

# **STS-88 SPACE SHUTTLE MISSION REPORT**

---

February 1999



**National Aeronautics and  
Space Administration**

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

## NOTE

The STS-88 Space Shuttle Mission Report was prepared from inputs received from the Flight Projects Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

Kenneth L. Brown  
713-483-3891

Orbiter and Subsystems

James Yeager, MSFC  
205-544-3963

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

Elmer Taylor  
713-483-1217

Payloads/Experiments

Ralph V. Anderson, JSC  
713-483-1271

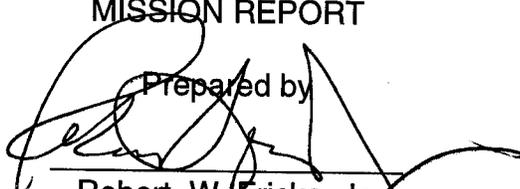
FCE and GFE

STS-88

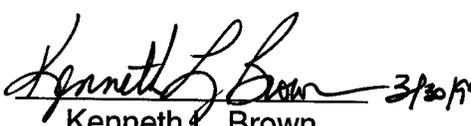
SPACE SHUTTLE

MISSION REPORT

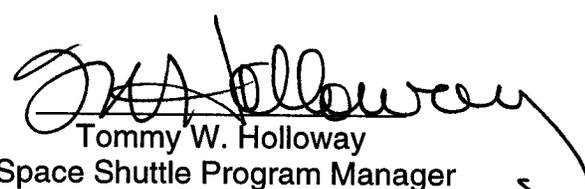
Prepared by

  
Robert W. Fricke, Jr.  
LMSMS&S/Operations Engineering Office

Approved by

 3/30/99  
Kenneth L. Brown  
STS-88 Lead Mission Evaluation Room Manager

 3/31/99  
Ronald D. Dittmore  
Manager, Space Shuttle Vehicle Engineering Office

  
Tommy W. Holloway  
Space Shuttle Program Manager

Prepared by  
Lockheed Martin Space Mission Systems and Services  
for the  
Space Shuttle Vehicle Engineering Office

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

February 1999

## STS-88 Table of Contents

<u>Title</u>	<u>Page</u>
<u>INTRODUCTION</u> .....	1
<u>MISSION SUMMARY</u> .....	3
<u>PAYLOADS AND EXPERIMENTS OPERATIONS</u> .....	11
FLIGHT OBJECTIVES .....	11
SATELLITE DE APLICACIONES/CIENTIFICO-A. ....	12
MIGHTYSAT .....	13
IMAX CARGO BAY CAMERA. ....	13
GET-AWAY SPECIAL. ....	14
SPACE EXPERIMENT MODULE .....	14
SHUTTLE IONOSPHERIC MODIFICATION. ....	16
<u>VEHICLE PERFORMANCE</u> .....	17
SOLID ROCKET BOOSTERS. ....	17
REUSABLE SOLID ROCKET MOTORS. ....	17
EXTERNAL TANK. ....	19
SPACE SHUTTLE MAIN ENGINES .....	19
SHUTTLE RANGE SAFETY SYSTEM .....	20
ORBITER SUBSYSTEMS. ....	20
<u>Main Propulsion System</u> .....	20
<u>Reaction Control Subsystem</u> . ....	21
<u>Orbital Maneuvering Subsystem</u> . ....	23
<u>Power Reactant Storage and Distribution Subsystem</u> . ....	24
<u>Fuel Cell Powerplant Subsystem</u> . ....	24
<u>Auxiliary Power Unit Subsystem</u> . ....	25
<u>Hydraulics/Water Spray Boiler Subsystem</u> . ....	25
<u>Electrical Power Distribution and Control Subsystem</u> . ....	26
<u>Orbiter Docking System</u> .....	26
<u>Atmospheric Revitalization Pressure Control System</u> . ....	27
<u>Atmospheric Revitalization Subsystem</u> . ....	27
<u>Active Thermal Control Subsystem</u> .....	28
<u>Supply and Waste Water Subsystem</u> . ....	28
<u>Waste Collection Subsystem</u> .....	29
<u>Airlock Support System</u> .....	29
<u>Smoke Detection and Fire Suppression Subsystem</u> ..	30
<u>Flight Data Subsystem</u> .....	30
<u>Flight Software</u> . ....	30
<u>Flight Control System</u> .....	31
<u>Displays and Controls Subsystem</u> .....	31
<u>Communications and Tracking Subsystems</u> .....	32
<u>Operational Instrumentation/Modular</u>	
<u>Auxiliary Data System</u> .....	33
<u>Structures and Mechanical Subsystems</u> .....	33

