

NSTS-37421

# **STS-91 SPACE SHUTTLE MISSION REPORT**

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July 1998



**National Aeronautics and  
Space Administration**

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

### NOTE

The STS-91 Space Shuttle Mission Report was prepared from inputs received from the Flight Projects Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

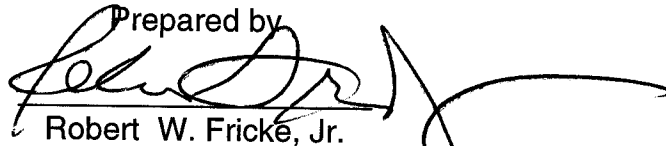
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STS-91

SPACE SHUTTLE

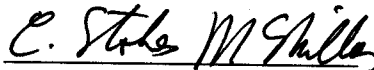
MISSION REPORT

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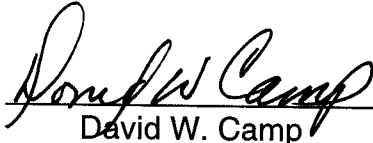


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## INTRODUCTION

The STS-91 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during this ninth and final Mir rendezvous mission. The report also summarizes the mission activities and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this ninety-first mission of the Space Shuttle Program. STS-91 was the sixty-sixth flight since the return to flight, and the twenty-fourth flight of the (Discovery) Orbiter vehicle.

The flight vehicle consisted of the OV-103 Orbiter; an ET that was designated ET-96, which was the first super lightweight tank (SLWT); three SSMEs that were designated as serial numbers (S/N) 2047 (Block IIA), 2040 (Block I), and 2042 (Block I) in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-091. The two RSRMs were designated RSRM 066 with one installed in each SRB. The individual RSRMs were designated 360W066A for the left SRB, and 360W066B for the right SRB.

The STS-91 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 objectives of the STS-91 flight were to rendezvous and dock with the Mir Space Station, and return the NASA 7 Mir Astronaut. A single Spacehab module was to carry Russian Logistics, science experiments and Risk Mitigation Experiments (RMEs). The Orbiter was to transfer water in support of the Phase 1 Program requirements. A second primary objective of this flight was to accomplish the requirements of the Alpha Magnetic Spectrometer (AMS) payload. Secondary objectives of this flight were to accomplish the requirements of the Solid Surface Combustion Experiment (SSCE); the Space Experiment Module (SEM) Payload; seven Get-Away Special (GAS) Carrier Payloads; and as a payload of opportunity, the Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX).

The STS-91 mission was a planned 10-day plus 2-contingency-day mission during which logistics for the Mir station would be transferred and experiments would be performed. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. There were four docked days with the Mir. The STS-91 sequence of events is shown in Table I, the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List is shown in Table II, and the Marshall Space Flight Center (MSFC) Problem Tracking List is shown 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 used in this report. All times are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The seven crewmembers of the STS-91 mission consisted of Charles J. Precourt, Col., U. S. Air Force, Commander; Dominic L. Pudwill Gorie, Commander, U. S. Navy, Pilot;

Franklin R. Chang-Diaz, Ph. D., Civilian, Mission Specialist 1; Wendy B. Lawrence, Commander, U. S. Navy, Mission Specialist 2; Janet Lynn Kavandi, Ph. D., Civilian, Mission Specialist 3; Valery Victorovich Ryumin, Russian Cosmonaut, Mission Specialist 4; and Andrew S. W. Thomas, Ph. D., Civilian, Mission Specialist 5 (docking through landing). STS-91 was the sixth Space Shuttle flight for Mission Specialist 1, the fourth Space Shuttle flight for the Commander, the third Space Shuttle flight for Mission Specialist 2 and Mission Specialist 5 (descent), and the first Space Shuttle flight for the Pilot, Mission Specialist 3, and Mission Specialist 4. However, Mission Specialist 4 has also flown three times on the Soyuz spacecraft and Mir Space Station.

## MISSION SUMMARY

Following power reactant storage and distribution (PRSD) subsystem cryogenic loading during prelaunch operations, a simultaneous trip of all four oxygen (O<sub>2</sub>) tank 5 heater current-limit sensors occurred. The anomaly repeated two more times during the countdown. The sensors were reset by launch processing system (LPS) command after the first two occurrences and with the crew station switch on the third occurrence. The three occurrences were characterized by a 0.8- to 1.0-ampere differential load on the preflight bus and were isolated to the trip circuitry. As a result of the short launch window, a Launch Commit Criteria (LCC) waiver was pre-approved in case another identical nuisance trip occurred late in the countdown. This waiver would have allowed the launch to proceed without resetting the current limit sensors. There were no additional occurrences of the anomalous trip during either prelaunch operations or the flight.

The STS-91 mission was launched on time at 153:22:06:24.008 G.m.t. (5:06 p.m. e.d.t.). The ascent phase was satisfactory and the planned orbit was achieved. All Orbiter subsystems performed nominally with the exception of two reaction control subsystem (RCS) thrusters, which failed off at External Tank (ET) separation.

All SSME and RSRM start sequences occurred as expected and the launch phase performance was satisfactory in all respects. First stage ascent performance was as expected. The SRB separation, entry, deceleration, and water impact occurred as anticipated, and both SRBs were successfully recovered. Performance of the SSMEs, ET, and main propulsion system (MPS) was nominal. Approximately 39.16 seconds after SSME ignition, the SSME 1 main combustion chamber (MCC) chamber pressure (P<sub>c</sub>) channel A measurement was disqualified (Flight Problem STS-91-E-01). This problem is discussed in the SSME section of this report.

An evaluation of vehicle propulsive performance during ascent was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine specific impulse (I<sub>sp</sub>) determined for the time period between SRB separation and start of 3g throttling was 453.5 seconds as compared to a MPS tag value of 453.19 seconds.

At ET separation, the R2U and F2U RCS thrusters failed off and were deselected by the redundancy management (RM) system. The F2U thruster P<sub>c</sub> reached only 17.8 psia (normally 160 psia) (Flight Problem STS-91-V-02). Both the fuel and oxidizer injector temperatures dropped indicating that there was some flow of each propellant. Likewise, in the case of the R2U thruster, the P<sub>c</sub> only reached 11.4 psia (Flight Problem STS-91-V-01). Again, both the fuel and oxidizer injector temperatures dropped indicating some flow of both propellants. In both cases, full flow was suspected for one propellant and only pilot valve flow from the other propellant. Both thrusters remained deselected for the remainder of the mission. The loss of these thrusters did not impact the flight.

Prior to liftoff, the miniature airborne Global Positioning System (GPS) receiver (MAGR) performance was nominal. However, about 4 seconds after liftoff, the navigation solution became completely erroneous. Only one satellite was being tracked instead of



the normal four that are tracked. Even after the heads-up roll maneuver, which provides better exposure of the GPS antenna, the receiver could not track more than one satellite. About 26 minutes into the flight, the MAGR acquired four satellites and began operating nominally.

The orbital maneuvering subsystem (OMS) maneuvers performed during the flight are shown in the following table. A nominal orbit of 177 by 129 nautical miles was achieved as a result of the satisfactory OMS 2 maneuver shown in the following table.

#### OMS MANEUVERS

Maneuver	Time, G.m.t. and MET	Duration, seconds	$\Delta V$ , ft/sec
OMS-1	Not required		
OMS-2 Two engine	153:22:50:34.8 G.m.t. 00:00:44:10.8 MET	105.2	169
OMS-3 Two engine	154:01:47:41.9 G.m.t. 00:03:41:17.9 MET	55.0	84
OMS-4 Right engine	154:14:34:14.7 G.m.t. 00:16:27:50.7 MET	18.6	14.3
OMS-5 Two engine	154:21:23:31.9 G.m.t. 00:23:17:07.9 MET	28.2	44
OMS-6 Right engine	155:11:59:00.5 G.m.t. 01:13:52:36.5 MET	31.2	23.4
OMS-7 Two engine	162:16:30:00.3 G.m.t. 08:18:23:36.3 MET	12.4	20
Deorbit (OMS-8) Two engine	163:16:52:25.3 G.m.t. 09:18:46:01.3 MET	249.8	414.6

The payload bay doors were opened at 153:23:51:20 G.m.t. (00:01:44:56 MET). Dual motor times were achieved during the door-opening activity.

After Ku-band activation, the system failed to radiate any radio frequency (RF) energy when placed in the communication mode (Flight Problem STS-91-V-03). The operate bit was low. The Ku-band system power was cycled to off, and the activation procedure was performed again with no success. Troubleshooting did not recover the Ku-band system communications mode operation, and the signature appeared to be the result of a failure in either the signal processor assembly (SPA) or the deployed electronics assembly (DEA). The system operated properly in the radar mode as discussed later in this report. As a result of this failure, the operations recorder could not be dumped, no Ku-band television or Orbiter Communications Adapter (OCA) information could be transmitted, and the Alpha Magnetic Spectrometer (AMS) (payload) high data rate mode could not be used with the Ku-band.

An in-flight maintenance (IFM) procedure to allow downlinking of the AMS payload data via the high data rate mode was completed at 154:22:24 G.m.t. (01:00:17:36 MET). The Ku-band signal processor was bypassed, and the data were patched through the frequency modulation (FM) signal processor. The data were acquired by the Electronic Systems Test Laboratory (ESTL) here at the Johnson Space Center (JSC). Support of the FM data recovery was also provided by other ground stations.

During the flight day following docking, an IFM procedure was performed in an unsuccessful attempt to recover operation of the Ku-band system in the communications mode. The IFM determined that the transmit-enable signal produced by the Ku-band SPA was present in the SPA output. It had been speculated that this signal was not present, and the IFM was designed to inject this signal. Based on the results of this IFM, the indication was that the failure was probably in the deployed electronics assembly. As a result, the Ku-band communications mode was not available during the flight.

A successful PRSD current-level limit sensor test of the O<sub>2</sub> tanks was performed at 154:19:05 G.m.t. (00:20:55 MET). The sensor-trip function operated properly.

The fuel cell 3 relief valve, which was determined to be leaking during the super lightweight tank (SLWT) tanking test, leaked throughout the mission following fuel cell 3 activation. The leak rate varied as a function of system configuration.

During rendezvous with the Mir, the crew had a problem with the trajectory control system/rendezvous proximity operations program (TCS/RPOP). The RPOP tracks vehicle position using four different methods which include the radar solution, the on-board state-vector solution and the TCS navigation solution. The TCS navigation solution apparently provided a valid solution until the vehicle was approximately 170 feet from the Mir. When it was determined that the TCS navigation solution was no longer valid, a request was made to reinitialize the RPOP. Approximately 10 marks after the reinitialization, the problem recurred. These events are now understood. As the distance between the two vehicles decreased, the errors in the radar and state vector solutions began increasing. At this point, only data from the TCS navigation solution and hand-held laser were to be used. However, the data from all four solutions were being plotted on the RPOP payload and general support computer (PGSC). A button exists to turn off the solutions from the radar and the state vector, if the Pilot or Commander no longer wishes to view the diverging solutions being plotted along with the good solutions. However, a code problem exists in that if the button is depressed to turn off the radar and state-vector solutions, the TCS navigation solution is also turned off. The crew has confirmed that for both instances of the invalid TCS navigation solution, the button was pushed to clean up the data being plotted. This is a known phenomenon documented in RPOP Operations Note 048 dated January 6, 1997.

The Orbiter Docking System (ODS) performed nominally throughout the docking sequence with the Mir. Capture occurred nominally at approximately 155:16:58:19 G.m.t. (01:18:51:55 MET) at a closing rate of 0.124 ft/sec and with nominal misalignments. The structural hooks were closed and docking was completed at approximately 155:17:12:00 G.m.t. (01:19:05:36 MET). This was the first docking to use the International Space Station (ISS) Androgynous Peripheral Attachment System (APAS) docking mechanism.

The Ku-band radar successfully tracked the Mir from a range of 103,000 feet down to 89 feet before the system was taken out of the radar mode.

Orbiter consumables were used to repressurize the combined Orbiter-Mir stack from 12.7 to 14.7 psi. Five contingency water containers (CWC's) of water were delivered to Mir during the first docked day.

The remote manipulator system (RMS) was powered up at 157:12:26 G.m.t. (03:14:20 MET) and uncradled at 157:12:44 G.m.t. (03:14:38 MET). A complete checkout of the RMS in all of its operational modes was successfully completed, and the RMS was then maneuvered in support of the RMS situational awareness display (RSAD) evaluation tests. The RMS was cradled and latched in the manipulator positioning mechanisms (MPM's) at 157:15:13 G.m.t. (03:17:07 MET). The MPMs were stowed at 157:15:21 G.m.t. (03:17:15 MET), and the RMS was deselected.

During the RMS unberthing, the mid-MPM-pedestal manipulator retention latch (MRL) ready-to-latch (RTL) microswitch indications (2 of 2) failed to transfer off. These microswitch indications remained on throughout the entire period of RMS operations. RMS berthing and latching was assisted by using closed circuit television (CCTV) camera B and the targets on the MPM pedestals to verify that the RMS was within the capture envelope of the mid-MRL. In addition, the RMS joint alignment was verified as being within the nominal limits.

