally turns off at 175 °F. This problem was noted during the STS-83 mission, and troubleshooting was deferred until after the STS-94 mission because of the lengthened turnaround flow interval. This condition did not impact the mission.

During ascent, WSB 3 experienced a slight under-cooling condition that resulted in the APU 3 lubrication-oil temperature reaching 281 °F before achieving spray cooling (File IX requirement is no more than 275 °F.). As expected, the under-cooling condition was immediately followed by an over-cooling condition to 237 °F before steady-state cooling at 253 °F was achieved. This event occurred on the WSB A controller, but it is not believed to be a controller problem. The behavior is believed to be caused by ice forming on the WSB spray bars, and this condition has been observed on numerous previous flights of all vehicles. The under-cooling did not impact mission operations.

The hydraulic system 1 reservoir quantity dropped 17.3 percent at landing gear deployment. This is not a violation of any requirements or specifications, although the expected drop is no more than 15 percent. On the previous mission (STS-83), the drop was 18 percent. The postflight inspections revealed no leaks after either flight.

The APU hydraulics and WSB subsystem performed nominally during the FCS checkout. No water spray boiler operation occurred due to the short APU run time.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed nominally throughout the mission. No in-flight anomalies and only one minor problem were identified from the data analysis.

Mid-body motor control assembly 3 status bits 7, 8, 11, and 12 logic power delayed turn-off for approximately 2 to 4 hours when the switch was moved to the off position after the crew egressed the vehicle postlanding. This condition has occurred multiple times and is not an impact to flight, since the logic power is flown on during all mission phases. This problem was identified pre-flight as expected to recur, and no postflight action was required or taken.

The hydraulic system 2 circulation pump was allowed to run while main busses B and C were remaining tied together. Usually, during Spacelab missions, the busses are untied during system 2 circulation pump operation to minimize voltage transients to the Spacelab payloads. However, analysis of previous flight data showed that the voltage transients would not adversely affect Spacelab.

Pressure Control Subsystem

The pressure control subsystem performed normally throughout the duration of the flight. During the redundant component check, the pressure control configuration was switched to the alternate subsystem. Both subsystems performed nominally.

Atmospheric Revitalization Subsystem

All atmospheric revitalization subsystem (ARS) hardware performed satisfactorily during the mission.

At liftoff, the cabin temperature was 74.1 °F and the humidity was 31.3 percent. The on-orbit peak cabin parameters showed the cabin heat exchanger outlet temperature to be 57.8 °F (flight day 13), and the peak cabin temperature to be 79.5 °F (flight day 14). The cabin humidity reached a peak value of 54.4 percent on flight day 7. The ARS conditions during entry and landing were nominal.

Active Thermal Control Subsystem

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

On two of the three previous flights (STS-78 and STS-83) of this Orbiter (OV-102), the flash evaporator system (FES) high-load duct temperatures dropped off sharply during ascent while using the system A high-load duct heater. As a result, STS-94 was launched with both the system A and B high-

load duct heaters activated. During ascent, the hi-load inboard duct temperature dropped to 223 °F just prior to MECO and recovered slightly before decreasing to 175 °F by 182:18:14 G.m.t. (00:00:12 MET) (Flight Problem STS-94-V-01). The temperature normally remains above 190 °F with only one heater activated. Throughout the occurrence, the evaporator outlet temperatures were stable. The hi-load outboard duct temperature did not decrease significantly when the inboard duct temperatures dropped. On the last flight of this vehicle (STS-83), the inboard duct temperature was as low as 62 °F, whereas, on STS-80 the comparable lowest temperature reading was 184 °F. On STS-78 when indications of high- load duct icing were noted during ascent, the temperatures lowest point was 120 °F. Both high-load spray valves were replaced after STS-78, as well as the Freon coolant loop flow was reduced to lower the pressure difference between the two loops. It is suspected that excess water carryover was the cause of the duct-temperature drop. No mission impact resulted from this condition, and the FES performed nominally for the rest of the mission. The postflight troubleshooting found no abnormality. Both primary A and B spray valves were replaced prior to STS-80, and the FES duct temperature response has been abnormal since that replacement.

The radiator cold-soak provided cooling during entry through landing plus five minutes at which time the ammonia boiler system B was activated. System B operated for 40 minutes after which it was disconnected in preparation for the connection of ground cooling.

The flow proportioning valve (FPV) on Freon coolant loop (FCL) 1 was taken to the payload position at 182:23:19 G.m.t (00:05:17 MET) to support Spacelab cooling. The FPV on FCL 2 was not taken to the payload position until approximately 20 hours later to provide more cooling to the warm Orbiter cabin the first day. The Orbiter provided satisfactory cooling to the Spacelab throughout the flight. Radiator deployment was not required during the flight.

