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STS-89 SPACE SHUTTLE MISSION REPORT

April 1998



**National Aeronautics and
Space Administration**

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

NOTE

The STS-89 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.

Kenneth L. Brown
713-483-3891

Orbiter and Subsystems

M. George Harsh, MSFC
205-544-4827

MSFC Elements (SRB,
RSRM, SSME, ET,
SRSS, and MPS)

Anne M. Patterson
713-483-3367

Payloads/Experiments

Ralph V. Anderson, JSC
713-483-1271

FCE and GFE

STS-89

SPACE SHUTTLE

MISSION REPORT

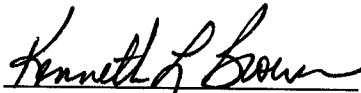
Prepared by



Robert W. Fricke, Jr.

LMSMS&S/Operations Engineering Office

Approved by



Kenneth L. Brown

STS-89 Lead Mission Evaluation Room Manager



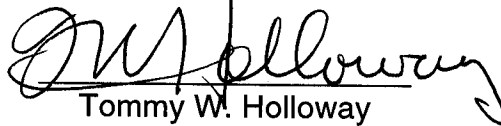
David W. Camp

for
Manager, Operations Engineering Office



Ronald D. Dittmore

Manager, Space Shuttle Vehicle Engineering Office



Tommy W. Holloway

Space Shuttle Program Manager

Prepared by

Lockheed Martin Space Mission Systems and Services
for

Operations Engineering Office

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

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INTRODUCTION

The STS-89 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during this eighth 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 eighty-ninth mission of the Space Shuttle Program. STS-89 was the sixty-third flight since the return to flight, and the twelfth flight of the OV-105 (Endeavour) Orbiter vehicle.

The flight vehicle consisted of the OV-105 Orbiter; an ET that was designated ET-90; three block IIA SSMEs that were designated as serial numbers (S/N) 2043, 2044, and 2045 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-093. The two RSRMs were designated RSRM 064 with one installed in each SRB. The individual RSRMs were designated 360T064A for the left SRB, and 360T064B for the right SRB.

The STS-89 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-89 flight were to rendezvous and dock with the Mir Space Station, and perform the exchange of a Mir astronaut. A double Spacehab module and the crew compartment carried science experiments and hardware, Risk Mitigation Experiments (RMEs), Russian Logistics, Astroculture (AST), two Mechanics of Granular Materials (MGM), Cosmic Radiation Effects and Activation Monitor (CREAM), and Space Acceleration Measurement system (SAMS) in support of the Phase 1 Program requirements. As a payload of opportunity, the requirements for the Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) were performed. In addition, the secondary objectives of this flight were to perform the requirements of Get-Away Special (GAS), Closed Equilibrated Biological Aquatic System (CEBAS), Human Performance (HP), and Microgravity Plant Nutrient Experiment (MPNE).

The STS-89 mission was a planned 9-day plus 1 day plus 2-contingency-day mission during which logistics for the Mir station would be transferred and experiments would be performed. The plus 1 day provided an opportunity for docking on flight day 4 should the phasing angle or other problems have prevented the docking on flight day 3. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. There were five docked days with the Mir. The STS-89 sequence of events is shown in Table I, and the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List is shown in Table II. 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 eight crewmembers of the STS-89 mission consisted of Terrence W. Wilcutt, Lt. Col., U. S. Marine Corps, Commander; Joe Frank Edwards, Jr., Commander, U. S. Navy, Pilot; James F. Reilly, II, Ph. D., Civilian, Mission Specialist 1; Michael P.

Anderson, Major, U. S. Air Force, Mission Specialist 2; Bonnie J. Dunbar, Ph. D., Civilian, Payload Commander and Mission Specialist 3; Salizhan Shakirovich Sharipov, Russian Cosmonaut, Mission Specialist 4; Andrew S. W. Thomas , Ph. D., Civilian, Mission Specialist 5 (ascent through docking with the Mir); and David A. Wolf, M. D., Civilian, Mission Specialist 6 (docking through landing). STS-89 was the fifth Shuttle space flight for Mission Specialist 3, the third Space Shuttle flight for the Commander and Mission Specialist 6 (descent), the second Space Shuttle flight for Mission Specialist 5 (ascent), and the first Space Shuttle flight for the Pilot, Mission Specialist 1, Mission Specialist 2, and Mission Specialist 4.

MISSION SUMMARY

The STS-89 vehicle was launched on time at 023:02:48:15.017 G.m.t. (9:48:15 p.m. e.s.t.) on January 22, 1998, after a flawless countdown with no unplanned holds. The ascent was nominal and only one Orbiter problem was noted from the data analysis. An analysis of vehicle performance during ascent was made using vehicle acceleration and preflight propulsion data. From these data, the average flight-derived engine specific impulse (I_{sp}) for the time period between SRB separation and 3g throttling was 452.8 seconds as compared to a main propulsion system (MPS) tag value of 452.20 seconds.

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. SRB separation, entry, deceleration and water impact occurred as anticipated. Both SRBs were recovered after suffering significant damage at water impact. Performance of the SSMEs, ET and main propulsion system (MPS) was normal.

Data review indicated that following the shutdown of the Space Shuttle main engines (SSMEs), the liquid hydrogen (LH₂) 4-inch disconnect failed to close pneumatically within the required time (Flight Problem STS-89-V-02). The actual closing time was 11.75 seconds from signal-to-switch compared to the Operations and Maintenance Requirements Document (OMRSD) File IX requirement of 2.8 seconds maximum (typical times are around 1.7 seconds). The disconnect is commanded closed shortly after main engine cutoff (MECO). The open indicator was not lost until approximately 11.5 seconds later. This coincided with Orbiter umbilical retraction which occurred 11.4 seconds after the MECO command. The initial evaluation indicated that the disconnect closed mechanically in the backup mode as the Orbiter umbilical plate separated from the ET umbilical. This disconnect was replaced during the STS-89 flow as part of the recycle program to eliminate 4-inch disconnects with chrome-flaking problems.

The direct ascent trajectory was nominal; consequently, no orbital maneuvering subsystem (OMS) -1 maneuver was required. The OMS-2 maneuver was performed at 023:03:30:03.4 G.m.t. [00:41:48.4 mission elapsed time (MET)]. The maneuver was 136 seconds in duration and provided a differential velocity (ΔV) of 213.5 ft/sec. The resultant orbit was 163 by 162 nmi.

At approximately 023:03:38 G.m.t. (00:00:50 MET), the backup flight system (BFS) general purpose computer (GPC) was commanding the lower left forward (LLF) S-band antenna, but the upper left forward (ULF) antenna was being selected (Flight Problem STS-89-V-07). At the time, the S-band antenna switch electronics system 2 was being used. After the systems management (SM) GPC was configured and the BFS was taken down, the ULF antenna continued to be selected although the SM GPC was commanding the LLF antenna. The ground controllers subsequently commanded the LLF antenna, but still the ULF antenna was selected. At 023:04:02 G.m.t. (00:01:14 MET), the S-band antenna switch electronics system 1 was selected as well as the LLF antenna, and nominal operation was noted. System 2 was reselected for a short time to perform troubleshooting. The crew used the antenna-select panel switch to select each of the eight S-band antennas, and normal operation was noted in all positions. Following this troubleshooting, system 1 was reselected. On flight day 4, system 2 was selected a second time to perform additional troubleshooting to evaluate

the capabilities of the GPC to control antenna switching. Again, all operations were nominal. The GPC mode of antenna selection was verified utilizing a multiple stored-program-command to cycle through the switch positions, and no anomalies were noted. Following this troubleshooting, system 1 was reselected. On flight day 7, system 2 was selected again for troubleshooting. Testing of the S-band antenna-switch electronics was performed by selecting the system 2 unit for one orbit. Again, no anomalies were noted. Troubleshooting of the S-band antenna-switch electronics system 2 was again performed on flight day 8 by selecting the system 2 unit for several orbits. All of the GPC commanding was performed properly without repeating the original anomaly. System 1 was reselected for the crew-sleep period and used for the remainder of the mission.

At approximately 023:03:44 G.m.t. (00:00:56 MET), the GPC 3 was reconfigured to a guidance, navigation and control operational sequence 2 (G2) "freeze-dry" GPC. The crew reported that when taking the GPC 3 mode switch from the run to the standby position, there was no detent in the standby position and the switch went into the halt position (Flight Problem STS-89-V-01). Subsequent mode switch changes confirmed that the freeze-dry procedure had failed because GPC put-away processing was not completed when the mode switch was inadvertently taken to halt. On flight day 2, a hardware initiated stand alone memory (HISAM) dump of the GPC 3 software was performed. Analysis of the dump revealed no GPC hardware failures or primary avionics software system (PASS) problem. GPC 3 was successfully initial program loaded (IPL'ed), moded to run, and added to the redundant set, in which it was running G2 software with GPCs 1 and 2. GPC 2 was subsequently configured as a G2 "freeze-dry" GPC. The GPC 3 mode switch was kept in the run position for the remainder of the mission.

During preparations to gain access to the Spacehab, the crew reported that they were only able to open the D hatch to a position approximately six inches above the support pads on the floor of the airlock. The crew reported interference from a stowage bag and an air duct from the inlet side of the hard duct in the external airlock (Flight Problem STS-89-V-08). The crew removed the stowage bag pallet and disconnected the air duct and completed the opening of the hatch. With the hatch properly opened and stowed, the air duct was reinstalled. The airlock is an International-Space-Station (ISS)-configured external airlock that has electrical shrouds below the forward hatch area. This condition causes the air duct 'tee' to be rotated towards the center of the airlock, thus causing the interference.

At 023:06:37:22.2 G.m.t. (00:03:49:07.2 MET), a dual OMS straight-feed NC 1 rendezvous maneuver was initiated. The maneuver was 34.7 seconds in duration, and a ΔV of 56.3 ft/sec was imparted to the vehicle. At 023:18:03:13 G.m.t. (00:15:14:58 MET), a dual OMS straight-feed NC 2 rendezvous maneuver was initiated. The maneuver was 45.3 seconds in duration, and a ΔV of 73 ft/sec was imparted to the vehicle. The NPC rendezvous maneuver, scheduled for 023:22:34 G.m.t. (00:19:46 MET), was not required. The reaction control system (RCS), in the multi-axis mode, was used for the NC 3 maneuver. The RCS performed nominally during the 12-second firing, imparting a ΔV of 2.9 ft/sec.

The Orbiter docking system (ODS) was powered up for the docking-ring extension at approximately 024:04:25 G.m.t. (01:01:37 MET). The docking ring was extended from the final position to the initial position in preparation for docking with the Russian Mir Space Station. The ODS was powered down at approximately 024:04:33 G.m.t. (01:01:45 MET).

All Orbiter subsystems performed nominally during the successful rendezvous and docking with the Mir Space Station. The following table lists the OMS and RCS maneuvers, as well as the pertinent parameters, that were performed to complete the rendezvous with the Mir Space Station.

Maneuver	Time, G.m.t./MET	ΔV , ft/sec	Duration, seconds
NC 4/OMS 5 Right OMS	024:16:19:00 G.m.t. 01:13:30:45 MET	7.9	9.8
NCC/RCS	024:16:53:41 G.m.t. 01:14:05:26 MET	1.0	3.0
TI/OMS 6 Left OMS	024:17:51:23 G.m.t. 01:15:03:08 MET	8.3	11.0
MC1/RCS	024:18:11:24 G.m.t. 01:15:23:09 MET	1.1	4.0
MC2/RCS	024:18:44:00 G.m.t. 01:15:55:45 MET	0.6	2.0
MC3/RCS	not required	-	-
MC4/RCS	024:19:11:00 G.m.t. 01:16:22:45 MET	1.8	7.0

The ODS hardware performed nominally throughout the docking sequence. Capture occurred nominally at approximately 024:20:14 G.m.t. (01:17:26 MET) with a closing rate of 0.114 ft/sec and with nominal misalignments. The docking mechanism attenuated the relative motion between the Orbiter and the Mir, retracted the two spacecraft, and the structural hooks were closed at approximately 024:20:23 G.m.t. (01:17:35 MET).

At approximately 026:03:19 G.m.t. (03:00:31 MET), the oxidizer injector temperature on vernier RCS thruster L5D began behaving erratically (Flight Problem STS-89-V-03). The indicated temperature rapidly decreased to below the 130 °F leak detection limit, and this resulted in the automatic deselection of thruster L5D by redundancy management (RM). A review of the data confirmed that the erratic temperature indication was an instrumentation problem and not an actual oxidizer leak. The indicated oxidizer injector temperature remained offset-low in the 75 to 125 °F range until approximately 026:06:07 G.m.t. (03:03:19 MET) when the measurement recovered. When the failure initially occurred, attitude control of the Orbiter/Mir stack was passed to the Mir. Due to Mir propellant concerns, attitude control was passed back to the Orbiter at approximately 026:07:48 G.m.t. (03:05:00 MET).

To recover partial vernier leak detection using the fuel injector temperature, a GPC memory (GMEM) write procedure was developed to change the oxidizer injector temperature leak detection limit of all vernier thrusters from 130 °F to off-scale-low. The GMEM procedure was uplinked to the vehicle at 026:20:57 G.m.t. (03:18:08 MET) after verification was completed in the Shuttle Avionics Integration Laboratory (SAIL). Vernier thruster redundancy management was re-enabled, and vernier leak detection was performed by the on-board system using the only fuel injector temperatures. This same anomaly occurred on STS-68 and STS-67, the seventh and eighth flights of OV-105. Extensive troubleshooting did not duplicate or isolate the anomaly. The thruster was removed and replaced after STS-68.