At approximately 156:02:00 G.m.t. (02:03:54 MET), the ground controllers were commanding CCTV camera C and observed that it would not pan or tilt. The crew confirmed that the pan/tilt circuit breaker on panel R14D was engaged. The crew also confirmed that camera C would not pan or tilt (Flight Problem STS-91-V-04). The crew cycled the pan/tilt circuit breaker five times in an attempt to clear the potential corrosion/oxidation from the circuit-breaker contacts. This action did not recover the pan/tilt function of CCTV camera C. The crew cycled the circuit breaker for the pan and tilt heater. Following this recycling, another attempt was made to pan and tilt the camera, but it was not successful. The loss of camera C had only a minimal impact on the Mir survey and the Spektr gas release, both of which occurred after undocking.

The Phase 1 Program was brought to a highly successful conclusion with the completion of the logistics transfer operations and the retrieval of the seventh and final astronaut (Andrew S. W. Thomas) after almost five months of operations on the Mir. During STS-91, a total of 12 ½ CWCs of water (1220 lb) were delivered to the Mir. The transfer operations were completed with 100 percent of the Russian resupply items transferred, 103 percent of the U. S. return items transferred, and 96 percent of the Russian return items transferred. The total percentage of items transferred, based on the tracking log, was 101 percent.

The ODS hatch was closed at approximately 159:13:08 G.m.t. (05:15:02 MET). Following hatch closure, the vestibule depressurization began at 159:13:36 G.m.t. (05:15:30 MET) and was completed 6 minutes later. The undocking was accomplished at 159:16:01:46 G.m.t. (05:17:55:22 MET). The ODS performed nominally during the undocking sequence of the Orbiter from the Russian Mir space station and successfully demonstrated the operation of the new ISS docking mechanism.

The rendezvous separation maneuver was a +X firing of the RCS primary thrusters L3A and R3A for 12 seconds. The maneuver resulted in a  $\Delta V$  of 2.9 ft/sec. All thruster firings during the separation and fly-around phases were nominal.

At 158:20:00 G.m.t. (04:21:54 MET), after the auxiliary power unit (APU) heaters were changed from system A to B, the APU 2 fuel pump/line/gas generator valve module (GGVM) system B heater thermostat was cycling within a 10 °F deadband, as indicated

by the bypass-line temperature. On the previous flight of this APU (S/N 403 in position 3 on STS-83), this thermostat cycled in a 15 °F deadband, which was down from about 20 °F on the thermostat's initial flight (STS-75). This thermostat is located on a fuel line that is attached to the APU. Previous experience has shown that a thermostat located at this position will eventually fail once it begins to show signs of set-point shifting or erratic behavior. The heater operated with the 10 °F deadband for the remainder of the mission. The thermostat will be replaced during the postflight turnaround activity.

At approximately 160:06:19 G.m.t. (06:08:12 MET) during a Tracking and Data Relay Satellite (TDRS) hand-over from West to East, the software failed to select the East satellite even though the West satellite was out of view (obscured by the earth). The software continued to select the antenna that pointed to the West satellite. There were no indications of a communication systems hardware failure and the antennae were operating nominally. Prior to these events, the general purpose computer (GPC) 1 error counter was rapidly counting up (Flight Problem STS-91-V-05). The errors started at about 160:05:48 G.m.t. (06:07:41 MET). However, no GPC error messages appeared on the Fault Summary page. As a result, the ground controllers manually commanded the antennas to point correctly.

As a result of the excessive GPC error count discussed in the previous paragraph, the following tasks were performed.

- a. The MAGR was commanded to self-test with anomalous results. The MAGR was powered cycled but did not recover, and the MAGR was powered off.
- b. An operations (OPS) transition was performed and it was unsuccessful in that no change in GPC error rate nor any change in the systems management (SM) transferred state vector occurred.
- c. Software dumps were performed for GPC's 1 and 4. GPC 1 was then powered off and the G2 freeze-dried GPC (GPC 2) was activated and operated as the single G2 GPC. As soon as GPC 2 took over the guidance, navigation and control (GNC) function, the state vector in the SM GPC began updating. When this occurred, the antenna management software resumed selecting the correct antenna and TDRS. The positional vector was previously frozen in the SM GPC, and the antenna management software continuously selected TDRS West.
- d. At approximately 160:17:30 G.m.t (06:19:24 MET), an OPS transition was performed to ensure the GPS software was moded to off.

The data analysis determined that an interruption of the handshake between the GPC and the MAGR was the root cause of the excessive GPC error count. Once this handshake condition occurs, it cannot be reestablished. A timing mismatch provided the conditions for the interruption of the handshake. It is known, however, that when a handshake is interrupted, the MAGR vector within the GPC grows. Eventually this MAGR vector growth causes GPC internal errors to be enunciated.

A GMEM change was developed to patch the IPL software to operate as if there was no MAGR. The patch was determined not to be needed because with the MAGR off and with an OPS transition, the error propagation effect is eliminated.

All indications are that the Space Integrated Global Positioning System/Inertial Navigation System (SIGI) performed well for the entire mission. The crew performed several SIGI auto-initializations, which checked the SIGI GPS state vector, the blended GPS/inertial navigation system (INS) state vector, and the attitude against the existing Shuttle parameters. Initializations are performed if the parameters are out of bounds. The crew reported that no initializations were required as the GPS and Blended GPS/INS state vectors were reasonable, and the SIGI attitude was within one degree per axis of the Orbiter attitude.

A RMS survey was made of the area around the fuel-cell relief nozzle to search for ice that may have formed because of the fuel cell 3 water venting. During this second RMS deployment of the mission, all of the MPM pedestal RTL switch indications (6 of 6) transferred to off when the RMS was unberthed. During the first RMS unberthing that is discussed earlier in this report, the mid MPM pedestal RTL switch indications (2 of 2) failed to transfer off. During the second RMS berthing operation, all of the MPM pedestal RTL switch indications (6 of 6) transferred to on when the RMS was berthed.

The survey of the fuel-cell relief nozzle, the surrounding midfuselage sidewall, and starboard payload bay door was conducted in two steps. In the first step, supply water tank A was maintained at approximately 22.0 psia while the crew viewed the relief nozzle and surrounding area. In the second step, viewing of the relief nozzle and payload bay door was conducted with supply water tank A pressurized to approximately 30.0 psia. The crew reported that small pieces of ice would form and attach to the area surrounding the fuel-cell water-relief nozzle, but would then break free. The crew also reported that there was no ice on the payload bay door.

The flight control system (FCS) checkout was performed using APU 1. APU 1 was started at 162:12:20:19 G.m.t. (08:14:13:55.069 MET) and ran for 9 minutes 23.023 seconds with a fuel consumption of 25 lb. APU 1 and hydraulic system 1 performed nominally during the checkout. Because of the relatively long run time of APU 1, water spray boiler (WSB) 1 operation was required. Its performance was nominal.

The right outboard elevon actuator displayed a ringing tendency during FCS checkout at hydraulic system activation. It was apparent during the aerosurface drive test as well as the secondary actuator test. The ascent data did not show any ringing. The outboard elevons have a greater tendency for this condition to occur because of the higher gains in those servo loops. The ringing did not affect the operation of the actuator, and was damped as soon as the surface had an aerodynamic load during entry.

The RCS hot-fire was performed following FCS checkout. No problems were noted.

At approximately 162:10:00 G.m.t. (08:11:54 MET), the crew called down an error code on the STS-3 PGSC. The error code indicated a failed system board, and the PGSC was stowed for the remainder of the flight.

During the OMS 7 SIMPLEX dual-engine firing, the valve 1 position indicated 99-percent open, as expected. At the termination of the SIMPLEX firing, the left OMS engine ball valve 1 position indicator continued to indicate that the valve was open (96-percent open), where it should have been 0-percent open (Flight Problem STS-91-V-06). When

the left OMS engine was ignited during the deorbit maneuver, the valve 1 position returned to the 99-percent open indication. At the termination of the firing, the indicator continued to read 99-percent open when it again should have been 0-percent open. It is believed to be most likely a failure of the valve position instrumentation as opposed to an actual failure of the valve to close.

The payload bay doors were closed and latched for landing at 163:14:18:38 G.m.t. (09:16:12:14 MET). The dual-engine deorbit maneuver for the first landing opportunity at the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) was performed on orbit 154 at 163:16:52:25.3 G.m.t. (09:18:46:01.3 MET). The maneuver was 249.8 seconds in duration with a  $\Delta V$  of 414.6 ft/sec.

During entry, three instances of water spray boiler 2 over-cooling (lubrication oil outlet temperature at least 15 °F below steady-state) occurred. On the first occurrence, the lubrication oil outlet temperature dropped to 200 °F. On the second and third occurrences, the lubrication oil outlet temperature dropped to 196 °F and 234 °F, respectively. These occurrences did not impact entry operations.

Entry was completed satisfactorily, and main landing gear touchdown occurred on SLF concrete runway 15 at 163:18:00:24 G.m.t. (09:19:54:00 MET) on June 12, 1998. The nose gear touchdown occurred at 163:18:00:28 G.m.t. and the Orbiter drag chute was deployed at 163:18:00:29 G.m.t. The drag chute was jettisoned at 163:18:00:58 G.m.t. with wheels stop occurring at 163:18:01:28 G.m.t. The rollout was normal in all respects. The flight duration was 9 days 19 hours 54 minutes 00 seconds. The APUs were shut down 17 minutes 29 seconds after landing.

## **PAYLOADS AND EXPERIMENTS**

All of the payloads major mission objectives were successfully met, and over 100 percent of the planned transfers between the two vehicles (Mir and Orbiter) were successfully completed.

### **ALPHA MAGNETIC SPECTROMETER**

As a result of the Ku-band failing after activation, the Alpha Magnetic Spectrometer (AMS) payload high-data-rate mode could not be used with the Ku-band. An in-flight maintenance (IFM) procedure to allow downlinking of the AMS payload data via the high data rate mode using the frequency modulation (FM) system was completed at 154:22:24 G.m.t. (01:00:17:36 MET). Also, an IFM procedure was performed in an unsuccessful attempt to recover operation of the Ku-band system.

Onboard recording of the science data by the AMS digital data recorder system (DDRS) resulted in over 200 million events being recorded. AMS temperatures were maintained within operational limits throughout the mission; however, changes in vehicle attitude were required as certain attitudes resulted in the temperatures trending higher. The data were acquired from the FM system by the Electronic Systems Test Laboratory (ESTL) at the Johnson Space Center (JSC) as well as by other ground stations. A total of 1125 minutes of high-rate data snapshots were received, and the snapshots varied in length from 30 seconds to 15 minutes.

### **PHASE 1 PROGRAM**

The Phase 1 Program was brought to a highly successful conclusion with the completion of the logistics transfer operations and the retrieval of the seventh and final astronaut (Andrew S. W. Thomas) after almost five months of operations on the Mir. During STS-91, a total of 12 ½ contingency water containers (CWCs) of water (1220 lbm) were delivered to the Mir. The transfer operations were completed with 100 percent of the Russian resupply items transferred, 103 percent of the U. S. return items transferred, and 96 percent of the Russian return items transferred. The total percentage of items transferred, based on the tracking log, was 101 percent.

### **SPACEHAB SUBSYSTEMS**

All Spacehab subsystems operated nominally, except for the following three items:

- a. The video switching unit (VSU) had an intermittent port. The Public Affairs camcorder power cable was moved to another available port and normal operations were resumed. This condition did not impact the flight as the camcorder operated on battery power when the Orbiter power was not present.
- b. A current transducer failed on experiment circuit panel 3 (EXCP3). The current insight on EXCP3 was lost; however, the current was monitored through the direct current (dc) experiment bus. The loss did not impact the completion of mission requirements.

- c. The preflight data multiplexer unit (DMU) random access memory (RAM) software load for the Serial Converter Unit (SCU) that supported the Spacehab Universal Communications System (SHUCS) was not compatible with the SHUCS software. This condition caused down-link problems. A revised DMU RAM software load was uploaded late in the mission, and it provided a larger bandwidth for down-linking data.

## **RISK MITIGATION EXPERIMENTS**

STS-91 was a very successful flight for the International Space Station Risk Mitigation Experiments (RMEs), with all major objectives accomplished. All transfers of RME hardware and equipment was completed as scheduled except for one of two Space Portable Spectroreflectometer (SPSR) batteries and a roll of gray tape. A discussion of the five activities associated with the RMEs is found in the following paragraphs.

### **RME 1312 - Real-Time Radiation Monitoring Device**

All Real-Time Radiation Monitoring Device (RRMD) hardware and software performed properly. The operating times for the detector units were rescheduled to optimize data collection in response to real-time solar activity. All samples were activated and deactivated properly with no leakage. For the short-term and long-term samples, with no Ku-band to downlink the video, a diagram was sent up to the crew for guidance when reading down the bubble sizes. The Principal Investigator was able to determine in real-time which of the 24 tubes were to be deactivated over a four-day run time. The Phantom Torso Experiment (PTE) was performed as planned with the exception of the early termination of two of the active dosimeters because of low battery power. The RRMD and the PTE were deactivated nominally on flight day 10.

### **RME 1319 - Inventory Management System**

The Inventory Management System (IMS) bar code readers (BCRs) completed all planned activities. The super memory checker (SMEM) software recorded single-event-upsets (SEUs) and the file was copied onto the payload and general support computer (PGSC). The BCR scanning tests were performed on two crewmembers as scheduled and the files copied onto the PGSC and downlinked to the Mission Control Center for evaluation.

### **RME 1320 - Radiation Monitoring Equipment**

The East/West orientation data and the calibration data collection was completed on the Mir Space Station. A total of eight memory module change-outs were completed. The final memory module change-out was accomplished at 159:12:26 G.m.t. (05:14:20 MET), and the hardware was stowed in the middeck with both main modules active for entry. Data that were not downlinked after the final memory module change-out was retrieved from the crew flight data file after landing.