Supply and Waste Water Subsystem

The supply and waste water subsystem performed normally throughout the mission. All of the associated in-flight checkout requirements that were scheduled to be performed were satisfied.

Supply water was managed through the use of the FES and the water dump system. Seven supply water dumps were performed with an average dump rate of 1.61 percent/minute (2.66 lb/min). The supply water dump line temperature was maintained between 77 °F and 108 °F throughout the mission with the operation of the line heater.

Waste water was gathered at about the predicted rate. Five waste water dumps were performed with an average dump rate of 1.96 percent/minute (3.23 lb/min). The waste water dump line temperature was maintained between 54 °F and 79 °F throughout the mission. The vacuum vent line temperature was

maintained between 59 °F and 75 °F, with the vacuum vent nozzle temperature between 104 °F and 150 °F.

Waste Collection Subsystem

The waste collection system (WCS) performed normally throughout the mission.

Airlock Support System

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

Smoke Detection and Fire Suppression Subsystem

The smoke detection and fire suppression subsystem showed no indications of smoke generation during the flight. Use of the fire suppression subsystem was not required.

Flight Data System

The flight data systems performed satisfactorily throughout the mission with no in-flight anomalies noted in the data.

Flight Software

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

Flight Control Subsystem

The flight control subsystem performed nominal during the ascent, on-orbit, and entry phases of the mission, and one in-flight anomaly was identified and is discussed in the following paragraph.

The inertial measurement unit (IMU) performance was very satisfactory. Nominal compensations were performed twice during the flight; flight day 2 and flight day 11.

At 189:15:54:30 G.m.t. (06:21:52:30 MET), the aerosurface servo amplifier (ASA) 4 power-on command-C switch-scan measurement and the associated remote power controller (RPC) output discrete measurement went from on to off, indicating loss of redundant power to ASA 4 (Flight Problem STS-94-V-03). This contact of the ASA 4 switch receives its power from one contact of the FCS channel 4 switch, which also provides power to a contact of the ascent thrust vector control (ATVC) 4 power switch. A separate contact of the ASA 4 switch,

which provides control power to a redundantly powered remote power controller (RPC) continued to indicate on, thus maintaining power to ASA 4. Approximately two hours 10 minutes later, these discrete measurement values returned to the normal on-state. The measurements then again returned to the off-state approximately 3 hours 39 minutes later.

Initial troubleshooting of the ASA 4 condition was performed by cycling the ATVC 4 power switch to on for about 15 seconds to determine if the FCS channel 4 switch contact was supplying power from control bus CA2 to ASA 4 and the ATVC 4 switch. When the ATVC 4 switch was placed to on, power was transferred properly. At the same time, the ASA 4 power-on command-C and RPC output discrete values both changed to on and remained on after the ATVC 4 switch was taken back to off. These indications continued to be correct for the remainder of the mission. FCS checkout and entry/landing had no effect on ASA 4 power. After the crew egressed, ground personnel cycled the ATVC 4 power switch several times without affecting ASA 4 power. Postflight troubleshooting activity identified a loose solder particle within the ATVC 4 switch as the most probable cause of this condition.

The FCS checkout was performed using APU 1. The APU and hydraulics subsystems performed nominally during the checkout. FCS performance was nominal.

Displays and Controls Subsystem

The displays and control performed satisfactorily during the mission with no in-flight anomalies noted.

Communications and Tracking Subsystem

The communications and tracking subsystems performed nominally, and no in-flight anomalies were identified from the data. Two problems were noted and these are discussed in the following paragraphs.

Initial dumps of the 60-kbps ascent data through the Ku-band system at 16:1 (960 kbps) in the frequency modulation (FM) mode had two data drop-outs per minute in a relatively cyclic pattern. The 60-kbps Space Shuttle main engine (SSME) data were dumped at 16:1 (960 kbps) through the Ku-Band system without any problem. An attempt to redump the 60-kbps ascent data through the Ku-Band in the phase modulation (PM) mode also was not successful. The ground equipment would periodically lock onto the 1.070 kbps data and then break lock. When locked, it indicated that the data were at a 960-kbps rate; and when not locked, the ground equipment indicated that it was locked to 1,070-kbps data.

On-orbit troubleshooting appeared to eliminate the operations (OPS) recorders as the source of the problem since the dropouts occurred using both recorders.

The problem occurred on both the East and West Tracking and Data Relay Satellites (TDRSs), although the East TDRS appeared to be more susceptible to the condition. The nominal on-orbit dump rate of 1,024 kbps remained locked for all Ku-Band configurations. Further analysis of dumped 192 kbps data through the Ku-Band (channel 3 was 32 Mbps in the PM mode) showed that the ground remained locked to the data for the entire dump. Additional data were recorded on one of the OPS recorders, and the data were dumped at 960 kbps through the Ku-Band (channel 3 was 16 Mbps in the PM mode). The ground remained locked to these data during both the forward and reverse dump operations. The condition did not significantly impact the mission.