At 027:02:06 G.m.t. (03:23:18 MET), the reaction jet driver (RJD) forward-2 (F2) F5 remote power controller (RPC) 2 failed off (Flight Problem STS-89-V-04). Shortly after this occurred, vernier thruster F5R was commanded to fire, resulting in an F5R fail-off due to the lack of driver power, and loss of vernier-thruster attitude-control of the mated vehicle. After cycling the vernier driver switch and then turning on the forward reaction jet logic and driver power for the forward primary thrusters, the RJD power was restored. Vernier thruster F5R was re-selected and vernier control of vehicle attitude was re-established. The fail-off of the reaction jet driver RJD F2 is believed to have been caused by a failure in the latch circuit in the forward load control assembly (FLCA) 3. As a result, the RJD F2 logic power switch for forward RCS manifolds 4 and 5 were left on while the Orbiter was docked to the Mir. The troubleshooting of the failed-off RJD F2 F5 RPC 2 was performed following undocking and the orbit-adjust maneuver. The troubleshooting was initiated by taking the RJD F2 logic power switch to off to test the latch with the vernier driver power. Vernier logic power remained on indicating that the latch was not hard failed. The logic power switch was left off during the crew-awake period and taken back to on during the crew-sleep period.

Troubleshooting of the fail-off of the RJD F2 F5 RPC 2 was also performed for flight day 9. As a part of the post-sleep reconfigurations, troubleshooting was initiated by taking the RJD F2 logic power switch to off to test the latch with the vernier driver power. Vernier logic and driver power failed-off about 39 minutes later, repeating the earlier failure. The crew returned the logic power switch to on about a minute later. Since a forward vernier thruster was not commanded to fire during the time that the logic and driver power was off, vernier control was not lost. Further troubleshooting was terminated, and the logic power switch remained on for the remainder of the mission. During postflight troubleshooting at KSC, the problem was isolated to FLCA 3. The unit was scheduled for replacement.

During the planned RCS regulator reconfiguration, the right RCS fuel helium-isolation-valve B failed to open (Flight Problem STS-89-V-05). The valve position indication (VPI) telemetry indicated that the valve did not move (the close VPI stayed on and the open VPI stayed off), and the crew reported a barberpole talkback. The right RCS helium-pressurization B switch was cycled from open to close and back to the open position; however, the fuel helium-isolation-valve B still did not open. The switch was then taken to close, and the right RCS was returned to the A regulators (the right RCS helium-pressurization A switch was taken to open).

At approximately 028:07:38 G.m.t. (05:04:50 MET), the -Z star tracker annunciated a pressure-fail BITE (Flight Problem STS-89-V-06). The BITE has remained for the remainder of the mission. The star tracker is normally pressurized with argon gas to 17.58 psia to prevent moisture and contamination from entering the star tracker during entry and ground operations. The BITE indicates that the -Z star tracker pressure has leaked below 14.7 psia. There was no impact to flight operations.

All planned equipment transfers to Mir were completed. A total of 16 contingency water containers (CWCs), containing approximately 1615 lb of water, were transferred. Final ODS hatch closure occurred at approximately 028:22:27 G.m.t. (05:19:39 MET).

The ODS performed nominally during the undocking of the Orbiter with the Russian Mir Space Station. The ODS was powered up at approximately 029:16:29 G.m.t. (06:13:41 MET). The structural hooks were activated in the open direction with travel from approximately 92 percent to the nominal 6 percent where the hooks were

deactivated. The undocking-complete signal was received at 029:16:57 G.m.t. (06:14:09 MET), and the ODS was powered down 30 minutes later.

The initial separation maneuver using the RCS was initiated at 029:16:57 G.m.t. (06:14:09 MET). The maneuver was approximately 12 seconds in duration and imparted a ΔV of 2.8 ft/sec to the Orbiter. Following daylight, a fly-around of the Mir Space Station was performed. The final separation maneuver from the vicinity of the Mir was performed at 029:18:16:37 G.m.t. (06:15:28:22 MET). An orbit-adjust maneuver was performed using the left orbital maneuvering engine (OME). The firing, which was initiated at 029:23:32 G.m.t. (06:20:44 MET), had a duration of 22.4 seconds and imparted a ΔV of 18.7 ft/sec.

The RCS hot-fire was performed at approximately 030:14:55 G.m.t. (07:12:07 MET). All primary thrusters fired nominally during the hot-fire. One unusual occurrence was noted when the primary thruster R2D fuel injector temperature dropped to 23 °F following its hot-fire. Typically, a fuel injector temperature drops into the 50 to 60 °F range. The thruster was not annunciated fail-leak because leak-detection redundancy management (RM) for a fuel leak is 20 °F. The injector temperature subsequently recovered, so the thruster was considered to be good and not leaking.

Following the RCS hot-fire, the flight control system (FCS) checkout was performed using APU 1. The FCS, APU 1 and hydraulic system 1 performed nominally during the checkout. APU 1 was started at 030:15:25:31 G.m.t. (07:12:37:16 MET) and ran for 5 minutes 42 seconds with a fuel consumption of 16 lb. No water spray boiler operation occurred due to the short APU run time.

The right OME was fired in support of the Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) payload. The firing, which was initiated at 030:21:50:21 G.m.t. (07:19:02:06 MET), had a duration of 9.2 seconds and imparted a ΔV of 8.2 ft/sec to the vehicle.

Development test objective (DTO) 119, the test to obtain thermal data for the airlock external water lines, was successfully completed. Ten hours of an attitude with the top of the Orbiter facing the Sun were flown to obtain these data.

The payload bay doors were closed and latched for landing at 031:18:54:02 G.m.t. (08:16:05:47 MET). The dual-engine deorbit maneuver for the first landing opportunity at the Shuttle Landing Facility (SLF) was performed on orbit 138 at 031:21:27:55 G.m.t. (08:18:39:40 MET). The maneuver was 204 seconds in duration with a ΔV of 340.6 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on KSC concrete runway 15 at 031:22:35:10 G.m.t. (08:19:46:55 MET) on January 31, 1998. The Orbiter drag chute was deployed at 031:22:35:13 G.m.t. and the nose gear touchdown occurred 8 seconds later. The drag chute was jettisoned at 031:22:35:53 G.m.t. with wheels stop occurring at 031:22:36:21 G.m.t. The rollout was normal in all respects. The flight duration was 8 days 19 hours 46 minutes 55 seconds. The APUs were shut down 16 minutes 45 seconds after landing.

PAYLOADS AND EXPERIMENTS

The payload and experiment operations were very successful during the STS-89 mission. All planned equipment transfers to and from Mir were completed. In excess of 3578 lb of hardware, equipment and consumables were transferred to the Mir plus 16 contingency water containers (CWCs), containing approximately 1615 lb of water. Approximately 2207 lb were transferred from the Mir to the Orbiter for return.

SPACEHAB OPERATIONS

All Spacehab subsystems performed satisfactorily, and 100 percent of the planned transfer items to the Mir were completed. Approximately 86 percent of the planned return items were transferred to the Spacehab. This reduced amount of transfers resulted from 25 bags containing used food containers, lithium hydroxide canisters, and other return items being deleted from the return list. A stowage reconfiguration plan and center of gravity (c.g.) concerns that resulted from the significant reduction in return items were resolved without any significant problems.

The enhanced Orbiter Refrigerator/Freezer (EOR/F) performed satisfactorily in the freezer mode. The EOR/F was used to stow down-transfer samples and operated nominally.

PHASE 1 PROGRAM SCIENCE

Advanced X-Ray Detector - The Advanced X-Ray Detector (ADV XDT) performed satisfactorily. The unit was deactivated and the powered transfer to the Mir Space Station was completed at 027:20:49 G.m.t. (04:18:01 MET).

Advanced Commercial Generic Bioprocessing Apparatus - The Advanced Commercial Generic Bioprocessing Apparatus (CGBA) was transferred in the powered state from the Mir to the Orbiter on flight day 6. Unattended operations for the remainder of the mission were nominal.

Mechanics of Granular Materials - The Mechanics of Granular Material (MGM) encountered a video downlink anomaly shortly after deactivation. This condition was corrected by reconfiguring the video switching unit (VSU). Six samples were processed; however, during the sample 4 deactivation erratic pressure readings (11.4 to 35 psi) were noted. These were believed to be caused by a faulty pressure sensor. Alternate activation and deactivation procedures were implemented and operations were continued for the remainder of the samples. The initial indications are that sample 4 was not compromised and all samples were successfully processed.

MIDDECK SCIENCE AND PAYLOADS

Advanced Astroculture - The Advanced Astroculture (ADV ASC) experiment was transferred to the Mir on flight day 6 without incident.

Biochemistry of Three Dimensional Tissue Biotechnology Refrigerator - The Biochemistry of Three Dimensional Tissue Biotechnology Refrigerator (BIO3D BTR) unit was transferred in the powered condition to the Orbiter middeck on flight day 5. The unit operated nominally for the remainder of the mission.

Thermal Electric Holding Module - The Thermal Electric Holding Module (TEHM) operated nominally. The TEHM was used as a refrigerator (4 °C) during ascent and descent for stowage of refrigerated Mir transfer and Shuttle samples.

Thermal Electric Holding Facility - The Thermal Electric Holding Facility (TEHOF) was transferred to the Mir; however, the assembly was not complete. The outer shell installation was completed in the Mir after the Orbiter undocked from the Mir. The unit was stored in the Krystall Module and the necessary Shuttle tools required for installation of the shell were left with the Mir crew for assembly of the experiment.

Closed Equilibrated Biological Aquatic System - The Closed Equilibrated Biological Aquatic System (CEBAS) operated nominally throughout the mission.

Coculture - The Coculture (COCULT) experiment hardware began showing error messages early in the mission. Troubleshooting concluded that a pressure sensor had failed and fresh nutrient media was no longer being infused into the COCULT rotating vessel. A manual infusion procedure was performed by the crew to re-establish an acceptable nutrient balance. An in-flight maintenance (IFM) procedure during which an internal inspection of the hardware was performed on flight day 5, and no leaks or definitive cause for the automatic infusion anomaly was found. The hardware was transferred to the Mir on flight day 5.

Cosmic Radiation Effects and Activation Monitor - The Cosmic Radiation Effects and Activation Monitor (CREAM) components were deployed inside the Mir Space Station at 025:17:03 G.m.t. (02:14:15 MET), and the active monitor was activated in the Mir core area. After three days aboard the Mir, the CREAM's short-duration passive components were retrieved from the Mir. The short-components from STS-89 along with the long-duration components from STS-86 were stowed in the Orbiter for return. The long-duration STS-89 components left on the Mir will be retrieved during the STS-91 mission. The positions of the various components on the Mir were documented with the electronic still camera (ESC).

EarthKAM - Students from 51 middle schools in three nations participated in the EarthKAM program which allowed the students to investigate our planet from their classrooms. This program was building on the success that was produced by the KidSat program, which was flown on some earlier Space Shuttle missions.

This EarthKAM operations produced 300 images from the pre-docked and post-undocked phases of the mission. Low voice levels were present early in the mission between the Mission Control Center (MCC) and the University of California, San Diego, and these were resolved with a work-around. During the post-undocked operations, a problem developed with the maintaining of a satisfactory battery charge on the ESC camera. This problem was resolved by trading components in the set-up and ultimately achieving a good battery-charging indication.

Human Performance - The Human Performance (HP) experiment was completed with nominal results. The initial data takes were completed on flight day 4. The data takes planned for flight day 5 were delayed because of the shortened crew work day, but were successfully completed on flight day 8 along with two more data takes than were planned for that day. The results of this experiment will be reported in separate documentation.

Microgravity Plant Nutrient Experiment - The main goal of the Microgravity Plant Nutrient Experiment (MPNE) was to test a nutrient-delivery technology that will support plant growth in space. Postflight analysis will be required to determine the success of this experiment, as a number of problems were evident during the mission. The results of the evaluation will be published in separate documentation.

Shuttle Ionospheric Modification with Pulsed Local Exhaust - A successful orbital maneuvering subsystem (OMS) firing was completed over the Arecibo, Puerto Rico ground station at approximately 30:21:50:13 G.m.t. (07:19:01:58 MET). The firing used a single OMS engine for 10 seconds. The firing was out-of-plane to the orbit and produced an exhaust plume in the northwest direction. In addition, the nominal deorbit firing was performed over the Alice Springs site in Australia.

RISK MITIGATION EXPERIMENTS

RME 1301 - Enhanced Dynamic Load Sensors - The Enhanced Dynamic Load Sensors (EDLS) hardware was transferred from the Mir to the Spacehab and partially stowed. The six PCMCIA data disks and pouches could not be located on the Mir. Discussions revealed that no data had been recorded on these disks and later return would not be required.

RME 1303-2 - Mir Structural Dynamics Experiment - All Mir Structural Dynamics Experiment (MiSDE) hardware was transferred to the Spacehab except for two of the eight accelerometer sensor heads (one uniaxial and one triaxial) and two Personal Computer Memory Card International Association (PCMCIA) disks and pouches that could not be located. The sensor may be planned for return on STS-91 and the missing data disks contain backup data that has been recovered from the prime disks.