### **RME 1331 - Shuttle Condensate Collection for International Space Station**

The Shuttle Condensate Collection for International Space Station (SSCI) experiment data collection was performed on Shuttle before docking and after undocking. A CWC



was also used to collect condensate throughout the docked phase. It is believed that approximately half of the CWC contains condensate.

## **SECONDARY PAYLOADS**

### **Cosmic Radiation Effects and Active Monitor**

All Cosmic Radiation Effects and Active Monitor (CREAM) hardware was retrieved from the Mir, except for a roll of gray tape, and the hardware was stowed in the middeck.

### **Commercial Protein Crystal Growth**

The Commercial Protein Crystal Growth (CPCG) payload operated nominally throughout the flight. The hardware and data have been returned to the Principal Investigator for analysis.

### **Solid Surface Combustion Experiment**

The crew successfully performed the tenth Solid Surface Combustion Experiment (SSCE). Two different cylindrical polymethyl methacrylate (PMMA) samples were burned. Film and video of the burning was recorded as well as the fuel temperatures and chamber pressure.

### **Get-Away Specials**

Four Get-Away Specials (GAS) and two Space Experiment Module (SEM) payloads were successfully operated. Data and hardware have been returned to the sponsors for analysis. The GAS and SEM payloads were as follows:

- a. G-090 - Four experiments that are:
  1. Chemical Unit Process;
  2. Nucleic Boiling;
  3. Crystal Growth; and
  4. Popcorn and Radish Seed Exposure Comparison.
- b. G-648 - Atlantic Canada Thin Organic Semiconductors (ACTORS);
- c. G-743 - DNA Damage from Exposure to Space Radiation; and
- d. G-765 - Microgravity Industry Related Research for Oil Recovery (MIRROR);

### **Shuttle Ionospheric Modification with Pulsed Local Exhaust**

The OMS 7 12-second two-engine firing was accomplished in support of the Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) experiment at 162:16:30:00.3 G.m.t. (08:18:23:36.3 MET). The firing was performed in view of the SIMPLEX ground station in Alice Springs, Australia. The initial data from the firing was inconclusive. However, the Principal Investigator indicated that postflight analysis is required to determine the ionospheric effects. Processing of the radar data is often required to obtain the level of detail sought.

## **HUMAN EXPLORATION AND DEVELOPMENT OF SPACE TECHNOLOGY DEMONSTRATION**

The Human Exploration and Development of Space Technology Demonstration (HTD) - 1401/SHUCS was not able to complete a voice, facsimile or data exchange because of the software incompatibility, which was corrected late in the flight. The payload did successfully uplink and downlink data between the SHUCS onboard hardware and the ground via the Spacehab data system. The crew reported that a dial tone was present, and this verified that SHUCS did make contact with a satellite; however, completion of the SHUCS transmitter/receiver loop via the satellite was not achieved. The SHUCS team believes that valuable data were obtained from this flight demonstration.

## **VEHICLE PERFORMANCE**

### **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 Specification Document (OMRSD) violations occurred, nor were any in-flight anomalies identified from the data.

Both SRBs were successfully separated from the External Tank (ET) at approximately liftoff plus 123.004 seconds. Visual reports from the recovery area indicate that all deceleration subsystems performed as designed. The SRBs were recovered and towed back to Cape Canaveral.

The postflight inspection of the SRBs revealed that the two SRBs were in excellent condition. The SRBs were disassembled and refurbishment activities were in progress as this report was written.

### **REUSABLE SOLID ROCKET MOTORS**

The Reusable Solid Rocket Motors (RSRMs) performed as designed throughout the first stage of ascent. No LCC or OMRSD violations were noted during the countdown and no in-flight anomalies were found during the data analysis and review. RSRM prelaunch operations were normal. Power up and operation of all igniter joint 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 temperatures within the required LCC ranges was on the low range throughout the countdown and, as planned, was switched to the high range at liftoff minus 15 minutes. The calculated flex bearing mean bulk temperature was 82 °F, which was satisfactory.

Data show that the flight performance of both RSRMs was well within the allowable performance envelopes and was also typical of the performance observed on previous flights. The table on the following page reflects the RSRM propulsion performance during ascent. The RSRM propellant mean bulk temperature (PMBT) was 77 °F at liftoff. The maximum trace shape variation of pressure versus time during the 62- to 80-second time frame was calculated to be -0.41 percent at 72 seconds for the left RSRM and +0.62 percent at 79 seconds for the right RSRM. These values were well within the 3.2 percent allowable limits. A within-limit thrust imbalance also existed on the left RSRM at one second after liftoff and the value was -48,000 lbf.

### **EXTERNAL TANK**

#### **Super Lightweight Tank Tanking Test**

As this External Tank (ET) was the first super lightweight tank (SLWT) to be flown in the Space Shuttle Program, a tanking test was performed on May 18, 1998. The primary objectives of the test were to evaluate predicted environments and operational

## RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 77 °F		Right motor, 77 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	65.99	65.93	66.23	66.19
I-60, 10 <sup>6</sup> lbf-sec	175.74	175.73	176.27	176.49
I-AT, 10 <sup>6</sup> lbf-sec	296.89	296.24	296.76	297.04
Vacuum Isp, lbf-sec/lbm	268.6	268	268.6	268.8
Burn rate, in/sec @ 60 °F at 625 psia	0.3681	0.3689	0.3691	0.3694
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	109.2	108.6	108.7	108.3
50 psia cue time	118.9	118.3	118.4	118.1
Action time <sup>b</sup>	120.9	120.6	120.5	120.4
Separation command	123.8	-----	123.8	-----
PMBT, °F	77	77	77	77
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	3.0	2.8	3.0
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		677.8	

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

<sup>a</sup>All times are referenced to ignition command time except where noted by a <sup>b</sup>

<sup>b</sup>Referenced to liftoff time (ignition interval).

procedures before the first flight of the Aluminum Lithium SLWT. The test was successfully completed with all test objectives being fulfilled.

All objectives and requirements established for the ET propellant loading and special operations were successfully met. All ET electrical equipment and instrumentation operated nominally. The ET purge and heater operations were monitored and all performed properly. No violations of the LCC or the OMRSD were noted during the test.

No unexpected ice/frost formations were observed on the ET during the countdown. The sanded area of the LO<sub>2</sub> tank ogive exhibited no anomalies. There was no observed ice or frost on the acreage areas of the ET. Normal quantities of ice or frost were found in the expected locations based on previous ET experience. The ET pressurization performed nominally. No significant hazardous gas concentrations were noted during the countdown with the maximum concentration level reaching a very favorable level of 80 ppm, which compares very favorably with previous data for this vehicle.

Following the SLWT tanking test approximately two weeks prior to launch, the Ice/Frost team found a piece of loose foam thermal protection system (TPS) material in three places on the ET. All of the damage sites were typical of an ET detanking. All of the conditions were considered acceptable for flight, and no repairs were required prior to launch. However, a 0.5-inch void was found in the approximate center of a repair on the

LH<sub>2</sub> feedline to aft-dome closeout. The loose foam was removed and the area was repaired prior to launch. There were no constraints found following the tanking test that would prevent the launch cryogenics loading.

### **Super Lightweight Tank Flight Operations**

The prelaunch countdown and flight performance of the ET, which was the first super lightweight tank (SLWT), was nominal. All requirements and objectives of the ET operations of propellant loading and flight operations were satisfied. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operations were monitored and all performed properly. No ET LCC or OMRSD violations were identified nor were any in-flight anomalies identified from the data.

As expected from preflight predictions, no unexpected ice/frost formations were observed on the ET during the countdown. No ice or frost was observed on the acreage areas of the ET. However, normal quantities of ice or frost were present on the LO<sub>2</sub> and LH<sub>2</sub> feed-lines, the pressurization line brackets, or along the LH<sub>2</sub> protuberance air load (PAL) ramps. All ice and frost observations were within the historical conditions as referenced in the NSTS 08303 document. The Ice/Frost Team reported that there were no anomalous thermal protection system (TPS) conditions.

The ET pressurization system functioned properly throughout engine start and flight. The LO<sub>2</sub> tank bulge mode for the SLWT was very comparable to the previously flown lightweight tank. The amplitude was slightly less and the frequency was greater than predicted (3.7 Hz versus 3.3 Hz predicted) but still, as expected, less than the lightweight tank (3.9 Hz). The minimum LO<sub>2</sub> ullage pressure during the ullage pressure slump was 14.3 psid, which was very close to the predicted pressure.

ET separation occurred as planned with ET entry and breakup within the predicted footprint. The postflight predicted ET intact impact point was approximately 35 nmi. uprange of the preflight prediction.

Following separation of the ET from the Orbiter, the crew reported that the ET was venting and tumbling. The rotation was about 1 deg/sec, and the venting sometimes appeared to be continuous from the intertank area of the ET. The postflight evaluation of the photography verified the crew observations.

### **SPACE SHUTTLE MAIN ENGINE**

All Space Shuttle main engine (SSME) parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. No LCC or OMRSD violations occurred; however, one in-flight anomaly was identified during the review of the data.

Engine ready was achieved at the proper time; all LCC were met; and engine start and thrust buildup were normal. Flight data indicate that the SSME performance during mainstage, throttling, shut down and propellant dump operations was normal. The high pressure oxidizer turbopump (HPOTP) and the high pressure fuel turbopump (HPFTP) temperatures were well within specification throughout engine operation. Space Shuttle main engine cutoff (MECO) occurred approximately 509.674 seconds after liftoff.

The was one failure identification (FID) posted approximately 39.16 seconds after engine start for SSME 1 main combustion chamber (MCC) chamber pressure ( $P_c$ ) channel A disqualification (Flight Problem STS-91-E-01). Channel A exceeded a 200-psi comparison check with  $P_c$  reference. This disqualification did not impact SSME 1 operation or vehicle performance as nominal operations for SSME 1 continued using channel B. The smart nature of this failure resulted in the compromise of the  $P_c$  low redline protection from 39.16 seconds until the measurement recovered at 506 seconds. The investigation of this problem is continuing; however, the most probable cause of the failure was contamination. No other significant SSME problems were identified.

## **SHUTTLE RANGE SAFETY SYSTEM**

The Shuttle range safety system (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits turned off at the appropriate times. All SRSS measurements indicated that the system operated as expected throughout the countdown. Analysis of the flight data showed that the right-hand SRB signal strength A exceeded the range safety minimum requirement of -85 dBm when tracking with the Cape Canaveral Command Site. This condition did not affect system operation as data indicate that the combined signal strength of all four SRB SRSS integrated receiver decoders (IRDs) was always high enough to maintain satisfactory system operation to SRB separation. The cause of this low signal strength is the vehicle roll maneuver which shades the right-hand SRB antenna.

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

## **ORBITER SUBSYSTEM PERFORMANCE**

### **Main Propulsion System**

The overall performance of the MPS was as expected. The liquid oxygen ( $LO_2$ ) and liquid hydrogen ( $LH_2$ ) loading were performed with no stop-flows or reverts. The volumes of the SLWT  $LO_2$  and  $LH_2$  tanks were increased as compared to the previous tanks and this resulted in slightly larger liquid loads for each tank. No LCC or OMRSD violations were noted in the data. One problem was identified and it is discussed in a later paragraph of this section. The ascent MPS performance was nominal; however, one SSME in-flight anomaly was noted in the ascent data.

Throughout the period of prelaunch operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment, which occurred after the start of fast-fill, was approximately 97 ppm. This level compares favorably with previous data from this vehicle.

As SSME 1 throttled down for the maximum dynamic pressure (Max q), a Failure Identification (FID) was issued (Flight Problem STS-91-E-01). Channels A1 and A2 failed to follow the expected reference chamber pressure, and the pressure transducer was disqualified from all subsequent mixture ratio control. This anomaly is discussed in depth in the Space Shuttle Main Engine section of this report.

The minor problem occurred approximately 6 minutes into the ascent phase when the SSME 3 LH<sub>2</sub> pressure transducer shifted up approximately 4 psi. The transducer also failed to react fully to pressure changes during the dump and vacuum inerting procedure following MECO. The data appear to be scaled such that the measurement only responds at about 1/3 of the actual pressure change (as evidenced by the manifold pressure and two other inlet pressures). These transducers have additional compensating resistors for the cryogenic application. This was the first flight of this transducer and it is possible that part of the compensating circuit failed. Failure analysis of the transducer is continuing.

Data indicate that the LO<sub>2</sub> and LH<sub>2</sub> pressurization systems performed nominally. All net positive suction pressure (NPSP) requirements were met throughout the flight. The overall GH<sub>2</sub> system in-flight performance was nominal. All three flow control valves (FCVs) performed nominally. Likewise, the GO<sub>2</sub> fixed orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely match the actual ET ullage pressure measurements.

Helium system performance for the SSME and pneumatic helium systems were normal. Entry helium usage was 62.2 lbm, which is within the requirements.

### Reaction Control Subsystem

The reaction control subsystem (RCS) performed nominally except for the two thrusters that failed off at ET separation. The loss of these two thrusters did not impact the successful completion of the Mir rendezvous mission.

