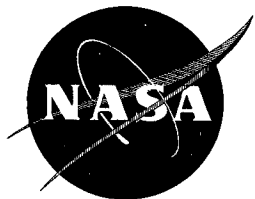


# **STS-99 SPACE SHUTTLE MISSION REPORT**

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March 2000



**National Aeronautics and  
Space Administration**

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

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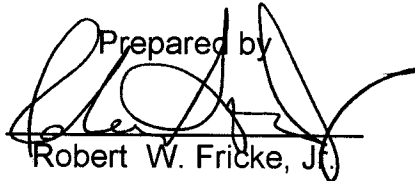
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STS-99

SPACE SHUTTLE

MISSION REPORT

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## STS-99 Table of Contents

<u>Title</u>	<u>Page</u>
<u>INTRODUCTION</u> .....	1
<u>MISSION SUMMARY</u> .....	2
<u>PAYLOADS</u> .....	9
SHUTTLE RADAR TOPOGRAPHY MISSION .....	9
EARTHKAM .....	11
<u>VEHICLE PERFORMANCE</u> .....	12
SOLID ROCKET BOOSTERS .....	12
REUSABLE SOLID ROCKET MOTORS .....	12
EXTERNAL TANK .....	13
SHUTTLE RANGE SAFETY SYSTEM .....	14
SPACE SHUTTLE MAIN ENGINES .....	14
ORBITER SUBSYSTEMS PERFORMANCE .....	15
<u>Main Propulsion System</u> .....	15
<u>Reaction Control Subsystem</u> .....	16
<u>Orbital Maneuvering Subsystem</u> .....	19
<u>Power Reactant Storage and Distribution Subsystem</u> ..	19
<u>Fuel Cell Powerplant Subsystem</u> .....	20
<u>Auxiliary Power Unit Subsystem</u> .....	21
<u>Hydraulics/Water Spray Boiler Subsystems</u> .....	22
<u>Electrical Power Distribution and Control Subsystem</u> ..	23
<u>Atmospheric Revitalization Pressure Control</u> <u>Subsystem</u> .....	23
<u>Atmospheric Revitalization Subsystem</u> .....	23
<u>Active Thermal Control Subsystem</u> .....	24
<u>Supply and Waste Water Subsystem</u> .....	24
<u>Waste Collection Subsystem</u> .....	25
<u>Airlock Support System</u> .....	26
<u>Smoke Detection and Fire Suppression Subsystem</u> ..	26
<u>Flight Data Subsystem</u> .....	26
<u>Flight Software</u> .....	27
<u>Flight Control Subsystem</u> .....	27
<u>Displays and Controls Subsystem</u> .....	28
<u>Communications and Tracking Subsystems</u> .....	29
<u>Operational Instrumentation/Modular</u> <u>Auxiliary Data System</u> .....	29
<u>Structures and Mechanical Subsystems</u> .....	29
<u>Integrated Vehicle Heating and Thermal</u> <u>Interfaces</u> .....	30
<u>Thermal Control Subsystem</u> .....	30

## STS-99 Table of Contents

<u>Title</u>	<u>Page</u>
<u>Aerothermodynamics</u> .....	31
<u>Thermal Protection Subsystem and Windows</u> .....	31
<u>Gas Sample Analysis</u> .....	33
<u>GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW</u>	
<u>EQUIPMENT</u> .....	34
<u>CARGO INTEGRATION</u> .....	35
<u>POSTLAUNCH PAD INSPECTION</u> .....	36
<u>DEVELOPMENT TEST OBJECTIVE/DETAILED SUPPLEMENTARY</u>	
<u>OBJECTIVES</u> .....	37
DEVELOPMENT TEST OBJECTIVES .....	37
DETAILED SUPPLEMENTARY OBJECTIVES .....	38
<u>PHOTOGRAPHY AND TELEVISION ANALYSIS</u> .....	40
LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS .....	40
ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS .....	40
LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS .....	40

### List of Tables

TABLE I - STS-103 SEQUENCE OF EVENTS .....	41
TABLE II - SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST .....	43
A - <u>DOCUMENT SOURCES</u> .....	A-1
B - <u>ACRONYMS AND ABBREVIATIONS</u> .....	B-1

## INTRODUCTION

The Space Transportation System (STS) -99 flight was the only planned flight of the Shuttle Radar Topography Mission (SRTM), which acquired high-resolution radar topographic images of the Earth's land mass between 60 °N and 56 °S latitude. The data from this mission will be used to produce a land map that is 30 times more precise than any map in existence prior to the mission.

This STS-99 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during the mission. In addition, this report summarizes the activities of the STS-99 mission, and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this ninety-seventh mission of the Space Shuttle Program. STS-99 was the seventy-second flight since the return to flight, and the fourteenth flight of the OV-105 (Endeavour) vehicle.

The flight vehicle consisted of the OV-105 Orbiter; an ET, which was a Lightweight Tank (LWT), and it was designated ET-92; three Block IIA SSMEs that were designated as serial numbers 2052, 2044, and 2047, in positions 1, 2, and 3, respectively; and two SRBs that were designated BI100. The two RSRMs were designated RSRM-71 with one installed in each SRB. The individual RSRMs were designated as 360W071A for the left SRB, and 360W071B for the right SRB.

The primary objective of the STS-99 flight was to successfully perform the operations of the SRTM/Space Radar Laboratory-3 (SRL-3). In addition, the secondary objectives of this flight were to perform the requirements of the EarthKAM.

The STS-99 flight was planned as a 11-day plus 2-contingency-day flight. The two contingency days were available for bad weather avoidance for landing or other Orbiter contingency operations. The sequence of mission events is shown in Table I, and the Orbiter In-Flight Anomaly List is shown in Table II.

Appendix A lists the sources of data, both formal and informal, that were used in the preparation of this report. Appendix B provides the definition of acronyms and abbreviations used throughout this report. All times during the flight are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The six-person crew of the STS-99 flight consisted of Kevin R. Kregel, Civilian, Commander; Dom L. Gorie, CDR. U. S. Navy, Pilot; Gerhard P. J. Thiele, Ph.D., Civilian, European Space Agency (ESA), Mission Specialist 1; Janet L. Kavandi, Ph. D., Civilian, Mission Specialist 2; Janice Voss, Ph. D., Civilian, Mission Specialist 3 and Payload Commander; and Mamoru Mohri, Ph. D., Civilian, National Space Development Agency of Japan (NASDA), Mission Specialist 4. STS-99 was the fifth space flight for Mission Specialist 3, the fourth space flight for the Commander, the second space flight for the Pilot, Mission Specialist 2 and Mission Specialist 4, and the first space flight for Mission Specialist 1.

## MISSION SUMMARY

The launch attempt of STS-99 on January 31, 2000, was scrubbed because of unacceptable weather conditions at the launch site. However, late in the count, an anomaly occurred with the enhanced master events controller (EMEC) 2, which also would have prevented the launch on that day. As a result of the anomaly, the decision was made to remove and replace EMEC 2 and reschedule the launch. The EMEC anomaly is discussed in the following paragraphs.

During the T-29 minute preflight built-in test equipment (BITE) test of EMEC 2, all four primary avionics software system (PASS) general purpose computers (GPCs) indicated input/output (I/O) errors and errors were also indicated in the EMEC 2 BITE words. Data evaluation indicated a good preflight BITE command followed by the I/O errors (bad address and parity) that were detected by all four PASS GPCs (Flight Problem STS-99-V-01). The errors occurred when receiving the first response word. The software then automatically retried the preflight BITE command and received all 18 response words from the pre-flight BITE test. However, words 8 and 9 had six bits set at 1 that should have been set at 0.

Following the launch scrub, additional testing of EMEC 2 was performed. This testing included 20 cycles of the preflight BITE test and 30 cycles of a non-critical command, all of which were successful. Additionally, the data evaluation continued and a fault tree was developed and analyzed. The analysis indicated that the problem was most likely in the EMEC; however, no single failure in the EMEC could be identified that could cause the signatures observed and also be a non-critical failure. This uncertainty led to the decision to remove and replace the EMEC. This decision resulted in the rescheduling of the launch to February 11, 2000.

Through subsequent data evaluation and computer simulation, a failure mode within the EMEC was identified that could have resulted in the failure signature observed. Additionally, after further analysis, there was no indication that a flight software or GPC problem could have caused the observed errors.

Approximately 4 hours prior to launch on February 11, 2000, the crew support personnel reported several times that the main propulsion system (MPS) liquid hydrogen (LH<sub>2</sub>) engine-manifold-pressure tape-meter oscillated erratically from 18 to 60 psia, but always returned to the normal reading of approximately 16 psia. The telemetry data from the pressure transducer was nominal throughout the launch countdown. The flight crew did not report any instances of this erratic operation after they ingressed the vehicle. Although tape-meter operation was not a constraint to launch, troubleshooting was performed to verify proper operation of the caution and warning system for this parameter. Troubleshooting of the dedicated signal conditioner, wiring and tape-meter on the vehicle was performed, and the anomaly was not repeated. The tape meter will be removed and replaced.

An unexpected pressure drop occurred in hydraulic system 1 approximately three hours prior to the launch. Discussions were held that explained the cause of the pressure drop to be a sequence of events, which consisted of the repositioning of flight control

system (FCS) actuators, Space Shuttle main engine (SSME) valve cycling and the opening of FCS actuator thermal bypass valves. These discussions resulted in a 13-minute 40-second launch delay.

The STS-99 mission was successfully launched at 042:17:43:39.997 G.m.t. (February 11, 2000) on an inclination of 57 degrees. Ascent was nominal in all respects except for a slight violation of the low-pressure limit of the External Tank (ET) gaseous hydrogen (GH<sub>2</sub>) ullage pressure at main engine cutoff (MECO); a minor auxiliary power unit (APU) 2 lubrication oil undercooling condition; and an unusual APU 2 drain-line temperature signature. Each of these conditions is discussed in following paragraphs.

An orbital maneuvering subsystem (OMS) assist maneuver was performed during ascent at 42:17:45:55.741 G.m.t (00:00:02:15 MET). The maneuver was 102.2 seconds in duration, and the OMS performed satisfactorily.

During the final stage of the SSMEs ascent run, the ET GH<sub>2</sub> ullage pressure dropped below the 32-psia lower limit at approximately 42:17:52:00 G.m.t. (00:00:08:20 MET), as measured by the ullage pressure measurement controlling flow control valve (FCV) 2. The pressure was 31.9 psia at MECO [42:17:52:14 G.m.t. (00:00:08:34 MET)], as measured by the ullage pressure measurements controlling FCVs 2 and 3. The ET GH<sub>2</sub> ullage pressure failed the File IX requirement, which requires that the pressure be controlled within the 32-34 psia range.

A review of the Orbiter MPS GH<sub>2</sub> FCV performance revealed no anomalies that could be attributed to the Orbiter subsystem. The ullage pressure at the time of the last FCV cycle was 32.7 psia after which it drifted slowly lower until eventually violating the requirement. Review of the FCV cycles showed no traces of sluggishness on any of the cycles. The 2-inch disconnect pressure data showed proper performance of the ullage pressurant at that disconnect. A review of the ullage pressure trip points showed nominal performance from the Orbiter FCV signal conditioners. The failure had no affect on the overall ascent performance, and no effects occurred during the remainder of the mission.

Approximately one week into the mission, using Orbiter, SSME and ET flight data, a reconstruction analysis of the ET GH<sub>2</sub> pressurization system performance was completed and reported to the Propulsion Systems Integration Group (PSIG). The reconstruction closely duplicated the ullage-pressure profile showing that the violation was a function of the day-of-launch conditions of the total system when integrated as a whole and not the result of any individual input-parameter failure. The PSIG will continue to evaluate this issue for any corrective actions. However, no additional investigation or postflight checkout was performed for the Orbiter MPS, and this item was closed as an explained condition.

At MECO [42:17:52:10 G.m.t (00:00:08:30 MET)], the APU 2 drain line temperature increased from 84 °F to 132 °F in a period of approximately 60 minutes. Following this rise, thermal performance of the line was as expected. During ascent, the increase in pressure in the line was as expected based on the initial line pressure and the temperature rise experienced. There was no mission impact, and the cause of this signature will be investigated during the postflight turnaround period.



During ascent, a water spray boiler (WSB) 2 undercooling condition occurred and the APU 2 lubrication-oil return-temperature reached 284 °F before the WSB began spraying while operating on controller A. Almost simultaneous with the beginning of spraying on controller A, the crew was given permission to switch to controller B. After the switchover, spraying continued on controller B. The temperature returned to nominal levels where it remained for the rest of APU 2 operation. Controllers A and B were used on WSB 2 during entry and landing, and WSB 2 performance on both controllers was nominal. No ground checkout was required.

The evaluation of the vehicle performance during ascent was made using vehicle acceleration and preflight propulsion-prediction data. The average flight-derived engine specific impulse ( $I_{sp}$ ) was 453.0 seconds as compared with the MPS tag value of 452.0 seconds at the 104.5 percent power level.