RME 1307 - Optical Properties Monitor - The Optical Properties Monitor (OPM) installation in the Spacehab was successfully completed at 025:02:49 G.m.t. (01:23:26 MET). Downlink video of the rack installation was provided for verification of the fit.

RME 1312 - Real-Time Radiation Monitoring Device - The Real-Time Radiation Monitoring Device (RRMD) operated nominally until flight day 9 when it was reported that the Data Recording Unit (DRU) did not record data during a pass through the South Atlantic Anomaly. A suspected DRU tape jam was confirmed, and a power cycle and a time-table reload recovered nominal operations. Onboard data were recorded during the Spacehab 32 kilobits/second checkout test. Good data were also received on the ground for the Bonner Bell Neutron Detector (BBND) experiment. The BBND experiment was changed over to the RRMD detector unit at 027:05:18 G.m.t. (04:12:30 MET). The short and long deoxyribonucleic acid (DNA) samples were deployed, incubated and deactivated successfully.

RME 1324 - Volatile Organic Analyzer - The Volatile Organic Analyzer (VOA) failed to activate at the initial start-up when various fail error messages were exhibited, and an attempt to repower the VOA was unsuccessful. The VOA experiment personnel stated that this anomaly had not been seen during ground testing, and a bad sector in the experiment computer hard drive was suspected to be the cause of the anomaly. Two IFM procedures were successfully implemented on flight day 6. A four-hour bake-out was completed prior to re-initiating sample processing on flight day 7. Subsequently,

three automatic and two manual samples were taken and these adequately met the experiment's science objectives.

RME 1326 - Volatile Removal Assembly - A premature shut-down of the Volatile Removal Assembly (VRA) was reported at 028:18:15 G.m.t. (02:15:27 MET). The experiment experienced a low-flow situation and a shut-down of the automatic pump occurred. An unsuccessful power cycle was performed about 20 hours later when a shut-down recurred in response to a low-flow rate condition. The inaccessibility of the regulator and lack of an operational work-around prevented further troubleshooting. Operations were terminated for the remainder of the mission.

RME 1331 - Shuttle Condensate Collection for International Space Station - All CWC and sample bag collections were completed satisfactorily. The greater-than-expected rate of condensation resulted in a faster filling than anticipated. Stowage concerns were alleviated when it was determined that a full CWC could be stowed in the middeck starboard ceiling bag. The CWC when filled contains 44 liters of water weighing approximately 100 lb.

RME 1332 - Test of PCS Hardware - The desired hard drive was successfully transferred from the Mir to the Spacehab for return.

GET-AWAY SPECIAL PAYLOADS

The four Get-Away Special (GAS) payloads were activated and performed nominally. The four GAS payloads were:

- a. G-093 - Vortex Ring Transit Experiment sponsored by the University of Michigan, Ann Arbor, Michigan.
- b. G-141 - Structure of Marangoni Convection in Floating Zones sponsored by the German Aerospace Center in conjunction with the University Giessen, Germany.
- c. G-145 - Glass Fining sponsored by a collaboration of the German Aerospace Center and the Technical University of Clausthal.
- d. G-432 - Consisted of five experiments that were sponsored by the Chinese Academy of Sciences.

VEHICLE PERFORMANCE

The flight evaluation results for the SRB, RSRM, ET, SSME, SRSS and Orbiter subsystems are discussed in this section of the report.

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. No in-flight anomalies were identified from the review and analysis of the flight data.

During the prelaunch countdown, the heated ground purge in the SRB aft skirts, which is used to maintain the case/nozzle joint temperatures within the required LCC ranges, was on the high-range continuously.

Both SRBs were successfully separated from the External Tank (ET) approximately 123.324 seconds after SRB ignition. The SRBs were not observed during descent because of darkness; however, reports from the recovery forces indicate that the deceleration subsystems performed as designed. The recovery was successfully completed; however, the high seas delayed the recovery of the SRBs. The SRBs were returned to Kennedy Space Center (KSC) for disassembly and refurbishing.

The postflight inspection revealed that the SRBs sustained significant damage at water impact. The damage was attributed to the rough seas (7 to 9 ft. seas with 25 to 30 knot winds from the east to southeast), which were present at the time of water impact. This damage is summarized in Space Shuttle STS-89 Flight Evaluation Report Volume II - Solid Rocket Booster Project. A detailed description of the damage is contained in USBI SRB Postflight Assessment Report document. The rough seas continued through the retrieval operations and contributed to the loss of the left and right SRB main parachutes. Data recorded through the period of water immersion showed that this condition was caused by the rough seas and was not an in-flight anomaly.

Evaluation of the thrust vector control (TVC) data showed that the TVC subsystem responded as expected to the SSME trim modifications (part of the Shuttle Performance Enhancements). This was the second flight for these SSME trim changes which close the included angle between the SSME and the SRB thrust vectors during first stage flight. The SRB thrust vectors were then trimmed to maintain moment balance. This trimming of the SRB thrust vectors resulted in the TVC actuator positions being outside their experience base during certain specific time frames. The overall actuator position experience base was not exceeded, only certain areas of the time specific (second by second) experience base were expanded.

REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motors (RSRMs) performed satisfactorily throughout the ascent phase, and no RSRM LCC or OMRSD violations occurred. No in-flight anomalies were identified from the review and analysis of the flight data.

Power up and operation of all igniter and field-joint heaters was accomplished as planned during the countdown. All RSRM temperatures were maintained within

acceptable limits throughout the countdown. The igniter-joint heaters operated for 13 hours during the countdown, and the field-joint heaters operated for 13 hours 9 minutes during the countdown.

The aft skirt purge operated for a total of 32 hours and 21 minutes. During the countdown, the aft skirt purge was activated to maintain the nozzle/case joint temperatures above the minimum LCC temperature, which was done satisfactorily. The calculated flex bearing mean bulk temperature was a nominal 82 °F.

Ascent data indicates that the flight performance of both RSRMs was well within the Contract End Item (CEI) limits. The maximum head-end pressure for the right motor set a new historical maximum, and the action time for the right motor set a new historical minimum. Both of these conditions are attributed to the high burn rate that was present on the right motor. The maximum trace shape variation of pressure versus time during the 62 to 80 second time frame was calculated to be 1.58 percent at 71.5 seconds (left motor), and -0.82 percent at 79 seconds (right motor). The left motor experienced one trace shape data point that was slightly outside the maximum historical family, and it was caused by a pressure perturbation at 71.5 seconds. The right motor had several points that were outside the minimum historical population; however, these values were well within the 3.2 percent allowable limits.

The RSRM propellant mean bulk temperature (PMBT) was 65 °F at liftoff. The table on the following page delineates the RSRM propulsion systems performance during ascent.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 65 °F		Right motor, 65 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	65.85	65.82	65.86	65.97
I-60, 10 ⁶ lbf-sec	175.42	175.82	175.45	175.57
I-AT, 10 ⁶ lbf-sec	296.78	296.82	296.73	295.21
Vacuum Isp, lbf-sec/lbm	268.5	268.5	268.5	267.1
Burn rate, in/sec @ 60 °F at 625 psia	0.3707	0.3708	0.3708	0.3731
Event times, seconds ^a				
Ignition interval	0.232	N/A	0.232	N/A
Web time ^b	109.3	108.8	109.3	108.5
50 psia cue time	119.1	119.0	119.0	118.0
Action time ^b	121.1	121.3	121.1	120.0
Separation command	124.0	123.3	124.0	123.3
PMBT, °F	65	65	65	65
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	2.8
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		1070.1	

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

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

^bReferenced to liftoff time (ignition interval).

Extensive water impact damage was observed on the right-hand forward and forward-center segments, the right-hand aft dome, and the left-hand aft exit cone joint 1. The joint 1 damage resulted from the aft exit cone detaching from the forward exit cone. In addition, one area of heavy polysulfide extrusion was noted on the left-hand nozzle-to-case joint. No polysulfide was observed in the primary O-ring groove, and no polysulfide remnants were adhered to the primary O-ring.

EXTERNAL TANK

All objectives and requirements associated with the ET loading and flight operations were satisfactorily met. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operations were performed properly, with the exception of the nose-cone purge whose compartment temperature unexpectedly dropped below the OMRSD limit for about a 2000-second period of time. The relative humidity was low enough and the ambient temperature was high enough to prevent the formation of ice, and therefore, the compartment temperatures were acceptable per the LCC. No data correlation could be made to explain the sudden and unexpected drop in temperature. The measured nose-cone mass flow-rate was within the Interface Control Document (ICD) requirement as it has been since the critical flow nozzle was installed to limit flow rate. No ET LCC violations were identified.

The intertank purge heater and temperature control system operated satisfactorily. The intertank temperatures were maintained within accepted limits, all components within the intertank performed satisfactorily, and there were no hazardous gas violations.

Propellant loading was performed nominally. The start of liquid hydrogen (LH₂) chilldown was delayed approximately two hours because the fixed service structure 750-psi gaseous nitrogen pressure exceeded the OMRSD limit. The technicians were able to reconfigure valves to isolate the faulty primary leg and provide a secondary GN₂ source.

There were no unexpected or unacceptable ice/frost formations observed on the ET during the countdown, nor was any ice or frost observed on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen (LO₂) and LH₂ feed-lines, the pressurization line brackets, and along the LH₂ protuberance air load (PAL) ramps. All observations were acceptable based on NSTS 08303. The Ice/Frost Red Team did not identify any anomalous thermal protection system (TPS) conditions during their inspections.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO₂ ullage pressure experienced during the ullage-pressure slump was a nominal 13.4 psid.

Post-separation ET photographs were taken by the crew. Because of the time of launch, the ET was approximately 4 km away from the Orbiter before lighting conditions allowed photography. The ET images at that distance did not show definitively that the TPS problems that were noted during the STS-87 Orbiter postflight inspection had been resolved. The STS-89 Orbiter postflight inspection suggests that the material removal improved the situation in terms of size of the particles lost and the severity of the resultant tile damage. It also indicated that the debris generation had not been eliminated. The umbilical well cameras provided no additional information on the intertank condition because of the lighting conditions present at separation. The assessment teams formed to investigate the STS-87 anomaly will continue to function in

an attempt to determine the cause of the material loss and the actions necessary to mitigate the issue for future vehicles.

ET separation occurred as planned with ET entry and breakup within the predicted footprint. The postflight predicted ET intact impact point was approximately 66 nmi uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

On this first flight of the Block IIA Space Shuttle main engines (SSMEs), all SSME parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine ready was achieved at the proper time; all LCC were met; and engine start and thrust build-up were normal, and no in-flight anomalies were identified from the data review and analysis.

Flight data indicate that SSME performance during main-stage, throttling, shutdown and propellant-dump operations was normal and revealed no in-flight anomalies. The high pressure oxidizer turbopump (HPOTP) and the high pressure fuel turbopump (HPFTP) temperatures were well within specification. Cutoff times were 517.21, 517.33, and 517.44 seconds for SSMEs 1, 2, and 3, respectively. The Space Shuttle main engine cutoff (MECO) occurred 509.04 seconds after liftoff.

SHUTTLE RANGE SAFETY SYSTEM

Analysis of the flight data indicated nominal performance of the Shuttle Range Safety System (SRSS) during ascent.

The 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 appropriate times. All SRSS measurements indicated that the system operated as expected throughout the countdown.

Data analysis indicated nominal performance of all SRB subsystems except that during ascent, the right-hand SRB signal strengths A and B exceeded the Range Safety minimum requirements of -85 dBm when tracking with the Cape Command Site. The lowest observed right-hand SRB signal strength A was -88.0 dBm (0.91 Vdc) at T + 106.04 seconds which did not exceed the right-hand SRB Command sensitivity of -108.6 dBm and did not affect system operation. The lowest observed right-hand SRB signal strength B was -90.2 dBm (0.83 Vdc) at T + 117.52 seconds which did not exceed the right-hand SRB command sensitivity of -110.6 dBm and did not affect system operation. Telemetry data indicate that the combined signal strength of all four SRB SRSS Integrated Receiver Decoders (IRDs) was always sufficiently high to maintain system operation to SRB separation.

As planned, the SRB S&A devices were safed, and SRB system power was turned off prior to SRB separation. The ET system was deleted from this and a number of previous vehicles.

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion System

The overall prelaunch and in-flight performance of the main propulsion system (MPS) was satisfactory. The LO₂ and LH₂ loadings were performed with no stop-flows or reverts. Also, there were no LCC or OMRSD violations. The T-20 hold was lengthened because of a computer error message, and the T-9 minute hold was shortened so that the launch could be completed at the planned time. Data review indicated a problem following MECO and it is discussed in a following paragraph.

No significant hazardous gas concentrations were detected during the preflight operations period. The maximum hydrogen concentration level in the Orbiter aft compartment, occurring just after the start of fast-fill, was approximately 160 ppm. This level compares favorably with previous data for this vehicle.

Loading was delayed for approximately 1.5 hours because of a problem with the LH₂ loading console software. LH₂ loading operations were normal through fast-fill, topping and replenish. The start of LH₂ chilldown was delayed approximately two hours because the fixed service structure 750-psi gaseous nitrogen pressure exceeded the OMRSD limit. The technicians were able to reconfigure valves to isolate the faulty primary leg and provide a secondary gaseous nitrogen (GN₂) source.