**STS-88 Table of Contents (Concluded)**

<b><u>Page</u></b>	<b><u>Title</u></b>
	<b><u>Integrated Vehicle Heating and Thermal</u></b>
	<b><u>Interfaces</u></b> ..... 34
	<b><u>Thermal Control Subsystem</u></b> ..... 34
	<b><u>Aerothermodynamics</u></b> ..... 34
	<b><u>Thermal Protection Subsystem and Windows</u></b> ..... 34
	<b><u>EXTRAVEHICULAR OPERATIONS</u></b> ..... 37
	<b><u>REMOTE MANIPULATOR SYSTEM OPERATION</u></b> ..... 39
	<b><u>GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW</u></b>
	<b><u>EQUIPMENT</u></b> ..... 41
	<b><u>CARGO INTEGRATION</u></b> ..... 43
	<b><u>POSTLAUNCH PAD INSPECTION</u></b> ..... 44
	<b><u>DEVELOPMENT TEST OBJECTIVE/DETAILED SUPPLEMENTARY</u></b>
	<b><u>OBJECTIVES</u></b> ..... 45
	DEVELOPMENT TEST OBJECTIVES ..... 45
	DETAILED SUPPLEMENTARY OBJECTIVES ..... 46
	<b><u>PHOTOGRAPHY AND TELEVISION ANALYSIS</u></b> ..... 47
	<b><u>LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS</u></b> ..... 47
	<b><u>ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS</u></b> ..... 47
	<b><u>LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS</u></b> ..... 48

**List of Tables**

TABLE I - STS-86 SEQUENCE OF EVENTS.....	49
TABLE II - STS-86 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST.....	52
A - <b><u>DOCUMENT SOURCES</u></b> .....	A-1
B - <b><u>ACRONYMS AND ABBREVIATIONS</u></b> .....	B-1

## INTRODUCTION

The STS-88 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during the mission. The report also summarizes the mission activities and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this ninety-third mission of the Space Shuttle Program. STS-88 was the sixty-eighth flight since the return to flight, and the thirteenth flight of Orbiter-105 (Endeavour) vehicle.

The flight vehicle consisted of the OV-105 Orbiter; an ET that was designated ET-97, which was the third super lightweight tank (SLWT); three Block IIA SSMEs that were designated as serial numbers (S/N) 2047, 2044, and 2045 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-095. The two RSRMs were designated RSRM 67 with one installed in each SRB. The individual RSRMs were designated 360W067A for the left SRB, and 360W067B for the right SRB. For this mission, the vehicle was erected on Mobile Launch Platform (MLP) 3 and the launch was completed from launch pad 39A.

The STS-88 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirements as documented in NSTS 07700, Volume VII, Appendix E. The requirement is that each organizational element supporting the Program will report the results of their hardware and software evaluation and mission performance plus identify all related in-flight anomalies.

The primary objectives of the STS-88 mission were to deliver and assemble the 2S Launch Package (LP) to the orbiting International Space Station (ISS) Stage 1. Prior to rendezvous, the Cargo Element (CE), which consisted of Node 1 with Pressurized Mating Adapter-1 (PMA-1) and PMA-2 pre-integrated on the Node 1 axial ports, was installed on the Orbiter Docking System (ODS) using the Shuttle Remote Manipulator System (SRMS). After final approach to Stage 1, the SRMS was used to capture Stage 1 and berth it to the PMA-1 Androgynous Peripheral Docking System (APDS). Prior to undocking, three scheduled extravehicular activities (EVA's) were performed to connect three sets of umbilicals and to install EVA tools/hardware. The secondary objectives of this flight are to perform IMAX Cargo Bay Camera (ICBC) operations, perform Alkali Metal Thermal-to-Electric Converter/Automated Wafer Cartridge System (AMTEC/AWCS) operations, deploy Mighty Sat 1 and deploy Satellite de Aplicaciones/Cientifico-A (SAC-A).

The STS-88 mission was a planned 11 day plus 2-contingency-day mission during which items listed in the previous paragraph will be performed. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. The STS-88 sequence of events is shown in Table I, and the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List is shown in Table II. Appendix A lists the sources of data, both informal and formal, that were used in the preparation of this report. Appendix B provides the definitions of all acronyms and abbreviations used in this report. All times are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The seven crewmembers of the STS-88 mission consisted of Robert D. Cabana, Col., U. S. Marine Corps, Commander; Frederick W. Sturchow, Major, U. S. Marine Corps, Pilot; Jerry L. Ross, Col., U. S. Air Force, Mission Specialist 1; Nancy J. Currie, Ph. D., Lt. Col., U. S. Army, Mission Specialist 2; James H. Newman, Ph.D., Civilian, Mission Specialist 3; and Sergei K. Krikalev, Civilian, Russian Cosmonaut, Mission Specialist 4. STS-88 was the sixth Space Shuttle flight for Mission Specialist 1, the fourth Space Shuttle flight for the Commander, the third Space Shuttle flight for Mission Specialist 2 and Mission Specialist 3, the second Space Shuttle flight for Mission Specialist 4, and the first Space Shuttle flight for the Pilot. However, Mission Specialist 4 has also had three expeditions to the Mir Space Station during which he logged over 1 year in the space environment.