The OMS 2 maneuver was successfully performed at 42:18:18:39.741 G.m.t. (00:00:35.00 MET). The maneuver was 115 seconds in duration and the differential velocity ( $\Delta V$ ) was 182.8 ft/sec. The resultant orbit was 126.4 by 130.0 nmi.

At approximately 42:18:30 G.m.t. (00:00:46 MET), the fuel cell 2 alternate water line temperature began to increase from approximately 80 °F to 135 °F in a 30-minute period. The fuel cell 2 alternate water line temperature remained steady at 138 °F, which is near the fuel cell 2 product water line temperature of 141 °F. This behavior indicates leakage past the fuel cell 2 alternate water line check valve. Additionally, leakage was also seen past the fuel cell 3 water line check valve. The leakage was less than that seen on the fuel cell 2 valve, but more than is typically seen. There was no mission impact and both valves will be removed and replaced.

During the transition of the software to on-orbit operations at 42:18:37 G.m.t. (00:00:53 MET), the GPCs annunciated a cathode ray tube (CRT) 1 BITE error. The BITE status register indicated a keyboard channel B failure. The crew reassigned CRT 1 to GPC 1, and the error was again annunciated. After a power cycle of CRT 1, it was again reassigned to GPC 1, and CRT 1 operated nominally for the remainder of the mission. The display electronics unit (DEU) 1 will be removed and replaced.

The opening of the payload bay doors was completed successfully at 42:19:16:08 G.m.t. (00:01:32:39 MET).

The first reaction control subsystem (RCS) orbit adjustment maneuver was performed at 42:21:57:40 G.m.t. (00:04:14:00 MET). The maneuver was 7.6 seconds in duration and provided a  $\Delta V$  of 1.8 ft/sec. The resultant orbit was 126.5 by 128.7 nmi.

The second RCS orbit adjustment maneuver was performed at 42:22:58:40 G.m.t. (00:05:15:00 MET). The maneuver had a duration of 5.9 seconds and provided a  $\Delta V$  of 1.4 ft/sec. The resultant orbit was 126.7 by 128.9 nmi.

The Shuttle Radar Topography Mission (SRTM) mast was deployed successfully to its full length, and the antenna was turned to its operation position. After a successful checkout of the radar systems, mapping began at 43:05:31 G.m.t. (00:11:47 MET).

Analysis of playbacks of the radar data depicted nominal performance throughout the mission.

The vernier RCS pulse tests were completed at 43:01:46:00 G.m.t. (00:08:02:20 MET). The vernier RCS 1 test indicated that the caged damper system response was as expected. Following uncaging of the damper system, the vernier RCS 2 pulse-test was performed. Observed results from the vernier RCS 2 test were inconsistent with the expected uncaged system response, indicating some form of stiff damper failure had occurred since all of the frequencies, amplitudes and damping precisely matched the initial caged damper test. A recommendation was made to recage the dampers prior to approving the deadband collapse. The composite notch filters that were uplinked prior to flight were acceptable for deadband collapse and science operations with the caged damper system, but were unacceptable in a damper-uncaged configuration without further testing to verify nominal behavior.

The high- and low-impulse RCS tests for the payload were performed using the primary RCS aft-firing thrusters. Thrusters L1A and R1A were fired three times and each time the firing was 1.76 seconds in duration. Test 1 consisted of one pulse at 43:18:25:40.34 G.m.t. (01:00:42:00.37 MET). Test 2 consisted of two pulses with the first pulse at 43:18:35:40.26 G.m.t. (01:00:52:00.29 MET) and the second pulse at 43:18:35:45.54 G.m.t. (01:00:52:05 MET). All portions of the test were passed satisfactorily, and approval was given for single-pulse, multi-pulse, and doublet fly-cast orbit-correction maneuvers.

During an attitude-hold period for payload mapping at approximately 43:20:44 G.m.t. (01:03:01 MET), it was determined that the Orbiter RCS propellant usage had doubled from 0.07 to 0.15 percent an hour. This increase in Orbiter propellant usage was caused by a failure of the payload cold-gas thrust system that was used to provide a constant torque on the vehicle and offset the effects of gravity-gradient operations at the required mapping attitude. As a result of this failure, Orbiter propellant was being used at a higher-than-planned rate to maintain the attitude of the vehicle. A variety of measures designed to reduce the expenditure of propellant were evaluated. Based on these analyses, enough propellant-saving measures were identified and implemented to complete the planned 9-day 9-hour science mission.

At 44:07:43 G.m.t. (01:14:00 MET), the Orbiter performed a "fly-cast maneuver" (RCS trim 1 maneuver). This was a +X firing consisting of three pulses of 1.8, 11.8 and 1.8 seconds, respectively. The total  $\Delta V$  gained was 3.3 ft/sec.

The RCS Trim 2 maneuver (fly-cast maneuver) was initiated at 45:08:36:40 G.m.t. (02:14:53:00 MET). This was a +X maneuver consisting of 3 pulses. The first pulse lasted 1.8 seconds, the second 12.7 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 3.6 ft/sec and produced a resultant orbit of 127.3 by 126.1 nmi.

At 45:02:14 G.m.t. (02:08:30 MET) and at 45:18:33 G.m.t. (03:00:49 MET), the Operations (OPS) 2 recorder failed to go in the reverse direction to the beginning-of-tape when commanded. Instead the recorder wound in the forward direction. In both cases, the commands were issued multiple times and the commands resulted in the

recorder pulling the tape in the forward direction. The recorder operated properly prior to the two periods and operated properly following the two periods for the remainder of the mission. The playback command always resulted in the recorder operating in the proper direction and could be used had the condition recurred. Postflight troubleshooting will be performed.

The RCS Trim 3 maneuver (fly-cast maneuver) was initiated at 46:07:22:40 G.m.t. (02:13:39:00 MET). This was a +X maneuver consisting of 3 pulses. The first pulse had a duration of 1.8 seconds, the second 12.2 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 3.4 ft/sec and produced a resultant orbit of 127.4 by 124.7 nmi.

The RCS Trim 4 maneuver (fly-cast maneuver) was initiated at 47:08:06:20 G.m.t. (04:14:22:40 MET). This was a +X maneuver consisting of 3 pulses. The first pulse had a duration of 1.7 seconds, the second 8.9 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 2.6 ft/sec and resulted in an orbit of 127.1 by 124.1 nmi.

The RCS Trim 5 maneuver (fly-cast maneuver) was initiated at 48:08:09:40 G.m.t. (05:14:26:00 MET). This was a +X maneuver consisting of 3 pulses. The first pulse had a duration of 1.8 seconds, the second 9.1 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 2.9 ft/sec and resulted in an orbit of 128.7 by 125.7 nmi.

At approximately 47:22:18 G.m.t. (05:04:34 MET), the crew reported that the top segment of the tens digit of the minutes display on the forward mission timer was no longer illuminated. This timer was configured to operate as a mission-elapsed-time (MET) display. Evaluation determined that there was no potential for an erroneous mapping of one numeric digit into another digit such that the crew might be misled. The crew later reported that the failure of the element was intermittent. At 53:04:50 G.m.t. (10:11:06 MET), the crew reported that another segment on the timer had failed. The failed segment was the right upper vertical segment of the hundreds digit of the days display. These failures did not impact the mission operations. Postflight, the timer was removed and replaced.

At 47:20:02 G.m.t. (05:02:18 MET), a reconfiguration of the right RCS fuel Helium regulators was performed. The A-leg isolation valve was closed and the B-leg isolation valve was opened. Following this reconfiguration, the right RCS fuel-tank ullage and outlet pressures began to rise at the rate of 1 psi/hr. At 48:04:47 G.m.t. (05:10:53 MET), the right RCS fuel Helium regulators were reconfigured again, this time closing the B-leg isolation valve and opening the A-leg isolation valve. This was done when the fuel-tank pressure reached 263 psia and exceeded the oxidizer-tank pressure by approximately 12 psi. A flight rule exists that prohibits RCS vernier operation when the fuel-tank pressure exceeds the oxidizer-tank pressure by more than 20 psi. There was no mission impact, and the B-leg isolation valve was opened during the deorbit maneuver preparations for entry operations, and all operations were nominal. Postflight functional testing of the regulator was performed and the regulator performance was within specification requirements. It is believed that the leakage was

caused by contamination that was cleared by the functional test. The regulator will remain on the vehicle.

The RCS Trim 6 maneuver (fly-cast maneuver) was initiated at 49:07:39:40 G.m.t. (06:13:56:00 MET). This was a +X maneuver consisting of 3 pulses. The first pulse had a duration of 1.8 seconds, the second 12.5 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 3.5 ft/sec and resulted in an orbit of 125.0 by 127.7 nmi.

As a propellant savings measure, the Trim 6 and 7 maneuvers were altered so that the RCS Trim 8 maneuver would not be required. Adequate Orbiter propellant margins allowed the extension of mapping operations from 52:02:44 G.m.t. (09:09:00 MET) until 52:11:44 G.m.t. (09:18:00 MET).

The RCS Trim 7 maneuver (fly-cast maneuver) was initiated at 50:20:36:40 G.m.t. (08:02:53:00 MET). This was a +X maneuver consisting of 3 pulses. The first pulse had a duration of 1.8 seconds, the second 18.0 seconds, and the third 1.8 seconds. The maneuver imparted a total  $\Delta V$  of 4.6 ft/sec and resulted in an orbit of 124.7 by 127.7 nmi.

At 52:03:57:50 G.m.t. (09:10:14:10 MET), RCS thruster L5D was automatically deselected when the indicated oxidizer injector temperature became erratic. The temperature dropped below the redundancy management (RM) limit of 130 °F, and the thruster was automatically deselected. The fuel injector temperature was normal and remained steady. This condition has been observed on a number of previous flights and based on the fuel injector temperature, it was determined that this was an instrumentation problem, and the thruster was operating properly. A preflight-approved GPC memory (GMEM) patch was uplinked to lower the vernier oxidizer injector RM temperature limit from 130 °F to 0 °F to allow the vernier thruster to be reselected. This failure had no impact on the mission or on payload activities. Postflight troubleshooting will be performed.

During the initiation of an fifteenth Orbiter supply water dump at 52:04:01 G.m.t. (09:46:17 MET), the dump-nozzle heaters operated nominally and the dump valve was opened. However, no decrease in either the nozzle temperatures or tank quantities was identified in the data, indicating that no water was being dumped (Flight Problem STS-99-V-02). The dump valve was cycled with no response, followed by the crew removing the dump-line purge device and closing the dump valve. Changes in the dump-nozzle heater profiles during this time indicated that ice was being ejected from the water line and/or the nozzle. The dump valve was opened again and the supply dump was performed nominally. No additional supply water dumps were performed through the nozzle during the mission. Postflight testing is being performed in an attempt to determine the cause of the apparent blockage. As of the writing of this section, a minor leak of the dump valve has been discovered and the valve will be removed and replaced.

The FCS checkout was performed using APU 1, which was started at 52:18:04:31 G.m.t. (10:00:20:51 MET). The data showed that the FCS and APU performance was nominal. The APU run time lasted 4 minutes and 11 seconds, and

18 lb of fuel were consumed. Because of the short run-time of the APU, WSB 1 cooling was not required as the APU 1 lubrication-oil-return temperature only reached 189 °F.

The RCS hot fire was started at 52:18:48:00 G.m.t. (10:01:04:20 MET) and concluded 8 minutes later. The hot-fire procedure was performed only once, as opposed to the usual "twice through" because of the propellant constraints. All primary thrusters were fired at least once, with several forward RCS thrusters, F1L, F2R, F3L, F4R, F3D, and F4D, being fired twice. All thrusters demonstrated nominal performance.

At 52:11:56 G.m.t. (09:18:12 MET), SRTM mapping was terminated. The first SRTM mast-retraction attempt began at 52:13:37:41 G.m.t. (09:19:54:01 MET) and was nominal until the last several inches. The last 90 seconds of the retraction was at or near the stall current, which was approximately 1.1 amperes/phase) at the selected torque level. The mast power was reapplied at 52:14:44:34 G.m.t. (09:21:00:54 MET), and the stall current was present for 33 seconds without success. After warm-up with the canister heaters and the latches were re-opened, maximum motor torque was selected and the motor was powered on at 52:15:08:06 G.m.t. (09:21:24:26 MET), and this attempt resulted in 2.5 amperes/phase for 30 seconds without success. The third attempt resulted in the mast being fully retracted and latched at 52:15:50:24 G.m.t. (09:22:06:44 MET) using high-torque operation of the motor for a period of 6 seconds.

The payload bay doors were closed and latched for landing at 53:18:16:32 G.m.t. (11:00:32:52 MET). The deorbit maneuver for the first Kennedy Space Center (KSC) landing opportunity was waived because of unacceptable weather conditions. The deorbit maneuver for the second KSC landing opportunity was performed on orbit 181 at 53:22:25:10.1 G.m.t. (11:04:41:30.1 MET). The maneuver was 139.6 seconds in duration with a  $\Delta V$  of 236.8 ft/sec.