Based on an analysis of the loading system data, the LH₂ load at the end of replenish was 231,339 lbm, which when compared with the inventory (predicted) load yielded a small difference that was well within the required MPS loading accuracy of ± 0.37 percent.

The LO₂ loading operations were normal through chill-down, slow fill, fast fill, topping and replenish. Based on an analysis of the loading system data, the LO₂ load at the end of replenish was 1,388,338 lbm. Comparison of the actual load with the planned load showed a difference of -0.03 percent, which is well within the required loading accuracy of ± 0.43 percent.

Ascent MPS performance was nominal with the exception of the problem discussed in the following paragraph. Data indicate that the LO₂ and LH₂ pressurization and feed systems performed nominally and satisfied all tank ullage pressure and SSME inlet net positive suction pressure (NPSP) requirements. The minimum LO₂ ullage pressure experienced during the period of the ullage pressure slump was 13.35 psid, which violated historical low limits during flight. A brief violation occurred at T+ 43 seconds, and this was followed by continuous violations from T+ 160 to T+ 346 seconds with the maximum violation being 0.2 psi. Below average gaseous oxygen (GO₂) pressurant supply pressures and temperatures, as well as the smallest average GO₂ fixed orifice size were contributing factors.

Data review indicated that following the shutdown of the SSMEs, the LH₂ 4-inch disconnect failed to close pneumatically within the required time (Flight Problem STS-89-V-02). The actual closing time was 11.75 seconds from signal-to-switch compared to the OMRSD File IX requirement of 2.8 seconds maximum (typical times are around 1.7 seconds). The disconnect is commanded closed shortly after MECO. The open indicator was not lost until approximately 11.5 seconds later. This coincided with Orbiter umbilical retraction which occurred 11.4 seconds after the MECO command.

The evaluation indicated that the disconnect closed mechanically in the backup mode as the Orbiter umbilical plate separated from the ET umbilical.

Inspection of the Orbiter disconnect after landing did not reveal any apparent anomalies. The pneumatic actuator was fully retracted and no damage was noted to the disconnect sector gear or the actuator mechanism. The Orbiter-side flapper seal was cracked at one point on the seal circumference. This is believed to be the result of the backup mechanical separation. Inspection of the disconnect pneumatic solenoid valves and lines revealed no anomalies. The disconnect was replaced and the anomalous valve was sent to the NASA Shuttle Logistics Depot (NSLD) for failure analysis. Review of the umbilical well ET separation film did not reveal any data because separation occurred in the dark. Possible explanations include mechanical binding in the ET half disconnect, icing of the disconnect actuation mechanism, and failure of the disconnect pneumatics or electrical system. Further testing of the disconnect hardware is being performed, and the results will be reported in separate documentation.

This disconnect was replaced during the STS-89 flow as part of the recycle program to eliminate 4-inch disconnects problems of chrome-flaking of the shaft seal. A number of issues occurred during the installation process, including sector-gear alignment and the 4-inch to 17-inch disconnect alignment. All of the issues were resolved prior to Orbiter rollout.

A similar failure occurred on STS-55 when the 4-inch disconnect failed to close after a pad abort. Closure finally occurred when the topping valve was opened and it applied a large pressure surge to the Orbiter-side flapper. The actuator and solenoids were changed after the pad abort and the checkout at ambient conditions was successful. However, the failure repeated at MECO and closed at umbilical retract. The failure could not be repeated during postflight testing at the Orbiter manufacturing facility.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed acceptably throughout the mission. Three RCS anomalies occurred during the flight and these are discussed in later paragraphs of this section. Of the total propellants consumed by the RCS (4005.8 lbm), 1913.7 lbm were provided by the orbital maneuvering subsystem (OMS) during left- and right-pod interconnect operations. The primary RCS had a total of 3925 firings, and a total firing time of 848.41 seconds. The vernier RCS had a total of 21,562 firings, and a total firing time of 39,732.6 seconds. A forward RCS dump of 25.5 seconds was performed near the end of the flight. The table on the following page identifies the maneuvers performed with the RCS.

At approximately 026:03:19 G.m.t. (03:00:31 MET) while docked with the Mir Space Station, the oxidizer injector temperature on vernier RCS thruster L5D began behaving erratically (Flight Problem STS-89-V-03) and resulted in an erroneous fail-leak indication and thruster deselection. The indicated temperature rapidly decreased to below the 130 °F leak detection limit, and this resulted in the automatic deselection of thruster L5D by redundancy management (RM). A review of the data confirmed that the erratic temperature indication was an instrumentation problem and not an actual oxidizer leak, and the thruster was re-enabled. The indicated oxidizer injector temperature remained offset-low in the 75 to 125 °F range. When the failure initially occurred, attitude control of the Orbiter/Mir stack was passed to the Mir. Due to Mir propellant concerns, attitude control was passed back to the Orbiter at approximately 026:07:48 G.m.t.

RCS MANEUVERS

Maneuver	Time, G.m.t./MET	ΔV , ft/sec	Duration, seconds
-X Trim	023:03:17:37 G.m.t.	0.9	2.0
NC-3	024:04:01:14 G.m.t. 01:01:12:59 MET	2.9	12
NCC	024:16:53:41 G.m.t. 01:14:05:26 MET	1.0	3.0
MC1	024:18:11:24 G.m.t. 01:15:23:09 MET	1.1	4.0
MC2	024:18:44:13 G.m.t. 01:15:55:58 MET	0.6	2.0
MC3	Canceled	-	-
MC4	024:19:11:18 G.m.t. 01:16:13:03 MET	1.8	7.0
DTO 258	024:19:54:17 G.m.t. 01:17:06:02 MET	-	16 firing pulses in 17 minutes
Undocking	029:16:57:18 G.m.t. 06:14:09:03 MET	-	-
Separation	029:18:16:37 G.m.t. 06:15:28:22 MET	2.8	11.4

(03:05:00 MET). At the end of the flight, the thruster cooled and the L5D oxidizer temperature began reading nominal values.

To recover partial vernier leak detection using the fuel injector temperature, a GPC memory (GMEM) write procedure was developed to change the oxidizer injector temperature leak detection limit of all vernier thrusters from 130 °F to off-scale-low. The GMEM procedure was uplinked to the vehicle at 026:20:57 G.m.t. (03:18:08 MET) after verification was completed in the Shuttle Avionics Integration Laboratory (SAIL). Vernier thruster redundancy management was re-enabled, and vernier leak detection was once again being performed by the on-board system using the only fuel injector temperatures. This same anomaly occurred on STS-68 and STS-67, the seventh and eighth flight of OV-105. Extensive troubleshooting did not duplicate or isolate the anomaly. The thruster was removed and replaced after STS-68. A non-invasive postflight troubleshooting plan has been developed for the vehicle/thruster connector.

At 027:03:19:11 G.m.t. (04:00:31:56 MET), the reaction jet driver (RJD) forward-2 (F2) F5 remote power controller (RPC) 2 failed off (Flight Problem STS-89-V-04). Shortly after this occurred, vernier thruster F5R was commanded to fire, resulting in an F5R fail-off due to the lack of driver power, and loss of vernier-thruster attitude-control of the mated vehicle. After cycling the vernier driver switch and then turning on the forward reaction jet logic and driver power for the forward primary thrusters, the RJD power was restored. Vernier thruster F5R was re-selected and vernier control of vehicle attitude was re-established. A detailed discussion of this failure is contained in the Flight Control Subsystem section of this report.

During the planned RCS regulator reconfiguration, the right RCS fuel helium-isolation-valve B failed to open (Flight Problem STS-89-V-05). The valve position indication (VPI) telemetry indicated that the valve did not move (the close VPI stayed on and the open

VPI stayed off), and the crew reported a barberpole talkback. The right RCS helium-pressurization B switch was cycled from open to close and back to the open position; however, the fuel helium-isolation-valve B still did not open. The switch was then taken to close, and the right RCS was returned to the A regulators (the right RCS helium-pressurization A switch was taken to open).

The initial Mir separation maneuver using the RCS was initiated at 029:16:57 G.m.t. (06:14:09 MET). The maneuver was approximately 12 seconds in duration and imparted a ΔV of 2.8 ft/sec to the Orbiter. Following daylight, a fly-around of the Mir Space Station was performed. The final separation maneuver from the vicinity of the Mir was performed at 029:18:16:37 G.m.t. (06:15:28:22 MET). An orbit-adjust maneuver was performed using the left orbital maneuvering engine (OME). The firing, which was initiated at 029:23:32 G.m.t. (06:20:44 MET), had a duration of 22.4 seconds and imparted a ΔV of 18.7 ft/sec.

The RCS hot-fire was performed beginning at approximately 030:14:55 G.m.t. (07:12:07 MET). All primary thrusters fired nominally during the hot-fire. One unusual occurrence was noted when the primary thruster R2D fuel injector temperature dropped to 23 °F following its hot-fire. Typically, a fuel injector temperature drops into the 50 to 60 °F range. The thruster was not annunciated fail-leak because leak-detection RM for a fuel leak is 20 °F. The injector temperature subsequently recovered, which confirmed that the thruster was not leaking and was again in a healthy condition.

Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the mission with a total of eight maneuvers performed with nominal results. No LCC or OMRSD deviations occurred prior to launch, and no in-flight anomalies occurred during the mission. A total of 19,015.8 lbm of OMS propellants were consumed during the mission, and of this total 1913.7 lbm were consumed by the RCS during interconnect operations. The table on the following page provides data concerning each of the OMS maneuvers.

The direct ascent trajectory was nominal; consequently, no OMS-1 maneuver was required.

The dual-engine deorbit maneuver for the first landing opportunity at the Shuttle Landing Facility (SLF) was performed on orbit 138 at 031:21:27:55 G.m.t. (08:18:39:40 MET).

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 2294 lbm of oxygen and 289 lbm of hydrogen for the production of electricity. In addition, the environmental control and life support system (ECLSS) was supplied 162 lbm of oxygen of which 56.4 lbm was supplied to the Mir Space Station. An 83-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 98-hour mission extension was available.

OMS MANEUVERS

Maneuver	Time, G.m.t./MET	Duration, seconds	ΔV , ft/sec
OMS-2 2 engine	023:03:30:03 G.m.t. 00:00:31:48 MET	133	213.4
OMS-3/NC1 2 engine	023:06:37:22 G.m.t. 00:03:49:07 MET	34.7	56.3
OMS-4/NC2 2 engine	023:18:03:13 G.m.t. 00:15:14:58 MET	45.3	74.0
OMS 5/NC4 Right OMS	024:16:19:09 G.m.t. 01:13:30:54 MET	9.8	8.0
OMS 6/TI Left OMS	024:17:51:23 G.m.t. 01:15:03:08 MET	11.0	8.4
OMS-7 Left OMS	029:23:32:03 G.m.t. 06:20:43:48 MET	22.4	18.7
OMS-8 Right OMS	030:21:50:21 G.m.t. 07:19:02:06 MET	9.9	8.3
OMS-9 Deorbit	031:21:27:54 G.m.t. 08:18:39:39 MET	205	359.2

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 15.7 kW and 514 amperes. The fuel cells produced 3328 kWh of electrical energy and 2583 lbm of by-product potable water, using 2294 lbm of oxygen and 289 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 as predicted for fuel cell 1, 0.1 Vdc below predicted for fuel cell 2, and 0.1 Vdc above predicted for fuel cell 3.

STS-89 was the first flight of the fuel cell monitoring system (FCMS) on this vehicle and the second flight of the Space Shuttle Program for the FCMS. The FCMS demonstrated that it could provide insight into individual cell voltages during both the prelaunch and on-orbit periods. 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 ± 0.5 percent of full-scale tolerance on each FCMS single cell voltage measurement. This tolerance is calculated to be ± 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.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission. No in-flight anomalies or significant problems were noted during the course of the mission. The APU run times and fuel consumption are shown in the following table.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 406) (a) (b)		APU 2 (S/N 203) (a)		APU 3 (S/N 207) (a)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	21:11	50	21:19	60	21:28	55
FCS checkout	5:42	16				
Entry ^a	61:16	131	89:26	186	61:26	127
Total	88:09	197	110:45	246	82:54	182

^a APUs were shut down 16 minutes 45 seconds after landing.

^b APU 1 was used for the FCS checkout.

At 027:16:50 G.m.t. (04:14:02 MET), the APU 3 fuel pump/line/gas generator valve module (GGVM) system B heater thermostat began cycling within a 4 °F deadband, as indicated by the bypass-line temperature. Prior to this time, the thermostat deadband had been about 14 °F. This thermostat is located on a fuel line that is attached to the APU. Previous experience has shown that a thermostat located at this position will eventually fail once it begins to show signs of set-point shifting or erratic behavior. Generally, a set-point change is the first step followed by more erratic operation of the thermostat prior to failure. Also, this heater system has an over-temperature thermostat as well as a redundant-heater circuit. This APU was removed and replaced after this flight and returned to the APU manufacturer because of the life limits on the gas generator valve module welds. The thermostat will be replaced during the rework at the APU manufacturer.