## MISSION SUMMARY

At 337:08:53:42 G.m.t. (approximately liftoff minus 4½ minutes) during the final countdown for the planned launch on December 3, 1998, a master alarm was annunciated for a Launch Commit Criteria (LCC) violation and the countdown was held at that point (Flight Problem STS-88-V-07). The hydraulic system 1 supply pressure B dropped to 1636 psia, well below the 2400-psia master-alarm trigger point, during transition from low pressure to normal pressure. The backup flight system (BFS) did not receive the fault message because the pressure recovered prior to the second data scan below the lower limit. Data analysis confirmed the expected switching valve operation, and confirmed that an insufficient flow demand did not cause the pressure drop. A review of the flight data indicated that the system 1 depressurization valve was momentarily energized at the time of the pressure drop. Troubleshooting and switch tests on the vehicle documented that switch tease was the most likely cause of the momentary actuation of the depressurization valve. The troubleshooting also showed that the hydraulic system 1 depressurization switch had good stability in the normal-pressure position. Proper remote power controller (RPC) operation with the switch in the normal-pressure position was verified on this vehicle during the STS-89 mission. Based on the results of the data evaluation and the vehicle tests, the decision was made to make no changes to the vehicle and fly as-is.

The STS-88 mission was launched on an inclination of 51.6 degrees at 338:08:35:34.019 G.m.t. (3:36 a.m. e.s.t.) on December 4, 1998, following a scrub of the first launch attempt on December 3, 1998. The ascent phase was nominal with the exception of water spray boiler 2, which under-cooled the auxiliary power unit (APU) 2 lubrication oil. The lubrication oil outlet temperature reached 325 °F prior to the beginning of spraying. This under-cooling condition did not impact APU 2 operations during the remainder of the mission.

All Space Shuttle main engine (SSME) and Reusable Solid Rocket Motor (RSRM) start sequences occurred as expected and their launch performance was satisfactory in all respects. First and second stage ascent performance was as expected. The Solid Rocket Booster (SRB) separation, entry, deceleration and water impact was nominal. Both SRBs were successfully recovered and were returned to KSC for disassembly and refurbishment.

A determination of ascent propulsion performance was made using vehicle acceleration and preflight propulsion system prediction data. From these data, the average flight-derived engine specific impulse ( $I_{sp}$ ) that was determined for the time period between SRB separation and start of 3g throttling was 453.2 seconds. This compares well with the SSME tag value of 452.73 seconds.

An orbital maneuvering subsystem (OMS) assist maneuver was performed during ascent. The maneuver was approximately 102.5 seconds in duration. The OMS performed satisfactorily during this maneuver.

The OMS-2 maneuver was performed at 338:09:19:15.7 G.m.t. [00:00:43:41.7 mission elapsed time (MET)]. The maneuver was 67.2 seconds in duration and provided a differential velocity ( $\Delta V$ ) of 102 ft/sec. The resulting orbit was 175 by 87.2 nmi.

The payload bay doors were opened at 338:10:16:17 G.m.t. (00:01:40:43 MET). Dual motor times were recorded during the opening activities.

The Ku-band antenna was deployed in nominal dual motor times at 338:10:25 G.m.t. (00:01:50 MET). The initial self-test of the antenna was completed with a failed indication; however, the second self-test was completed with a passed indication. The Ku-band antenna operated properly throughout the mission.

The OMS-3 NC1 rendezvous maneuver was performed with only the left engine at approximately 338:12:25 G.m.t. (00:03:50 MET). The engine firing was approximately 14 seconds in duration and imparted a  $\Delta V$  of 10.6 ft/sec to the vehicle. Three subsequent rendezvous maneuvers (NC2, NPC, and NC3) were canceled as the maneuvers were not required.

Upon installing the galley iodine removal assembly (GIRA) hose at approximately 338:13:45 G.m.t. (00:05:00 MET), the crew found an incompatible connection between the activated carbon ion exchange (ACTEX) cartridge and the ACTEX hose assembly (Flight Problem STS-88-V-08). An in-flight maintenance (IFM) procedure was performed that replaced the male quick disconnect (QD) at the end of the ACTEX hose with a female QD from a hose that was a part of the contingency hose and cable kit. The GIRA operated properly thereafter.

The crew compartment was depressurized to 10.2 psia to pre-breathe the two crewmembers who were to perform the extravehicular activities (EVA's). This began at 339:01:33 G.m.t. (00:16:00 MET) and was completed approximately 30 minutes later with the cabin pressure stabilized at 10.25 psia.