Entry interface occurred at 53:22:50:08 G.m.t. (11:05:06:28 MET), and entry was completed satisfactorily. Main landing gear touchdown occurred on Shuttle Landing Facility (SLF) concrete runway 33 at 53:23:22:24 G.m.t. (11:05:38:43 MET) on February 22, 2000. The nose gear touchdown occurred at 53:23:22:34 G.m.t. The drag chute was deployed at 53:23:22:36 G.m.t. The drag chute was jettisoned at 53:23:23:06 G.m.t. with wheels stop occurring at 53:23:23:23 G.m.t. The rollout was normal in all respects. The flight duration was 11 days 05 hours 38 minutes 44 seconds. The three APUs were shut down 14 minutes 02 seconds after landing.

## PAYLOADS

The STS-99 mission demonstrated two payloads, the first being the Shuttle Radar Topography Mission (SRTM) and the second being the EarthKAM. The mission was highly successful in achieving approximately 95 percent of the SRTM objectives and far surpassing the objective of the EarthKAM with more photographs taken on this one mission than taken over the last four Space Shuttle missions.

### **SHUTTLE RADAR TOPOGRAPHY MISSION**

The SRTM was an advanced radar system that employed a C-band and X-band antenna at the end of a 60-meter (200-foot) mast. The mast was successfully deployed and mapping began at 43:05:31 G.m.t. (00:11:47 MET). This mast-antenna configuration constituted the longest deployed structure ever flown in space. This mission was the first use of a dual-antenna imaging radar, which enables scientists to use a technique called interferometry to map terrain elevation in a single pass. This technique will result in maps between 60 °N and 56 °S latitude that are 30 times more precise than any map available prior to the mission.

The total area that was mapped at least once was 119,500,000 square kilometers and the area that was mapped twice was 112,700,000 square kilometers. The percentage of the targeted one-pass coverage obtained was 99.96 percent of the SRTM criteria, and 94.6 percent of the targeted two-pass coverage.

The mast deployment and the antenna flip to the operational position were successful. The on-orbit checkout was completed ahead of schedule, and mapping began at 43:05:33 G.m.t. (00:11:50 MET). C-band and X-band radar performance was verified by on-orbit instrumentation and downlinked data. The low-impulse primary reaction control subsystem (RCS) test was completed and mast deflection was 5 inches, with up to 11 inches being acceptable. The SRTM global positioning system (GPS) receiver 1 was tracking all four targets, whereas SRTM GPS receiver 2 was tracking two and sometimes three out of four targets.

The vernier RCS pulse tests were completed at 43:01:46:00 G.m.t. (00:08:02:20 MET). The vernier RCS 1 test indicated that the caged damper system response was as expected. The damping in the uncaged configuration was the same as the caged configuration when the vernier RCS 2 pulse-test was performed. A recommendation was made to recage the dampers prior to approving the deadband collapse. The composite notch filters that were uplinked prior to flight were acceptable for deadband collapse and science operations with the caged damper system, but were unacceptable in a damper-uncaged configuration without further testing to verify nominal behavior. The actual in-flight mast performance with the dampers caged was acceptable for all science and mast safety concerns. The dampers were installed on the mast to provide additional damping margin.

Early problems were experienced with the star tracker assembly, but these were resolved when the flight controllers changed the modes from fast track to window track.

The GPS receivers experienced intermittent problems tracking the required four satellites; however, the outages were of short duration and did not impact the mission.

Cold gas usage was initially higher than preflight predictions. Recycling the system resulted in venting quantities closer to mission projections, but no positive propulsive effect was observed.

During an attitude-hold period for payload mapping at approximately 43:20:44 G.m.t. (01:03:01 MET), it was determined that the Orbiter RCS propellant usage had doubled from 0.07 to 0.15 percent an hour. This increase in Orbiter propellant usage was caused by a failure of the payload cold-gas thrust system that was used to provide a constant torque on the vehicle to offset the effects of gravity-gradient operations at the required mapping attitude. As a result of this failure, Orbiter propellant was being used at a higher-than-planned rate to maintain the attitude of the vehicle. The cold gas system was subsequently allowed to bleed down and then turned off for the duration of the mission. An evaluation team was organized to develop and evaluate ways in which adequate RCS propellants would be available to complete the SRTM mapping portion of the mission as well as have adequate consumables for possible contingencies and entry.

The initial developments from the team to save propellant for the payload resulted in the following options that were implemented by the Flight Control Team.

1. Changed the mapping attitude dead-band to 0.2 degree from 0.1 degree;
2. Performed all maneuvering to or from the trim maneuver attitude at 0.2 deg/sec;
3. Eliminated the attitude dead-band collapse after maneuvering to the trim maneuver attitude;
4. Incrementally collapsed the dead-band after maneuvering from the trim maneuver attitude to the mapping attitude; and
5. Implemented supply water dumps as a propellant-saving procedure.

Based on the results of these measures, enough propellant-savings were identified to complete the planned 9-day 9-hour science mission.

Additionally, the evaluation of end-of-mission options intended to further reduce the expenditure of Orbiter propellant and satisfy Orbiter and payload thermal requirements was made. The efforts on attitude-timeline options for the nominal end-of-mission, one-day and two-day mission extension attitudes identified an option that satisfied both Orbiter thermal and payload thermal requirements. With the deletion of the RCS Trim 8 maneuver, the option also satisfied the Orbiter propellant requirements. The Mission Management Team approved this attitude timeline for implementation by Mission Operations Directorate (MOD) flight-management personnel.

The requirement to perform an unscheduled extravehicular activity (EVA) for mast stowage was removed and the propellant-savings was applied to the mapping effort. As a result, mapping was extended 9 hours.

Seven fly-cast (trim) maneuvers were performed during the mission in support of the SRTM payload. The average deflection of the outboard antenna was observed to be 10 inches.

At 52:11:56 G.m.t. (09:18:12 MET), SRTM mapping was terminated. The first SRTM-mast-retraction attempt began at 52:13:37:41 G.m.t. (09:19:54:01 MET) and was nominal until the last several inches. The last 90 seconds of the retraction was at or near the stall current, which was approximately 1.1 amperes/phase) at the selected torque level. The mast power was reapplied at 52:14:44:34 G.m.t. (09:21:00:54 MET), and the stall current was present for 33 seconds without success. After warm-up with the canister heaters and re-opening of the latches, maximum motor torque was selected and the motor was powered on at 52:15:08:06 G.m.t. (09:21:24:26 MET), and this attempt resulted in 2.5 amperes/phase for 30 seconds without success. The third attempt resulted in the mast being fully retracted and latched at 52:15:50:24 G.m.t. (09:22:06:44 MET) using high-torque operation of the motor for a period of 6 seconds.

### **EARTHKAM**

EarthKAM produced more photographs for students than all previous EarthKAM flights combined. A total of 2,715 images were taken during the mission. Of the 84 schools involved in EarthKAM, 83 actively participated, having submitted and received images. Images from this mission as well as past missions can be viewed by the schools and general public at the web site [www.earthkam.ucsd.edu](http://www.earthkam.ucsd.edu), by clicking on data search and then clicking list images or geo.search link.



## VEHICLE PERFORMANCE

### SOLID ROCKET BOOSTERS

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

SRB cutoff occurred 125.524 seconds after liftoff. The SRBs were successfully separated from the vehicle satisfactorily, and all recovery systems operated satisfactorily. Recovery of the SRBs and parachutes was successfully completed. The SRBs were returned to Kennedy Space Center for inspection, disassembly and refurbishment. The postflight inspection showed the SRBs to be in excellent condition.

### REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motor (RSRMs) operated satisfactorily. No LCC or OMRSD violations or in-flight anomalies occurred. The motor performance was within the Contractor End Item (CEI) specification limits. One single spike to 993.5 psi in the chamber pressure measurement was noted about 100 seconds after launch. The spike was a precursor of a one-second data dropout that included multiple measurements associated with other Space Shuttle subsystems. The pressure spike was attributed to a telemetry data system error. The delivered burn rates for the RSRMs were nominal (0.3685 and 0.3694 in/sec) for the left and right motors, respectively.

The field-joint heaters operated for 12 hours 20 minutes during the launch countdown. Power was applied to the heating elements 58-percent (average) of the time during the LCC time frame. The field-joint heaters were operated a total of 31 hours 4 minutes during the two countdowns, and all heaters performed nominally.

The igniter joint heaters operated 22 hours 8 minutes during the final countdown. Power was applied to the heaters 84-percent of the time and the igniter joints were maintained in their normal operating range. The igniter joint heaters had powered applied for 55 hours 7 minutes during the countdowns.

All RSRM temperatures were maintained within acceptable limits throughout the countdown. The heated, ground-supplied, aft skirt purges were powered for 10 hours 36 minutes prior to launch. The aft skirt purge was operated 15 times prior to and during the three countdowns for an operational time of 68 hours 58 minutes. The heaters also maintained the case/nozzle joint and flex bearing temperatures within the required LCC ranges. The final flex bearing mean bulk temperature (FBMBT) at liftoff was a very satisfactory 79 °F.

Reconstructed propulsion performance is summarized in the following table. The calculated RSRM propellant mean bulk temperature (PMBT) was 59 °F at liftoff. The maximum trace-shape variation of pressure versus time was calculated to be 2.3 psi at 74 seconds (left motor) and 0.9 psi at 70 seconds (right motor). Both values were well within the 3.2 percent allowable limits.

Data indicates that the flight performance of both RSRMs was well within the allowable performance envelopes, and the performance was typical of the performance observed on previous flights. The postflight inspection of the RSRMs indicated that the hardware was in good condition and that no pocket/wash erosion was observed in either nozzle.

### RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 70 °F		Right motor, 70 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	64.39	64.32	64.80	64.31
I-60, 10 <sup>6</sup> lbf-sec	172.86	172.70	173.79	172.74
I-AT, 10 <sup>6</sup> lbf-sec	296.86	296.78	297.07	296.55
Vacuum lsp, lbf-sec/lbm	268.4	268.3	268.4	267.9
Burn rate, in/sec @ 60 °F at 625 psia	0.3684	0.3680	0.3696	0.3687
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	110.8	111.4	110.2	110.9
50 psia cue time	120.9	121.1	120.3	120.5
Action time <sup>b</sup>	123.2	123.6	122.5	122.9
Separation command	125.3	--	125.3	--
PMBT, °F	59	59	59	59
Maximum ignition rise rate, psia/10 ms	90.8	N/A	90.8	N/A
Decay time, seconds (59.4 psia to 85 K)	3.2	3.5	3.1	3.4
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		543.4	

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

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

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

### EXTERNAL TANK

All External Tank (ET) objectives and requirements associated with propellant loading and flight operations were met. No significant oxygen or hydrogen leakage concentrations were detected in the intertank area. All ET electrical equipment and instrumentation operated properly. The purge and heater operations were monitored and all operations were nominal. No ET LCC or OMRSD violations occurred.

The nose-cone purge heater and temperature control operated successfully. However, data spikes were observed in the primary nose-cone temperature measurement that appeared to exceed the OMRSD limit. Postflight analysis showed that the faulty data was caused by an instrumentation problem. The secondary measurement showed no spikes or excessive values.

Some frost was present on the acreage areas during tanking, but the frost dissipated as the ambient temperature increased. Normal quantities of ice or frost were present on the liquid oxygen (LO<sub>2</sub>) and liquid hydrogen (LH<sub>2</sub>) feedlines, the pressurization line brackets, and along the LH<sub>2</sub> protuberance air load ramps.

Four cracks in the ET thermal protection system (TPS) were visible in the +Y longeron-strut foam closeout, and the Ice/Frost Team documented them. These cracks ranged from 4 to 24 inches long by 1/16 to 1/8 inch wide. A review of these TPS cracks revealed no TPS debris, or thermal, stress or propellant quality concerns. Ice was not present at liftoff.

Photography from the umbilical wells showed number of conditions. Those conditions ranged from small divots and popcorning of the TPS to a number of places where it appeared that larger pieces of TPS were missing. None of these condition were significant to the ascent of the vehicle and caused no impact on the flight.

The pressurization systems functioned properly throughout engine start and flight. The minimum LO<sub>2</sub> ullage pressure, experienced during the ullage-pressure slump, was 13.7 psid.

ET separation occurred as planned, with entry and breakup of the ET occurring approximately 69 nmi. downrange of the preflight predicted point and well within the predicted footprint for impact.

### SHUTTLE RANGE SAFETY SYSTEM

The Shuttle range safety system (SRSS) performed as designed. 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 the appropriate times. As planned, the SRB S&A devices were safed, and SRB power was turned off at the appropriate times. All SRSS measurements indicated that the system operated satisfactorily.

### SPACE SHUTTLE MAIN ENGINES

Prelaunch operations were smooth with no problems noted. All three engines were the Block IIA design. Flight operations were also nominal with no in-flight anomalies noted.

After main engine cutoff (MECO), a failure identification (FID) on SSME 1 of the digital controller unit (DCU) channel B was noted. Analysis showed that the two power switches to the engine controller were not switched off simultaneously, and this caused the noted problem.