Of the total propellants consumed by the RCS (5996.8 lbm), 1887.6 lbm were provided by the orbital maneuvering subsystem (OMS) during left- and right-pod interconnect operations. The primary RCS had a total of 3756 firings, and a total firing time of 939.36 seconds. The vernier RCS had a total of 21,887 firings, and a total firing time of 33,813.7 seconds. A forward RCS dump of 25.4 seconds was performed near the end of the flight. The following table identifies the maneuvers performed with the RCS.

Maneuver	Time, G.m.t./MET
Terminal Phase Initiation	155:13:34:38/01:15:28:14
Midcourse Correction 1	155:13:54:43/01:15:48:19
Midcourse Correction 2	155:14:25:55/01:16:19:31
Midcourse Correction 3	155:14:42:55/01:16:36:31
Midcourse Correction 4	155:14:52:55/01:16:46:31
Docking	155:17:12:00/01:19:05:36
Undocking	159:16:01:46/05:17:55:22
Separation	159:17:27:00/05:19:20:36

At ET separation at 153:22:15:11 G.m.t. (00:00:08:47 MET), the R2U and F2U RCS thrusters failed off and were subsequently deselected by the redundancy management (RM) system. The F2U thruster chamber pressure (P<sub>c</sub>) reached 18 psia (normally 160 psia) (Flight Problem STS-91-V-02). The fuel injector temperature dropped from 89 °F to 77 °F, and the oxidizer injector temperature dropped from 88 °F indicating that there was some flow of each propellant. The thruster had 652 firings and over

91 seconds of firing time since its installation prior to the STS-82 mission. Since there were no data to suspect the fuel valve had a problem, the failure of the oxidizer valve to fully open because of iron nitrate contamination is the most probable cause of the thruster failure. The thruster remained deselected for the remainder of the mission, and this condition did not impact the overall success of the flight.

Likewise, in the case of the R2U thruster, the  $P_c$  only reached approximately 11 psia (Flight Problem STS-91-V-01). Again, both the fuel and oxidizer injector temperatures dropped indicating some flow of both propellants. This thruster had 274 firings and 43.2 seconds of firing time since its installation prior to the STS-82 mission. The fuel valve signature was similar to that of other valves with extruded fuel pilot valve seats noted during White Sands Test Facility testing. Consequently, this thruster failure is suspected of being a fuel valve extruded seat preventing adequate opening of the fuel valve. The thruster remained deselected for the remainder of the mission. The loss of this thruster did not impact the overall success of the flight.

The RCS hot-fire was performed following FCS checkout. No problems were noted. Thruster operation during entry was also satisfactory.

### Orbital Maneuvering Subsystem

The OMS performed nominally during the mission with the exception of the failure of a valve position indicator that did not impact the mission. This in-flight anomaly is discussed in a later paragraph in this section. No LCC or OMRSD deviations occurred prior to launch. A total of 20,000 lbm of OMS propellants were consumed during the mission, and of this total 1877.9 lbm were consumed by the RCS during interconnect operations.

The OMS maneuvers performed during the flight are shown in the table on the following page.

#### OMS MANEUVERS

Maneuver	Time, G.m.t. and MET	Duration, seconds	$\Delta V$ , ft/sec
OMS-1	Not required		
OMS-2 Two engine	153:22:50:34.8 G.m.t. 00:00:44:10.8 MET	104.8	161
OMS-3 Two engine	154:01:47:41.9 G.m.t. 00:03:41:17.9 MET	54.7	84
OMS-4 Right engine	154:14:34:13.7 G.m.t. 00:16:27:49.7 MET	18.2	14
OMS-5 Two engine	154:21:23:30.9 G.m.t. 00:23:17:06.9 MET	28	44
OMS-6 Right engine	155:11:59:00.5 G.m.t. 01:13:52:36.5 MET	30.8	23
OMS-7 Two engine	162:16:30:00.1 G.m.t. 08:18:23:36.1 MET	12.4	20
Deorbit (OMS-8) Two engine	163:16:52:25.3 G.m.t. 09:18:46:01.3 MET	249.6	415



Following the propellant loading during prelaunch operations, it was discovered that when the ground support equipment (GSE) flowmeters were removed, the ground-half couplings were still mated to the Orbiter. Because the possibility existed that helium had been forced into the crossfeed line, special temperature excursion tests were performed which showed that helium was present in the crossfeed line. This condition could cause a deselection of vernier thrusters and because STS-91 was a Mir rendezvous mission, this condition was unacceptable. As a result, the OMS tanks were off-loaded to a propellant level of minus 7 percent and then reloaded in accordance with the OMRSD. Further testing showed that no bubbles were present.

During the OMS 7 SIMPLEX dual-engine firing, the left ball valve 1 position indicated 98.3-percent open, as expected. At the termination of the SIMPLEX firing, the left OMS engine ball valve 1 position indicator continued to indicate that the valve was open (96.3-percent open), where it should have been 0-percent open, and all other engine parameters were nominal. When the left OMS engine was ignited during the deorbit maneuver, the valve 1 position returned to the 98.2-percent open indication. At the termination of the firing, the indicator continued to read 98.2-percent open when it again should have been 0-percent open (Flight Problem STS-91-V-06). Based on this information, the most likely cause of the failure was the valve position instrumentation as opposed to an actual failure of the valve to close. Postflight troubleshooting showed the valve to be closed, indicating a failure of the valve position indicator instrumentation.

### **Power Reactant Storage and Distribution Subsystem**

The power reactant storage and distribution (PRSD) subsystem performance was nominal throughout the mission, and no in-flight anomalies were noted during the mission and postmission data review. The subsystem provided the fuel cells with 2717 lbm of oxygen and 342 lbm of hydrogen for the production of electricity. In addition, the environmental control and life support system (ECLSS) was supplied 143 lbm of oxygen of which 46 lbm was supplied to the Mir Space Station. An 66-hour mission-extension capability existed at touchdown at the average mission power level, and at an extension-day power level of 13.2 kW, a 83-hour mission extension was available.

Following power reactant storage and distribution (PRSD) subsystem cryogenic loading during prelaunch operations, a simultaneous trip of all four oxygen (O<sub>2</sub>) tank 5 heater current-limit sensors occurred. The anomaly repeated two more times during the countdown. The sensors were reset by launch processing system (LPS) command after the first two occurrences and by the crew station switch on the third occurrence. This anomaly is discussed in more detail in the Electrical Power Distribution and Control System section of this report.

A successful PRSD current-level sensor test of the tanks was performed at 154:19:05 G.m.t. (00:20:55 MET). The sensor trip function operated properly.

### **Fuel Cell Powerplant Subsystem**

Performance of the fuel cell powerplant subsystem was nominal throughout the mission with no in-flight anomalies identified from the data. The average electrical power level and load for the mission was 16.7 kW and 547 amperes. The fuel cells produced

3946 kWh of electrical energy and 3059 lbm of by-product potable water, using 2717 lbm of oxygen and 342 lbm of hydrogen. Four purges of the fuel cells using both the automatic and manual systems were performed satisfactorily during the mission. The actual fuel cell voltages at the end of the mission were 0.10 Vdc above predicted for fuel cell 1, 0.15 Vdc above predicted for fuel cell 2, and 0.05 Vdc above predicted for fuel cell 3. The fuel cells operating times for the mission were 266:20 hours for fuel cell 1, 265:53 hours for fuel cell 2, and 265:23 hours for fuel cell 3.

STS-91 was the first flight of the fuel cell monitoring system (FCMS) on this vehicle and the fourth flight of the Space Shuttle Program for the FCMS. The FCMS provided insight into individual cell voltages during both the prelaunch and on-orbit periods. Full-rate data for a 12-minute duration was successfully recorded on two separate occasions and down-linked to the evaluation personnel. Individual cell measurements indicated that 286 of the 288 cells were healthy, and the voltage levels and stability showed that none of the cells were experiencing reactant crossover. The bias on cells 34 and 35 in fuel cell 3 (the two cells that were indicated as unhealthy) was attributed to a known condition for which a pin soldering fix is in process. A comparison of the FCMS data with the cell performance monitor (CPM) showed differences between the two of  $\pm 0.5$  percent of full-scale tolerance on each FCMS single cell voltage measurement. This tolerance is calculated to be  $\pm 6.25$  mV per cell. Neither momentary fluctuations in individual cell voltages nor offsets between the CPM output and the FCMS differential voltage hindered the ability of the FCMS to successfully interpret single cell voltage and verify the health of the fuel cells.

The fuel cell 3 relief valve, which was determined to be leaking during the SLWT tanking test, leaked throughout the mission since fuel cell 3 activation. The leak rate varied as a function of system configuration. Preliminary estimates of the amount of fuel cell 3 water being dumped overboard averaged approximately 1.6 lb/hr during the second sleep period when the water tanks were depressurized to cabin pressure (0 psig). This rate constituted about 36 percent of the fuel cell 3 water production rate. This leakage did not impact the mission except for the decreased amount of water that could be transferred to the Mir; however, more water (12.5 CWCs) was transferred to the Mir than planned.

The survey of the fuel-cell relief nozzle, the surrounding midfuselage sidewall, and starboard payload bay door was conducted in two steps. In the first step, supply water tank A was maintained at approximately 22.0 psia while the crew viewed the relief nozzle and surrounding area. In the second step, viewing of the relief nozzle and payload bay door was conducted with supply water tank A pressurized to approximately 30.0 psia. The crew reported that small pieces of ice would form and attach to the area surrounding the fuel-cell water-relief nozzle, but would then break free. The crew also reported that there was no ice on the payload bay door.

### **Auxiliary Power Unit Subsystem**

The auxiliary power unit (APU) subsystem performed nominally with no in-flight anomalies noted in the data. The following table provides data concerning the run times and fuel consumption of the APUs during the mission.

## APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (a) (b)	(S/N 310)	APU 2 (a)	(S/N 403)	APU 3 (a)	(S/N 404)
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	19:55	52	20:02	58	20:06	56
FCS checkout	9:26	25				
Entry <sup>a</sup>	61:06	126	90:11	191	62:14	146
Total	91:17	203	110:13	249	82:20	202

<sup>a</sup> APUs were shut down 17 minutes 29 seconds after landing.

<sup>b</sup> APU 1 was used for the FCS checkout.

At 158:20:00 G.m.t. (04:21:54 MET), after the APU heaters were changed from system A to B, the APU 2 fuel pump/line/gas generator valve module (GGVM) system B heater thermostat was cycling within a 10 °F deadband, as indicated by the bypass-line temperature. On the previous flight of this APU (S/N 403 in position 3 on STS-83), this thermostat cycled in a 15 °F deadband, which was down from about 20 °F on the thermostat's initial flight (STS-75). This thermostat is located on a fuel line that is attached to the APU. Previous experience has shown that a thermostat located at this position will eventually fail once it begins to show signs of set-point shifting or erratic behavior. The heater operated with the 10 °F deadband for the remainder of the mission. The thermostat will be replaced during the postflight turnaround activity.

### Hydraulics/Water Spray Boiler Subsystem

APU 1 and hydraulic system 1 performed nominally during the FCS checkout. Because of the relatively long run time of APU 1, water spray boiler (WSB) 1 operation was required. Its performance was nominal. No in-flight anomalies were identified in the review of the data.

The hydraulics/WSB system performed nominally during ascent and on-orbit; however, three instances of WSB 2 over-cooling (lubrication oil outlet temperature at least 15 °F below steady-state) occurred during entry. On the first occurrence, the lubrication oil outlet temperature dropped to 195.8 °F, and on the second occurrence the lubrication oil outlet temperature dropped to 197.2 °F. The last over-cooling occurred 27 minutes after the second occurrence, and the lubrication oil outlet temperature dropped to 234 °F. The three occurrences did not impact entry operations.

### Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed satisfactorily throughout the flight.

During the prelaunch countdown and following the completion of PRSD tanking, a false simultaneous trip of all four O<sub>2</sub> tank 5 heater current level limit sensors occurred. The sensors were successfully reset with a LPS command. The sensor test function

provides a differential current through the current level detectors. Each detector issues an inhibit to its associated heater control circuit and a lock signal to its associated sensor trip latch-up signal. The trip latch circuit powers the heater inhibit until a reset is issued. The next day the anomaly repeated and once again it was reset by LPS command. Three hours later, the anomaly occurred for the third time. This time the O<sub>2</sub> tank 5 heaters were commanded on but the heaters did not receive power as designed due to the heater inhibit signals. As a result, the cockpit switch was used to provide the sensor reset and the heaters came on as expected.

The data review showed that on the first occurrence, the preflight bus exhibited a 1.0 ampere differential load. During the second and third occurrences, the preflight bus exhibited a 0.8 ampere differential load. A test of the circuit using the cockpit switch was performed two hours after the third occurrence, and the preflight bus exhibited a 0.5 ampere differential load. As a result of the short launch window, an LCC waiver was pre-approved in case another identical nuisance trip occurred late in the countdown. This waiver would have allowed the launch to proceed without resetting the current limit sensors. There were no additional occurrences of the anomalous trip during prelaunch operations or during the flight.

A successful current-limit level sensor test of the tanks was performed at 154:19:05 G.m.t. (00:20:55 MET). The sensor trip function operated properly.

### **Orbiter Docking System**

The Orbiter Docking System (ODS) performed nominally throughout the docking sequence with the Mir. Capture occurred nominally at approximately 155:16:58:19 G.m.t. (01:18:51:55 MET) at a closing rate of 0.124 ft/sec and with nominal misalignments. The structural hooks were closed and docking was completed at approximately 155:17:12:00 G.m.t. (01:19:05:36 MET). This was the first docking to use the International Space Station (ISS) Androgynous Peripheral Attachment System (APAS) docking mechanism.