At 194:10:05:48 G.m.t. (11:16:03:48 MET) while the Ku-Band system was in the general purpose computer (GPC) steering mode, the alpha gimbal made an unexplained 1-degree rapid movement away from the TDRS signal, and this resulted in the loss of the forward and return link signals. At the time, the Ku-Band was being used for two-way communications, and the loss resulted in a fail-over to the S-Band system. Approximately ten seconds later, the Ku-Band antenna reacquired the TDRS signal. Evaluation of the data did not provide a clear explanation of the cause of the anomaly. Conditions were repeated on-orbit with no problems noted. The occurrence is viewed as a possible single-event upset, and KSC will perform the normal Ku-Band turnaround troubleshooting.

Operational Instrumentation/Modular Auxiliary Data System

Initial dumps of the 60-kbps ascent data through the Ku-band system at 16:1 (960 kbps) in the frequency modulation (FM) mode had two drop-outs per minute in a relatively cyclic pattern. The 60-kbps SSME data were dumped at 16:1 (960 kbps) through the Ku-Band system without any problem. An attempt to redump the 60-kbps ascent data through the Ku-Band in the phase modulation (PM) mode also was not successful. Troubleshooting showed that the problem was not caused by the onboard recorders. See the Communications and Tracking section of this report for more details of this problem.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. The table on the following page presents the performance of the mechanical system during the landing.

The crew reported a debris impact on the starboard overhead window 7 that they estimated as 0.5 centimeter in diameter by 1 millimeter deep. The damage was located approximately 5 inches from the inboard edge and halfway back on the thermal panel. Pictures of the impact were downlinked and evaluated. There was no mission concern from the damage. The window was replaced during postflight turnaround activities.

The tires appeared to be in average condition for a landing on the KSC Shuttle Landing Facility (SLF) concrete runway. Some ply under-cutting occurred on the main landing gear (MLG) left inboard and right outboard tires.

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	3132.7	205.7	2.21	N/A
Nose gear touchdown	6611.1	151.78	N/A	-5.05
Brake initiation speed		109.1 knots		
Brake-on time		34.03 seconds		
Rollout distance		8909.7 feet		
Rollout time		55.5 seconds		
Runway		33 (Concrete) KSC		
Orbiter weight at landing		230,910.9 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	1020	Left-hand inboard	14.67	
Left-hand inboard 3	1020			
Left-hand outboard 2	1004	Left-hand outboard	14.36	
Left-hand outboard 4	1004			
Right-hand inboard 1	1197	Right-hand inboard	18.11	
Right-hand inboard 3	1197			
Right-hand outboard 2	1255	Right-hand outboard	19.17	
Right-hand outboard 4	1255			

The ET/Orbiter separation devices (EO-1, EO-2, and EO-3) functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. The EO-2 and EO-3 retainer springs were dislodged. This condition has been observed on previous flights. One clip from the EO-2 and two clips from the EO-3 "salad bowls" were missing. A black deposit adhered to the inside of the LO₂ ET door.

Integrated Aerodynamics, 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 than normal with evidence of bluing of the metal, and the nozzles met the material hardness test requirements.

Thermal Control Subsystem

The thermal control subsystem performance was nominal during all phases of the mission. All subsystem temperatures were maintained within acceptable limits. There were no heater or instrumentation failures during the mission. The APU heater reconfiguration from system A to B, which normally occurs after FCS checkout, was performed earlier in the mission to allow enough time for the B heaters to cycle and thereby satisfy the File IX requirements.

A new method for keeping the forward vernier thrusters warm was successfully implemented on this mission. Since the F5R and F5L vernier thrusters were cold despite tightening the attitude deadband, the R5R and L5L vernier thrusters were deselected for six days and one hour. Vehicle control continued to be adequate in the mode, and the forward vernier thrusters remained warmer due to more frequent firings.

The end-of-mission thermal conditioning attitudes were modified to add 10 hours of bottom-Sun as well as an additional 2.5 hours of payload bay-to-Earth. These attitudes eliminated a potential main landing gear tire temperature issue while still meeting the entry-interface bondline temperature limits. No violations of the entry interface limits or tire pressure landing limit occurred.

The alternate water line heater for fuel cell 2 stopped cycling at 194:05:02 G.m.t. (11:11:00 MET). The temperature of the line stabilized within 1 to 2 degrees of the nominal heater turn-on temperature of approximately 78 °F. Analysis determined that the environmental temperature in the vicinity of the thermostat was rising due to the increasing solar-beta angle. This benign warming of the environment stopped the thermostat from cycling. There was no concern for the health of the alternate water line heater.