Hydraulics/Water Spray Boiler Subsystem

The overall hydraulics and water spray boiler (WSB) subsystem performance was nominal. There were no under-cooling or over-cooling conditions that occurred, and no in-flight anomalies were identified from the data. One item of interest is discussed in the following paragraph.

A seven-minute APU hot-fire test was performed on all three hydraulic systems prior to the flight because of the installation of three new APUs. The post-hot-fire inspections revealed hydraulic leakage on the system 1 main pump return (suction) hose and on the system 3 main pump supply (discharge) hose. The leakage was greater than the specification allowed and the discharge hose was replaced on system 3 and the system 1 suction hose was retorqued to the maximum allowable level. A second hot-fire was performed and the leakage levels still exceeded the OMRSD specification of no more than 2 drops in 30 minutes. Waivers were approved by the Space Shuttle Program to fly the STS-89 mission in the as-is condition. The postflight inspection revealed that the leakage was less than calculated based on the preflight conditions. Postflight microscopic inspections will be made of the conditions in an attempt to determine the cause of the excessive leakage.

Electrical Power Distribution and Control Subsystem

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

Orbiter Docking System

The Orbiter docking system (ODS) performed nominally throughout the three phases of docked operation, which were docking ring extension, docking and undocking.

The ODS was powered up for the docking-ring extension at approximately 024:04:24:50 G.m.t. (01:01:36:35 MET). The docking ring was extended from the final position to the initial position in preparation for docking with the Russian Mir Space Station. The ODS was powered down at approximately 024:04:33:21 G.m.t. (01:01:45:06 MET).

The ODS hardware performed nominally throughout the docking sequence. Capture occurred nominally at approximately 024:20:14:20 G.m.t. (01:17:26:05 MET) with a closing rate of 0.114 ft/sec and with nominal misalignments. The docking mechanism attenuated the relative motion between the Orbiter and the Mir, retracted the two spacecraft, and the structural hooks were closed at approximately 024:20:22:16 G.m.t. (01:17:34:11 MET). Likewise, all Orbiter subsystems performed nominally during the successful rendezvous and docking with the Mir Space Station.

The ODS performed nominally during the undocking of the Orbiter with the Russian Mir Space Station. The ODS was powered up at approximately 029:16:28:55 G.m.t. (06:13:40:40 MET). The structural hooks were activated in the open direction with travel from approximately 92 percent to the nominal 6 percent where the hooks were deactivated. The undocking-complete signal was received at 029:16:56:55 G.m.t. (06:14:08:40 MET), and the ODS was powered down 30 minutes later.

Atmospheric Revitalization Pressure Control Subsystem

The atmospheric revitalization pressure control subsystem (PCS) performed nominally throughout the duration of the flight. After docking with the Mir Space Station and checking the Orbiter/Mir docking system interface, the Mir and Orbiter total pressures were equalized to 13.03 psia. Prior to opening the equalization valves, the Orbiter and ODS volume was pressurized to 14.70 psia. After opening the valves, the Orbiter/Mir volume was pressurized to 14.62 psia, using the Orbiter PCS.

During the vestibule leak check, a large leak in the vestibule was apparent. The crew closed the circuit breakers associated with the vestibule depressurization and depressurization isolation valves to check the configuration and three of the four valves were found open. The crew then closed the valves and performed a nominal leak check. The hatch to the Mir was opened at 024:22:22 G.m.t. (01:19:34 MET). These valves should have been closed during preflight preparations; however, the final procedure did not contain the step to verify that the valves were closed. Procedures will be modified to ensure that these steps are incorporated.

Before undocking, the Orbiter/Mir volume was pressurized to 15.49 psia using Orbiter oxygen. The total consumables transferred to the Mir during the docked phase was

133.4 lbm of nitrogen and 56.4 lbm of oxygen. The nitrogen was used for Mir pressurization, and the oxygen was used for additional crew metabolic consumption during docked operations as well as raising the Mir pressure and PPO₂ prior to undocking. The total pressure before undocking was 15.49 psia and the PPO₂ was 3.98 psia.

Atmospheric Revitalization System

On this first flight of the OV-105 vehicle following the Orbiter Maintenance Down Period (OMDP), the atmospheric revitalization system performed satisfactorily. During the OMDP, the regenerative carbon dioxide removal system (RCRS) was removed from the vehicle and avionics bay 3 had additional ducting incorporated for cooling International Space Station (ISS) payloads. In addition, a new infrared partial pressure carbon dioxide sensor (PPCO₂) was installed and it provided a significantly enhanced response when compared with the sensor flown on the last flight (STS-77) before the OMDP. Both modifications provided results within the expected ranges.

Active Thermal Control Subsystem

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

Radiator flow was initiated approximately 1 hour 30 minutes into the flight, and the payload bay doors were opened approximately 12 minutes after radiator flow was initiated. The flash evaporator system (FES) primary A system was turned off and the FES primary B was turned on at 00:01:31 G.m.t (023:04:19 MET). This allowed the FES to use water from supply tanks C and D and save the water in tanks A and B for Mir water transfer. The port radiator was deployed approximately 15 ½ hours into the mission to help save water for transfer to the Mir. At the completion of the Mir water transfer, the supply tanks were configured back to the nominal on-orbit configuration and the FES was reconfigured to the primary A system.

The radiator cold-soak provided adequate cooling for entry. The radiator started to lose temperature control about 3 minutes prior to landing and two minutes after landing, the configuration was switched to ammonia boiler system (ABS) B and the secondary controller. System B operated for 31 minutes at which time the crew switched to A Primary for 8 minutes. Ground cooling was initiated about 3 minutes later. The radiator cold-soak did not last as long on this flight because of the warmer payload bay temperatures that resulted from the top-to-Sun attitude flown prior to deorbit to support the airlock water line Development Test Objective (DTO).

Supply and Waste Water System

The supply waste water systems performed normally throughout the mission, and all in-flight checkout requirements were met.

Supply water was managed through the use of the flash evaporator system (FES) and the transfer of 1614.9 lb of water to the Mir Space Station. The supply water dump line temperature was maintained between 73.6 °F and 98.4 °F throughout the mission with the operation of the line heater.

Sixteen contingency water containers (CWC's) were filled for the water transfer. The water was de-iodinated as the CWC's were filled. Silver biocide and minerals were added to the potable water transferred, and only silver biocide was added to the technical water transferred.

A newly incorporated medical requirement was established to limit the amount of iodine consumed by the crew to 0.5 mg/day. One set of iodine removal cartridges was used to remove iodine from the crew drinking water and from the water transferred to the Mir Space Station. The crew installed the hardware on orbit to remove the iodine from the water. A microbial check valve (MCV) was installed at the ambient inlet to the galley. The various extra hardware reduced iodine levels to zero in the chilled water and to 1.5 to 2.0 ppm in the ambient hot water.

Humidity condensate was collected in a CWC during the docked phase of the mission. Some condensate samples were also taken prior to docking. The samples were evaluated postflight and the results as well as the samples were used in the development of an electrolyzer for use in the ISS. A decrease in waste water production was observed during the time of sampling. Otherwise, waste water was gathered at the predicted rate. Three waste water dumps were performed at an average rate of 1.98 percent/minute (3.27 lb/min). The waste water dump line temperature was maintained between 53.4 °F and 77.3 °F throughout the mission.

Postlanding data from the zone 1 potable water supply line sensor and the zone 1 liquid cooling garment (LCG) 2 water supply line sensor indicate that the signals may be switched. The possibility exists that a thermostat is mislocated or the potable water line sensor is mislocated. The postflight troubleshooting revealed that the sensors were incorrectly spliced, and the wiring will be corrected in accordance with the blueprints.

Waste Collection Subsystem

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

Airlock Support System

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

After docking with the Mir and during the vestibule leak check, a large leak in the vestibule of the Mir consumables was apparent and the repressurization was stopped. The crew closed the circuit breakers associated with the vestibule depressurization and depressurization isolation valves to check the configuration and found three of the four valves were open. The crew then closed the valves and performed a nominal leak check. The hatch to the Mir was opened at 024:22:22 G.m.t. (01:19:34 MET). During preflight preparations, the valves were closed; however, during the ODS floodlight troubleshooting, the valves were misconfigured. Johnson Space Center (JSC) and KSC procedures are being modified to ensure that these valves are in the closed position.

During preparations to gain access to the Spacehab, the crew reported that they were only able to open the D hatch to a position approximately six inches above the support pads on the floor of the airlock. The crew reported interference from a stowage bag and an air duct from the inlet side of the hard duct in the external airlock (Flight Problem STS-89-V-08). The crew removed the stowage bag pallet and disconnected the air duct

and completed the opening of the hatch. With the hatch properly opened and stowed, the air duct was reinstalled. The airlock is an ISS-configured external airlock that has electrical shrouds below the forward hatch area. This condition causes the air duct 'tee' to be rotated towards the center of the airlock, thus causing the interference.

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-89 mission.

During the countdown, general purpose computer (GPC) 5 was accidentally moded from standby to run instead of placing its output switch to the backup position. As a result, the backup flight system (BFS) assumed control of the payload busses and annunciated two fault messages because the Spacehab module was powered down. Recognizing the erroneous switch operation, GPC 5 was moded back to standby and the GPC was placed in backup. The erroneous switch movement did not affect the remainder of the countdown or the flight performance.

At approximately 023:03:44 G.m.t. (00:00:56 MET), the GPC 3 was reconfigured to a guidance, navigation and control operational sequence 2 (G2) "freeze-dry" GPC. The crew reported that when taking the GPC 3 mode switch from the run to the standby position, there was no detent in the standby position and the switch went into the halt position (Flight Problem STS-89-V-01). A more complete discussion of this anomaly is contained in the Displays and Controls section of this report.

Flight Software

The flight software performed nominally throughout the mission with no in-flight anomalies identified from the review of the data. All software flight objectives were satisfied.

Approximately 9 minutes after landing, the BFS GPC logged an error while processing a square-root computation. The square-root routine contains standard recovery processing, therefore, there were no negative effects on the BFS software. The GPC error occurred about 3 seconds after the PASS was taken to the G9 mode. When the PASS enters this mode, the BFS loses visibility into the flight critical operations. However, the BFS was in Major Mode 305 with guidance and navigation processing still running. Without valid data from the flight critical operations, the computational values are expected to diverge. Because of the sample rate of the data at this time in the mission, it cannot be conclusively proven exactly what occurred. However, the data do show that at the time of the GPC error, the values used in computing vehicle ground-speed were approaching the situation that would result in taking the square root of a negative number. A flight note will be prepared to cover this condition.

Flight Control System

The flight control system performed satisfactorily throughout the mission with two in-flight anomalies identified.

At 027:03:19:11 G.m.t. (04:00:31:56 MET), the reaction jet driver (RJD) forward-2 (F2) F5 remote power controller (RPC) 2 failed off (Flight Problem STS-89-V-04). Shortly after this occurred, vernier thruster F5R was commanded to fire, resulting in an F5R fail-off due to the lack of driver power, and loss of vernier-thruster attitude-control of the mated vehicle. After cycling the vernier driver switch and then turning on the forward reaction jet logic and driver power for the forward primary thrusters, the RJD power was restored. Vernier thruster F5R was re-selected and vernier control of vehicle attitude was re-established. The fail-off of the reaction jet driver RJD F2 is believed to have been caused by a failure in the latch circuit in the forward load control assembly (FLCA) 3. As a result, the RJD F2 logic power switch for forward RCS manifolds 4 and 5 were left on while the Orbiter was docked to the Mir. The troubleshooting of the failed-off RJD F2 F5 RPC 2 was performed following undocking and the orbit-adjust maneuver. The troubleshooting was initiated by taking the RJD F2 logic power switch to off to test the latch with the vernier driver power. Vernier logic power remained on indicating that the latch was not hard failed. The logic power switch was left off during the crew-awake period and taken back to on during the crew-sleep period.

Troubleshooting of the fail-off of the RJD F2 F5 RPC 2 was also performed for flight day 9. As a part of the post-sleep reconfigurations, troubleshooting was initiated by taking the RJD F2 logic power switch to off to test the latch with the vernier driver power. Vernier logic and driver power failed-off about 39 minutes later, repeating the earlier failure. The crew returned the logic power switch to on about a minute later. Since a forward vernier thruster was not commanded to fire during the time that the logic and driver power was off, vernier control was not lost. Further in-flight troubleshooting was terminated, and the logic power switch remained on for the remainder of the mission. Postflight troubleshooting determined that the output of FLCA 3 that turns on the vernier power RPC was experiencing momentary dropouts, which were causing the circuit to unlatch. This FLCA was replaced with a spare unit.

At approximately 028:07:38 G.m.t. (05:04:50 MET), the -Z star tracker annunciated a pressure-fail BITE (Flight Problem STS-89-V-06). The BITE remained on for the remainder of the mission. The star tracker is normally pressurized with argon gas to 17.58 psia to prevent moisture and contamination from entering the star tracker during entry and ground operations. The BITE indicates that the -Z star tracker pressure has leaked below 14.7 psia. There was no impact to flight operations. The star tracker was replaced during ground turnaround operations at KSC.

The inertial measurement unit (IMU) performance was satisfactory throughout the flight. On-orbit, only one accelerometer compensation was required for each unit and this reflects nominal operation. In addition, two of the IMUs required one drift compensation adjustment and this also is nominal operation.