After completion of the docking with the Mir, the vestibule was repressurized using the Mir equalization valve, and the Orbiter/Mir docking system interface leak check was nominal. Subsequently, the external airlock-to-vestibule hatch equalization valve was used to equalize the Mir and Orbiter habitable volume pressures. The active system monitor parameters indicated a normal output throughout the flight duration.

The ODS hatch was closed at approximately 159:13:08 G.m.t. (05:15:02 MET). Following hatch closure, the vestibule depressurization began at 159:13:36 G.m.t. (05:15:30 MET) and was completed 6 minutes later. The undocking was accomplished at 159:16:01:46 G.m.t. (05:17:55:22 MET). The ODS performed nominally during the undocking sequence of the Orbiter from the Russian Mir Space Station and successfully demonstrated the operation of the new ISS docking mechanism.

### **Atmospheric Revitalization Pressure Control System**

The atmospheric revitalization pressure control system (ARPCS) performed normally throughout the duration of the flight. After docking with the Russian Space Station Mir, and leak checking the Orbiter/Mir docking system interface, the Orbiter airlock upper

hatch equalization valves were opened and the Mir and Orbiter volumes were equalized to a total pressure of 12.72 psia. Prior to opening these valves, the Orbiter cabin and ODS pressure was 14.70 psia. After the Orbiter to Mir transfer hatches were opened, the entire Orbiter/Mir volume was pressurized to 14.62 psia using the Orbiter oxygen. Total consumables transferred to the Mir during the docked phase was 149.4 lbm of nitrogen and 46.6 lbm of oxygen. The nitrogen was used for Mir pressurization and the oxygen was used for the additional crew (Orbiter personnel moving between the Orbiter and Mir) metabolic consumption during docked operations, as well as for raising the Mir pressure and PPO<sub>2</sub> before undocking. The total pressure before undocking was 15.28 psia and the PPO<sub>2</sub> was 3.98 psia.

### **Atmospheric Revitalization Subsystem**

The atmospheric revitalization subsystem (ARS) performed nominally throughout the flight. At 156:08:40 (02:10:34 MET), the cabin fan was powered down for a routine lithium hydroxide (LiOH) cartridge change, and the fan remained off for more than 16 minutes. This non-cooling time for the powered avionics exceeded the continued operation limit as found in the OMRSD by 11 minutes for powered avionics equipment. The ground controllers were operating in accordance with a flight rule which allows a maximum off-time of 20 minutes for this equipment without cooling. No apparent damage resulted from this extended power-down. An evaluation is being made to determine if the 5-minute requirement should be rewritten.

During the postflight debriefings, the crew reported that several problems were experienced with the flexible ducts in the external airlock. The duct located between the booster fan outlet and the external airlock duct inlet was too short. A hard elbow exists at each end of the duct and the flexible duct would pop off of the elbow on a regular basis. The crew also noted that the duct section (flexible duct in Spacehab tunnel) just aft of the hatch was too long. Difficulty was experienced installing the duct.

### **Active Thermal Control Subsystem**

The active thermal control subsystem (ATCS) operations were satisfactory throughout the mission. Ascent performance was nominal with radiator flow initiated about 12 minutes before the payload bay doors were fully open. However, the radiators were not deployed during this flight.

At 153:23:39 G.m.t. (00:01:33 MET), the flash evaporator system (FES) primary A was turned off and the FES primary B was turned on. This change to FES primary B enabled use of water from water tanks C and D and thereby saved the water in tanks A and B for transfer to the Mir after docking.

The freon coolant loop (FCL) 2 flow proportioning valve (FPV) was taken to the payload position at 154:01:25 G.m.t. (00:03:19 MET) to provide cooling for the Spacehab module.

At 154:15:31 G.m.t. (00:17:25 MET), the FES primary B was turned off to allow the depressurization of the supply water tanks. Depressurization was required to reduce the pressure on the fuel cell relief line and thereby reduce the amount of fuel cell 3 water that was leaking overboard. After the completion of the Mir water transfer (1220 lbm),

the supply water tanks were configured back to their nominal on-orbit configuration. The FES primary A was turned back on at 160:09:17 G.m.t. (06:13:11 MET), and FCL 2 was changed back to the interchanger position at 162:23:19 G.m.t. (09:01:13 MET). The payload bay doors were closed approximately three hours after the FCL 2 reconfiguration.

The radiator cold-soak provided cooling during entry. The radiators began to lose control approximately one minute after landing and continued to climb until about five minutes after landing when the radiators were taken to the high set point and ammonia boiler system (ABS) A was activated using the primary GPC controller. Ammonia boiler system A was turned off after 36 minutes and ground cooling was initiated three minutes later. FCL 2 was also switched to the payload position to provide cooling for the Spacehab.

### **Supply and Waste Water Subsystem**

The supply water subsystem performed nominally throughout the mission with no in-flight anomalies identified. Additionally, all in-flight checkout requirements were satisfactorily satisfied.

The supply water was managed through the use of the FES and water transfer to the Mir Space Station. The supply water dump line temperature was maintained between 64.8 °F and 96.3 °F throughout the mission with the operation of the line heater.

During the SLWT tanking test, which took place approximately two weeks prior to launch, the fuel cell 3 overboard relief valve leaked water overboard. Tank A was pressurized at the time. After reaching orbital conditions, water tank A was repressurized and fuel cell 3 began leaking between 80 and 90 percent of the fuel-cell-3-produced water overboard. After completion of the filling of the first CWC, all water tanks were depressurized to 5 psig and the overboard leak rate dropped to approximately 40 percent of the fuel cell 3 production. The tanks were vented to 5 psig rather than zero psig to prevent the ingesting of air into the potable water system through the galley needle. This was required because when the tanks are depressurized and the quantity is less than 60 percent, the tank bellows are in compression and are capable of drawing air into the system. However, this is not a concern when the galley supply valve is closed. Consequently, the galley supply valve was closed and the tanks were depressurized to 0 psig.

Throughout the docked phase of the mission, the water tanks were depressurized to 5 psig between CWC refills and to 0 psig overnight. These conditions enabled the filling of 12.5 CWCs (1220 lbm) instead of the projected 15 CWCs that was to be given to the Mir

Humidity condensate was collected in a CWC for test purposes during the docked phase of the mission. Since the waste tank was depressurized for much of the time, insufficient pressure existed to direct the condensate into the CWC. Therefore, the waste tank collected water at about the predicted rate. Four waste water dumps were performed at an average rate of 1.91 percent per minute (3.15 lb/min). The waste water dump line temperature was maintained between 56.8 °F and 98.9 °F throughout the mission.

The vacuum vent line temperature was maintained between 59.7 °F and 83.3 °F.

### **Waste Collection Subsystem**

The waste collection subsystem (WCS) performed satisfactorily throughout the mission. No problems or in-flight anomalies were noted or reported. The WCS was modified to include an automatic start device, which automatically started the fan separator motor prior to its use. With the new design, which is similar to the ISS design, the fan separator motor is activated when the urinal pre-filter housing is removed from the cradle. In addition, the urine monitoring system (UMS) interface panel was updated to include permanent connections and to add a fan separator 2 capability.

### **Airlock Support System**

Use of the airlock depressurization valve was not required because no extravehicular activity (EVA) was performed.

### **Smoke Detection and Fire Suppression Subsystem**

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

### **Flight Data Systems**

The flight data system performance was nominal during the STS-91 mission. The problem that is discussed in the following paragraphs did not impact the successful completion of the flight and planned objectives.

At approximately 160:06:19 G.m.t. (06:08:12 MET) during a Tracking and Data Relay Satellite (TDRS) hand-over from West to East, the software failed to select the East satellite even though the West satellite was out of view (obscured by the earth). The software continued to select the antenna that pointed to the West satellite. There were no indications of a communication systems hardware failure and the antennae were operating nominally. Prior to these events, the general purpose computer (GPC) 1 error counter was rapidly counting up (Flight Problem STS-91-V-05). The errors started at about 160:05:50 G.m.t. (06:07:43 MET). However, no GPC error messages appeared on the Fault Summary page. As a result, the ground controllers manually commanded the antennas to point correctly.

As a result of the excessive GPC error count discussed in the previous paragraph, the following tasks were performed.

- a. The MAGR was commanded to self-test with anomalous results. The MAGR was powered cycled but did not recover, and the MAGR was powered off.
- b. An operations (OPS) transition was performed and it was unsuccessful in that no change in GPC error rate nor any change in the systems management (SM) transferred state vector occurred.
- c. Software dumps were performed for GPC's 1 and 4. GPC 1 was then powered off and the G2 freeze-dried GPC (GPC 2) was activated and operated as the single G2 GPC. As soon as GPC 2 took over the guidance,

navigation and control (GNC) function, the state vector in the SM GPC began updating. When this occurred, the antenna management software resumed selecting the correct antenna and TDRS. The positional vector was previously frozen in the SM GPC, and the antenna management software continuously selected TDRS West.

- d. At approximately 160:17:30 G.m.t (06:19:24 MET), an OPS transition was performed to ensure the GPS software was moded to off.

The data analysis determined that the once-per-minute GNC-to-GPS aiding function was halted. This allowed the GPS vector within the GPC to propagate unbounded, eventually exceeding the maximum limits of an internal software library routine and generating the GPC error counts. As a result, the GNC GPC 1 quit sending state vector data to the SM GPC (4), thus freezing the antenna management software pointing function.

A GMEM change was developed to patch the IPL software to operate as if there was no MAGR. The patch was determined not to be needed because with the MAGR off and with an OPS transition, the error propagation effect is eliminated.

The three inertial measurement units (IMUs) performed satisfactorily during the prelaunch checkout and throughout the mission as well. Onboard accelerometer compensations were required only once for IMUs 1 and 3 and not all on IMU 2. In addition, no drift compensations were required on any of the three units.

### **Flight Software**

STS-91 was the first flight of the OI-26B flight software and the first use of the single-string Global Positioning System (GPS) capability. The software performed nominally throughout the mission.

### **Flight Control System**

The flight control system (FCS) performed satisfactorily during the rendezvous, docking, mated operations, as well as during entry. No dynamic stability concerns were observed during the docked phase of the mission.

The FCS checkout was performed satisfactorily using APU 1. The right outboard elevon actuator displayed a ringing tendency during FCS checkout at hydraulic system activation. It was apparent during the aerosurface drive test as well as the secondary actuator test. The ascent data did not show any ringing, checkout data during the turnaround flow and the on-orbit FCS checkout data from STS-85 (last previous flight of OV-103) did not show any ringing. The outboard elevons have a greater tendency for this condition to occur because of the higher gains in those servo loops. The ringing did not affect the operation of the actuator, and was damped as soon as the surface had an aerodynamic load. The elevons did not show any ringing when the hydraulics system was activated to high pressure prior to entry interface. FCS performance was nominal during entry.



### **Displays and Controls Subsystem**

The displays and controls subsystem performed satisfactorily throughout the mission. No problems or in-flight anomalies were noted in the data.

### **Communications and Tracking Subsystems**

The communications subsystems provided good communications throughout the mission. However, one in-flight anomaly was recorded and this anomaly prevented the use of the Ku-Band system for the remainder of the mission.

The Ku-band, after activation, failed to radiate any radio frequency (RF) energy when placed in the communication mode (Flight Problem STS-91-V-03). The operate bit was low. The Ku-band system power was cycled to off, and the activation procedure was performed again with no success. Troubleshooting did not recover the Ku-band communication system communications mode operation, and the signature appeared to be the result of a failure in either the signal processor assembly (SPA) or the deployed electronics assembly (DEA). The system operated properly in the radar mode as discussed later in this report. As a result of this failure, the operations recorder could not be dumped, no Ku-band television or Orbiter Communications Adapter information could be transmitted, and the Alpha Magnetic Spectrometer (AMS) (payload) high data rate mode could not be used with the Ku-band.

An in-flight maintenance (IFM) procedure to allow downlinking of the AMS payload data via the high data rate mode was completed at 154:22:24 G.m.t. (01:00:17:36 MET). The Ku-band signal processor was bypassed, and the data were patched through the FM signal processor. The data were acquired by the Electronic Systems Test Laboratory (ESTL) here at the Johnson Space Center. Support of the FM data recovery was also provided by other ground stations.

During the flight day following docking, an IFM procedure was performed in an unsuccessful attempt to recover operation of the Ku-band system in the communications mode. The IFM determined that the transmit-enable signal produced by the Ku-band SPA was present in the SPA output. It had been speculated that this signal was not present, and the IFM was designed to inject this signal. Based on the results of this IFM, the indication is that the failure is probably in the deployed electronics assembly. As a result, the Ku-band communications mode was not available during the flight. Initial postflight troubleshooting has revealed that the failure is repeatable. Further troubleshooting using a breakout box will be performed to isolate the cause of the anomaly.

The Ku-band radar successfully tracked the Mir from a range of 103,000 feet down to 89 feet before the system was placed back into the communications mode.

### **Operational Instrumentation/Modular Auxiliary Data System**

The operational instrumentation (OI) and Modular Auxiliary Data System (MADS) performed satisfactorily throughout the mission. No problems or in-flight anomalies were identified in the data review.

## Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the duration of the mission. No in-flight anomalies were noted during the review and analysis of the data. The landing and braking data from this flight is shown in the following table.

### LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	1308.6	206.5	-3.4	N/A
Nose gear touchdown	4543.5	166.6	N/A	-5.70
Brake initiation speed		140.0 knots		
Brake-on time		52.80 seconds		
Rollout distance		10729.9 feet		
Rollout time		70.4 seconds		
Runway		15 (Concrete) KSC		
Orbiter weight at landing		226725.4 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	1123	Left-hand inboard	24.33	
Left-hand inboard 3	1123			
Left-hand outboard 2	1118	Left-hand outboard	18.78	
Left-hand outboard 4	1118			
Right-hand inboard 1	773	Right-hand inboard	21.88	
Right-hand inboard 3	773			
Right-hand outboard 2	634	Right-hand outboard	11.12	
Right-hand outboard 4	634			

The payload bay doors operated properly during both the opening and closing operations. Dual motor run times were exhibited in both cases. The radiators were not deployed.

The tires, which exhibited ply undercutting only on the right-hand inboard tire, were described as being in average condition for a landing on the KSC SLF runway.

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 fitting retainer springs were in the normal configuration. No clips were missing from the "salad bowls". Also, virtually no umbilical closeout foam or white room temperature vulcanizing (RTV) material adhered to the umbilical plate near the LH<sub>2</sub> recirculation line disconnect.

All drag chute hardware was recovered and appeared to have functioned normally. The two pyrotechnic devices on the reefing line cutters had been expended.

### **Integrated Vehicle Heating and Thermal Interfaces**

The prelaunch thermal interface purges were normal with no problems noted. The ascent aerodynamic and plume heating was normal. The entry aerodynamic heating on the SSME nozzles was also normal.

### **Thermal Control Subsystem**

The thermal control subsystem (TCS) performance during the STS-91 mission was nominal during all phases of the countdown and mission. All subsystem temperatures were maintained within acceptable limits. The overboard water flow from the fuel cell 3 water relief system nozzle did not adversely affect the mission.

Prior to the flight, the attitude time-line assessment of the docked phase indicated no potential Orbiter thermal constraints; however, one minor change to the docked attitude was made, and this change produced two degrees more sun below the wing plane. This slight change increased the sun on the main landing gear (MLG) and this provided a desirable increase in the temperature of the main landing gear. In addition, numerous changes in the attitude of the vehicle were made during the undocked portions of the flight to accommodate the AMS payload thermal requirements.

### **Aerothermodynamics**

The boundary layer transition was asymmetrical and MADS data showed boundary layer transition from laminar to turbulent flow occurred early on the left wing at Mach 17.0. The fuselage transition to turbulent flow occurred at Mach 9.7 and 1139 seconds after entry interface. No data were available from the right wing; however, it is assumed to have occurred at the same Mach number as the fuselage. The aileron deflection history indicates that the asymmetrical at Mach 18, and jumped to symmetrical at Mach 9.5. The cause of the asymmetric transition is being evaluated. The overall vehicle acreage heating was normal for a heavy, high-inclination entry; however, the left wing experienced very high heating but all temperatures were within certification limits.

Local heating inspections were continuing as this report was written. The initial findings showed a 17 slumped tiles in various areas of the vehicle. Also there was a large number of charred filler bars on the left wing.

### **Thermal Protections Subsystem and Windows**

The thermal protection subsystem (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was higher than normal based on structural temperature rise data, particularly in the wings where the rise was 18 °F higher than previously observed on this vehicle. MADS data showed transition from turbulent to laminar flow occurred twice at 1190 and 1237 seconds after entry interface and was asymmetric. Also, one measurement on the outboard left wing indicated a transition time of 950 seconds which is very early.

Based on data from the debris team inspection, overall debris damage was above average. The Orbiter TPS sustained a total of 198 hits (damage sites) of which 50 had a major dimension of 1 inch or larger. The total number of hits and their distribution, shown in the following table, 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.

**TPS DAMAGE SITES**

<b>Orbiter Surfaces</b>	<b>Hits &gt; 1 Inch</b>	<b>Total Hits</b>
Lower Surface	45	145
Upper Surface	0	3
Right Side	1	11
Left Side	1	7
Right OMS Pod	2	5
Left OMS Pod	1	5
Window Area	0	22
<b>Total</b>	<b>50</b>	<b>198</b>

Based on data from the postflight debris inspection team reports, the total number of damage sites was slightly greater than the fleet average, and the number of damage sites that was 1 inch or larger was also greater than the fleet average. Also, the average size and quantity of damage sites were greater than the favorable trend established on the STS-89 and STS-90 flights, as can be seen in the following table.

**COMPARISON OF DAMAGE SITE DATA FROM LAST FIVE FLIGHTS**

<b>Parameter</b>	<b>STS-86</b>	<b>STS-87</b>	<b>STS-89</b>	<b>STS-90</b>	<b>STS-91</b>	<b>Fleet Average</b>
Lower surface total hits	100	244	95	76	145	83.2
Lower surface hits > 1 in.	27	109	38	11	45	13.3
Longest damage site, in.	7	15	2.8	3.0	3.0	N/A
Deepest damage site, in.	0.4	1.5	0.2	0.25	0.5	N/A

Most of the lower surface damage sites were concentrated aft of the nose to the main landing gear wheel wells on both the left and right chines. Virtually no damage occurred on the Orbiter centerline. These damage sites follow the same location/damage pattern that has been documented on the previous four flights shown in the above table. It should be noted, however, that this was the first flight of the new super lightweight tank (SLWT).

The largest lower surface damage site forward of the main landing gear doors was located on the left chine and measured 3 inches long by 1.25 inches wide by 0.25 inch deep. The deepest lower surface damage site of 0.5 inch was located on the right chine. Also, the right-hand nose landing gear door had one significant slump between two tiles and the centerline thermal barrier was debonded.

The left-hand main landing gear door thermal barriers were badly torn/frayed and one tile had a large area of lip damage. Also, there were slumped tiles on both the

inboard and outboard elevon leading edge tiles. The toughened unified fibrous insulation (TUFI) tiles on the base heat shield looked to be in good shape, and the upper body flap tiles in the plume impingement area were not damaged. This is the first Orbiter with all of the upper body tiles installed in the plume impingement area.

One damage site measuring 3.5 inches long by 0.38 inch wide by 0.25 inch deep was located on the right inboard elevon, and it did not appear to have been caused by an ice impact from the LO<sub>2</sub> ET/Orbiter umbilical. This damage site is directly aft of the right chine damage areas and may have been caused by a secondary debris impact. The damage sites around and aft of the LH<sub>2</sub> and LO<sub>2</sub> ET/Orbiter umbilicals were much less than usual in size and quantity. This damage is usually caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The usual amounts of tile damage occurred on the base heat shield. A clustering of tile damage sites were located at the acoustical focal point between SSMEs 1 and 3 (14 hits with 12 larger than 1-inch in size), but the damage was not mirrored on the -Y side between SSMEs 1 and 2. All SSME dome-mounted heat shield (DMHS) closeout blankets were in excellent condition. Two small hits were located on the tiles adjacent to the drag chute cavity. Two small tile hits on the stinger were caused by debris in the plume recirculation rather than contact with the drag chute risers.

No unusual tile damage occurred on the leading edges of the OMS pods. However, a 2.5-inch long by 0.75-inch wide by 0.25-inch deep gash on the left OMS pod may have been caused by ice from the waste water dump nozzle. A 5-inch long by 1.5-inches wide by 1.5-inches deep cavity along the edge of a blanket on the left OMS pod probably was caused by a portion of a blanket coming loose and flailing in the air flow. An adjacent white tile did not appear to be damaged. Three small damage sites were noted on the leading edge of the vertical stabilizer.

Hazing and streaking of the forward-facing Orbiter windows was moderate to heavy. Damage sites on the window perimeter tiles were less than usual in quantity and size. Some of the damage sites were attributed to old repair material falling out and were not included in the assessment.

## RENDEZVOUS OPERATIONS

The rendezvous operations were completed satisfactorily with the docking to the Russian Space Station Mir being completed on time and as planned.

During rendezvous with the Mir, the crew had a problem with the trajectory control system/rendezvous proximity operations program (TCS/RPOP). The RPOP tracks vehicle position using four different methods which include the radar solution, the on-board state-vector solution and the TCS navigation solution. The TCS navigation solution apparently provided a valid solution until the vehicle was approximately 170 feet from the Mir. When it was determined that the TCS navigation solution was no longer valid, a request was made to reinitialize the RPOP. Approximately 10 marks after the reinitialization, the problem recurred. These events are now understood. As the distance between the two vehicles decreased, the errors in the radar and state vector solutions began increasing. At this point, only data from the TCS navigation solution and hand-held laser were to be used. However, the data from all four solutions were being plotted on the RPOP payload and general support computer (PGSC). A button exists to turn off the solutions from the radar and the state vector, if the Pilot or Commander no longer wishes to view the diverging solutions being plotted along with the good solutions. However, a code problem exists in that if the button is depressed to turn off the radar and state-vector solutions, the TCS navigation solution is also turned off. The crew has confirmed that for both instances of the invalid TCS navigation solution, the button was pushed to clean up the data being plotted. This is a known phenomenon documented in RPOP Operations Note 048 dated January 6, 1997.

The rendezvous separation maneuver was a +X firing of the RCS primary thrusters L3A and R3A for 12 seconds. The maneuver resulted in a  $\Delta V$  of 2.9 ft/sec. All thruster firings during the separation and fly-around phases were nominal.

## **REMOTE MANIPULATOR SYSTEM**

The overall performance of the remote manipulator system (RMS) was satisfactory with no in-flight anomalies noted during the operations or the data analysis.

The RMS was powered up at 157:12:26 G.m.t. (03:14:20 MET) and uncradled at 157:12:44 G.m.t. (03:14:38 MET). A complete checkout of the RMS in all of its operational modes was successfully completed, and the RMS was then maneuvered in support of the RMS situational awareness display (RSAD) evaluation tests. The RMS was cradled and latched in the manipulator positioning mechanisms (MPM's) at 157:15:13 G.m.t. (03:17:07 MET). The MPMs were stowed at 157:15:21 G.m.t. (03:17:15 MET), and the RMS was deselected.

During the RMS unberthing, the mid-MPM-pedestal manipulator retention latch (MRL) ready-to-latch (RTL) microswitch indications (2 of 2) failed to transfer off. These microswitch indications remained on throughout the entire period of RMS operations. RMS berthing and latching was assisted by using closed circuit television (CCTV) camera B and the targets on the MPM pedestals to verify that the RMS was within the capture envelope of the mid-MRL. In addition, the RMS joint alignment was verified as being within the nominal limits. There was no mission impact.

A RMS survey was made of the area around the fuel-cell relief nozzle to search for ice that may have formed because of the fuel cell 3 water venting. During this second RMS deployment of the mission, all of the MPM pedestal RTL switch indications (6 of 6) transferred to off when the RMS was unberthed. During the first RMS unberthing that is discussed earlier in this report, the mid MPM pedestal RTL switch indications (2 of 2) failed to transfer off. During the second RMS berthing operation, all of the MPM pedestal RTL switch indications (6 of 6) transferred to on when the RMS was berthed.

## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The Government furnished equipment/flight crew equipment (GFE/FCE) performed satisfactorily throughout the mission with only one in-flight anomaly reported. This anomaly is discussed in the following paragraph.

At approximately 156:02:00 G.m.t. (02:03:54 MET), the ground controllers were commanding CCTV camera C and observed that it would not pan or tilt. The crew confirmed that the pan/tilt circuit breaker on panel R14D was engaged. The crew also confirmed that camera C would not pan or tilt (Flight Problem STS-91-V-04). The crew cycled the pan/tilt circuit breaker five times in an attempt to clear the potential corrosion/oxidation from the circuit-breaker contacts. This action did not recover the pan/tilt function of CCTV camera C. The crew cycled the circuit breaker for the pan and tilt heater. Following this recycling, another attempt was made to pan and tilt camera C, but it was not successful. The loss of camera C had only a minimal impact on the Mir survey and the Spektr gas release, both of which occurred after undocking. After the return of the camera to JSC, troubleshooting of and repairs to the camera will be made.

At approximately 162:10:00 G.m.t. (08:11:54 MET), the crew called down an error code on the STS-3 payload and general support computer (PGSC). The error code indicated a failed system board, and the PGSC was stowed for the remainder of the flight.



## CARGO INTEGRATION

The integration hardware performance was nominal throughout the mission with no issues or in-flight anomalies identified.

## **DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES**

### **DEVELOPMENT TEST OBJECTIVES**

**DTO 685 - Onboard Situational Awareness Displays for Ascent/Entry** - This experiment was performed as planned. The data have been given to the sponsor of the Development Test Objective (DTO). The results of the analysis will be reported in separate documentation.

**DTO 690 - Urine Collection Device** - This experiment was performed as planned. The data have been given to the sponsor of the DTO. The results of the analysis will be reported in separate documentation.

**DTO 700-11 - Orbiter Space Vision System Flight Testing** - The Orbiter Space Vision System (OSVS) operations were conducted on two flight days and performed satisfactorily. The flight day 2 activities included the successful completion of equipment unstowing and set-up and checkout of camera B. The camera C checkout and the camera B control test were performed on flight day 8. Because of the camera C pan/tilt unit failure, the flight day 8 operations were limited to OSVS power-up and the camera B control test.