At 339:02:04 G.m.t. (00:17:29 MET), the crew reported a binding condition with the payload bay closed circuit television (CCTV) camera B pan drive mechanism (Flight Problem STS-88-V-01). In the fast pan/tilt rate, camera B failed to pan the required 90 degrees. The binding did not appear to repeat when the camera was operated in the SLOW pan/tilt rate. As a result, camera B was not used for Orbiter Space Vision System (OSVS) checkout, and was left in an acceptable pan position to support upcoming berthing operations. On flight day 8 at 345:01:16 G.m.t. (06:16:41 MET), additional troubleshooting was performed. The camera appeared to experience binding during fast-rate operation. When the binding occurred, the camera moved sluggishly or stopped moving altogether. When the camera was panned using the slow-rate operation, binding appeared not to occur. Video of camera B was taken using camera C and that data was used for analysis of the problem.

Power was applied to the remote manipulator system (RMS) at 339:02:09 G.m.t. (00:17:33:26 MET). The RMS checkout was completed successfully followed by a payload bay survey. The arm was then powered down and cradled, latched and placed in the temperature-monitor mode. All RMS operations were nominal.

The extravehicular mobility unit (EMU) checkout was performed at 339:06:19:36 G.m.t. (00:21:44:02 MET). All three suits performed nominally and were ready for the planned EVA's.

Checkout was performed only on CCTV camera C with the OSVS because of a possible problem with the camera B pan-and-tilt operation. The checkout was nominal. Docking ring extension was successfully completed at 339:09:31:54.9 G.m.t. (01:00:56:20 MET). Activation of Orbiter interface units (OIU's) 1 and 2 was performed, and the OIU's performed nominally.

The RMS was repowered at 339:21:20 G.m.t. (01:12:45 MET), and the arm was maneuvered from its pre-cradle position to the Node 1 pre-grapple position. Node 1 was grappled by the RMS at 339:22:05 G.m.t. (01:13:30 MET). The RMS was used to unberth and move Node 1 to the Orbiter docking system (ODS) pre-installation position. At 339:23:42 G.m.t. (01:15:07 MET), with four inches of separation between Node 1 and the ODS, the RMS was switched into the test mode. At 339:23:43 G.m.t. (01:14:58 MET), the automatic brakes were inhibited by general purpose computer (GPC) command. At that time, the RMS was in a "limp" configuration and the Orbiter primary reaction control subsystem (RCS) thrusters were fired to complete the mating of Node 1 and the ODS. The first contact of the Orbiter docking ring by the pressurized mating adapter (PMA) 2 was at 339:23:44:43 G.m.t. (01:15:09:09 MET). At 339:23:45 G.m.t. (01:15:10 MET), a successful connection between Node 1 and the ODS was confirmed. The ring retraction was completed at 339:23:50:01 G.m.t. (01:15:14:27 MET) and closing of the hook drive was completed at 339:23:52:25 G.m.t. (01:15:16:51 MET). The Node 1 installation was completed at 339:23:52 G.m.t. (01:15:17 MET) with all docking systems performing nominally. The RMS was ungrappled from Node 1 at 340:00:10 G.m.t. (01:15:45 MET).

To verify successful connectivity and control of the PMA 1 docking mechanism through the ODS and PMA 2, a PMA 1 docking ring extend-and-retract cycle was successfully performed. The RMS was then maneuvered to the PMA 1 interface survey position. RMS Node 1 operations were completed, and the RMS was powered down at 340:02:36 G.m.t. (01:18:01MET). The arm was cradled, latched and placed in the temperature-monitor mode.

The OMS-4 NC4A rendezvous maneuver was performed with the left engine of the OMS straight feed at 340:03:32:02.0 G.m.t. (01:18:56:28.0 MET). The maneuver duration was 110.4 seconds and a  $\Delta V$  of 85.7 ft/sec was imparted to the vehicle.

At approximately 340:03:46 G.m.t. (01:19:11 MET), the crew reported a problem with the cable which allows the ODS audio/video cables to connect directly with a crewman communications umbilical (CCU) for audio. This cable was to be used only in this application. As a result, this condition did not impact any future operations during this mission. Postflight troubleshooting will be required to determine the cause of the problem.

The RCS NC4 rendezvous maneuver was canceled. The RCS NC5 maneuver, a +X firing, was performed at 340:06:28:57.970 G.m.t. (01:21:53:23.951MET). The firing was 6.24 seconds in duration and a  $\Delta V$  of 1.4 ft/sec was imparted to the vehicle. Approximately two hours later, the forward RCS was used to perform the NC5A maneuver, which was also a +X firing. The firing was approximately 5 seconds in duration and a  $\Delta V$  of 1.2 ft/sec was imparted to the vehicle. The purpose of this firing was to avoid a collision with a Delta II rocket casing.