Following the RCS hot-fire, the flight control system (FCS) checkout was performed using APU 1. The FCS performed nominally during the checkout.

Displays and Controls Subsystem

The displays and controls operated satisfactorily with the exception of the issues that are discussed in the following paragraph.

At approximately 023:03:44 G.m.t. (00:00:56 MET), GPC 3 was reconfigured to a guidance, navigation and control operational sequence 2 (G2) "freeze-dry" GPC. The crew reported that when taking the GPC 3 mode switch from the run to the standby

position, there was no detent in the standby position and the switch went into the halt position (Flight Problem STS-89-V-01). Subsequent mode switch changes confirmed that the freeze-dry procedure had failed because GPC put-away processing was not completed when the mode switch was inadvertently taken to halt. On flight day 2, a hardware initiated stand alone memory (HISAM) dump of the GPC 3 software was performed. Analysis of the dump revealed no GPC hardware failures or primary avionics software system (PASS) problem. GPC 3 was successfully initial program loaded (IPL'ed), moded to run, and added to the redundant set, in which it was running G2 software with GPCs 1 and 2. GPC 2 was subsequently configured as a G2 "freeze-dry" GPC. The GPC 3 mode switch was kept in the run position for the remainder of the mission. During postflight troubleshooting, panel 06 was removed and sent to the NSLD for switch replacement.

The forward starboard floodlight (no. 2) and the mid-port floodlight (no. 3) both failed to illuminate when the crew activated the switch at 031:18:37 G.m.t. (08:15:48 MET). A data review of the mid-power controller assembly main bus B currents for each indicated a 13.6 ampere current draw for 2.2 seconds before returning to the original value. This condition is indicative of an RPC trip. Both floodlights operated satisfactorily when the payload bay doors were opened. Both floodlights are of the new design. During postflight turnaround activities, the problem was found in the floodlight electronics assemblies (FEAs), which were removed and sent to the NSLD for ballast replacement.

Communications and Tracking Subsystems

The communications and tracking subsystems performed satisfactorily throughout the mission. One in-flight anomaly was identified concerning the S-band antenna switching under GPC control. Also, two minor closed circuit television problems occurred and these are discussed in the Government Furnished Equipment/Flight Crew Equipment section of this report.

At approximately 023:03:38 G.m.t. (00:00:50 MET), the backup flight system (BFS) general purpose computer (GPC) was commanding the lower left forward (LLF) S-band antenna, but the upper left forward (ULF) antenna was being selected (Flight Problem STS-89-V-07). At the time, the S-band antenna switch electronics system 2 was being used. After the systems management (SM) GPC was configured and the BFS was taken down, the ULF antenna continued to be selected although the SM GPC was commanding the LLF antenna. The ground controllers subsequently commanded the LLF antenna, but still the ULF antenna was selected. At 023:04:02 G.m.t (00:01:14 MET), the S-band antenna switch electronics system 1 was selected as well as the LLF antenna, and nominal operation was noted. System 2 was reselected for a short time to perform troubleshooting. The crew used the antenna-select panel switch to select each of the eight S-band antennas, and normal operation was noted in all positions. Following this troubleshooting, system 1 was reselected. On flight day 4, system 2 was selected a second time to perform additional troubleshooting to evaluate the capabilities of the GPC to control antenna switching. Again, all operations were nominal. The GPC mode of antenna selection was verified utilizing a multiple stored-program-command to cycle through the switch positions, and no anomalies were noted. Following this troubleshooting, system 1 was reselected. On flight day 7, system 2 was selected again for troubleshooting. Testing of the S-band antenna-switch electronics was performed by selecting the system 2 unit for one orbit. Again, no anomalies were noted. Troubleshooting of the S-band antenna-switch electronics system 2 was again performed on flight day 8 by selecting the system 2 unit for several orbits. All of the GPC commanding was performed properly without repeating the original anomaly.

System 1 was reselected for the crew-sleep period and used for the remainder of the mission.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation and modular auxiliary data system (MADS) operated satisfactorily throughout the mission. No in-flight anomalies were noted in these systems.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. No in-flight anomalies were noted in the review of the data and inspection of the hardware. The landing and braking parameters for the mission are shown in the following table.

LANDING AND BRAKING PARAMETERS

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

STS-89 was the first flight of the OV-105 vehicle since it completed the OMDP. As a result, each of the payload bay doors was initially driven open for approximately 15 seconds and then reclosed before being opened fully. The door-opening sequence was completed at 023:04:36:24 G.m.t. (00:01:48:09 MET) in nominal dual-motor operating time.

The payload bay doors were closed and latched for landing at 031:18:54:02 G.m.t. (08:16:05:47 MET).

The postlanding inspection revealed that the tires were in excellent condition for a landing on the KSC concrete runway. The tires exhibited no signs of ply undercutting or other damage from the landing.

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

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 performed satisfactorily throughout the mission, and no in-flight anomalies were noted. All three heater systems on the newly installed airlock water lines cycled nominally. Likewise, the two structural heater systems on the external airlock cycled nominally.

Two periods when attitude control was lost because of the vernier thrusters being deselected did not cause any thermal problems or concerns because attitude control was regained. The cause of the loss of attitude control is discussed in the Reaction Control Subsystem section of this report.

Aerothermodynamics

The boundary layer transition was symmetrical and MADS data showed boundary layer transition from laminar to turbulent flow occurred at Mach 6.8 and 1291 seconds after entry interface. Acreage heating was normal, and all temperatures were within certification limits. Also, local heating was normal overall. A slight slumping of the elevon gap ablator tiles was noted, and it was attributed to the accumulated effects of past flights.

Thermal Protection Subsystem and Windows

The thermal protection subsystem (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was normal based on structural temperature rise data. MADS data showed transition to occurred later than average at 1300 seconds after entry interface and it was symmetric.

The Orbiter TPS sustained a total of 138 hits (damage sites) of which 40 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

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	38	95
Upper Surface	0	1
Right Side	1	7
Left Side	1	3
Right OMS Pod	0	5
Left OMS Pod	0	6
Window Area	0	21
Total	40	138

Based on data from the postflight debris inspection team reports as well as the comparison with statistics from 72 previous flights of similar configuration, the total number of damage sites was slightly greater than average, and the number of damage sites that was 1 inch or larger was significantly greater than average.

Most of the lower surface damage was concentrated near the outboard edges in a line generally running from the nose landing gear to the main landing gear. The damage sites follow the same location pattern that was documented on STS-86 and STS-87. Although the number of damage sites were greater than the fleet averages for the lower surface, the quantity, sizes, and depths of the damage sites were substantially less than STS-87.

COMPARISON OF DAMAGE SITE DATA FROM PREVIOUS THREE FLIGHTS

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

The initial evaluation indicates that no lower surface tiles will be scrapped. The largest lower surface tile damage site was located on the right inboard elevon. The site measured 4 inches in length by 1 inch in width by 0.2 inch deep, and the damage was most likely caused by an impact from ET/Orbiter umbilical ice. The deepest lower surface tile damage site, which was 0.5 inch, was located aft of the ET/Orbiter umbilicals on the body flap and was probably also associated with an ice impact.

Tile damage sites around and immediately aft of the LH₂ and LO₂ ET/Orbiter umbilicals were less than usual. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the air-stream.

More than usual tile damage occurred on the base heat shield. The damage sites were located just forward of SSME 2 and 3 with approximately 30 areas larger than 1-inch. Most of the sites exhibited loss of tile surface coating material, and at least nine of the sites had estimated depths of 0.25 inch. The damage sites appeared to be caused by vibration/acoustics rather than debris impacts.

The SSME 2 and 3 dome mounted heat shield (DMHS) closeout blankets were in good condition. However, the blanket panels on SSME 1 were torn/frayed at the 5:00 and 7:00 o'clock positions.

No unusual tile damage occurred on the leading edges of the vertical stabilizer and OMS pods. Most of the tile damage on the OMS pods was attributed to old surface coating material that had flaked off. Three protruding gap fillers were also noted.

Hazing and streaking of the forward-facing Orbiter windows was less than usual. The 21 small damage sites on the window perimeter tiles were less than usual in quantity and size. The larger damage sites were attributed to old material falling out and were not included in this assessment. The underlying strain isolation pad (SIP) was visible in two damage sites around window 3 and at one site around window 2, where the perimeter tile meets the glass, but there was no residue or streak nearby on the glass, which would indicate a debris impact.

The postlanding walkdown of runway 15 was performed immediately after landing and no debris concerns were noted. All drag chute hardware was recovered and appeared to have functioned normally. The two pyrotechnic devices on the reefing line cutters had been expended.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

Overall, the Government furnished equipment/flight crew equipment (GFE/FCE) performed nominally throughout the mission. Two minor problems occurred with the closed circuit television (CCTV) cameras; however, these problems did not impact the mission.

Closed circuit television camera B was unable to control the iris when in any automatic light control (ALC) mode. The iris opened fully, but the ALC logic did not adjust the iris for incoming light. The iris properly responded when in the manual mode which has a fixed iris position. Power cycling of the camera did not correct the problem. Postflight testing of the camera will be performed

CCTV camera D exhibited a bluish tint, and appears to have lost its red component. The camera was power cycled and its settings were varied in an unsuccessful attempt to clear the problem. The ground compensated for the loss of the red component. Postflight troubleshooting of the camera will be performed.

CARGO INTEGRATION

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

**DEVELOPMENTAL TEST OBJECTIVES/DETAILED SUPPLEMENTARY
OBJECTIVES**

DEVELOPMENT TEST OBJECTIVES

DTO 119 - Airlock External Waterline Thermal Data - Development test objective (DTO) 119, the test to obtain temperature and pressure data for the airlock external water lines, was successfully completed after undocking. Ten hours of an attitude with the top of the Orbiter facing the Sun were flown to obtain these data. The maximum pressure reached on the liquid cooling garment (LCG) lines was 6 psig, and the maximum temperature on the lines was 157 °F. No limits were violated during this attitude test.

A momentary pressure drop occurred in both external airlock LCG water lines about 3.5 hours into the performance of DTO 119. The system 1 pressure was 2.57 psig and it decreased to 2.09 psig. System 2 pressure was 4.01 psig and it decreased to 3.54 psig. The pressure drop in each line lasted for about two seconds and then pressures returned to the previous levels. Data evaluation did not indicate any leakage that may have caused the pressure drop, because the pressure recovered after about 30 seconds. Other possible causes are that a kink in the water line may have reshaped, or a crew member may have inadvertently moved the service and cooling umbilical (SCU) line, or a coiled SCU line may have uncoiled. As a result of the evaluation, the exact cause could not be determined and it does not appear to be a problem.

DTO 258 - Shuttle Proximity Operations with One Nose X Thruster - The reaction control subsystem (RCS) thruster F3F was used to perform this DTO for reduced plume impingement on the Mir Space Station, and in preparation for docking operations with the International Space Station (ISS). The performance of this DTO provided operational experience for piloting technique, docking contact conditions, procedures development and training for ISS assembly flights. This DTO demonstrated the Shuttle final approach to the Mir on the R-Bar axis using only the F3F (X-axis) thruster for translation and with the vehicle in the nose-forward attitude. Preliminary indications are that the DTO was successful. The results will be published in separate documentation.

DTO 312 - External Tank Thermal Protection System Performance - Thirty seven images of the ET were acquired using the 35 mm Nikon camera with a 400 mm lens. Exposure and focus were good. On many of the images, most of the ET is in shadow because of the Sun angle. Views of the sides, nose, and at dome of the ET were acquired. No venting from the ET was observed. The average tumble rate was estimated to be approximately 12 deg/sec. The normal SRB separation burn scars and aerodynamic-heating marks were noted on the TPS.

The ET was estimated to be 4 to 5 km from the Orbiter in the first picture. This greater than normal distance between the Orbiter and the ET (because of the terminator) resulted in the minimum resolvable object size on the ET being between 15 and 20 inches under ideal conditions, and this size hindered the analysis of the photography. The first picture was taken 31 minutes 11 second after liftoff.

Two rolls of 16 mm umbilical well camera film were also received from the cameras located in the LH₂ umbilical well. The 35 mm film from the LO₂ umbilical well was unusable because of the darkness and it was not printed.

The left SRB separation appeared normal on the umbilical well films. Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably charred insulation) were seen throughout the SRB separation sequence. Typical ablation and charring of the ET/Orbiter LH₂ umbilical electric cable tray and the aft surface of the -Y upper strut fairing was observed prior to SRB separation. Numerous pieces of irregular shaped debris were noted near the base of the left SRB electric cable tray prior to SRB separation. Normal blistering of the fire barrier material on the outboard side of the LH₂ umbilical was seen. Ablation of the TPS on the aft dome was normal.

DTO 700-11 - Orbiter Space Vision System Flight Unit Testing - The Orbiter Space Vision System (OSVS) survey verification procedures were completed as planned, but the roll characterization procedure was not completed because of problems in receiving the correct vertical interval telemetry from the Orbiter camera B. An in-flight maintenance (IFM) procedure was performed in which a spare OSVS keyboard was connected to a different payload and general support computer (PGSC). The entire OSVS checkout was performed using both cameras B and C. The performance was nominal with both cameras and consistent with previous ground checkout results.