Main engine cutoff occurred 503.44 seconds after SRB ignition, 0.2 second later than predicted. The specific impulse ( $I_{sp}$ ) was 453.0 seconds, which was approximately 1.0 second higher than predicted based on acceptance tests.

## ORBITER SUBSYSTEMS PERFORMANCE

### Main Propulsion Subsystem

The main propulsion subsystem (MPS) performed nominally throughout ascent. No LCC violations occurred during prelaunch operations. Two problems were noted during prelaunch operations, but both were resolved with analysis and testing prior to liftoff. These problems are discussed in the following paragraphs.

Approximately 4 hours prior to launch, the crew support personnel reported several times that the MPS LH<sub>2</sub> engine-manifold- pressure tape-meter oscillated erratically from 18 to 60 psia, but always returned to the normal reading of approximately 16 psia. The telemetry data from the pressure transducer was nominal throughout the launch countdown. The flight crew did not report any instances of this erratic operation after they ingressed the vehicle. Although tape-meter operation was not a constraint to launch, troubleshooting was performed to verify proper operation of the caution and warning system for this parameter. A waiver was approved to accept the violation of the OMRSD, File III.

During the final stage of the SSMEs ascent run immediately prior to MECO, the ET GH<sub>2</sub> ullage pressure dropped below the 32-psia lower limit at approximately 42:17:52:00 G.m.t. (00:00:08:20 MET), as measured by the ullage pressure measurement controlling flow control valve (FCV) 2. The pressure was 31.9 psia at MECO [42:17:52:14 G.m.t. (00:00:08:34 MET)], as measured by the ullage pressure measurements controlling FCVs 2 and 3. The ET GH<sub>2</sub> ullage pressure failed the File IX requirement, which requires that the pressure be controlled within the 32-34 psia range.

A review of the Orbiter MPS GH<sub>2</sub> FCV performance determined that no anomalies could be attributed to the Orbiter hardware. All of the FCV 1 and 2 cycles were prior to the throttle bucket with both valves staying in the high-flow position for the remainder of ascent. FCV 3 had eight cycles after the throttle bucket, and moved to the high-flow position approximately 6 minutes 18 seconds after liftoff. The ullage pressure at the time of the last FCV cycle was 32.7 psia after which it drifted slowly lower until eventually violating the requirement. Review of the pressure data from upstream of the FCVs showed no traces of sluggishness on any of the cycles. The 2-inch disconnect pressure data showed proper performance of the ullage pressurant at that disconnect. A review of the ullage pressure trip points showed nominal performance from the Orbiter FCV signal conditioners. The failure had no effect on the overall ascent performance, nor any effects during the remainder of the mission.

Using Orbiter, SSME and ET flight data, a reconstruction analysis of the ET GH<sub>2</sub> pressurization system performance was completed and reported to the Propulsion Systems Integration Group (PSIG). The reconstruction closely duplicated the ullage-pressure profile showing that the violation was a function of the day-of-launch conditions of the total system when integrated as a whole and not the result of any individual input-parameter failure. The PSIG continues to evaluate this issue for any corrective actions. However, no additional investigation or postflight checkout was performed for the Orbiter MPS, and this item was closed as an explained condition.

No significant hazardous gas concentrations were detected prior to liftoff. The maximum corrected hydrogen concentration level in the Orbiter aft compartment (occurred during fast-fill) was a corrected value of 150 ppm, and the steady-state level was 40 ppm. This level compares favorably with previous data for this vehicle.

Data indicate that the LO<sub>2</sub> and LH<sub>2</sub> pressurization systems performed as planned, and that the engine-inlet net-positive suction-pressure requirements were met throughout the flight. The three flow control valves performed nominally as did the Helium system.

### Reaction Control Subsystem

The reaction control subsystem (RCS) performed satisfactorily throughout the mission. There were two problems, a leaking regulator and an erratic vernier-thruster temperature, which are discussed in the following paragraphs. No LCC or OMRSD violations were noted prior to launch and no in-flight anomalies or significant problems were noted during the mission. The table on the following page shows all of the major RCS maneuvers performed during the mission.

A total of 4690.2 lbm of RCS propellants (2859.3 - oxidizer, 1830.9 - fuel) were used during the mission. In addition, a total of 3635.6 lbm of orbital maneuvering subsystem (OMS) propellants were used during OMS-RCS interconnect operations. The primary RCS thrusters had 2380 firings and a total firing time of approximately 777.56 seconds. The vernier RCS thrusters had 82,412 firings and a total firing time of 65329.78 seconds.

The vernier RCS pulse test 1 indicated that the caged damper system response was as expected. Following uncaging of the damper system, the vernier RCS pulse test 2 was performed. Observed results from the vernier RCS pulse test 2 were inconsistent with the expected uncaged system response, indicating some type of anomaly in the damper system. A recommendation was made to recage the dampers prior to approving the deadband collapse. The composite notch filters that were uplinked prior to flight were acceptable for deadband collapse and science operations with the caged damper system, but were unacceptable in a damper-uncaged configuration without further testing to verify nominal behavior.

The high- and low-impulse RCS tests for the payload were performed using the primary RCS aft-firing thrusters. Thrusters L1A and R1A were fired three times and each time the firing was 1.76 seconds in duration. Test 1 consisted of one pulse at 43:18:25:40.34 G.m.t. (01:00:42:00.37 MET). Test 2 consisted of two pulses with the first pulse at 43:18:35:40.26 G.m.t. (01:00:52:00.29 MET) and the second pulse at 43:18:35:45.54 G.m.t. (01:00:52:05 MET). All portions of the test were passed satisfactorily, and approval was given for single-pulse, multi-pulse, and doublet fly-cast orbit-correction maneuvers.

During an attitude-hold period for payload mapping at approximately 43:20:44 G.m.t. (01:03:01 MET), it was determined that the Orbiter RCS propellant usage had doubled from 0.07 to 0.15 percent an hour. This increase in Orbiter propellant usage was caused by a failure of the payload cold-gas thrust system that was used to offset the gravity-gradient torque of the mast. As a result of this failure, Orbiter propellant was

being used at a higher-than-planned rate to maintain the attitude of the vehicle. A variety of measures designed to reduce the expenditure of propellant were evaluated. Based on these analyses, enough propellant-saving measures were identified to complete the planned 9-day 9-hour science mission.

### RCS MANEUVERS

RCS Maneuver	Ignition time, hr:min:sec	Differential Velocity, ft/sec	Firing time, seconds	Resultant orbit, nmi.
Orbit adjust 1	42:21:57:40 G.m.t. 00:04:14:00 MET	1.8	7.6	126.5 by 128.7
Orbit adjust 2	42:22:58:40 G.m.t. 00:05:15:00 MET	5.9	1.4	126.7 by 128.9
Vernier pulse test 1	43:00:54:55 G.m.t. 00:07:11:15 MET	N/A	1.5 and 1.6	N/A
Vernier pulse test 2A and 2B	43:01:41:40 G.m.t. 00:07:58:00 MET	N/A	1.5, 1.5 and 1.5	N/A
Primary low impulse	43:06:07:40 G.m.t. 00:12:24:00 MET	N/A <sup>1</sup>	0.4, 0.8	N/A
Primary high impulse	43:18:35:40 G.m.t. 01:00:52:00 MET	N/A <sup>1</sup>	1.76, 1.76 and 1.76	N/A
Vernier trim 1 <sup>2</sup>	44:07:43:40 G.m.t. 01:14:00:00 MET	3.3	1.8, 11.8 and 1.8	N/A
Vernier trim 2 <sup>2</sup>	45:08:36:40 G.m.t. 02:14:53:00 MET	3.6	1.8, 12.7 and 1.8	127.3 by 126.1
Vernier trim 3 <sup>2</sup>	46:07:22:40 G.m.t. 03:14:53:00 MET	3.4	1.8, 12.2 and 1.8	127.4 by 124.7
Vernier trim 4 <sup>2</sup>	47:08:06:20 G.m.t. 04:07:22:40 MET	2.6	1.8, 8.9 and 1.8	127.1 by 124.1
Vernier trim 5 <sup>2</sup>	48:08:09:40 G.m.t. 05:04:26:00 MET	2.9	1.8, 9.1 and 1.8	128.7 by 125.7
Vernier trim 6 <sup>2</sup>	49:07:39:40 G.m.t. 06:13:56:00 MET	3.5	1.8, 12.5, and 1.8	125.0 by 127.7
Vernier trim 7 <sup>2</sup>	50:20:36:40 G.m.t. 08:02:53:00 MET	4.6	1.8, 18.0 and 1.8	124.7 by 127.7
Vernier trim 8 <sup>2</sup>	Cancelled	N/A	N/A	N/A
RCS hot-fire	53:18:48 G.m.t. 11:01:04 MET	N/A	N/A	N/A

<sup>1</sup> Pulses were used to test the dynamic response of the mast and no change in Orbiter velocity was imparted.

<sup>2</sup> These maneuvers were known during the mission as fly-cast maneuvers

Additionally, the evaluation of end-of-mission attitude timeline options intended to further reduce the expenditure of Orbiter propellant and satisfy Orbiter and payload thermal requirements was made. The efforts on attitude-timeline options for the nominal end-of-mission, one-day and two-day mission extension attitudes identified an option, which satisfied both Orbiter thermal and payload thermal requirements. With

the deletion of the RCS Trim 8 maneuver, the option also satisfied the Orbiter propellant requirements. The Mission Management Team approved this attitude timeline for implementation by Mission Operations Directorate (MOD) flight-management personnel.

During prelaunch operations for the first launch attempt, the right RCS fuel Helium pressure regulators leaked following pressurization to the flight level. Since both regulators were on-line, it was not known which regulator was exhibiting the leakage through the primary stage. Documentation of the condition was made and a one-flight waiver was approved to allow use of the leaking regulator.

Subsequently, at 47:20:02 G.m.t. (05:02:18 MET), a reconfiguration of the right RCS fuel Helium regulators was performed. The A-leg isolation valve was closed and the B-leg isolation valve was opened. Following this reconfiguration, the right RCS fuel-tank ullage and outlet pressures began to rise at the rate of 1 psi/hr. At 48:04:47 G.m.t. (05:10:53 MET), the right RCS fuel Helium regulators were reconfigured again, this time closing the B-leg isolation valve and opening the A-leg isolation valve. This was done when the fuel-tank pressure reached 263 psia and exceeded the oxidizer-tank pressure by approximately 12 psi. A flight rule exists that prohibits RCS vernier operation when the fuel-tank pressure exceeds the oxidizer-tank pressure by more than 20 psi. There was no mission impact, and the B-leg isolation valve was opened during the deorbit maneuver preparations for nominal entry operations. This reconfiguration to the A leg was maintained until the OMS deorbit maneuver preparations were begun. At that time the B leg was opened for the nominal entry configuration. Data analysis determined that the primary stage of the B leg was leaking at a rate of 7050 scch. Troubleshooting and testing of the valve was performed during turnaround operations. A full functional test was performed and regulator performance was within the specification requirements. It is believed that the leakage was caused by contamination that was cleared by the functional test. The regulator will remain in the vehicle.

At 52:03:57:50 G.m.t. (09:10:14:10 MET), RCS thruster L5D was automatically deselected when the indicated oxidizer injector temperature became erratic. The temperature dropped below the redundancy management (RM) limit of 130 °F, and the thruster was automatically deselected. The fuel injector temperature was normal and remained steady. This condition has been observed on a number of previous flights and based on the fuel injector temperature, it was determined that this was an instrumentation problem, and the thruster was operating properly. Initially, the thruster was reselected with RM inhibited and vernier thruster temperatures were monitored on the ground. A preflight-approved GPC memory (GMEM) patch was uplinked to lower the vernier oxidizer injector RM temperature limit from 130 °F to 0 °F to allow the vernier thruster to be reselected and the RM to be reenabled. As a result of this preplanned action, this failure had no impact on the mission or on payload activities. This problem first appeared on STS-68, which was the seventh flight of this vehicle. It has repeated on four of the last eight flights. The thruster was removed and replaced after STS-88. Ground troubleshooting has not been able to duplicate this anomalous condition. A troubleshooting plan was developed and will be implemented. This troubleshooting will consist of the inspection of accessible wiring near the thruster.

The use of the vernier thrusters on this mission was much greater than previously recorded on a Space Shuttle mission. Vernier thruster F5L had a total of 24,163 pulses

and thruster L5L had 20,482 pulses. Vernier thruster L5D had an operating time of 25,049 seconds, and thruster L5L had an operating time of 16,759 seconds.

The RCS hot fire was started at 52:18:48:00 G.m.t. (10:01:04:20 MET) and concluded 8 minutes later. The hot-fire procedure was performed only once, as opposed to the usual "twice through" because of the propellant constraints. All primary thrusters were fired at least once, with several forward RCS thrusters, F1L, F2R, F3L, F4R, F3D, and F4D, being fired twice. Thruster performance was satisfactory.

### Orbital Maneuvering Subsystem

The OMS performed satisfactorily in every aspect of the subsystem. Pertinent data concerning the three dual-engine OMS maneuvers is shown in the following table.