The control tests consisted of individual pan, tilt and zoom command sequences, followed by combinations of these sequences. Three final tests were conducted of the entire automatic camera set-up in which the OSVS unit corrected errors in pan, tilt, zoom, focus and initiated the camera calibration procedure.

**DTO 700-14 - Single String Global Positioning System (Global Positioning System Operations Option/No Payload and General Support Computer** - Prior to liftoff, the miniature airborne Global Positioning System (GPS) receiver (MAGR) performance was nominal. However, about 4 seconds after liftoff, the navigation solution became completely erroneous. Only one satellite was being tracked. Even after the heads-up roll maneuver, which provides better exposure of the GPS antenna, the receiver could not track more than one satellite. After 26 minutes, the MAGR acquired four satellites and began operating and experienced periodic upsets during the first few days of on-orbit operation.

At approximately 160:06:19 G.m.t. (06:08:12 MET) during a Tracking and Data Relay Satellite (TDRS) hand-over from West to East, the antenna management software failed to select the East satellite even though the West satellite was out of view (obscured by the earth). The software continued to select the antenna that pointed to the West satellite. There were no indications of a communication systems hardware failure and the antennae were operating nominally. Prior to these events, the general purpose computer (GPC) 1 error counter was rapidly counting up. The errors started at about 160:05:48 G.m.t. (06:07:41 MET). However, no GPC error messages appeared on the Fault Summary page. As a result, the ground controllers manually commanded the antennas to point correctly.

Because of the excessive GPC error count, the MAGR was commanded to self-test with anomalous results. The MAGR was powered cycled but did not recover, and the MAGR

was powered off. The MAGR was powered on briefly on June 10 and 11 with nominal controlled testing results; however, the decision was made by the Mission Management Team to leave the MAGR powered off for entry and landing.

The data analysis determined that an interruption of the handshake between the GPC and the MAGR was the root cause of the excessive GPC error count. Once this handshake condition occurs, it cannot be reestablished. A timing mismatch provided the conditions for the interruption of the handshake. It is known, however, that when a handshake is interrupted, the MAGR vector within the GPC grows. Eventually this MAGR vector growth causes GPC internal errors to be annunciated. A GMEM change was developed to patch the IPL software to operate as if there was no MAGR. The patch was determined not to be needed because with the MAGR off and with an OPS transition, the error propagation effect is eliminated.

#### **DTO 700-15 - Space Integrated Global Positioning System/Inertial Navigation**

**System** - The Space Integrated Global Positioning System/Inertial Navigation System (SIGI) performance during the STS-91 mission was excellent. Although very little data were able to be downlinked because of the Ku-band problems, the data which were obtained (approximately three minutes of data each day) in conjunction with the crew reports indicate that the SIGI navigation position, velocity, and attitude were accurate throughout the mission. The SIGI was stowed, but it continued to record data until 45 minutes after landing. The SIGI PGSC has been given to the sponsors of this DTO, and the results of the analysis will be reported in separate documentation.

**DTO 805 - Crosswind Landing Performance** - The crosswind were not of the magnitude to meet the minimum requirements of this DTO. As a result, no data were collected.

**DTO 1118 - Mir Photo Survey** - A short Mir photo ground-based survey was performed on flight day 3. During the docked phase, Mir Photo Survey activities were performed by the crew. Following the undocking from the Mir and during the fly-around activity, Spektr gas-release activities were performed. The leak rate of the gas was slower during the actual test than it was during the pre-test conducted on the previous day. The crew did not observe any debris particles or fluorescing gas. Video and photography acquired during the test are being analyzed as this report was being written.

### **DETAILED SUPPLEMENTARY OBJECTIVES**

**DSO 802 - Educational Activities** - The planned activities were performed by the crew. These data have been returned to the sponsor of this Detailed Supplementary Objective (DSO) for use in the educational programs. The results of the analysis of the documented activities will be reported in separate publications.

## **PHOTOGRAPHY AND TELEVISION ANALYSIS**

### **LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

The 25 launch photography films and the 24 videos were reviewed by KSC, MSFC, and JSC. Much of the long-range tracker imagery was degraded because of atmospheric haze. No anomalous vehicle-related conditions were noted in any of the photography or videos.

Umbilical well cameras flew for the first time on OV-103 on STS-91. Two rolls of the STS-91 16-mm umbilical well film, and one roll of 35-mm umbilical well film. The film quality is very good on the three umbilical well camera films. OV-103 provided timing data to the 16 mm umbilical well cameras.

#### **35-mm Umbilical Well Camera Film**

The LH<sub>2</sub> tank and the LO<sub>2</sub> tank/orbiter thermal protection system (TPS) appeared to be in excellent condition on the close-up 35-mm umbilical well camera film. The sanded area on the LO<sub>2</sub> nose cone appeared undamaged. Similar to STS-90 and other previous missions, a gray-colored band of pock-marked or possible missing TPS was visible on the +Z axis of the ET nose just aft of the ET nose-cone fairing. Discoloration in this area was probably due to aerodynamic friction and heating.

The intertank TPS appeared to be in better condition than usual with only a very small divot visible on an aft intertank stringer head forward of the bipod. The visible portion (+Z/+Y axis) of the right SRB thrust panel was in shadow on the 35-mm umbilical well film. Digital enhancements were made from the film in an attempt to detect TPS damage on the right ET intertank thrust panel. However, the presence of damage on this panel could not be confirmed. The left SRB thrust panel was not imaged on the 35-mm umbilical well film. A divot, approximately seven inches in size, was visible under the ET/Orbiter attachment bipod in the LH<sub>2</sub> tank-to-intertank closeout flange. The divot was not deep enough to show primed substrate. A shallow light-colored mark (possible divot) approximately three inches in size was visible just aft of the left leg of the bipod in the LH<sub>2</sub> tank TPS. The bipod jack pad closeouts appeared intact.

Minor TPS chipping and very small divots (typical of previous missions) were seen on the LO<sub>2</sub> feedline, feedline flanges, the forward end of the +Y axis ET/Orbiter thrust strut, and on the vertical section of the +Y-axis electric cable tray adjacent to the LO<sub>2</sub> umbilical. The face of the LO<sub>2</sub> umbilical carrier plate face appeared to be in excellent condition (the lightning contact strips appeared to be in place).

#### **16-mm Umbilical Well Camera Film**

The left SRB separation appeared normal on the 16-mm umbilical well camera films. Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB-separation film sequence. Typical ablation and charring were seen on the ET/Orbiter LH<sub>2</sub> umbilical electric cable tray and the aft surface of the -Y axis upper strut fairing prior to SRB separation. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the left SRB electric cable tray

prior to SRB separation. Two pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y axis ET vertical strut. Normal blistering of the fire-barrier material on the outboard side of the LH<sub>2</sub> umbilical was seen. Ablation of the TPS on the aft dome was normal. Both the left and right SRB nose caps were visible during SRB separation.

The ET separation from the Orbiter appeared to be normal. Vapor and multiple light-colored pieces of debris were seen after the umbilical separation. Several pieces of white debris (frozen hydrogen) were seen striking the forward surface of the LH<sub>2</sub> electric cable tray. No damage to the cable tray was detected. A linear-shaped, flexible piece of debris (possibly tape from the umbilical purge barrier material) was seen near the base of the LH<sub>2</sub> umbilical during ET separation.

No anomalies were noted on the face of the LH<sub>2</sub> umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH<sub>2</sub> 17-inch connection.

A large bright-colored area of possible divots was noted on the forward portion of the visible (-Y/+Z axes) left-intertank thrust panel. Other light-colored marks were seen on the left-intertank thrust panel. However, some of these light-colored marks appeared to coincide with small ramps on the thrust panel that were seen in the closeout photography and may not indicate damage.

A divot was visible under the ET/Orbiter attachment bipod in the LH<sub>2</sub> tank-to-intertank closeout flange. Two divots were visible in the LH<sub>2</sub> tank-to-intertank flange closeout in the -Y/+Z axes quadrant. A divot, approximately 10 inches in diameter, was also visible in the same flange near the lower right corner of the left thrust panel. Dark-colored linear-shaped marks, possibly caused by shock waves from the left SRB attachment-point fitting, were visible extending diagonally across the -Y/+Z axes intertank stringer heads toward the bipod.

#### **ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

Thirty-three images of the ET were acquired using the hand-held 35-mm Nikon camera with a 400-mm lens. Timing data were present on the hand-held film. The first picture was taken at 153:22:22:53 G.m.t. (00:00:16:29 MET). The +X translation maneuver was performed to facilitate the imaging of the ET with the umbilical well cameras. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the hand-held photography. The images of the ET were very faint and silhouetted by the late afternoon sun on the photography. The camera used for the ET hand-held photography was launched with the wrong camera settings, and these conditions resulted in under-exposed photography. Views of the sides, nose, and aft end of the ET were acquired. However, the +Y axis side of the ET was in shadow and too dark for analysis. The hand-held film of the ET was under-exposed but usable. The distance between the ET and the Orbiter could not be accurately measured from the photography because of the dark shadows on one side of the ET.

Damage to the ET, including both intertank thrust panels, was not confirmed from the available hand-held camera views. However, approximately five light-colored marks

were visible on the -Y axis thrust panel forward of the SRB attachment fitting. An additional three or four light-colored marks were noted on the closeout flange between the forward end of left intertank thrust panel and the LO<sub>2</sub> tank TPS. These light-colored marks may indicate possible damage, but this could not be confirmed because of the limited resolution.

Venting from what appeared to be the -Y axis intertank hydrogen vent was recorded on 10 frames.

The ET rate of tumble, i.e., the end-to-end rotation of the ET about its center of mass, was estimated to be approximately 11 deg/sec. The rate of roll about the ET X axis could not be determined due to shadowing. The following table contains a comparison of the averaged tumble rate measurements for the previous four Space Shuttle missions. Venting was seen on all four missions.

Mission	Tumble rate, degrees/second	Mission Elapsed Time, minutes:seconds
STS-87	11	17:23 - 18:08
STS-89	12	31:42 - 35:27
STS-90	3	14:30
STS-91	11	16:29 - 18:46

The normal SRB separation burn scars and aerodynamic-heating marks were noted on the -Y axis intertank and nose TPS of the ET. Images of white-colored, irregularly shaped debris were also acquired. This debris appears to be pieces of frozen hydrogen and are typically seen on the ET post-separation photography.

#### **LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

The landing videos and films were analyzed and no indication of any anomalous performance was noted.

**TABLE I.- STS-91 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	153:22:01:34.533 153:22:01:39.966 153:22:01:43.527
SRB HPU Activation <sup>a</sup>	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	153:22:05:56.088 153:22:05:56.248 153:22:05:56.408 153:22:05:56.568
Main Propulsion System Start <sup>a</sup>	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	153:22:06:17.458 153:22:06:17.577 153:22:06:17.689
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	153:22:06:24.008
Throttle up to 104/104.5 Percent Thrust <sup>ab</sup>	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	153:22:06:27.888 153:22:06:27.889 153:22:06:27.908
Throttle down to 67 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	153:22:06:56.049 153:22:06:56.050 153:22:06:56.069
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	153:22:07:14
Throttle up to 104/104.5 Percent Thrust <sup>a,b</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	153:22:07:23.550 153:22:07:23.569 153:22:07:23.570
Both RSRM's Chamber Pressure at 50 psi <sup>a</sup>	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	153:22:08:22.128 153:22:08:22.328
End RSRM <sup>a</sup> Action <sup>a</sup> Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	153:22:08:24.628 153:22:08:24.818
SRB Physical Separation <sup>a</sup>	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	153:22 08:27.008 153:22:08:27.008
SRB Separation Command	SRB separation command flag	153:22:08:27
Throttle Down for 3g Acceleration <sup>a</sup>	ME-3 command accepted ME-1 command accepted ME-2 command accepted	153:22:13:51.720 153:22:13:51.733 153:22:13:51.737
3g Acceleration	Total load factor	153:22:14:02.1
Throttle Down to 67 Percent Thrust <sup>a</sup>	ME-3 command accepted ME-1 command accepted ME-2 command accepted	153:22:14:47.401 153:22:14:47.414 153:22:14:47.418
SSME Shutdown <sup>a</sup>	ME-3 command accepted ME-2 command accepted ME-1 command accepted	153:22:14:53.682 153:22:14:53.694 153:22:14:53.698
MECO	MECO command flag MECO confirm flag	153:22:14:54 153:22:14:56
ET Separation	ET separation command flag	153:22:15:13

<sup>a</sup>MSFC supplied data

<sup>b</sup>SSME 1 was Block IIA with nominal power level of 104.5 percent.