DTO 700-14 - Single String Global Positioning System - The single string Global Positioning System (GPS) performance was highly successful for this mission. The miniature airborne GPS receiver-Shuttle (MAGR-S) performance was excellent. Data were successfully recorded on the dedicated PGSC, with only one single event upset noted during the mission.

On previous flights, the MAGR-S required periodic (approximately once per day) initializations and state vector updates. A problem was found in the software was isolated and corrected. As a result, no initializations occurred during the mission.

During entry, an anomaly was noted when several periods of unusually high geometric dilution of precision (GDOP) occurred with correspondingly high figures of merit (FOM) values. This condition can result in slightly degraded MAGR-S performance as the condition was caused, at least in part, by the MAGR-S tracking a less-than-optimum set of satellites. The end result of high GDOP is that MAGR-S may output a degraded state vector to the navigation system, or at least the MAGR-S indicates that the output state vector may be degraded. This condition existed for 6.5 minutes at one point during entry.

Initial analysis indicates that this phenomenon can occur during or following extended periods of satellite blackout, as during the "plasma" region of entry. However, the condition is only temporary and quickly recovers following blackout, with more than adequate time to spare before the MAGR-S state vector data are required.

STS-89 was the last flight of the MAGR-S interacting with only the backup flight system (BFS). An upgraded version (MAGR-S3S) is planned for future flights, and it will interact with the primary avionics software system (PASS) for the entire mission. This will lead to three-string GPS operation and replacement of the Tactical Air Navigation (TACAN) equipment.

DTO 700-15 - Space Integrated Global Positioning System/Inertial Navigation System - The Space Integrated Global Positioning System/Inertial Navigation System (SIGI) ascent data indicates much better navigation performance than STS-86; however, the inertial navigation system (INS) had unacceptable state vector drift. This condition occurred not only during ascent but throughout the mission. As an example, INS data from the ten on-orbit data takes showed differences as great as 4.5 million meters and 5300 meters/second from the GPS and blended solutions.

Overall, the blended and GPS solutions [position, velocity, and attitude (blended only)] agreed very well with each other while the SIGI was operating properly. The INS attitude performance agreed with the blended and general purpose compute (GPC) attitudes. When the GPC state vector was updated, the GPC state vector was comparable to the blended and GPS state vectors, indicating that the blended and GPS state vectors were consistent with the "truth". However, the INS position and velocity drift were significantly worse than the GPC performance.

DTO 805 - Crosswind Landing Performance - The Crosswind Landing Performance DTO was a DTO of opportunity. No data were collected as the crosswinds at landing were not of sufficient magnitude to meet the minimum requirements of this DTO.

DTO 914 - Space Linear Acceleration Mass Measurement Device - The Space Linear Acceleration Mass Measurement Device (SLAMMD) data were collected for all planned runs. The initial in-flight evaluation showed the data to be consistent with other data from this equipment. The final evaluation results will be provided in separate documentation.

DTO 1118 - Photography and Video Survey of Mir Space Station - All planned photographic and video opportunities were completed of the exterior of the Mir Space Station. The evaluation results from a review of the films and video will be provided in a separate document.

DTO 1125 - Measurement of Dose as a Function of Shielding Thickness (MDFST) - The blue and green spectrometer lock-ups and self resets occurred numerous times during the mission, but nominal operations were recovered each time and the science data were not impacted. The hardware for this DTO was located in the Spacehab module. The results of the data analysis will be reported in separate documentation.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 334 - In-Flight Evaluation of Telemedicine Instrumentation Pack - The in-flight evaluation of the telemedicine instrumentation pack (TIP) was successfully completed and all data files were downlinked, using the Orbiter Communications Adapter (OCA), to ground personnel for evaluation. The results of the evaluation will be published in separate documentation after the documentation is released.

DSO 496 - Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance - All planned activities were completed after landing. The results of this Detailed Supplementary Objective (DSO) will be published in separate documentation.

DSO 497 - Effects of Microgravity on Cell Mediated Immunity and Reactivation of Latent Viral Infections - All of the planned activities for this DSO were completed. The results of this DSO will be published in separate documentation.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

The launch photography consisted of video tapes from 24 video cameras and twenty films from 16-mm and 35-mm cameras. No anomalous events were noted in the review of the films.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Video of the OMS pod was sent down to the ground at approximately 5 hours MET. The video showed that the OMS pod was free of damage.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Twelve videos of landing were evaluated and no anomalous events were noted in any of the films.

TABLE I.- STS-86 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	023:02:43:27.878 023:02:43:28.772 023:02:43:29.524
SRB HPU Activation ^a	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	023:02:47:47.097 023:02:47:47.257 023:02:47:47.417 023:02:47:47.577
Main Propulsion System Start ^a	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	023:02:48:08.458 023:02:48:08.577 023:02:48:08.708
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	023:02:48:15.017
Throttle up to 104.5 Percent Thrust ^a	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	023:02:48:19.259 023:02:48:19.262 023:02:48:19.268
Throttle down to 67 Percent Thrust ^a	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	023:02:48:43.260 023:02:48:43.262 023:02:48:43.268
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	023:02:49:06
Throttle up to 104.5 Percent Thrust	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	023:02:49:11.900 023:02:49:11.903 023:02:49:11.909
Both RSRM's Chamber Pressure at 50 psi ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	023:02:50:12.857 023:02:50:13.777
End RSRM ^a Action ^a Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	023:02:50:15.267 023:02:50:16.557
SRB Physical Separation ^a	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	023:02:50:18.337 023:02:50:18.337
SRB Separation Command	SRB separation command flag	023:02:50:19
Throttle Down for 3g Acceleration ^a	ME-2 command accepted ME-3 command accepted ME-1 command accepted	023:02:55:41.184 023:02:55:41.190 023:02:55:41.197
3g Acceleration	Total load factor	023:02:56:27.3
Throttle Down to 67 Percent Thrust ^a	ME-2 command accepted ME-3 command accepted ME-1 command accepted	023:02:56:37.825 023:02:56:37.831 023:02:56:37.838
SSME Shutdown ^a	ME-2 command accepted ME-3 command accepted ME-1 command accepted	023:02:56:44.105 023:02:56:44.111 023:02:56:44.118
MECO	MECO command flag MECO confirm flag	023:02:56:45 023:02:56:46
ET Separation	ET separation command flag	023:02:57:04

^aMSFC supplied data

**TABLE I.- STS-89 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	023:03:04:36.108 023:03:04:44.353 023:02:04:57.349
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	023:03:30:03.5 023:03:30:03.6
OMS-2 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	023:03:32:17.0 023:03:32:17.1
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	023:04:32:36 023:04:36:24
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	023:06:37:22.5 023:06:37:22.6
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	023:06:37:57.5 023:06:37:57.6
OMS-4 Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	023:18:03:13.2 023:18:03:13.3
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	023:18:03:58.9 023:18:03:59.0
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 024:16:19:10.2
OMS-5 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 024:16:19:20.4
OMS-6 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	024:17:51:24.3 N/A
OMS-6 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	024:17:51:35.5 N/A
Ring Capture	Capture	024:20:14:21
Docking	Docking ring final position	024:20:22:31
Undocking	Undocking complete	029:16:56:56
OMS-7 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	029:23:32:03.7 N/A
OMS-7 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	029:23:25:26.3 N/A
Flight Control System Checkout Circulation Pump Start Circulation Pump Stop	APU 1 GG chamber pressure APU 1 GG chamber pressure	030:15:25:30.127 030:15:31.11.511
OMS-8 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 030:21:50:22.2
OMS-8 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 030:21:50:32.4
Payload Bay Door Closure	PLBD left close 1 PLBD right close 1	031:18:50:44 031:18:52:59
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	031:21:22:40.100 031:21:50:43.748 031:21:50:45.277

**TABLE I.- STS-86 SEQUENCE OF EVENTS
(Concluded)**

Event	Description	Actual time, G.m.t.
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	031:21:27:55.1 031:21:27:55.2
Deorbit Burn Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	031:21:31:20.4 031:21:31:20.5
Entry Interface (400K feet)	Current orbital altitude above	031:22:03:35
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	031:22:28:43
Main Landing Gear Contact	LH MLG inboard tire pressure 2 RH MLG outboard tire pressure 2	031:22:35:10 031:22:35:10
Main Landing Gear Weight on Wheels	RH main landing gear weight on wheels LH main landing gear weight on wheels	031:22:35:10 031:22:35:10
Drag Chute Deployment	Drag chute deploy 1 CP volts	031:22:35:12.8
Nose Landing Gear Contact	NLG RH tire pressure 1	031:22:35:20
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	031:22:35:21
Drag Chute Jettison	Drag chute jettison 1 CP Volts	031:22:35:53.3
Wheel Stop	Velocity with respect to runway	031:22:36:21
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	031:22:51:57.029 031:22:52:04.092 031:22:52:11.034

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

No.	Title	Reference	Comments
STS-89-V-07 (Continued)	S-Band Antenna Switch Electronics System 2 Failure (Continued)	023:03:38 G.m.t. 00:00:50 Met CAR 89RF07 IPR 88V-0012	<p>switch electronics system 1 was selected and the LLF antenna was selected.</p> <p>On flight day 2, antenna switch electronics system 2 was reselected for a short time to perform troubleshooting. The crew used the panel switch to select all eight S-band antennas. No anomalies were noted. Following the troubleshooting, system 1 was reselected. On flight day 4, the system was again reselected for a short time for additional troubleshooting. The GPC mode of antenna selection was verified using a multiple stored command (MSC) to cycle through the switch positions. Again, no anomalies were noted. Following this troubleshooting, system 1 was reselected. For further troubleshooting in the GPC mode, system 2 was reselected for one orbit on flight day 7 and several orbits on flight day 8 and again, no problems were noted.</p> <p>KSC: Troubleshooting will be performed.</p>
STS-89-V-08	D Hatch Interference with Air Duct	023:05:30 G.m.t. 00:02:42 Met	<p>After removing the airlock floor stowage bag, the crew reported that they were only able to open the D hatch to a position approximately 6 inches above the support pads on the floor of the airlock. The crew reported interference with the forward portion of the D hatch that would not allow the hatch to rest on the support pads. The crew reported that they removed the stowage bag pallet and disconnected the air duct from the inlet side of the hard duct in the external airlock. The crew were then able to complete the opening of the hatch. With the hatch in the proper position, the crew reinstalled the air duct.</p> <p>The airlock is an International Space Station configured external airlock which has electrical shrouds below the forward hatch area that cause the air duct 'tee' to be rotated towards the center of the airlock. In the OV-104 configuration, the electrical shrouds were not installed and the 'tee' was parallel to the airlock wall.</p> <p>The D hatch was checked in the building 9A trainer and the hatch could not be opened fully because of duct interference. Also, the hatch could not be closed without removing the air duct. The air duct was installed per a crew preference request. The air duct was not in place for the CEIT or during MVAK operations, and this is the reason that the interference was not discovered previously. The Orbiter contractor reported that the next time this interference was show up would be on STS-88. The EVA configuration could cause a similar interference. A technical order has been prepared to document the need to demate the fan package duct at the airlock tee location prior to aft hatch opening or closing. Crew procedures are being developed and will be in place for the STS-88 mission.</p>

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

No.	Title	Reference	Comments
STS-89-V-05	Right RCS Fuel Helium Isolation Valve B Failed to Open	027:13:47 G.m.t. 04:10:59 MET CAR 89RF06 IPR 88V-0005	<p>During the planned RCS regulator reconfiguration, the right RCS fuel helium isolation valve B failed to open. The valve position indicator (VPI) telemetry indicated that the valve did not move (close VPI stayed on and the open VPI stayed off). The crew reported the barber pole talkback. The right RCS helium pressure B switch was cycled from open to close and back to the open position. The fuel helium isolation valve B still did not open. The switch was then taken to close and the right RCS was returned to the A regulators (right RCS helium pressure A switch was taken to open).</p> <p>A similar problem with this valve (LV301) occurred during the STS-75 processing flow when the valve did not indicate closed after being commanded closed. After 2.5 minutes of applying the closed command, the valve finally indicated closed. Extensive troubleshooting over several subsequent flows could not reproduce the problem, and it was closed as an unresolved anomaly (UA) with the most probable cause being the VPI. During entry, the crew switched the right RCS helium A and B isolation valves to manual open. The B indicator showed a 'barberpole', and the B leg was switched to GPC. The B valve open position indication remained off following the switch positioning, and the closed indication remained on. This condition was present throughout entry.</p> <p>KSC: Troubleshooting found the valve to be hard closed. The Orbiter/Pod connector demate/vehicle troubleshooting found an open circuit at the B-coil on the pod side. The connector saver was removed and the test was repeated at the Orbiter/Pod interface connector. The open circuit was found there also. The Y-web and access door 56-44 was removed to allow resistance testing of the intermediate connector/electrical wiring. The open circuit was found again. The pod was removed, and continuity checks will be performed at the HMF on the pod wiring prior to committing to a valve replacement.</p>
STS-89-V-06	-Z Star Tracker Pressure Fail BITE	028:07:38 G.m.t. 05:04:50 MET CAR 89RF03 PR GNC-5-13-0088	<p>At approximately 028:07:38 G.m.t. (05:04:50 MET), the -Z star tracker announced a pressure fail BITE. The BITE remained on for the rest of the flight. The star tracker is normally pressurized with argon gas to 17.58 psia to prevent moisture and contamination from entering the start tracker during entry and ground operations. The BITE indicates that the -Z star tracker pressure has leaked below 14.7 psia. This condition did not impact normal flight operations.</p> <p>The star tracked had to be repressurized during the STS-89 flow.</p> <p>KSC: Troubleshooting of the star tracker was performed, and removal and replacement of the hardware was completed in the mid-March time period.</p>
STS-89-V-07	S-Band Antenna Switch Electronics System 2 Failure	023:03:38 G.m.t. 00:00:50 Met CAR 89RF07 IPR 88V-0012	<p>At approximately 023:03:38 G.m.t. (00:00:50 MET), the BFS GPC was commanding the lower left forward (LLF) S-band antenna, but the upper left forward (ULF) antenna was being selected. At the time, the S-band antenna switch electronics system 2 was being used. After the SM GPC was configured and the BFS was taken down, the ULF antenna continued to be selected although the SM GPC was commanding the LLF antenna. The ground subsequently commanded the LLF antenna, but still the ULF antenna was selected. AT 023:04:02 G.m.t. (00:01:14 MET), antenna</p>