At approximately 340:07:13 G.m.t. (01:22:36 MET), the crew reported that one of the five pistol grip tool batteries would not recharge. The battery was tried in other charger locations without success. At 340:20:11 G.m.t. (02:10:36 MET), the crew reported that the battery (S/N 1004) could be charged and it would be used it as a spare. The condition did not impact EVA operations.

At 340:19:34:37.5 G.m.t. (02:10:59:03.5 MET), the NC6 (OMS-5) rendezvous maneuver was performed using the right OMS engine. The maneuver was 191.0 seconds in duration and a  $\Delta V$  of 150.4 ft/sec was imparted to the vehicle.

At 340:20:16:58 G.m.t. (02:11:41:24 MET), the NCC rendezvous maneuver was performed using the primary RCS. The maneuver was 2.9 seconds in duration and 1.3 ft/sec were imparted to the vehicle.

At 340 21:14:42.2 G.m.t. (02:12:39:08.2 MET), the terminal phase initiation (TI) maneuver (OMS-6) was performed using the left OMS engine. The maneuver was 15.8 seconds in duration and 12.7 ft/sec were imparted to the vehicle. The rendezvous was completed satisfactorily with four small RCS midcourse correction (MCC) maneuvers.

The RMS was repowered at 340:19:56 G.m.t. (02:11:21 MET) and was maneuvered from its pre-cradle position to the Functional Cargo Block (FCB) poise-for-capture position at 340:21:26 G.m.t. (02:12:51 MET). The Ku-band radar acquired the FCB at a range of 144,000 feet (24 nmi.) and tracked the FCB to a range of 450 feet when the Ku-band was placed back into the communication mode. The FCB was grappled by the RMS at 340:23:47.02 G.m.t. (02:15:12:28 MET). The RMS was used to maneuver the FCB to the FCB/Node 1 pre-installation position. The RMS FCB pre-installation operations were completed followed by survey operations using the RMS cameras. To alleviate alignment problems during final docking of the FCB, it was necessary for the RMS to ungrapple the FCB. This prevented minor forces that are generated by the arm from pushing the FCB out of alignment.

The auxiliary power unit (APU) 2 drain line pressure 1 and 2 decreased from approximately 15.5 psia prelaunch to 11.1 psia at 340:22:33 G.m.t. (02:13:58 MET) (Flight Problem STS-88-V-02). A similar decrease occurred during STS-89 and it was attributed to a slight leak of the relief valve. However, this is the first flight of a modification that added a burst disk between these pressure measurements and the relief valve. The data showed a small gaseous nitrogen ( $\text{GN}_2$ ) leak of 1.3 psi/day; however, as the mission progressed, the leak rate reduced to 0.5 psi/day.

The OSVS was used as a confirming cue along with the RMS digital data and camera displays for FCB alignment with the Node. The crew reported that when it OSVS was operating, the OSVS data agreed to within one-half inch of the RMS digital information. Overall, the crew stated that the OSVS was not an acceptable means for berthing the Zarya to the Unity.

The performance of the trajectory control sensor (TCS) in support of the International Space Station (ISS) docking was nominal. Two units were used. Initial indications were that the units or cabling were switched. An investigation will be made of this condition following the flight. TCS unit 1 acquired the target at about 4600 feet. TCS unit 2

acquired the target at about 4300 feet. Both units tracked solidly in the pulse mode. Both units tracked the target to docking with only one retroreflector switch-over for each unit, as expected. Both units were powered down following the docking.

The RMS was repowered at 341:20:58 G.m.t. (03:12:23 MET) and maneuvered to the EVA egress position. A nominal ODS depressurization was completed in preparation for EVA 1.

EVA 1 officially began when battery power was selected on the EMUs at 341:22:09 G.m.t. (03:13:34 MET). The foot restraint installation to the RMS striker bar was performed at 341:22:55 G.m.t. (03:14:20 MET). All objectives of EVA 1 were successfully completed, and the Zarya module and Unity module cable interfaces were verified with no anomalies noted. Another task completed during EVA 1 was the inspection of the undeployed TORU antennas on the Zarya module. From the inspection, it was determined that the antenna pyrotechnics have fired, but the antennas did not deploy.

At approximately 342:00:34 G.m.t. (03:16:59 MET), a slide-wire carrier became loose from the EV1 crewmember and floated away. At approximately 342:03:15 G.m.t. (03:18:40 MET), a work-site interface (WIF) socket and a retractable tether also became loose from the EV1 crewmember. Both of these items floated away from the Orbiter and ISS and caused no impact hazard.