No deviations from the OMRSD or LCC requirements occurred during prelaunch operations. No in-flight anomalies were identified from the data review and analysis. The three OMS maneuvers consumed 17406 lbm of propellants during the mission.

### OMS MANEUVERS

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Duration, sec	Resultant Orbit, nmi.
OMS Assist	42:17:40:00 00:00:02:15	N/A	102.2	N/A
OMS 2	42:18:18:39 00:00:35:00	182.8	115	126.4 by 130.0
Deorbit	53:22:25:10.1 11:04:41:30.1	236.6	139.6	N/A

STS-99 was the first flight of engine (S/N105) after being refurbished by White Sands Test Facility (WSTF). The reconditioning was performed as a part of the maintenance plan to disassemble the engine and replace the soft goods and perform other maintenance as necessary. The demonstrated STS-99 flight performance was not altered by the refurbishment activities.

### Power Reactant Storage and Distribution Subsystem

The performance of the power reactant storage and distribution (PRSD) subsystem was nominal during the STS-99 mission. No in-flight anomalies were identified from the data analysis and review. The PRSD subsystem supplied a total of 3021 lbm of oxygen and 380 lbm of hydrogen to the fuel cells for electrical energy production. In addition, the PRSD supplied 117 lbm of oxygen to the environmental control and life support system (ECLSS) for life support. The oxygen and hydrogen manifold isolation valves were cycled once near the end of the mission to satisfy the OMRSD File IX in-flight checkout requirements.

A 45-hour mission-extension capability existed at landing based on the oxygen (limiting reactant) remaining at an average power level of 16.2 kW. However, at an extension-day power-level of 11.7 kW, a 63-hour mission-extension capability existed.



Pressure spikes in the hydrogen manifold occurred twice for a period of 6 hours and 7 hours during the mission. The first occurrence corresponded to the period when hydrogen tank 2 was the only hydrogen tank in use. Prior to the spikes, hydrogen tanks 3 and 4 were supplying reactant. The second occurrence corresponded to the period when hydrogen tank 5 was the only tank in use. This condition was observed on STS-68. These pressure spikes occur during single tank operation at high quantity and high flow rates. This condition did not cause any impact to the mission.

### Fuel Cell Powerplant Subsystem

The overall performance of the fuel cell powerplant subsystem was nominal, with the exception of the alternate water line check valve leakage that is discussed in the following paragraphs. No OMRSD or LCC violations occurred during prelaunch operations or the flight. Likewise, no in-flight anomalies were recorded during the mission.

The average electrical-power level and load for the 269.67-hour mission was 16.2 kW and 532 amperes. The fuel cells produced 3401 lbm of potable water and 4378 kWh of electrical energy from 3021 lbm of oxygen and 380 lbm of hydrogen. Four purges of the fuel cells were performed during the mission. The actual fuel cell voltages at the end of the mission were 0.10 V above predicted for fuel cells 1 and 3, and 0.15 V below predicted for fuel cell 2. The voltage margin above the minimum performance curve at the end of the mission was 1.1 V for fuel cell 1, 0.6 V for fuel cell 2 and 0.9 V for fuel cell 3.

The fuel cell monitoring system (FCMS) monitored individual cell voltages during prelaunch, on-orbit, and postlanding. Full-rate on-orbit data were recorded for 12 minutes during the flight. The cell performance monitor (CPM) values remained stable throughout the mission.

At approximately 42:18:30 G.m.t. (00:00:50 MET), the fuel cell 2 alternate water line temperature began to increase from approximately 80 °F to 135 °F in a 30-minute period. The fuel cell 2 alternate water line temperature remained steady at 138 °F for the majority of the mission, and that temperature was near the fuel cell 2 product water line temperature of 141 °F. This behavior indicates leakage past the fuel cell 2 alternate water line check valve. Also, leakage of the fuel cell 1 and 3 check valves was also seen to a lesser extent throughout the mission. There was no mission impact.

Although it is not unusual to have some leakage past the alternate water line check valves, leakage at the level seen from the fuel cell 2 check valve has only been seen once and that was on STS-66. Also, the fuel cell 3 check valve leakage was higher than what typically has been seen. As a result, the fuel cell 2 and 3 check valves will be removed and replaced.

Varying electrical load distributions between fuel cells and the main buses are normally dependent on fuel cell age and performance. Fuel cell 1 contained a new power section and fuel cell 2 was near the end of its life, therefore, a large load distribution shift toward fuel cell 1 resulted. The current level on fuel cell 1 reached 308 amperes, while the highest current level on fuel cell 2 was 242 amperes. At those levels, the voltage

on each fuel cell dropped to 29.325 V, which was well above the minimum bus voltage requirement of 28.325 V. The performance of each of the fuel cells was nominal with respect to its accumulated operating hours.

### Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed nominally throughout the STS-99 mission. There was an unusual drain-line temperature signature and an erratic gas generator (GG) bed temperature sensor, both of which are discussed in the following paragraphs. No APU in-flight anomalies were recorded. The operating time and fuel consumption for each of the APUs is summarized in the table on the following page.

#### APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 405)		APU 2 (S/N 303)		APU 3 (S/N 409)	
	(a) (b) Time, Min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel Consumption, Lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	20:28	50	20:31	56	20:34	52
FCS checkout	4:11	18				
Entry <sup>a</sup>	58:54	103	76:00	163	59:01	115
Total	83:22	171	96:31	219	79:35	167

<sup>a</sup> APUs were shut down 14 minutes 02 seconds after landing.

During the launch scrub, the APU 1 injector cycled three times when the temperatures reached 437 to 443 °F. Typically, the GG bed heaters are on 100-percent of the time during prelaunch operations since the aft compartment environment at this time does not allow the GG bed temperature to reach its upper control point. The GG bed temperature sensor is located in the same cavity as the injector temperature sensor. The upper LCC limit for this sensor is 444 °F. The cause of this increase in temperature was the increase in voltage from main bus A. Data have established that the GG heater is sensitive to voltage changes and will increase the bed temperature as much as 30 °F for a one-volt change in supply power. This condition was observed on a previous mission. As a result, the prelaunch electrical loads were adjusted on all three fuel cells to minimize the impact of main bus A voltage on APU 1 heater operation.

At 42:17:52:10 G.m.t (00:00:08:30 MET), the APU 2 drain line temperature increased from 84 °F to 132 °F in approximately 60 minutes. This event began at MECO. Following this rise, thermal performance of the line was as expected. During ascent, the increase in pressure in the line was as expected based on the initial line pressure and the temperature rise experienced.

During the entry operations, the APU 2 drain line temperature again exhibited an unexpected increase from 90 °F to 135 °F in approximately 45 minutes. The signature on the other temperature sensor on the line was nominal during both ascent and entry.

There was no mission impact. An investigation of the catch bottle and the associated drain line will be performed in an effort to determine the cause of this signature.

The FCS checkout was performed using APU 1, which was started at 52:18:04:31 G.m.t. (10:00:20:51 MET). The data showed that the FCS and APU performance was nominal. The APU run time lasted 4 minutes and 11 seconds, and 18 lb of fuel were consumed. Because of the short run-time of the APU, WSB 1 cooling was not required as the APU 1 lubrication-oil-return temperature only reached 189 °F.

The APU 1 gas generator injector tube temperature sensor became erratic after landing. The temperature dipped twice immediately after APU shutdown, which occurred 14 minutes after landing, and then recovered and was stable for 50 seconds. The temperature then dropped out twice to 250 °F and did not recover following the second dropout until approximately 2 hours later. Following the final recovery, the data were nominal. Postflight troubleshooting of this condition will be performed.

### **Hydraulics/Water Spray Boiler Subsystem**

The overall hydraulics/water spray boiler (WSB) subsystem performance was nominal, except for one undercooling condition on WSB 2 during ascent and two overcooling conditions on WSB 3 during entry. No in-flight anomalies were recorded for the hydraulics/WSB subsystem during the mission.

An unexpected pressure drop occurred in hydraulic system 1 approximately five hours prior to the launch. The pressure initially dropped from 480 psia to 463 psia and remained at this level for 16 minutes. At the time of the initial pressure drop, a repositioning of the flight control surfaces was being performed. SSME dithering began at the 16-minute point and the pressure dropped further to 440 psia over a five-minute period after which the pressure dropped a third time to approximately 390 psia. The third drop in pressure was caused by the opening of the thermal bypass valves in several of the FCS actuators. The pressure remained at that level for approximately 1.3 hours before slowly increasing back to the original value of 480 psia about 1.5 hours later. The increase was the result of the bypass valves closing. Discussions were held that explained the cause of the pressure drops to be the sequence of events, which consisted of the repositioning of FCS actuators, SSME valve cycling and the opening of FCS actuator thermal bypass valves. These discussions resulted in a 13-minute 40-second launch delay.

During ascent, a WSB 2 undercooling condition occurred and the APU 2 lubrication-oil return-temperature reached 284 °F before the WSB began spraying while operating on controller A. Almost simultaneous with the beginning of spraying on controller A, the crew was given permission to switch to controller B. After the switch-over, spraying continued on controller B. The temperature returned to nominal levels where it remained for the rest of APU 2 operation. Controllers A and B were used on WSB 2 during entry and landing, and WSB 2 performance on both controllers was nominal. No ground checkout was required. It is currently planned to use an antifreeze-like additive in this WSB during the next flight of OV-105.

During entry, WSB 3 experienced two overcooling conditions. The lubrication oil return temperature dropped from a steady-state temperature of 251 °F to 232 °F before returning back to the steady-state temperature of 251 °F. Approximately 1.5 minutes later, a second overcooling conditions was observed in which the lubrication oil return temperature dropped to 203 °F before returning to approximately 247 °F. Neither of these conditions impacted entry operations and no ground checkout is required.

The FCS checkout was performed using APU 1, which was started at 52:18:04:31 G.m.t. (10:00:20:51 MET). The data showed that the FCS and APU performance was nominal. The APU run time lasted 4 minutes and 11 seconds, and 18 lb of fuel were consumed. Because of the short run-time of the APU, WSB 1 cooling was not required as the APU 1 lubrication-oil return temperature only reached 189 °F.

### **Electrical Power Distribution and Control Subsystem**

The data review and analysis of all available electrical power distribution and control (EPDC) subsystem parameters revealed nominal values throughout the flight. No in-flight anomalies were identified, and all file IX requirements were fulfilled.

### **Atmospheric Revitalization Pressure Control Subsystem**

Both systems of the atmospheric revitalization pressure control subsystem (ARPCS) performed normally throughout the mission.

Because of a misconfiguration of the Kennedy Space Center (KSC) breathing air supply, the final prelaunch cabin integrity check was performed at 1.49 psid instead of at  $2.0 \pm 0.25$  psid. Cabin pressure and dp/dt sensors showed no leak indication, and the test was considered acceptable for flight.

During the second performance of the Heat Exchange Unit Development Test Objective (DTO) 686 evaluation, the unit was connected to the supply water dump purge device instead of to the cross-tie quick disconnect. The purge device allows cabin air to bleed overboard at a rate of 3 lb/hr when the dump valve is open. After 50 minutes of bleeding air overboard, the ARPCS switched to nitrogen flow and a high nitrogen alarm was annunciated. The crew reported that the unit was connected to the purge device. The crew was instructed to connect the unit directly to the cross-tie instead of the purge device. There was no mission impact.

### **Atmospheric Revitalization Subsystem**

The atmospheric revitalization subsystem (ARS) performed nominally throughout the mission.

During prelaunch operations, the avionics bay fan differential pressure ( $\Delta P$ ) for avionics bays 1 and 3 increased in bay 1 and decreased in bay 3 when compared with the previous flight. In both cases, the conditions were acceptable and resulted in no concern for flight operations.

During the flight, the heat exchanger outlet temperature peaked within satisfactory limits, and the cabin temperature and humidity were maintained within nominal limits.

### **Active Thermal Control Subsystem**

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

Ascent performance was nominal with little or no pre-evaporative cooling observed. Radiator flow was initiated at 42:19:01 G.m.t. (00:01:18 MET) and the payload bay doors were opened 24 minutes later. The radiators were not deployed on this flight. Freon coolant loop 2 was configured to cool the payload pallet at 42:20:00 G.m.t. (00:02:07 MET). Four water dumps were made through the flash evaporator system (FES) with the first two dumps 26 minutes apart. The FES dumps were inhibited and the FES heaters were turned off at 46:10:58 G.m.t. (03:15:14 MET) so that water dumps could be performed through the nozzle. This was done when it was determined that the water nozzle dumps in the SRTM attitude actually reduced Orbiter propellant usage. The FES remained deactivated for the next six days of the mission.

The FES duct heaters were restarted at 52:14:50 G.m.t. (09:21:06 MET), and the FES was activated 1 hour and 24 minutes later. Both Freon loops were configured from payload flow to interchanger flow as part of the payload power-down procedures and SRTM mast stowage operations. FES operations were satisfactory for the remainder of the mission.