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

No.	Title	Reference	Comments
STS-89-V-03 (Continued)	RCS Vernier Thruster L5D Oxidizer Temperature Erratic (Continued)	026:03:19 G.m.t. 03:00:01 MET CAR 89RF02 IPR 88V-0004 (Continued)	<p>the 75 °F to 125 °F range until approximately 026:06:07 G.m.t. (03:03:19 MET) when it recovered. It subsequently failed again at 026:11:30 G.m.t. (03:08:42 MET) and then failed and recovered several times during the remainder of the mission. When the failure initially occurred, attitude control of the Orbiter/Mir stack was passed to the Mir. Due to Mir propellant concerns, attitude control was passed back to the Orbiter at approximately 026:07:48 G.m.t. (03:05:00 MET). Note that TDRS-Z had been brought up to provide complete orbit coverage so that vernier leak detection could be performed by the ground.</p> <p>To recover partial leak detection capability for the vernier thrusters using the fuel injector temperatures, a GPC memory (GMEM) write procedure was developed and uplinked to change the oxidizer injector temperature leak detection limit of all vernier thrusters from 130 °F to off-scale low. A BITE 4 read test of MDM FA1 was performed with nominal results. This same anomaly occurred on STS-68 (OV-105/7) and STS-67 (OV-105/8). Extensive troubleshooting was not able to duplicate or isolate the anomaly. The thruster was removed and replaced after STS-68.</p> <p>KSC: A non-invasive troubleshooting plan has been developed. An inspection of the vehicle/thruster connector has been scheduled. After wiggle tests of the connector, the vehicle connector sockets pertaining to the temperature measurement were pulled and replaced. Failure analysis of the removed sockets will be performed. A pre-approved GMEM will be available prior to the next flight of the OV-105 vehicle.</p>
STS-89-V-04	RCS Vernier Driver F5 RPC 2 Failed Off.	027:02:06 G.m.t. 03:23:18 MET CAR 89RF05 IPR 88V-0006	<p>At 027:02:06 G.m.t. (03:23:18 MET), reaction jet driver forward-2 (RJDF2) F5 RPC 2 failed off. Shortly after this happened, RCS thruster F5R was commanded to fire, resulting in an F5R fail off due to the lack of driver power and loss of vernier thruster attitude control of the mated vehicle. After cycling the vernier driver switch and then turning on the forward reaction jet logic and driver power for the forward thrusters, RJDF2 F2 RPC 2 power was restored. Vernier thruster F5R1 was reselected and vernier control of the mated vehicle attitude was re-established. The fail-off of the RJDF2 F5 RPC 2 is believed to have been caused by a failure in the latch circuit in the forward load control assembly 3. As a result, the RJDF2 logic power switch for forward RCS manifolds 4 and 5 remained on while the Orbiter was docked with the Mir. In troubleshooting this failure following undocking, the RJDF2 logic power switch was taken to off to test the latch with the vernier driver power. Vernier logic power remained on indicating that the latch was not hard failed. The logic power switch was left off during the crew awake period and taken back to on during the crew sleep period. On flight day 9, the forward manifold 5 logic and driver power experienced another dropout. The logic switch had been off about 39 minutes before the logic power dropout. The logic switch was taken back to on approximately 1 minute after the dropout, prior to getting a forward vernier firing.</p> <p>KSC: Troubleshooting isolated the problem to the forward LCA no. 3 output. The hardware replacement was completed.</p>

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

No.	Title	Reference	Comments
STS-89-V-01	GPC 3 Mode Switch Standby Detent Failure	023:03:44 G.m.t. 00:00:56 MET 89RF01 IPR 88V-0003	<p>At approximately 023:03:44 G.m.t. (00:00:56 MET), the crew configured GPC 3 as a G2 "freeze dry" GPC. The crew reported that when taking the GPC 3 mode switch from the run to the standby position, there was no detent in the standby position and the switch went into the halt position. Subsequent mode switch changes confirmed that the freeze dry procedure had failed because GPC put-away processing was not completed when the mode switch was inadvertently taken to halt. Jiggling the switch seemed to provide sporadic contact in the standby position.</p> <p>On flight day 2, a HISAM dump of GPC 3 was performed. GPC 3 was then successfully IPL'ed and put into the G2 redundant set. The GPC 3 mode switch was placed in the run position for the remainder of the mission. A broken detent spring, which results in loss of detent in the standby and halt positions, is the most likely cause of the anomaly. A lever-lock bushing holds the switch in the run position.</p> <p>KSC: Troubleshooting of the switch operation was completed, and the switch replacement will be performed at the NASA Shuttle Logistics Depot (NSLD). A failure analysis will be performed on the switch after it has been removed.</p>
STS-89-V-02	MPS LH ₂ 4-inch Disconnect Failed to Pneumatically Close	023:02:56 G.m.t. 00:00:08 MET CAR 89RF04 IPR 88V-0002	<p>Data review indicates that following SSME shutdown, the LH₂ 4-inch disconnect failed to pneumatically close within the required time. The actual closing time was 11.75 seconds signal-to-switch compared to the OMRSD File IX requirement of 2.8 seconds maximum (typical times are about 1.7 seconds). The disconnect is commanded closed shortly after MECO. The open indicator was not lost until approximately 11.5 seconds later. This coincides with Orbiter umbilical retraction which occurs at 11.4 seconds after the MECO command. It appears that the disconnect closed mechanically in the backup mode as the Orbiter umbilical plate separated from the ET umbilical.</p> <p>The disconnect was replaced during the STS-89 flow as part of the recycle program to eliminate 4-inch disconnects with chrome flaking problems. Possible explanations include failure in the pneumatic system to provide closing pressure to the actuator (a solenoid or electrical wiring problem) or mechanical binding/ficing within the disconnect pair. This anomaly did not impact the mission.</p> <p>Postflying video revealed the LH₂ 4-inch actuator to be fully retracted. Also, video showed the flapper seal cracked which was the result of the mechanical closing of the valve.</p> <p>KSC: During troubleshooting, signature traces were taken and the data review showed no problems. NSLD has realigned the sector gear as it was slightly out of alignment. The valve was removed and replaced.</p>
STS-89-V-03	RCS Vernier Thruster L5D Oxidizer Temperature Erratic	026:03:19 G.m.t. 03:00:01 MET CAR 89RF02 IPR 88V-0004	<p>At approximately 026:03:19 G.m.t. (03:00:31MET), the oxidizer injector temperature on RCS vernier thruster L5D began to behave erratically. The indicated temperature rapidly decreased to below the 130 °F leak detection limit and this resulted in the automatic deselection of L5D by the RM. A review of the data confirmed that the erratic temperature indication was an instrumentation problem and not an actual oxidizer leak. The indicated oxidizer injector temperature remained offset low in</p>

DOCUMENT SOURCES

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

1. Flight Requirements Document
2. Public Affairs Press Kit
3. Customer Support Room (CSR) Daily Science Reports, and Final CSR Report
4. Mission Evaluation Room (MER) Daily Reports
5. MER Landing Report
6. MER Problem Tracking List
7. MER Event Times
8. Subsystem Manager Reports/Inputs
9. MOD Systems Anomaly List
10. MSFC Flash Report
11. MSFC Event Times
12. MSFC Interim Report
13. Crew Debriefing comments
14. Shuttle Operational Data Book
15. STS-89 Summary of Significant Events
16. Contractor Reports of Subsystem Operation
17. SSVEO In-Flight Anomaly Lists

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
ADV ASC	Advanced Astroculture
ADV XDT	Advanced X-Ray Detector
ALC	automatic light control
APU	auxiliary power unit
AST	Astroculture
ATCS	active thermal control system
BBND	Bonner Bell Neutron Detector
BFS	backup flight system
BIO 3D BTR	Biochemistry of Three Dimensional Tissue Biotechnology Refrigerator
BITE	built-in test equipment
CCTV	closed circuit television
CEBAS	closed Equilibrated Biological Aquatic System
CEI	contract end item
c.g.	center of gravity
CGBA	Commercial Generic Bioprocessing Apparatus
COCULT	Coculture
CPM	cell performance monitor
CREAM	Cosmic Radiation Effect and Activation Monitor
CWC	contingency water container
dBm	decibel/meter
DMHS	dome-mounted heat shield
DNA	deoxyribonucleic acid
DRU	Data Recording Unit
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔV	differential velocity
ECLSS	Environmental Control and Life Support System
EDLS	Enhanced Dynamic Load Sensors
EO	ET/Orbiter
EORF	Enhanced Orbiter Refrigerator/Freezer
EPDC	electrical power distribution and control
EPOS/EPS	European Proximity Operations Sensor
ESC	electronic still camera
e.s.t.	eastern standard time
ET	External Tank
EVA	extravehicular activity
FCE	flight crew equipment
FCMS	fuel cell monitoring system
FCS	flight control system
FEA	floodlight electronic assembly
FES	flash evaporator system
FLCA	forward load control assembly
FOM	figure of merit

ft/sec	feet per second
F2	forward 2 (location)
g	gravity
GAS	Get-Away Special
GDOP	geometric dilution of precision
GFE	Government furnished equipment
GGVM	gas generator valve module
GMEM	GPC memory
G.m.t.	Greenwich mean time
GN ₂	gaseous nitrogen
GO ₂	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
HISAM	hardware initiated stand alone memory
HP	human performance
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
ICD	Interface Control Document
IFM	in-flight maintenance
IMU	inertial measurement unit
INS	inertial navigation system
IPL	initial program load
IRD	integrated receiver decoder
I_{sp}	specific impulse
ISS	International Space Station
JSC	Johnson Space Center
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lb	pound
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LCG	liquid cooling garment
LH ₂	liquid hydrogen
LLF	lower left forward (antenna)
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO ₂	liquid oxygen
MADS	Modular Auxiliary Data System
MAGR-s	miniature airborne GPS receiver-Shuttle
MCC	Mission Control Center
MCV	microbial check valve
MDFST	Measurement of Dose as a Function of Shielding Thickness Experiment
MECO	main engine cutoff
MET	mission elapsed time
MGM	Mechanics of Granular Material
MiSDE	Mir Structural Dynamics Experiment
mm	millimeter
MPNE	Microgravity Plant Nutrient Experiment

MPS	main propulsion system
MSX	Midcourse Space Experiment
NASA	National Aeronautics and Space Administration
mV	millivolt
nmi.	nautical mile
NPC	rendezvous maneuver
NPSP	net positive suction pressure
NSLD	NASA Shuttle Logistics Depot
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OCA	Orbiter Communications Adapter
ODS	Orbiter docking system
OMDP	Orbiter Maintenance Down Period
OME	orbital maneuvering engine
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPM	Optical Properties Monitor
OSVS	Orbiter Space Vision System
PAL	protuberance air load
PASS	primary avionics software system
PCS	pressure control subsystem
PGSC	payload and general support computer
PMBT	propellant mean bulk temperature
ppm	parts per million
PPCO ₂	partial pressure carbon dioxide
PRSD	power reactant storage and distribution
psi	pound per square inch
psia	pound per square inch absolute
psid	pound per square inch differential
psig	pound per square inch gravity
RCRS	regenerative carbon dioxide removal system
RCS	reaction control subsystem
RJD	reaction jet driver
RM	redundancy management
RME	Risk Mitigation Experiment
RPC	remote power controller
RRMD	Real-Time Monitoring Device
RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAIL	Shuttle Avionics Integration Laboratory
SAMS	Space Acceleration Measurement System
SCU	service and cooling umbilical
SIGI	Space Integrated Global Positioning System/Inertial Navigation System
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SIP	strain isolation pad
SLAMMD	Space Linear Acceleration Mass Measurement Device
SLF	Shuttle Landing Facility
SM	systems management
S/N	serial number

SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
TACAN	Tactical Air Navigation System
TEHM	Thermal Electric Holding Module
TEHOF	Thermal Electric Holding Facility
TIP	telemedicine instrumentation pack
TPS	thermal protection system/subsystem
TVC	thrust vector control
ULF	upper left forward (antenna)
Vdc	Volts direct current
VOA	Volatile Organic Analyzer
VPI	valve position indicator
VRA	Volatile Removal Assembly
VSU	video switching unit
WCS	waste collection system
WSB	water spray boiler