While performing EVA 1 operations, the crew reported that the aft starboard, forward starboard, and mid port payload bay floodlights had failed off. All payload bay floodlights were turned on at 341:20:53 G.m.t. (03:12:18 MET). The aft and forward starboard payload bay floodlights failed off at 341:22:27 G.m.t. (03:13:52 MET). The mid port floodlight failed off at 342:01:56 G.m.t. (03:17:21 MET). Power was removed from the failed lights.

The nominal airlock repressurization following EVA 1 began at 342:05:30 G.m.t. (03:20:55 MET), and the EMUs performed nominally during the entire EVA. A very successful 7 hour and 21 minute EVA was completed. Water recharging of the EMUs was completed at 342:07:07 G.m.t. (03:22:32 MET) in preparation for the next EVA, and the EMU battery recharging began at 342:07:40 G.m.t. (03:23:05 MET). EVA 1 was performed using only the RCS vernier thrusters for attitude control.

The RMS successfully supported the EVA 1 activities and power was removed at 342:05:38 G.m.t. (03:21:03 MET). All arm operations were nominal. The RMS was cradled, latched and placed in the temperature-monitor mode until required for the second EVA.

The RCS was used to perform an ISS re-boost maneuver from 342:20:35:34 G.m.t. (04:12:00:00 MET) to 342:20:58:21 G.m.t. (04:12:22:47 MET). This 22-minute 47-second maneuver consisted of 11 firings of primary RCS thrusters L1A and R1A with corresponding firings on thrusters L5D and R5D. The estimated  $\Delta V$  for the maneuver was 11 ft/sec. As a result, the vehicle was placed in a 215 by 211 nmi. orbit. The RCS performed satisfactorily throughout the maneuver.

The RMS was repowered at 343:19:48 G.m.t. (05:11:13 MET) to support EVA 2. EVA 2 officially began when battery power was selected on the EMU's at 343:20:33 G.m.t. (05:11:58 MET). A nominal ODS depressurization in preparation for the EVA occurred at 343:20:13 G.m.t. (05:11:38 MET). All objectives of EVA 2 were successfully completed. An additional task completed on EVA 2 was the deployment of one of the Zarya module TORU antennas. The second TORU antenna was deployed during EVA 3. At approximately 344:00:52 G.m.t. (05:16:17 MET), a trunnion pin cover separated and floated away, thus only three of the four covers were installed on Unity. A new cover will be fabricated and installation of the fourth cover is planned for STS-96 (flight 2A.1). The EMUs performed nominally during the entire EVA. Only the RCS vernier thrusters were used for attitude control during the EVA. A nominal airlock repressurization following the EVA occurred at 344:03:35 G.m.t. (05:19:00 MET) to successfully conclude the 7-hour 2-minute EVA.

Following the EVA, the RMS was used to perform a survey of OSVS targets. Power was removed from the RMS at 344:05:49 G.m.t. (05:21:15 MET). The EMU water recharges were completed and a total of 7 pounds was added to both EMUs. The 20-hour EMU battery recharge was initiated at 344:04:59 G.m.t. (05:20:24 MET). The recharge on the pistol grip tool batteries and the EMU helmet light batteries was initiated at 344:05:16 G.m.t. (05:20:41 MET).

Node 1 of the ISS was ingresssed at 344:19:54 G.m.t. (06:11:21 MET), and the FGB was ingresssed at 344:21:11 G.m.t. (06:12:36 MET). The entire stack was repressurized to 14.7 psia between 344:22:36 G.m.t. (06:14:01 MET and 344:22:57 G.m.t. (06:14:21 MET).

The lights on panel A7 which indicate that payload bay camera B, an intensified television camera (ITVC), failed to illuminate. This condition is a known problem with this black-and-white camera as the data from the camera are interleaved in the video stream and the video switching unit (VSU) cannot always synchronize on these data. The history has shown that this condition occurs approximately 1/3 of the time, and a camera power-cycle usually clears the problem. However, in this case, the power was cycled at least eight times and the problem did not clear. A later power cycle did clear the problem, and the camera was left on for the remainder on on-orbit operations.

All transfer activities were completed, and all planned operations within the Functional Cargo Block (FGB) and Node 1 were also completed. A total of 1200 lb of hardware were transferred to the ISS and 335 lb were transferred from the ISS to the Orbiter. The FGB and Node 1 hatches were closed at approximately 346:00:25 G.m.t. (07:15:50 MET). The Orbiter was depressed to 10.25 psia in preparation for the third extravehicular activity at 346:01:06 G.m.t. (07:16:31 MET).