**TABLE I.- STS-91 SEQUENCE OF EVENTS  
(Continued)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	153:22:21:29.189 153:22:21:41.603 153:22:21:50.698
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	Right engine bi-prop valve position Left engine bi-prop valve position	153:22:50:34.8 153:22:50:34.9
OMS-2 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	153:22:52:20.0 153:22:52:20.0
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	153:23:50:02 153:23:51:21
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	154:01:47:41.9 154:01:47:41.9
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	154:01:48:36.9 154:01:48:36.9
OMS-4 Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 154:14:34:14.7
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 154:14:34:33.3
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	154:21:23:31.9 154:21:23:32.0
OMS-5 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	154:21:24:00.1 154:21:24:00.2
OMS-6 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 155:11:59:00.5
OMS-6 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 155:11:59:31.7
Ring Capture	Capture	155:16:58:19
Docking	Docking ring final position	155:17:12:00
Undocking	Undocking complete	159:16:01:46
Flight Control System Checkout Circulation Pump Start Circulation Pump Stop	APU 1 GG chamber pressure APU 1 GG chamber pressure	162:12:20:19.077 162:12:29:42.100
OMS-7 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	162:16:30:00.3 162:16:30:00.3
OMS-7 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	162:16:30:12.7 162:16:30:12.7
Payload Bay Door Closure	PLBD left close 1 PLBD right close 1	163:14:15:36 Data Not Available
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	163:16:47:32.044 163:17:15:38.640 163:17:15:40.665



**TABLE I.- STS-91 SEQUENCE OF EVENTS  
(Concluded)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
Deorbit Burn Ignition	Left engine bi-prop valve position	163:16:52:25.3
	Right engine bi-prop valve position	163:16:52:25.7
Deorbit Burn Cutoff	Right engine bi-prop valve position	163:16:56:35.1
	Left engine bi-prop valve position	163:16:56:35.1
Entry Interface (400K feet)	Current orbital altitude above	163:17:28:35
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	163:17:53:51
Main Landing Gear Contact	LH MLG inboard tire pressure 2	163:18:00:18
	RH MLG outboard tire pressure 2	163:18:00:18
Main Landing Gear Weight on Wheels	RH main landing gear weight on wheels	163:18:00:24
	LH main landing gear weight on wheels	163:18:00:24
Nose Landing Gear Contact	NLG RH tire pressure 1	163:18:00:27
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	163:18:00:28
Drag Chute Deployment	Drag chute deploy 1 CP volts	163:18:00:29.0
Drag Chute Jettison	Drag chute jettison 1 CP Volts	163:18:00:58.1
Wheel Stop	Velocity with respect to runway	163:18:01:28
APU Deactivation	APU-1 GG chamber pressure	163:18:17:30.670
	APU-2 GG chamber pressure	163:18:17:41.604
	APU-3 GG chamber pressure	163:18:17:53.036

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

No.	Title	Reference	Comments
STS-91-V-01	Primary RCS Thruster R2U Failed Off	153:22:15:07 G.m.t. 00:00:08:43 MET 91RF01 PR RP03-26-0989	<p>The primary RCS thruster R2U failed off during its first commanded firing following External Tank (ET) separation. During the firing, the chamber pressure (P<sub>c</sub>) did not rise above 12 psia and the thruster was deselected due to this low P<sub>c</sub> indication. Both the fuel and oxidizer injector temperatures dropped indicating some flow of both propellants. Full flow is suspected for one propellant and only pilot valve flow from the other propellant. The thruster remained deselected for the remainder of the mission. The loss of this thruster did not impact the mission.</p> <p>KSC: The thruster will be removed and replaced during turnaround activities.</p>
STS-91-V-02	Primary RCS Thruster F2U Failed Off	153:22:15:20 G.m.t. 00:00:08:56 MET CAR 91RF02 PR FRC3-25-0642	<p>The primary RCS thruster F2U failed off during its first commanded firing following External Tank (ET) separation. During the firing, the chamber pressure (P<sub>c</sub>) did not rise above 18 psia and the thruster was deselected due to this low P<sub>c</sub> indication. Both the fuel and oxidizer injector temperatures dropped indicating some flow of both propellants. Full flow is suspected for one propellant and only pilot valve flow from the other propellant. The thruster remained deselected for the remainder of the mission. The loss of this thruster did not impact the mission.</p> <p>KSC: The thruster will be removed and replaced during turnaround activities.</p>
STS-91-V-03	Ku-Band Failed to Radiate in Communications Mode	154:00:15 G.m.t. 00:02:08 MET CAR 91RF03 IPR 95V-0004	<p>After activation, the Ku-Band failed to radiate any RF when placed in the Communications (Comm) Mode. The operate bit was low. The Ku-Band system power was cycled to off and the activation procedure was performed again with no success. The Ku-Band operated satisfactorily in the Radar Mode. An IFM procedure was performed in an unsuccessful attempt to recover operation of the Ku-Band system in the Comm Mode. The IFM determined that the transmit-enable signal, which is produced by the Ku-Band signal processor, was present. It was speculated that this signal may not have been present, and the IFM was designed to inject this signal. The failure of this IFM to return satisfactory operation indicates that the failure is probably in the deployable electronics assembly.</p> <p>KSC: Troubleshooting has repeated the failure and correction action was taken to remove and replace the faulty unit.</p>
STS-91-V-04	CCTV Camera C Unable to Pan and Tilt	156:02:00 G.m.t. 02:03:54 MET IPR 95V-0006	<p>At approximately 156:02:00 G.m.t. (02:03:54 MET), the ground controller was commanding CCTV camera C and observed that it would not pan or tilt. The crew confirmed that the pan/tilt circuit breaker on panel R14D was engaged. The crew also confirmed that it camera would not pan or tilt using onboard controls. The crew cycled the pan/tilt circuit breaker five times in an unsuccessful attempt to clear potential corrosion/oxidation from the circuit breaker contacts. The also cycled the pan/tilt heater circuit breaker, and the pan/tilt motion of the camera was not restored. The camera was designated to be used during the Mir survey; however, camera D was used in place of camera C.</p> <p>KSC: Troubleshooting has repeated the anomaly, and the camera was removed and returned to JSC for repair.</p>

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

No.	Title	Reference	Comments
STS-91-V-05	Excessive GPC Error Counts	160:05:50 G.m.t. 06:07:44 MET	<p>At approximately 160:05:50 G.m.t. (06:07:44 MET), general purpose computer (GPC) 1 began logging errors at a high rate. In addition, on the next handover from Tracking and Data Relay Satellite-West (TDRS-W) to TDRS-East, the systems management (SM) GPC (GPC 4) was unable to point antennas to the correct satellite. The antennas continued to point at TDRS-W. The miniature airborne global positioning system (GPS) receiver (MAGR) was commanded to self-test with anomalous results. The MAGR was power cycled but did not recover, and the MAGR was powered off. An operations (OPS) transition was performed and it was unsuccessful in that no change in the GPC error rate nor any change in the SM transferred state vector occurred. Software dumps were performed for GPCs 1 and 4. GPC 1 was then powered off and the G2 freeze-dried GPC (GPC 2) was activated and operated as the single G2 GPC. As soon as GPC 2 took over the guidance., navigation and control (GNC) function, the state vector in the SM GPC began updating. When this occurred, the antenna management software resumed selecting the correct antenna and TDRS satellite. The positional vector was previously frozen in the SM GPC, and the antenna management software continuously selected TDRS-West. At approximately 160:17:30 G.m.t. (06:19:24 MET), an OPS transition was performed to ensure the GPS software was moded to off.</p> <p>The data analysis determined that a handshake between the GPC and MAGR was the root cause of the excessive GPC error count. Once a handshake between the GPC and the MAGR has been interrupted, it cannot be re-established. A timing mismatch allows for the interruption of the handshake.</p>
STS-91-V-06	Left OMS Bipropellant Valve 1 Open Indication	162:16:30 G.m.t. 08:18:24 MET CAR 95RF08 IPR 95V-0007	<p>A dual-engine, straight feed OMS firing (OMS-7 for SIMPLEX) was performed at 162:16:30 G.m.t. (08:18:24 MET). During the firing, the valve 1 position was indicated as 99 percent open, as expected. At the completion of the firing, the left OMS engine ball valve 1 position indicator only declined to the 96 percent open position, and should have shown 0 percent open. The indication remained at 96 percent until the next use of the engine during the deorbit maneuver. At the beginning of the deorbit maneuver, the valve 1 position indication increased to 98.4 percent. The indication remained at that level throughout the firing and after the firing was terminated.</p> <p>KSC: Postflight troubleshooting found the valve to be closed, indicating that there was a failure of the valve position instrumentation.</p>

TABLE III.-STS-91 MSFC PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-91-E-01	Main Combustion Chamber Channel A Failed the Qualification Check for Engine Control at Engine Start Plus 39.16 seconds.	153:22:07:03.16 G.m.t. 00:00:00:39.16 MET UCR A034085	Failure Identification (FID) 111-203 was posted at SSME 1 engine start plus 39.16 seconds. The Channel A main combustion chamber (MCC) chamber pressure (P <sub>c</sub> ) measurement violated the qualification for control limit and was permanently disqualified. The engine operated normally for the remainder of the flight using the Channel B sensors. Due to the smart nature of this failure, the MCC P <sub>c</sub> low redline protection for this engine was compromised from 39.16 seconds until the measurement recovered at 506 seconds after engine start. This nullified the redline for the remainder of the flight since the disqualified channel could not go below the low redline if there had been reason for that response. Sensor disqualification is expected to be caused by contamination of the sensor. Postflight testing and investigation are in progress.

## 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 Landing Report
6. Space Shuttle Vehicle Engineering Office In-Flight Anomaly 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. Shuttle Operational Data Book
14. STS-91 Summary of Significant Events
15. Contractor Reports of Subsystem Operation

## ACRONYMS AND ABBREVIATIONS

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

ABS	ammonia boiler system
AMS	Alpha Magnetic Spectrometer
APAS	Androgynous Peripheral Attachment System
APU	auxiliary power unit
ARS	atmospheric revitalization subsystem
ATCS	active thermal control system
BCR	bar code reader
BITE	built-in test equipment
CCTV	closed circuit television
c.g.	center of gravity
CPCG	Commercial Protein Crystal Growth
CPM	cell performance monitor
CREAM	Cosmic Radiation Effect and Activation Monitor
CWC	contingency water container
dBm	decibel/meter
dc	direct current
DDRS	digital data recorder system
DEA	deployable electronics assembly
deg/sec	degree per second
DMHS	dome-mounted heat shield
DMU	data multiplexer unit
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
$\Delta V$	differential velocity
ECLSS	Environmental Control and Life Support System
e.d.t.	eastern daylight time
EO	ET/Orbiter
EPDC	electrical power distribution and control
ESTL	Electronic Systems Test Laboratory
ET	External Tank
EVA	extravehicular activity
EXCP3	experiment circuit panel 3
FCE	flight crew equipment
FCL	Freon coolant loop
FCMS	fuel cell monitoring system
FCS	flight control system
FCV	flow control valve
FES	flash evaporator system
FID	Failure Identification
FM	frequency modulation
FPV	flow proportioning valve
ft/sec	feet per second
g	gravity
GAS	Get-Away Special

GFE	Government furnished equipment
GGVM	gas generator valve module
GH <sub>2</sub>	gaseous hydrogen
GMEM	GPC memory
G.m.t.	Greenwich mean time
GN <sub>2</sub>	gaseous nitrogen
GNC	guidance, navigation and control
GO <sub>2</sub>	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
GSE	ground support equipment
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
HTD	Human Exploration and Development of Space Technology Demonstration
IFM	in-flight maintenance
IMS	Inventory Management System
INS	inertial navigation system
IRD	integrated receiver decoder
I <sub>sp</sub>	specific impulse
ISS	International Space Station
JSC	Johnson Space Center
keas	knots estimated air speed
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lb	pound
lb/hr	pound per hour
lbf	pound force
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LH <sub>2</sub>	liquid hydrogen
LiOH	Lithium Hydroxide
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO <sub>2</sub>	liquid oxygen
LPS	Launch Processing System
MADS	Modular Auxiliary Data System
MAGR	miniature airborne GPS receiver
MCC	Mission Control Center/main combustion chamber
MECO	main engine cutoff
MET	mission elapsed time
MIRROR	Microgravity Industry Related Research for Oil Recovery
MLG	main landing gear
mm	millimeter
MPM	manipulator positioning mechanism
MPS	main propulsion system
MRL	manipulator retention latch
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration

mV	millivolt
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O <sub>2</sub>	oxygen
OCA	Orbiter Communications Adapter
ODS	Orbiter docking system
OI	Operational Instrumentation
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	operations
OSVS	Orbiter Space Vision System
PAL	protuberance air load
P <sub>c</sub>	chamber pressure
PCS	pressure control subsystem
PGSC	payload and general support computer
PMBT	propellant mean bulk temperature
PMMA	polymethyl methacrylate
ppm	parts per million
PPO <sub>2</sub>	partial pressure oxygen
PRSD	power reactant storage and distribution
psi	pound per square inch
psia	pound per square inch absolute
psig	pound per square inch gravity
PTE	Phantom Torso Experiment
RAM	random access memory
RCS	reaction control subsystem
RF	radio frequency
RM	redundancy management
RME	Risk Mitigation Experiment
RMS	remote manipulator system
RPOP	rendezvous proximity operations program
RRMD	Real-Time Monitoring Device
RSAD	RMS situational Awareness display
RSRM	Reusable Solid Rocket Motor
RTL	ready-to-latch
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SCU	serial converter unit
SEM	Space Experiment Module
SEU	single event upset
SHUCS	Spacehab Universal Communications System
SIGI	Space Integrated Global Positioning System/Inertial Navigation System
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SLF	Shuttle Landing Facility
SLWT	Super Light Weight Tank
SM	systems management
SMEM	super memory checker
S/N	serial number



SPA	signal processor assembly
SPSR	Space Portable Spectroreflectometer
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSCE	Solid Surface Combustion Experiment
SSCI	Shuttle Condensate Collection for ISS
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
TCS	trajectory control system
TDRS	Tracking and Data Relay Satellite
TPS	thermal protection system/subsystem
TUFI	toughened unified fibrous insulation
UMS	urine monitoring system
Vdc	Volts direct current
VSU	video switching unit
WCS	waste collection system
WSB	water spray boiler