The ammonia boiler system was activated approximately four minutes after the landing, and satisfactory cooling was provided until ground cooling was initiated.

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

The supply and waste water subsystem performed normally throughout the mission with the exception of the supply-water dump-nozzle anomaly discussed in the following paragraph.

Originally, no supply water dumps were to be performed this mission; however, a malfunction of the payload cold-gas-thruster system required that the Orbiter thrusters be used more than expected in maintaining the SRTM mapping attitude. This usage resulted in an Orbiter propellant concern. It was noted on a waste water dump that the attitude maintenance operations were actually aided by the water dumps. As a result, 15 overboard supply water dumps were performed during the mission. The average water-dump rate during the entire mission was a nominal 1.59 percent/hour (2.61 lb/min). The supply water dump line temperature was maintained between 60.6 °F and 104.7 °F throughout the mission with the use of the line heater.

During supply dump 3, an unusual temperature signature was noted at the dump nozzle. The temperature was erratic, fluctuating around 150 °F throughout the dump. After the third dump, DTO 686 was performed. This DTO involved a chill can that was connected to the supply water cross-tie quick disconnect (QD) for approximately 3.5 hours. This DTO was performed three times and on the first run, the crew

inadvertently connected the chill can to the tee on the air purge device instead of the cross-tie QD. The air purge device dumped cabin air overboard for approximately 50 minutes until the high-flow alarm sounded. The correct connections were made and the DTO was completed satisfactorily.

On dump 4 and subsequent dumps, erratic nozzle temperatures were observed during the heat-up and cool-down cycles of the nozzle heater. On water dumps 10, 11 and 12, the start of the dump occurred as much as two minutes after the dump valve was opened. It is suspected that a buildup of ice in the vicinity of the dump nozzle caused these delays.

During the initiation of an fifteenth Orbiter supply water dump at 52:04:01 G.m.t. (09:46:17 MET), the dump-nozzle heaters operated nominally and the dump valve was opened. However, no decrease in either the nozzle temperatures or tank quantities was identified in the data, indicating that no water was being dumped (Flight Problem STS-99-V-02). The dump valve was cycled with no response, followed by the crew removing the dump-line purge device and closing the dump valve. Changes in the dump-nozzle heater profiles during this time indicated that ice was being ejected from the water line and/or the nozzle. The dump valve was opened again and the supply dump was performed nominally. No additional supply water dumps were performed through the nozzle during the mission. Postflight data evaluation and troubleshooting are being performed. As of the time of this being written, a minor leak of the dump valve has been discovered and the valve will be removed and replaced.

Postflight samples of water from the galley exceeded the allowable bacteria limit. The bacterial level was 160 colony forming units (CFU) per 100 ml. The level should have been less than 100 CFU/100ml. The iodine levels remained low throughout the mission because the iodine removal cartridge that was installed at the inlet to the galley. Typically, the iodine is recirculated through the galley during sleep periods; however, those periods were cut short to about 1 hour per day due to the two-shift operations during this mission. In addition, the hot water tank was deactivated for much of the flight to conserve power. While the 150 °F hot water tank is not meant for sterilization, it does help control bacteria growth.

Waste water was gathered at approximately the predicted rate. Three waste water dumps were performed at an average rate of 1.93 percent/minute (3.20 lb/min). The waste water dump line temperature was maintained between 55.1 °F and 83.7 °F throughout the mission. Vacuum vent line temperature was maintained between 56.8 °F and 79.9 °F. In both cases, the temperatures were nominal.

### **Waste Collection Subsystem**

The waste collection subsystem performed normally throughout the mission with no in-flight anomalies or problems identified.

### Airlock Support System

Use of the airlock support components was not required because no extravehicular activity was required or performed. The active system monitor parameters indicated normal outputs throughout the mission.

### Smoke Detection and Fire Suppression Subsystem

The smoke detection system showed no indication of smoke generation during the mission. Use of the fire suppression system was not required.

### Flight Data Subsystem

The flight data subsystem performed nominally throughout the mission. One anomaly was defined from the preflight operations and that problem is discussed in the following paragraphs.

During the T-29 minute preflight built-in test equipment (BITE) test of EMEC 2, all four primary avionics software system (PASS) general purpose computers (GPCs) indicated input/output (I/O) errors, and errors were also indicated in the EMEC 2 BITE words. Data evaluation indicated a good preflight BITE command followed by the I/O errors (bad address and parity) that were detected by all four PASS GPCs. The errors occurred when receiving the first response word. The software then automatically retried the preflight BITE command and received all 18 response-words from the preflight BITE test. However, words 8 and 9 had six bits set at 1 that should have been 0 (Flight Problem STS-99-V-01).

Following the launch scrub, additional testing of EMEC 2 was performed. This testing included 20 cycles of the preflight BITE test and 30 cycles of a non-critical command, all of which were successful. Additionally, the data evaluation continued and a fault tree was developed and analyzed. The analysis indicated that the problem was most likely in the EMEC; however, no single failure in the EMEC could be identified that could cause the signatures observed as well as being a non-critical failure. This uncertainty led to the decision to remove and replace the EMEC. This decision resulted in the rescheduling of the launch to February 11, 2000.

Through subsequent data evaluation and computer simulation, a failure mode within the EMEC was identified that could have resulted in the failure signature observed. Additionally, after further analysis, there was no indication that a flight software or GPC problem could have caused the observed errors.

During the transition of the software to on-orbit operations at 42:18:37 G.m.t. (00:00:53 MET), the GPCs annunciated a cathode ray tube (CRT) 1 BITE error. The BITE status register indicated a keyboard channel B failure. The crew reassigned CRT 1 to GPC 1, and the error was again annunciated. After a power cycle of CRT 1, it was again reassigned to GPC 1, and the CRT 1 operated nominally for the remainder of the mission. A display electronics unit (DEU) experienced a similar failure in this slot during the first flight of the OV-105 vehicle. A potential failure mode was identified in the CRT select switch, and as a result, a resistance check of the switch was performed. The

test determined that the switch was operating properly, and the decision was made to remove and replace the DEU.

### Flight Software

The flight software performed flawlessly throughout the mission. No in-flight anomalies or problems were identified in the data review and analysis.

### Flight Control Subsystem

Flight control system (FCS) performance was satisfactory throughout the duration of the mission.

The vernier RCS pulse tests were completed at 43:01:46:00 G.m.t. (00:08:02:20 MET). The vernier RCS 1 test indicated that the caged damper system response of the primary roll mode was 5 to 7 percent lower than predicted. The flight control designs were robust to 10 percent uncertainty, thus the response was within preflight robustness boundaries.

Following uncaging of the damper system, the vernier RCS 2 pulse-test was performed. Observed results from the vernier RCS 2 test were inconsistent with the expected uncaged system response, indicating some form of stiff damper failure had occurred since all of the frequencies, amplitudes and damping precisely matched the initial caged damper test. The flight data also showed a non-linear effect in the roll and yaw frequencies for low amplitudes. Frequencies decayed with decreasing amplitude. The frequency shifts were determined to be acceptable at amplitudes significant to flight control. Based on the test results, the isolation of the non-linear effects and the flight system being within the 10 percent design criteria, a recommendation was made to recage the dampers prior to approving the deadband collapse. The composite notch filters that were uplinked prior to flight were acceptable for deadband collapse and science operations with the caged damper system.

The caged damper mast configuration was the most stressful configuration for the flight control system. This is the case because with the light structural damping and the tight 0.1-degree attitude deadbands, the flexible attenuation requirements are increased. To accommodate this condition, additional margin was built into the precise pointing configuration. The digital autopilot performed flawlessly under these conditions. Also, propellant consumption was near the preflight predictions made with the cold gas thruster system.

The high- and low-impulse RCS tests for the payload were performed using the primary RCS aft-firing thrusters. Thrusters L1A and R1A were fired three times and each time the firing was 1.76 seconds in duration. All portions of the test were passed satisfactorily, and approval was given for single-pulse, multi-pulse, and doublet fly-cast orbit-correction maneuvers.

During an attitude-hold period for payload mapping at approximately 43:20:44 G.m.t. (01:03:01 MET), it was determined that the Orbiter RCS propellant usage had doubled from 0.07 to 0.15 percent an hour. This increase in Orbiter propellant usage was



caused by a failure of the payload cold-gas thrust system that was used to provide a constant torque on the vehicle to offset the effects of gravity gradient at the required mapping attitude. As a result of this failure, Orbiter propellant was being used at a higher-than-planned rate to maintain the attitude of the vehicle. A variety of measures designed to reduce the expenditure of propellant were evaluated. Based on these analyses, enough propellant-saving measures were identified to complete the planned 9-day 9-hour science mission.

The inertial measurement unit (IMU) performance was nominal during prelaunch operations and during the mission.

Descent navigation performed nominally with no hardware failures or deselections by the redundancy management (RM). In addition, the global positioning system (GPS) performance during entry was very satisfactory. Two GPS navigation edits were observed while performing the Operations 2 GPS automatic incorporation section of DTO 700-14. Further analysis is required on the orbit best estimate trajectory (BET) data are available to determine whether the GPS or the onboard navigation was in error.

An evaluation of the -Y and -Z star tracker performance showed nominal operations. Both star trackers are flight worthy for the next planned mission of this vehicle.

The backup flight system (BFS) navigation data exhibited similar characteristics to the primary flight system. Postflight error analysis has shown good comparison between the primary flight system state vectors and the BFS state vectors.

### **Displays and Controls Subsystem**

The displays and controls subsystem performed nominally during the mission with the exception of two problems discussed in the following paragraphs. No in-flight anomalies were identified from the analysis of the data.

Approximately 4 hours prior to launch, the crew support personnel reported several times that the main propulsion system (MPS) liquid hydrogen (LH<sub>2</sub>) engine-manifold-pressure tape-meter oscillated erratically from 18 to 60 psia, but always returned to the normal reading of approximately 16 psia. The telemetry data from the pressure transducer was nominal throughout the launch countdown. The flight crew did not report any instances of this erratic operation after they ingressed the vehicle. Although tape-meter operation was not a constraint to launch, troubleshooting was performed to verify proper operation of the caution and warning system for this parameter. Troubleshooting of the dedicated signal conditioner, wiring and tape-meter on the vehicle was performed, and the anomaly was not repeated. The tape meter will be removed and replaced and sent to the NASA Shuttle Logistics Depot (NSLD) for test, teardown and evaluation (TT&E).

At approximately 47:22:18 G.m.t. (05:04:34 MET), the crew reported that the top segment of the tens digit of the minutes display on the forward mission timer, which was configured to operate as a mission-elapsed-time (MET) display, was no longer illuminated. The readout for each digit is comprised of seven segments. Evaluation

determined that there was no potential for an erroneous mapping of one numeric digit into another digit such that the crew might be misled. The 0, 2, 3, and 5 digits were impacted with the 1 and 4 unaffected. The crew later reported that the failure of the element was intermittent.

At 53:04:50 G.m.t. (10:11:06 MET), the crew reported that another segment on the timer had failed. The failed segment was the right upper vertical segment of the hundreds digit of the days display. For this mission, regardless of the usage, this digit was always a zero. Neither of these failures impacted the mission operations. The unit was removed and replaced during turnaround activities.

### **Communications and Tracking Subsystem**

The communications and tracking subsystems performed nominally. No in-flight anomalies were identified.

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

The operational instrumentation (OI) and the Modular Auxiliary Data System (MADS) performed satisfactorily throughout the mission. A few minor measurement problems were noted, but none of these problems had an impact on the mission. The operations recorder intermittent problem is discussed in the following paragraph.

At 45:02:14 G.m.t. (02:08:30 MET) and at 45:18:33 G.m.t. (03:00:49 MET), the Operations (OPS) 2 recorder failed to go in the reverse direction to the beginning-of-tape (BOT) when commanded. Instead the recorder pulled the tape in the forward direction. In both cases, the commands were issued multiple times and the commands resulted in the recorder pulling the tape in the forward direction. The recorder operated properly prior to the two periods and operated properly following the two periods for the remainder of the mission. Other than these two occasions, the rewind BOT command worked as expected and was used numerous times. The recorder was used in the nominal manner for the remainder of the mission, and the anomaly did not recur. The playback command always resulted in the recorder operating in the proper direction and could be used had the condition recurred. The recorder was used without problems to dump data postflight. Postflight troubleshooting will be performed.

### **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. Landing data are presented in the table on the following page.

The opening of the payload bay doors was completed successfully at 42:19:16:08 G.m.t. (00:01:32:39 MET). The payload bay doors were closed and latched satisfactorily for landing at 53:18:16:32 G.m.t. (11:00:32:52 MET).

The main landing gear tires were in good condition for a landing on the SLF runway. Ply undercutting was observed on both left-hand main landing gear tires and on the right-hand inboard main landing gear tire.