Aerothermodynamics

The boundary layer transition was asymmetrical and the onset time was earlier than nominal (Mach 17 vs. Mach 8), and this was caused by protruding gap filler on the lower surface. The acreage heating was higher than normal in the areas affected by the early transition. Local heating was also normal with the exception of the ET thermal barriers, which were hard from an over-temperature condition.

Thermal Protection Subsystem and Windows

The thermal protection system (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was higher than normal based on lower-surface structural temperature rise data. Boundary layer transition from laminar to turbulent flow was early and occurred at 1040 seconds after entry interface. The nominal time for transition is approximately 1210 seconds. The

early transition and higher heating was most likely caused by a protruding AMES gap filler on the lower surface.

As reported by the crew during the on-orbit phase and noted during the postflight inspection, overhead window 7 had an on-orbit impact. The crater was approximately ¼ inch in diameter.

The postflight inspection of the Orbiter revealed a total of 90 debris-impact sites of which 12 had a major dimension of 1-inch or larger. This total 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. Two of the lower surface impact sites appear to be the result of micrometeorite impacts. A comparison of the number of impact sites on STS-94 with the statistics from 69 previous flights of similar configuration, indicates that both the total number of impact sites as the number of sites with measurements of 1-inch or larger were less than average. The following table reflects the hits by areas of the Orbiter.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	11	34
Upper Surface	1	50
Right Side	0	0
Left Side	0	0
Right OMS Pod	0	3
Left OMS Pod	0	3
Total	12	90

The Orbiter lower surface sustained a total of 34 hits of which 11 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the right chine and measured 3.75 inches long by 1.75 inches wide by 1/8 inch deep. The shallow damage site was most likely caused by an impact from a low-density object, such as ET foam.

Tile damage sites around the LH₂ and LO₂ ET/Orbiter umbilical wells were less than usual in number and size. However, two significant damage sites were located forward of the right MLG wheel well. These damage sites were initially thought to be caused by micrometeorite impacts because of the ¾ inch diameter surface openings with larger, deep internal cavities. Closer examination revealed glazing and erosion, which indicates that the impacts occurred during ascent. No other on-orbit tile damage was identified during the postflight inspection.

Damage to the base heat shield tiles appeared to be less than usual. The SSME dome-mounted heat shield (DMHS) closeout blankets were in excellent

condition, though some fraying was noted on the SSME 2 DMHS blanket at the 3:00 to 4:00 o'clock position.

Tiles on the vertical stabilizer "stinger" were intact and undamaged. No unusual damage was noted on the leading edge of the vertical stabilizer. Although no significant tile damage was visible on the OMS pods, a 2-inch long by 1-inch wide piece of burned cloth tape was detected on the left OMS pod. Nearby, a 5-inch diameter room temperature vulcanizing (RTV) repair area had outgassed and charred.

Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size with the exception of a 7.5-inch long by 1.8-inch wide by 0.2-inch deep impact just forward of window 3. This damage spanned one white tile and two adjacent black tiles. These damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the forward RCS thrusters. In support of this conclusion, a 2-inch long scorched piece of forward RCS thruster paper cover was wedged between the window 2 glass and perimeter tiles adjacent to three tile damage sites. Hazing and streaking of the forward-facing windows was typical.

Three Ames gap fillers were found on the runway generally in the area below the right inboard elevon at the Orbiter wheel-stop point. However, the thin gap fillers most likely originated from near the nose of the Orbiter or the nose landing gear doors.

All drag chute hardware was recovered and appeared to have functioned normally. However, when the drag chute door impacted the runway, one of the TPS covered carrier panels was ripped off the door.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The Government furnished equipment/flight crew equipment (GFE/FCE) performed nominally throughout the mission.

In accordance with the nominal mission plan for approximately two days mission elapsed time, the crew removed the ASTRO/PGBA double-locker from the Orbiter middeck location (MF28K/M) and moved the double locker to the Spacelab Express Rack. Two lockers that were removed from the Spacelab were then moved to the MF28K and MF28M positions on the Orbiter middeck. When installing one of the lockers in the MF28K position, the crew reported that the Spacelab locker installation/removal tool would turn in both directions but could not be removed from the lower port fastener. This was caused by the Spacelab tool being of a slightly different design than the Orbiter tool. When the crew tried to force the tool out of the retainer, the retainer housing broke off. The fastener is a Milson fastener that has a retainer that captures a spring-loaded sleeve bolt. By removing an adjacent locker, the crew was able to verify that the barrel nut on the wire tray at the lower-left fastener location of the locker in the MF28K position was not damaged.