EVA 3 officially began when the EMU's were set to battery power at 346:20:33 G.m.t. (08:11:57 MET). A nominal Orbiter airlock depressurization in preparation for the EVA began at 346:20:17 G.m.t. (08:11:41 MET). The RMS was repowered at 346:19:51 G.m.t. (08:11:15 MET) to support the EVA. All objectives of EVA 3 were successfully completed, including the deployment of the second Zarya TORU antenna. The evaluation of the USA Simplified Aid for EVA Rescue (SAFER) which took place during this EVA achieved approximately 50 percent of its objectives due to uncertainties concerning the amount of gaseous nitrogen (GN<sub>2</sub>) propellant that remained. The EMU's

performed nominally during the entire EVA. A nominal airlock repressurization following EVA 3 occurred at 347:03:32 G.m.t. (08:18:56 MET) to successfully conclude the 6-hour 59-minute EVA. EMU water recharges were not performed and an additional EVA was not required. The 20-hour EMU battery recharge was initiated at 347:04:15 G.m.t. (08:19:40 MET). The recharge on the pistol grip tool batteries and the EMU helmet light batteries was initiated at 347:04:22 G.m.t. (08:19:47 MET).

Depressurization of the airlock vestibule was completed nominally with the performance of a successful leak check at 347:06:04 G.m.t. (08:21:29 MET).

Following the EVA, the RMS was used to perform a survey of OSVS targets. The RMS was cradled and latched at 347:05:56 G.m.t. (08:21:20 MET). Power was removed from the RMS as no more RMS activities were planned or required for this mission.

Undocking from the ISS was initiated at 347:20:24:34 G.m.t. (09:11:49:00 MET) followed by the fly-around inspection of the ISS. The separation maneuver from the ISS was initiated at 347:21:48:00 G.m.t. (09:13:11:26 MET), using the RCS -X thrusters. The duration of the maneuver was 20.5 seconds with a  $\Delta V$  of approximately 5.0 ft/sec.

The cabin was repressurized to 14.7 psia starting at 348:00:07 G.m.t. (09:15:32 MET) as no additional EVA's were planned.

The OMS-7 firing for the Shuttle Ionospheric Modification with Pulsed Localized Exhaust (SIMPLEX) experiment was performed at 348:02:15:32.3 G.m.t. (09:17:39:58.3 MET) using the right OMS engine in the straight-feed configuration. The firing lasted 9.8 seconds and imparted a  $\Delta V$  of 8.8 ft/sec that placed the Orbiter in a 209 by 214 nmi. orbit.

The flash evaporator system (FES) was inhibited from 348:00:39 G.m.t. (09:16:04 MET) through 348:05:19 G.m.t. (09:20:44 MET) for Satellite de Aplicaciones/Cientifico-A (SAC-A) deployment operations.

APU 1 and hydraulic system 1 were selected for flight control system (FCS) checkout, and the checkout was nominal in all respects. APU 1 was operated for 5 minutes 49 seconds and the hydraulic system and water spray boiler performance was satisfactory. Fuel consumption for the APU was 18 lb. No drop in hydraulic pressure was observed when the hydraulic main pump switch was taken from low pressure to normal pressure. Because of the short run time of the APU, lubrication oil spray cooling was not required.

At 348:13:44 G.m.t. (09:05:08 MET), the OMS pod starboard keel web heater did not cycle at 58 °F as had been observed in the previous flight data while operating on the system A heater string (Flight Problem STS-88-V-04). When the starboard oxidizer tank temperature reached 70 °F, the system B heater string was selected and nominal operations resumed.

The RCS hot-fire was performed, starting at 348:21:34 G.m.t. (10:12:59 MET). All primary RCS thrusters were fired, and thruster R2D was deselected as "failed leak" following its second pulse at 348:21:41:40 G.m.t. (10:13:06:06 MET) (Flight Problem STS-88-V-03). The thruster was not used for the remainder of the flight.

The Ku-band antenna was stowed at 349:07:56:00 G.m.t. (10:23:20:26 MET) in preparation for closing the payload bay doors prior to landing.

The payload bay doors were closed and latched for landing at 350:00:14:19 G.m.t. (11:15:38:45 MET). APU 2 was started five minutes prior to ignition for the deorbit maneuver. The dual-engine deorbit maneuver for the first landing opportunity at the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) was performed on orbit 184 at approximately 350:02:48:04 G.m.t. (11:18:12:29 MET). The maneuver was 181.2 seconds in duration with a  $\Delta V$  of 339.4 ft/sec. APUs 1 and 3 were started 13 minutes prior to entry interface.

During the deorbit maneuver, the left OMS engine bipropellant valve exhibited a slow opening time of approximately 1 second (Flight Problem STS-88-V-06). This opening time was twice the length of time that had been previously observed. Postflight testing will be performed to determine the cause of this anomaly.

Entry was completed satisfactorily, and main landing gear touchdown occurred on SLF concrete runway 15 at 350:03:53:32 G.m.t. (11:19:17:58 MET) on December 15, 1998. The nose gear touchdown occurred at 350:03:53:38 G.m.t. and the Orbiter drag chute was not deployed. Wheel stop occurred at 350:03:54:16 G.m.t. The rollout was normal in all respects. The flight duration was 11 days 19 hours 17 minutes 59 seconds. The APUs were shut down 17 minutes 1 second after landing.