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

### LANDING AND BRAKING PARAMETERS

Parameter	From Threshold, Ft	Speed, Keas	Sink rate, ft/sec	Pitch rate, Deg/sec
Main gear touchdown	2966.7	207.4	-1.31	N/A
Nose gear touchdown	6535.2	168.2	N/A	-5.55
Brake initiation speed		166.4 knots		
Brake-on time		46.89 seconds		
Rollout distance		9,953.9 feet		
Rollout time		58.20 seconds		
Runway		33 (Concrete) KSC		
Orbiter weight at landing		225,037.8 lb		
Brake sensor Location	Peak Pressure, psia	Brake assembly	Gross Energy, Million ft-lb	
Left-hand inboard 1	1308.2	Left-hand inboard	20.61	
Left-hand inboard 3	1308.2			
Left-hand outboard 2	1319.7	Left-hand outboard	17.44	
Left-hand outboard 4	1319.7			
Right-hand inboard 1	1841.4	Right-hand inboard	29.56	
Right-hand inboard 3	1841.4			
Right-hand outboard 2	1703.3	Right-hand outboard	27.57	
Right-hand outboard 4	1703.3			

### Integrated Vehicle Heating and Thermal Interfaces

The prelaunch thermal interface purges were nominal. The ascent aerodynamics and plume heating was also normal.

The entry aerodynamic heating to the SSME nozzles was nominal.

### Thermal Control Subsystem

The thermal control subsystem (TCS) performed satisfactorily, maintaining all temperatures within required limits. The heater performance was nominal during the prelaunch and on-orbit portions of the mission.

There were no hydraulic circulation pump runs as a result of the control sensors reaching their lower set points, which were set 25 to 30 °F lower for all three systems to

investigate cryogenic savings. Single runs of systems 1 and 2 were initiated by the ground to prevent the pump body temperature from reaching its 20 °F limit. The system 1 run was approximately 45 minutes in length. The system 2 run lasted only 1.5 minutes.

The RCS L5D vernier thruster-oxidizer telemetry-measurement failed during the mapping attitude, but the GPC software update was linked within the time required to prevent any loss of mapping since the failure occurred over an ocean pass. The sensor had periods when it appeared to recover, and high-rate data also exhibited intermittent spikes back to normal values. This same measurement has failed on previous flights. Loss of any single vernier RCS thruster measurement causes loss of attitude control until the primary RCS can be selected or a software update is uplinked.

Many attitude timeline operations were analyzed to reduce propellant usage because of the failure of the cold-gas thruster system on the payload. Also, attitude timelines were analyzed to support a contingency extravehicular activity (EVA) in the event of a payload-retraction failure, multiple deorbit opportunities and contingency mission-extension days. The final attitude timeline provided for a 9-hour extension of radar mapping activities, while still maintaining the thermal condition of the Orbiter.

### **Aerothermodynamics**

At the time of this writing, the MADS data has not been reduced so that a thorough evaluation of the aerothermodynamics can be made.

### **Thermal Protection Subsystem and Windows**

The thermal protection subsystem (TPS) performed satisfactorily. Entry heating was higher-than-normal based on lower-surface structural temperature response data. Boundary layer transition from laminar flow to turbulent flow was early and symmetrical based on the preliminary data from entry. The skin temperature data indicate temperatures that are indicative of the occurrence of early transition.

The Orbiter TPS sustained a total of 87 hits of which 21 had a major dimension on 1-inch or larger. In summary, both the total number of debris-damage sites and the number of damage sites that were 1-inch or larger were within nominal limits. However, the damage sites that were 1-inch or larger (25) were near the three sigma upper control limit of 29.

Approximately one-half of the damage was concentrated in the area from the nose landing gear to the main landing gear wheel wells, with the left chine receiving more damage than the right. The largest lower surface damage site was located just forward of the LH<sub>2</sub> ET/Orbiter umbilical and spanned three tiles. The damage was 4-inches long by 2-inches wide by 0.75-inch deep. The total number of damage sites and their distribution on the vehicle, as well as a comparison of damage-site data from the last nine flights, are shown in the tables on the following page.

### TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	21	75
Upper Surface	0	0
Window Area	2	10
Right Side	1	1
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	1	1
Total	25	87

### COMPARISON OF DAMAGE SITE DATA FROM LAST NINE FLIGHTS

Parameter	STS -86	STS -87	STS -89	STS -90	STS -91	STS -95	STS -88	STS -96	STS -93	STS -103	STS -99
Lower surface total hits	100	244	95	76	145	139	80	160	161	84	75
Lower surface hits > 1 in.	27	109	38	11	45	42	21	66	42	13	21
Longest damage site, in.	7	15	2.8	3.0	3.0	4.0	4.5	4.0	6.0	1.5	4.0
Deepest damage site, in.	0.4	1.5	0.2	0.25	0.5	0.4	0.5	0.5	0.5	0.25	0.75

Less than the usual tile damage occurred on the base heat shield. All SSME dome-mounted heat shield closeout blankets were in good condition though some small areas of material were torn or frayed. SSME 1 and 2 had blanket damage at the 6 and 3 o'clock positions, respectively.

A metal clip, 2.5 inches by 1 inch, was found 8 feet east of the runway centerline at the 3800-foot location. The metal clip has been identified as a flow restrictor that was part of the seal on the trailing edge of the rudder speedbrake.

Hazing and streaking of the forward-facing Orbiter windows was moderate. Damage sites on the window perimeter tile appeared to be less than usual in quantity and size with a total of 10 hits of which 2 were larger than 1 inch. This damage may be attributed to impacts from forward RCS thruster paper covers and RTV material.

### Gas Sample Analysis

STS-99 was a successful flight for the redesigned gas-sample bottles. The hardware provided six excellent gas samples on this, the twenty-ninth, flight of the redesigned system. The data obtained during ascent in the bottles were nominal. All six bottle-pressures were in the range expected. The hydrogen concentration was within the data base for all Space Shuttle vehicles. The oxygen data were also within the bands of error as is determined by the argon measurement, and the amount detected can be attributed to air.

STS-99 was the third flight for the reprocessed bottles. New pyrotechnic valves were installed on all bottles after being cleaned, using the same process that was used when the bottles were new.

## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The government furnished equipment/flight crew equipment (GFE/FCE) performed nominally during the mission with the exceptions noted in the following paragraphs. No in-flight anomalies were noted with the equipment.

At 44:18:50 G.m.t. (02:01:07 MET), the crew reported that all of the data packs for the Hasselblad camera were showing a red light-emitting diode (LED). The red LED indicates discharged or bad batteries. No spare batteries were onboard the vehicle. The problem did not affect the functioning of the camera, but the time stamp was not on the film. The batteries had been installed in the data packs since August of 1999, and the small current load required to maintain the internal clock apparently drained the batteries. Procedures were modified to preclude this occurrence on future missions.

As a result of the battery malfunction, approximately 80 percent (4000 frames) of the film rolls had no time stamp or mission-roll-frame designation. This malfunction resulted in hand-scribing the film and all film copies with the correct identifier. This operation was labor-intensive and resulted in increased costs of film reproduction as well as a delay of approximately two weeks in the delivery of the copies to JSC users.

Unprocessed images from the electronic still cameras (ESCs) revealed a red tint throughout the mission. Ground processing software was used to remove the red tint from the pictures. The cameras are Kodak 460s, and the problem has not been experienced with similar cameras in the ground laboratory. The red tint appears to vary from very light to harsh on a flight-to-flight basis. The red tint on this mission varied between medium and harsh. In addition, the cameras appear to have an increasing number of "dead" pixels in the unprocessed images. These conditions were observed on both cameras during this mission.

Postflight analysis determined that an 8mm-video-tape recording of landing that was made through the heads-up-display (HUD) was not acceptable. The condition was determined to be caused by a problem with the video recorder.

## CARGO INTEGRATION

Integration hardware performance was nominal throughout the mission.



## POSTLAUNCH PAD INSPECTION

The postlaunch inspection of the launch complex revealed minimal damage, which was typical of damage seen on previous flights. No flight hardware was found during the inspection.

No stud hang-up was experienced during the launch as the lateral acceleration at liftoff was 0.11 g, which is below the threshold for stud hang-ups. The erosion was typical on the south posts. The north hold-down post blast covers and T-0 umbilical exhibited typical exhaust plume damage.

The condition of the main launch platform (MLP) and the tail service masts (TSMs) was typical of that observed on previous flights. The Orbiter access arm appeared undamaged.

## DEVELOPMENT TEST OBJECTIVE/DETAILED SUPPLEMENTARY OBJECTIVE

### DEVELOPMENT TEST OBJECTIVES

**DTO 686 - Heat Exchange Unit Evaluation** - A commercial portable heat exchange unit that uses water as the refrigerant was evaluated. Chilling was effected by evaporating the water under reduced pressure that is obtained from the vacuum of space. After a required reconfiguration because of cabin air being inadvertently vented overboard during the initial setup, the unit performed nominally.

**DTO 690 - Urine Collection Device** - The urine collection device (UCD) is to be used as a backup device to the waste collection system. The purpose of this DTO was to evaluate several types and sizes of UCDs. Data were obtained by on-orbit subject evaluation and postflight debriefings.

**DTO 700-14 - Single String Global Positioning System (Payload Ground Support Computer Option) Miniature Air-To-Ground Receiver** - The miniature air-to-ground receiver (MAGR) payload and general support computer (PGSC) data recording program was activated approximately 26 hours prior to launch. The PGSC began recording MAGR data approximately 5 hours prior to launch when the MAGR was powered. Approximately 13 hours after launch, the crew unstowed the PGSC and performed the on-orbit setup procedures.

During flight day 3 activities, the crew observed that the Global Positioning System (GPS) PGSC data-recording program had terminated. The crew was able to restart the program satisfactorily. Initial estimates were that approximately 2 hours 20 minutes of MAGR data were lost. The data loss did not occur during any critical payload or MAGR data-take periods, and did not impact the mission. The data loss probably was caused by a "single-event upset" of the PGSC. This type of data loss has occurred on previous missions. Daily status reports following this incident indicated that the MAGR PGSC was properly recording GPS data.

At 45:23:29 G.m.t. (03:05:45 MET), a specific MAGR data set was successfully copied from the MAGR PGSC by the crew and downlinked using the Orbiter communications adapter (OCA). The data were given to the SRTM GPS personnel who reported that the downlinked sample of MAGR data was processed satisfactorily at the Jet Propulsion Laboratory. The MAGR pseudo-range data compared very well with the SRTM internal GPS data, thus confirming that the MAGR data would be a good backup data source.

The crew reported at 50:22:04 G.m.t. (08:04:20 MET) that the MAGR PGSC recording program had again terminated. The cause was determined to be in the software that would not allow proper rollover to the PGSC drive D partition when the world map was called up on the PGSC. The crew performed the MAGR PGSC contingency restart procedure, which was successful. Initial estimates are that 36 minutes of data were lost.

During the on-orbit operations, three periods of high "figure of merit" were noted, and these lasted between two and three minutes each. This condition is acceptable at this level as long as the condition did not occur during entry.

The MAGR PGSC was configured for entry about 10 hours prior to landing and that was well after SRTM operations had ceased. MAGR data recording to the PGSC was suspended at this time as planned, but data recording was resumed during deorbit preparations through landing.

**DTO 700-17A - High Definition Television Camcorder Performance** - This DTO was performed throughout the mission and all objectives of the DTO were met. Tapes from the evaluation were sent to the Public Affairs Office, Earth Observations Office and the NASDA in Japan.

**DTO 805 - Crosswind Landing Performance** - The purpose of this DTO of opportunity was to demonstrate the capability to perform a manually controlled landing in the presence of a crosswind. The DTO was attempted; however, the KSC wind tower data indicates that the crosswind was less than the DTO criteria. This criterion is a steady-state crosswind between 10 and 15 knots with a peak crosswind not exceeding 15 knots.

#### DETAILED SUPPLEMENTARY OBJECTIVES

**DSO 206 - Effect of Space Flight on Bone, Muscle, and Immune Function** - The objective of this study was to investigate the basic mechanism of the effects of space flight on the musculoskeletal system and immune function during long-term space flight. Data collection was completed during the preflight and postflight periods as no data were collected during the flight.

**DSO 493 - Monitoring Latent Virus Reactivation and Shedding in Astronauts** - Post-sleep saliva collection was completed for the purpose of assessing space-flight induced alterations in the immune response. Postflight sampling and assessment was also performed.

**DSO 496 - Individual Susceptibility to Post-Space-Flight Orthostatic Intolerance** - The cardiovascular function is altered in space flight, and the susceptibility is highly individualized. Testing that is designed to elucidate the preflight and postflight differences in susceptible as well as non-susceptible subjects was conducted during preflight preparations and repeated during the postflight period.

**DSO 498 - Space Flight and Immune Function** - The immune cells from subjects participating in space flight of longer than 10 days duration are collected during preflight preparations and postflight operations. These cells are used to characterize the effects of space flight on selected immune elements.

**DSO 802 - Educational Activities** - The crew responded to 30 questions from students in three locations during the live classroom event. The students of Morgan Elementary School (Hutchinson, KS) participated from the Kansas Cosmosphere; middle and high school students from eight regional schools on the Standing Rock

Indian Reservation in North Dakota participated from Sitting Bull College; and students from Sam Houston High School in San Antonio, Texas, also participated.