At 196:14:30 G.m.t. (13:20:27 MET) the crew successfully transferred the ASTRO/PGBA payload from the Spacelab module back to the mid-deck locker position that the payload occupied for ascent. Using the Orbiter locker installation/removal tool, the crew reported no problems in engaging and torquing any of the fasteners on either the ASTRO/PGBA or the two middeck lockers that were transferred to the Spacelab module.

CARGO INTEGRATION

The cargo integration hardware performed nominally throughout the mission with no anomalies identified.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES.

DEVELOPMENT TEST OBJECTIVES

DTO 255 - Wraparound Digital Autopilot Flight Test Verification - This DTO was enabled for the entire entry and performed satisfactorily during entry. The Wraparound DAP anticipates the required impulse, thus minimizing attitude control overshoot during entry. This minimization results in reduced wasting of RCS propellants. The DTO has shown that significant RCS propellant savings are accomplished during entry. The DTO is a very successful Space Shuttle performance enhancement.

DTO 312 - External Tank Thermal Protection System Performance - A total of 37 views of the External Tank (ET) were acquired following ET separation. A 35 mm Nikon camera with a 400 mm lens and a 2X extender was used to take the photographs. The OMS 2 maneuver was performed early to assist the crew members in acquiring the ET visually. A screening of the photographs reveal no anomalous conditions.

The first three views of the ET were of the -Z/+Y axis. The next five views were of the ET +Z/+Y axis and the aft dome, and the remaining 29 views were of the ET +Z/-Y axis. The film exposure varied from good to dark depending on the sun angle, and the focus was soft. The first picture was taken approximately 18 minutes after liftoff and the last picture was taken 2 minutes 29 seconds later. The ET was approximately 2.6 kilometers from the Orbiter in the first image, and the tank tumble rate was determined to be 1.8 deg/sec. The tank roll-rate was 0.3 deg/sec.

STS-94 was the first flight of the NCFI 24-124 thermal protection system (TPS) material on the LO₂ tank barrel and ogive, and the material appeared to be in good condition from the analysis of the photographs. STS-94 was the second flight of the NCFI 24-184 TPS material on the LH₂ sidewall, and it also appeared to be in good condition. The LH₂ tank aft dome TPS, first flown on STS-82, was in good condition. The new intertank access door was not imaged.

Three rolls of umbilical well camera film of the ET [two from 16 mm (LH₂ umbilical well), and one from 35 mm (LO₂ umbilical well)] were reviewed. Numerous light-colored pieces of debris (insulation and frozen hydrogen) and dark debris (probably charred insulation) were seen throughout the SRB separation sequence; however, no anomalous conditions were noted.

DTO 623 - Cabin Air Monitoring - The scheduled activities were completed, and the data have been given to the sponsor for evaluation. The results of this DTO will be reported in separate documentation.

DTO 667 - Portable In-Flight Landing Operations Trainer - The laptop computer was set-up, and the crew performed the scheduled activities.

DTO 677 - Evaluation of Microbial Capture Device in Microgravity - During the set-up of this DTO, it was noted that one of the color coordinating dots to aid in assembly was missing; the crewmember was able to assemble the device using the diagram in the procedures. All activities were performed as scheduled and the device was disabled, as planned, after 72 hours. The results of this experiment were given to the sponsor for evaluation, and the analysis results will be published in separate documentation.

DTO 684 - Radiation Measurement in Crew Compartment - All of the scheduled activities were completed by the crew. The data have been given to the sponsor for evaluation. The results of that evaluation will be reported in separate documentation.

DTO 805 - Crosswind Landing Performance - This DTO was not performed as crosswinds were not of sufficient magnitude to meet the minimum requirements of this DTO.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 331 - Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion - The necessary activities in support of this Detailed Supplementary Objective (DSO) (donning instrumentation for entry) were completed. The data were given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DSO 487 - Immunological Assessment of Crewmembers - All preflight and postflight activities required in support of this DSO were completed. The data have been given to the sponsor for evaluation, and the results of that evaluation will be reported in separate documentation.

DSO 493 - Monitoring Latent Virus Reactivation and Shedding in Astronauts - All required activities in support of this DSO were completed. The data have been given to the sponsor for evaluation, and the results of that evaluation will be reported in separate documentation.

PHOTOGRAPHY AND VIDEO DATA ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

A total of eleven 16 mm films, nine 35 mm films and 24 videos of the launch activities were screened for any evidence of abnormal operations. No anomalous events or occurrences were noted. All of the normally expected events of liftoff and ascent were noted to have occurred as planned.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

No requests for evaluation of on-orbit photography or video were received by the JSC Image Science and Analysis Group.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Twelve videos of the landing on runway 33 of the SLF were evaluated. All major events were timed and no anomalous conditions were noted in any of the documented activities. Numerous impact sites were noted on the vehicle during the postlanding walk-around; however, none of the sites were significant, and none will cause any delays in the turnaround operations.

TABLE I.- STS-94 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	182:17:57:11.720 182:17:57:12.753 182:17:57:13.506
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	182:18:01:32.103 182:18:01:32.263 182:18:01:32.423 182:18:01:32.583
Main Propulsion System Start ^a	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	182:18:01:53.448 182:18:01:53.551 182:18:01:53.683
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	182:18:01:59.993
Throttle up to 104 Percent Thrust ^a	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	182:18:02:03.871 182:18:02:03.883 182:18:02:03.888
Throttle down to 69 Percent Thrust ^a	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	182:18:02:34.112 182:18:02:34.122 182:18:02:34.129
Maximum Dynamic Pressure (g)	Derived ascent dynamic pressure	182:18:02:50
Throttle up to 104 Percent ^a	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	182:18:03:00:032 182:18:03:00:041 182:18:03:00:050
Both RSRM's Chamber Pressure at 50 psi ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	182:18:03:58.113 182:18:03:58.473
End RSRM ^a Action ^a Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	182:18:04:00.383 182:18:04:01.823
SRB Physical Separation ^a	LH rate APU A turbine speed - LOS LH rate APU B turbine speed - LOS RH rate APU A turbine speed - LOS RH rate APU B turbine speed - LOS	182:18:04:03.353 182:18:04:03.393 182:18:04:03.393 182:18:04:03.433
SRB Separation Command	SRB separation command flag	182:18:04:04
Throttle Down for 3g Acceleration ^a	ME-3 command accepted ME-1 command accepted ME-2 command accepted	182:18:09:32.020 182:18:09:32.029 182:18:09:32.039
3g Acceleration	Total load factor	182:18:09:32
Throttle Down to 67 Percent Thrust ^a	ME-3 command accepted ME-1 command accepted ME-2 command accepted	182:18:10:22.262 182:18:10:22.267 182:18:10:22.280
SSME Shutdown ^a	ME-3 command accepted ME-1 command accepted ME-2 command accepted	182:18:10:28.742 182:18:10:28.747 182:18:10:28.760
MECO	MECO command flag MECO confirm flag	182:18:10:29 182:18:10:30
ET Separation	ET separation command flag	182:18:10:48

^aMSFC supplied data

**TABLE I.- STS-94 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-1 GG chamber pressure	182:18:17:05.781
	APU 2 GG chamber pressure	182:18:17:23.714
	APU 3 GG chamber pressure	182:18:17:39.588
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	182:18:41:53.3
	Right engine bi-prop valve position	182:18:41:53.3
OMS-2 Cutoff	Right engine bi-prop valve position	182:18:44:16.3
	Left engine bi-prop valve position	182:18:44:16.3
Payload Bay Doors (PLBDs) Open	PLBD right open 1	182:19:37:23
	PLBD left open 1	182:19:38:46
Flight Control System Checkout APU 1 Start APU 1 Stop	APU 1 GG chamber pressure	197:07:16:01.832
	APU 1 GG chamber pressure	197:07:22.19.140
Payload Bay Doors Close	PLBD left close 1	198:07:02:15
	PLBD right close 1	198:07:04:00
APU Activation for Entry	APU-2 GG chamber pressure	198:09:38:52.647
	APU-1 GG chamber pressure	198:10:01:42.296
	APU-3 GG chamber pressure	198:10:01:43.060
Deorbit Burn Ignition	Left engine bi-prop valve position	198:09:43:45.2
	Right engine bi-prop valve position	198:09:43:45.3
Deorbit Burn Cutoff	Left engine bi-prop valve position	198:09:46:46.0
	Right engine bi-prop valve position	198:09:46:46.1
Entry Interface (400K feet)	Current orbital altitude above	198:10:14:39
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	198:10:40:07
Main Landing Gear Contact	RH main landing gear tire pressure 2	198:10:46:33
	LH main landing gear tire pressure 2	198:10:46:34
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels	198:10:46:35
	RH main landing gear weight on wheels	198:10:46:36
Drag Chute Deployment	Drag chute deploy 1 CP volts	198:10:46:36.7
Nose Landing Gear Contact	NLG LH tire pressure 1	198:10:46:45
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	198:10:46:45
Drag Chute Jettison	Drag chute jettison 1 CP Volts	198:10:47:11.9
Wheel Stop	Velocity with respect to runway	198:10:47:31
APU Deactivation	APU-1 GG chamber pressure	198:11:02:50.182
	APU-2 GG chamber pressure	198:11:03:03.265
	APU-3 GG chamber pressure	198:11:03:15.708