## PHOTOGRAPHY AND VIDEO DATA ANALYSIS

### LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

A total of 46 films and 26 videos of the launch were reviewed and analyzed. No anomalous conditions were noted in the films and videos that would be a concern for the flight. Many of the long-range tracking films were soft focused because of the atmospheric haze. All views showing the +Y longeron, containing the cracked thermal protection system material that was detected prior to launch, confirmed that no loss of the foam occurred within the field of view. Solid Rocket Booster (SRB) separation appeared normal with numerous pieces of slag visible before, during and after separation.

### ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

The hand-held 35-mm camera with the 400 mm lens was used to take 35 photographs of the External Tank (ET) after separation from the Orbiter. Timing data were on the film, and the first exposure was made at 42:18:02:24 G.m.t. (00:00:18:44 MET). The ET was calculated to be 2.1 km from the Orbiter at that time. A manual pitch maneuver was performed from the heads-up position to bring the ET into view from the Orbiter overhead windows. Views of the ET nose, aft dome and all sides were obtained. Shadows were present from the late afternoon Sun, and this condition hindered analysis of many of the views.

The normal SRB separation burn scars and aerodynamic heating marks were noted on the intertank and nose thermal protection system (TPS) material. Based on the distance and film resolution, divots greater than eight inches in size should have been detectable on the surface of the ET including the thrust panels. The review revealed only one possible divot, and this was located on the LH<sub>2</sub> tank-to-intertank closeout flange on the -Z side of the ET. On 10 of the exposures, venting was visible from the area of the -Y axis of the ET intertank. This condition has been noted on five of the recently flown missions and is not considered anomalous.

The 35mm and 16mm film from the umbilical wells was reviewed and analyzed. Overall, the ET and Orbiter were in good condition after ET separation from the Orbiter based on the screening of the 35mm film. Some pock marks were visible, but all of them were of a minor nature.

### LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

The videos and films of landing were received and screened. No major anomalies were noted in the approach, landing, and rollout video and film views screened. All observations were nominal.

**TABLE I.- STS-99 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	042:17:38:49.541 042:17:38:52.824 042:17:38:56.052
SRB HPU Activation <sup>a</sup>	RH HPU System B start command LH HPU System A start command LH HPU System B start command RH HPU System A start command	042:17:43:11.05 042:17:43:11.65 042:17:43:11.78 042:17:43:11.93
Main Propulsion System Start <sup>a</sup>	ME-3 Start Command accepted ME-2 Start Command accepted ME-1 Start Command accepted	042:17:43:33.439 042:17:43:33.560 042:17:43:33.691
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	043:17:43:39.997
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:43:43.978 042:17:43:43.979 042:17:43:44.011
Throttle down to 72 Percent Thrust	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:44:20.139 042:17:44:20.140 042:17:44:20.171
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	042:17:44:31
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:44:34.379 042:17:44:34.380 042:17:44:34.411
Both RSRM's Chamber Pressure at 50 psi <sup>a</sup>	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	042:17:45:40.40 042:17:45:40.76
End RSRM <sup>a</sup> Action <sup>a</sup> Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	042:17:45:43.14 042:17:45:43.82
SRB Physical Separation <sup>a</sup>	LH rate APU turbine speed - LOS	042:17 45:45.52
SRB Separation Command	SRB separation command flag	042:17:45:46
OMS Assist Maneuver Ignition	Right Engine Bi-Prop Valve Position Left Engine Bi-Prop Valve Position	042:17:45:55.7 042:17:45:55.7
OMS Assist Maneuver Cutoff	Right Engine Bi-Prop Valve Position Left Engine Bi-Prop Valve Position	042:17:47:38.1 042:17:47:38.1
Throttle Down for 3g Acceleration <sup>a</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:51:00.622 042:17:51:00.624 042:17:51:00.651
3g Acceleration	Total load factor	042:17:51:45.2
Throttle Down to 67 Percent Thrust <sup>a</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:51:56.943 042:17:51:56.944 042:17:51:56.972
SSME Shutdown <sup>a</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	042:17:52:03.463 042:17:52:03.465 042:17:52:03.491

<sup>a</sup>MSFC supplied data

**TABLE I.- STS-99 SEQUENCE OF EVENTS  
(Continued)**

Event	Description	Actual time, G.m.t.
MECO	MECO command flag	042:17:52:04
	MECO confirm flag	042:17:52:05
ET Separation	ET Separation Command flag	042:17:52:23
APU Deactivation	APU-1 GG chamber pressure	042:17:59:13.499
	APU 2 GG chamber pressure	042:17:59:19.714
	APU 3 GG chamber pressure	042:17:59:26.625
OMS-1 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
OMS-1 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	
OMS-2 Ignition	Left engine bi-prop valve position	042:18:18:39.8
	Right engine bi-prop valve position	042:18:18:39.8
OMS-2 Cutoff	Left engine bi-prop valve position	042:18:20:35.0
	Right engine bi-prop valve position	042:18:20:35.0
Payload Bay Doors (PLBDs) Open	PLBD right open 1	042:19:14:50
	PLBD left open 1	042:19:16:09
Flight Control System Checkout APU 1 Start APU 1 Stop	APU 1 GG chamber pressure	052:18:04:41.058
	APU 1 GG chamber pressure	052:18:08:38.469
Payload Bay Door Closure	PLBD left close 1	053:18:12:47
	PLBD right close 1	053:18:15:31
APU Activation for Entry	APU-2 GG chamber pressure	053:22:20:19.064
	APU-1 GG chamber pressure	053:22:37:18.348
	APU-3 GG chamber pressure	053:22:37:24.005
OMS Deorbit Burn Ignition	Right engine bi-prop valve position	053:22:25:10.4
	Left engine bi-prop valve position	053:22:25:10.4
OMS Deorbit Burn Cutoff	Right engine bi-prop valve position	053:22:27:29.8
	Left engine bi-prop valve position	053:22:27:29.8
Entry Interface (400K feet)	Current orbital altitude above	053:22:50:08
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	053:23:16:09
Main Landing Gear Contact	RH MLG inboard tire pressure	053:23:22:24
	LH MLG inboard tire pressure	053:23:22:24
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels	053:23:22:24
	RH main landing gear weight on wheels	053:23:22:28
Nose Landing Gear Contact	RGA 1 pitch rate	053:23:22:34
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	053:23:22:35
Drag Chute Deployment	Drag chute deploy 1 CP volts	053:23:22:35.8
Drag Chute Jettison	Drag chute jettison 1 CP Volts	053:23:23:04.9
Wheel Stop	Velocity with respect to runway	053:23:23:23
APU Deactivation	APU-1 GG chamber pressure	053:23:36:10.858
	APU-2 GG chamber pressure	053:23:36:16.762
	APU-3 GG chamber pressure	053:23:36:22.876

TABLE II- STS-99 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-99-V-01	GPC I/O Errors and EMEC Preflight BITE Error	031:16:48 G.m.t. Prelaunch PR OEL-5-15-2099 CAR 99RF01	<p>During the T-29 minute preflight BITE test of EMEC 2, all four PASS GPCs indicated I/O errors and errors were indicated in the EMEC 2 BITE words. Data Evaluation indicated a good preflight BITE command followed by the I/O errors (bad address and parity) detected by all four PASS GPCs. The errors occurred when receiving the first response word. The software then automatically retried the preflight BITE command and received all 18 response-words from the preflight BITE test. However, words 8 and 9 had 6 bits set at 1 that should have been 0.</p> <p>Following the launch scrub for bad weather, additional testing of EMEC 2 was performed. This testing included 20 cycles of wrap and preflight BITE tests and 30 cycles of a non-critical command, all of which were successful. Additionally, the data evaluation continued and a fault tree was developed and analyzed. The analysis indicated that the problem was most likely in the EMEC; however, it was unable to identify a single failure in the EMEC that could result in the signatures observed and be a non-critical failure. This uncertainty lead to the decision to remove and replace the EMEC.</p> <p>The EMEC was removed, replaced and successfully tested. Following further analysis of the data and computer simulations, a potential failure mode that could cause the errors seen was identified within the control logic of the MIA I/O module. The suspect circuits are part of the control logic that clears the command registers. Additionally, after further analysis, there was no indication of a flight software or GPC problem that could have resulted in the errors seen.</p> <p>KSC: The replaced EMEC was sent to the NASA Shuttle Logistics Depot (NSLD) for testing and evaluation. As of this writing, the failure has not been duplicated.</p>
STS-99-V-02	Supply Water Dump Nozzle Blockage	052:04:01 G.m.t. 09:10:17 MET IPR 97V-0010 CAR 99RF07	<p>During the initiation of the fifteenth Orbiter supply water dump at 052:04:01 G.m.t. (09:10:17 MET), the dump-nozzle heaters operated nominally and the dump valve was opened. However, no decrease in either the nozzle temperature or tank quantities was identified, indicating that no water was being dumped. The dump valve was cycled with no response, followed by the closing of the dump valve. Changes in the dump-nozzle temperature profile immediately following the last valve closure indicated that ice was being ejected from the water line and/or the nozzle. The dump valve was opened again and the supply water dump was performed nominally. No additional supply water dumps were performed during the remainder of the mission.</p> <p>Data evaluation indicated peculiarities in several of the water dumps performed during this mission, beginning with dump 3. Evaluation of the data as well as the post-dump purge and DTO 686 (chill can) procedures is continuing.</p> <p>KSC: Troubleshooting is in work.</p>



## DOCUMENT SOURCES

In an attempt to define the official as well as the unofficial sources of data for the STS-99 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. MER Daily Reports
5. MER Mission Summary Report
6. MER In-Flight Anomaly List
7. MER Problem Tracking List
8. MER Event Times
9. Subsystem Manager Reports/Inputs
10. MOD Systems Anomaly List
11. MSFC Flash Report
12. MSFC Event Times
13. MSFC Interim Report
14. Crew Debriefing comments
15. Shuttle Operational Data Book
16. STS-99 Summary of Significant Events
17. Contractor Reports of Subsystem Operation

## ACRONYMS AND ABBREVIATIONS

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

APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
BET	best estimate trajectory
BFS	backup flight system
BITE	built-in test equipment
BOT	beginning of tape
CEI	contractor end item
CFU	colony forming unit
CPM	cell performance monitor
CRT	cathode ray tube
DCU	digital controller unit
DEU	display electronics unit
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
°F	degrees Fahrenheit
$\Delta P$	differential pressure
$\Delta V$	differential velocity
deg/hr	degree per hour
EarthKam	Earth photography
ECLSS	environmental control and life support system
EMEC	enhanced mission event controller
EO	ET/Orbiter
EPDC	electrical power distribution and control subsystem
ESA	European Space Agency
ESC	electronic still camera
ET	External Tank
EVA	extravehicular activity
FMBT	flexible bearing mean bulk temperature
FCE	flight crew equipment
FCMS	fuel cell monitoring system
FCS	flight control system
FCV	flow control valve
FES	flash evaporator system
FID	Failure Identification
ft/sec	feet per second
g	gravity
GFE	Government furnished equipment
GG	gas generator
GH <sub>2</sub>	gaseous hydrogen
GMEM	GPC memory
G.m.t.	Greenwich mean time

GPC	general purpose computer
GPS	Global Positioning System
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
hr	hour
HUD	heads-up display
IMU	inertial measurement unit
I/O	input/output
IPL	initial program load
$I_{sp}$	specific impulse
JSC	Johnson Space Center
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt hour
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LED	light emitting diode
LH <sub>2</sub>	liquid hydrogen
LMSO	Lockheed Martin Space Operations
LO <sub>2</sub>	liquid oxygen
LWT	lightweight tank
MADS	modular auxiliary data system
MAGR	miniature air-to-ground receiver
MECO	main engine cutoff
MET	mission elapsed time
ml	milliliter
MLP	main launch platform
MOD	Mission Operations Directorate
MPS	main propulsion system
N	North
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
nmi.	nautical mile
NPSP	net positive suction pressure
NSLD	NASA Shuttle Logistics Depot
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OCA	Orbiter communications adapter
OI	operational instrumentation
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	operations
PAL	protuberance air load
PASS	primary avionics software system
PGSC	payload and general support computer
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution
psi	pound per square inch

psia	pound per square inch absolute
psid	pound per square inch differential
PSIG	Propulsion Systems Integration Group
psi/hr	pound per square inch per hour
QD	quick disconnect
RCS	reaction control subsystem
RM	redundancy management
RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing
S	South
S&A	safe and arm
scch	standard cubic centimeters per hour
SLF	Shuttle Landing Facility
S/N	serial number
SRB	Solid Rocket Booster
SRL	Space Radar Laboratory
SRSS	Shuttle range safety system
SRTM	Shuttle Radar Topography Mission
SSME	Space Shuttle main engine
STS	Space Transportation System
TCS	thermal control system
TPS	thermal protection subsystem
TSM	tail service mast
TT&E	test, teardown and evaluation
UCD	urine collection device
V	volt
WSB	water spray boiler
WSTF	White Sands Test Facility