TABLE II.- STS-94 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-94-V-01	High-Load FES Inboard Duct Temperature Response During Ascent	182:18:14 G.m.t. 00:00:12 MET CAR 94RF04 PR ECL-2-A0105	<p>On two of the three previous flights of this vehicle (0V-102), the FES high-load duct temperatures have dropped off sharply during ascent (STS-78 and STS-83). As a result, STS-94 was launched with both system A and B high-load duct heaters energized. During this mission, the inboard duct temperature dropped to 175 °F by 182:18:14 G.m.t. (approximately 00:00:12 MET). The temperature normally remains above 190 °F with only one heater activated. Throughout the occurrence, the evaporator outlet temperatures were stable. It is suspected that excess water carryover is the cause of the duct temperature drop. The cause of the carryover is under investigation. No mission impact resulted from this condition. A decision was made to use the primary B controller and spray valve for the STS-87 ascent, since all previous ascents have been flown using the A controller and spray valve.</p> <p>KSC: The postflight troubleshooting found no abnormality. Both primary A and B spray valves were replaced prior to STS-80, and the FES duct temperature response has been abnormal since that replacement.</p>
STS-94-V-02	Fuel Cell 3 Substack 2 CPM Output Shift	182:18:37 G.m.t. 00:00:35 MET CAR 94RF03 IPR 87V-0001	<p>A data review indicates that the fuel cell 3 (S/N 118) substack 2 CPM measurement increased 32 mV in 23 minutes, from 2 mV at 182:18:37 G.m.t. (00:00:35 MET) to 34 mV at 182:19:00 G.m.t. (00: 00:58 MET). The potential exists that this channel of the fuel cell 3 CPM is not functioning properly. A failure mode in the CPM circuitry exists that could cause incorrect CPM output signals that would not be detected by the self-test (self tests on this channel have been good). The vendor states that a failure of resistor R115 would cause a reading of 37 mV (0.375 V) if open for a positive bias voltage differential. It would remain at that value until the actual value increased to 185 mV, then it would jump to 500 mV. The CPM output that is displayed in the downlist is an even value of 2 mV per data bit. With instrumentation accuracy, the output could read 36 ± 6 mV. Throughout the mission, the measurement slowly increased from 36 mV to 44 mV, and decreased slightly during fuel cell purges. The next to last purge of the mission was deleted, and the reading climbed to 46 mV prior to landing. The CPM began decreasing during the normal power-down that occurs after landing and reached a steady-state value of 18 mV after landing.</p> <p>KSC: Standard postflight checkout activities confirmed the anomaly, and the CPM was replaced.</p>

TABLE II.- STS-94 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-94-V-03	ASA 4 Redundant Power Loss	189:15:54 G.m.t. 06:21:52 MET CAR 94RF05 IPR 87V-0003	<p>At 189:15:54:30 G.m.t.(06:21:52:30 MET), the ASA 4 power-on command C, which is a switch-scan measurement, and the associated RPC (powered by Main C APC 3) output discrete measurement went from on to off, indicating loss of redundant power to ASA 4. This contact of the ASA 4 switch receives its power from one contact of the FCS channel 4 switch (powered by CNTLCA2), which also provides power to a contact of the ATVC 4 power switch. A separate contact of the ASA 4 switch, which provides control power to a redundant power RPC (powered by Main A APC 1) continued to indicate on, maintaining power to ASA 4. At 189:18:05:03 G.m.t. (07:00:03:03 MET), the affected switch scan and RPC output discretely returned to the normal on state. At 189:21:42:44 G.m.t. (07:03:40:44 MET), the measurements again went to the OFF state.</p> <p>At 190:17:39:52 G.m.t. (07:03:40:44 MET), the ground had the crew cycle the ATVC 4 power switch to on for about 15 seconds to determine if the FCS channel 4 contact was supplying CNTL CA2 power to the ASA 4 and ATVC 4 switches. When the ATVC 4 switch was placed to on, it transferred properly. At the same time, the ASA 4 power-on command C and the associated RPC output discrete both changed to on and remained on for the remainder of the mission. FCS checkout and entry/landing had no effect on ASA 4 power.</p> <p>After the crew had egressed the vehicle, KSC ground personnel cycled the ATVC 4 power switch several times without affecting ASA 4 power.</p> <p>KSC: OPF testing found no anomalies. The ATVC 4 switch assembly was removed and replaced. An X-ray of the switch housing showed a loose solder particle, which most probably created a short between two switch contacts and caused the anomaly.</p>

TABLE III- KSC IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-94-01	Missing Right-Hand External Tank Attachment Ring Bolt	Postflight Inspection PR-SB-B1089-0002	<p>During the postflight assessment of the STS-94 Booster set, a fastener was missing on the aft side to the right-hand External Tank Attachment (ETA) ring bolt.</p> <p>KSC: All ETA ring foam was removed and all other bolts were verified to be installed. The insta-foam was removed from both SRB ring flanges in three suspect locations that had a bolt pattern transition with an obstructed view because of the cable bracket location. The results verified that all fasteners were installed. Engineering at KSC is still investigating to determine the root cause of this anomaly.</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-94 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.

ALPHA	American Loop Heat Pipe with Ammonia
APU	auxiliary power unit
ARS	atmospheric revitalization system
ASA	aerosurface servo amplifier
ATCS	active thermal control system
ATVC	ascent thrust vector control
BDND	Bubble and Drop Non Linear Dynamics
CFDHP	Cryogenic Flexible Diode Heat Pipe
CHT	Capillary-driven Heat Transfer
CPM	cell performance monitor
CRYOFD	Cryogenic Flexible Diode Experiment
CSLM	Coarsening in Solid-Liquid Mixtures
CSR	Customer Support Room
DAP	digital autopilot
DCE	Droplet Combustion Experiment
DMHS	dome-mounted heat shield
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔP	differential pressure
ΔV	differential velocity
ECLSS	Environmental Control and Life Support System
ECOS	Experiment computer operating system
EDO	extended duration Orbiter
e.d.t.	eastern daylight time
EO	ET/Orbiter
EPDC	electrical power distribution and control
ET	External Tank
ETA	External Tank attachment
EVA	extravehicular activity
EXPRESS	Expedite the Processing of Experiments to the Space Station
FCE	flight crew equipment
FCL	Freon coolant loop
FCP	fuel cell powerplant
FCS	flight control system
FDA	fault detection and annunciation
FES	flash evaporator system
FM	frequency modulation
FPV	flow proportioning valve
FSDC	Fiber Supported Droplet Combustion Experiment
ft/sec	feet per second
g	gravity
GFE	Government furnished equipment
GH ₂	gaseous hydrogen
G.m.t.	Greenwich mean time

GO ₂	gaseous oxygen
GPC	general purpose computer
H ₂	hydrogen
HI-PAC DTV	High-Packed Digital Television
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
HRM	high-rate multiplexer
IFFD	Internal Flows in a Free Drop Experiment
IFM	in-flight maintenance
I _{sp}	specific impulse
JSC	Lyndon B. Johnson Space Center
kbps	kilobits per second
KOH	potassium hydroxide
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LH ₂	liquid hydrogen
LIF	Large Isothermal Furnace
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO ₂	liquid oxygen
LSP	Laminar Soot Process
MECO	main engine cutoff
MER	Mission Evaluation Room
MET	mission elapsed time
MFD	Methane Flexible Diodes
MGBX	Middeck Glovebox
MLG	main landing gear
MMA	Microgravity Measurement System
MOD	Mission Operations Directorate
MPS	main propulsion system
MSFC	Marshall Space Flight Center
MSL-1	Microgravity Science Laboratory-1
MSX	Midcourse Space Experiment
mV	millivolts
NASA	National Aeronautics and Space Administration
NCU	network communication unit
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O ₂	oxygen
OARE	Orbital Acceleration Research Experiment
OCA	Orbiter Communications Adapter
OFD	Oxygen Flexible Diode
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPF	Orbiter Processing Facility

OPS	Operations
PAL	protuberance air load
PCAM	Protein Crystallization Apparatus for Microgravity
PGBA	Plant Generic Bioprocessing Apparatus
PGSC	payload general support computer
pH	parts hydrogen
PHaSE	Physics of Hard Spheres Experiment
PM	phase modulation
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution
psi	pounds per square inch
psia	pound per square inch absolute
psid	pound per square inch differential
QSAM	Quasi-Steady Acceleration Measurement
RCS	reaction control subsystem
RF	radio frequency
RIC	rack interface controller
RME	Risk Mitigation Experiment
RPC	remote power controller
RSRM	Reusable Solid Rocket Motor
RTLS	Return to Launch Site (abort)
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAMS	Space Acceleration Measurement System
SAREX-II	Shuttle Amateur Radio Experiment-II
scim	standard cubic inch(es) per minute
SLF	Shuttle Landing Facility
S/N	serial number
SOFBALL	Structure of Flame Balls at Low Lewis-numbers
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
STS	Space Transportation System
TDRS	Tracking and Data Relay Satellite
TEMPUS	Electromagnetic Containerless Processing Facility
TPS	thermal protection system/subsystem
WCS	Waste Collection System
WDAS	Wireless Data Acquisition System
WSB	water spray boiler