With the successful landing of the Space Shuttle, all 23 of the ISS flight objectives were completed as well as an additional three maintenance tasks.

During the postlanding RCS valve test, the right RCS ac motor valve 1/2 tank isolation valve talkback failed to indicate the valve was closed following the onboard commanded closure (Flight Problem STS-88-V-05). Repeated attempts to close the valve met with no success. Postflight troubleshooting will be performed to determine the cause of the failure.

## **PAYLOADS AND EXPERIMENTS OPERATIONS**

The launch of the Endeavour vehicle from KSC began the largest cooperative space construction project in the history of space flight; the building of the International Space Station (ISS). After a flawless rendezvous, docking and berthing of the ISS, three EVA's were performed to complete all of the electrical and communications connections between the two modules (Zarya and Unity). The crew ingressed the ISS and transferred 1200 lb of hardware to the ISS. The crew also transferred 335 lb of hardware from the ISS to the Orbiter for return to Earth. With the successful completion of the STS-88 mission, all 23 of the planned objectives of the mission were successfully completed plus an additional 3 maintenance tasks. The maintenance tasks were the replacement of a battery charging unit inside Zarya and the deployment of the two TORU antennas from the Zarya module.

### **FLIGHT OBJECTIVES**

The 23 ISS flight objectives are as follows:

1. Perform a rendezvous with the Functional Cargo Block (FCB) (Zarya) and berth Node 1 (Unity) to the FCB.
2. Activate Node 1 and complete Node survival tasks-
  - a. Complete umbilical connections;
  - b. Install dead-face connectors;
  - c. Install loop-back connectors;
  - d. Install term connectors;
  - e. Remove multiplexer/demultiplexer (MDM) thermal covers;
  - f. Activate MDM heaters; and
  - g. Install MDM sunshade.
3. Install the external early communications hardware and EVA translation aids-
  - a. Install hand-rails, slide-wire, gap-spanner and other EVA hardware;
  - b. Install early communications cables to FCB connectors; and
  - c. Install two early communications antennas;
4. Install internal early communications hardware and activate Node 1.
5. Transfer items from Node 1 to Orbiter middeck.
6. Transfer items from Orbiter middeck to Node 1.
7. Install items to extend thermal stability (minimize Node 1 heat leak)-
  - a. Install Node trunnion pin covers; and
  - b. Install MDM sunshade.
8. Install items required for 3A configuration thermal solution-
  - a. Install assembly power converter unit (APCU) jumpers; and
  - b. Remove zenith common berthing mechanism (CBM) launch restraint pins.
9. Perform EVA get-ahead tasks for 2A.1 mission and subsequent missions-
  - a. Disconnect PMA 1 androgynous peripheral docking system (APDS) harness at pressurized mating adapter (PMA) 2;
  - b. Install Node 1 EVA tool bag;
  - c. Perform final EVA tool installation and reconfiguration;
  - d. Remove nadir, starboard and port CBM launch restraint pins;
  - e. Restrain PMA 1 and PMA 2 umbilicals;

- f. Close PMA 1 and PMA 2 umbilical clamps.
10. Perform intravehicular tasks in FGB-
  - a. Replace harmful contaminant cartridge;
  - b. Complete the set-up, checkout and restowage of the early communications video camera;
  - c. Complete the set-up, checkout and restowage of the EPCS.
11. Photograph exterior of ISS during EVA for closeout purposes.
12. Perform photographic survey of exterior of ISS.
13. Fly-around the ISS after undocking.
14. Transfer items from FGB to Orbiter middeck-
  - a. EVA handrail; and
  - b. Public Affairs Office kit.
15. Perform EVA get-ahead tasks on FGB -
  - a. Install the FGB handrail; and
  - b. Inspect and photograph the FGB exterior.
16. Perform photographic and video survey of interior of Node 1 and FGB.
17. Complete Public Affairs event in Node 1.
18. Perform the 2A.1 mission EVA get-ahead tasks -
  - a. Remove launch restraints from Node 1 PFE/PBE lockers;
  - b. Remove launch restraints from FGB stowage panels and flaps;
  - c. Untorque all Node 1 stowage rack door fasteners;
  - d. Remove launch restraints from Node 1 nadir midbay; and
  - e. Install four foot restraints on foot bridges.
19. Perform intravehicular items for contingency access/maintenance-
  - a. Remove zenith/nadir alcove shear; and
  - b. Install rack pivot pin and remove launch restraint.
20. Perform 3A mission or increment get-ahead tasks by removing launch restraints from the remaining FGB stowage panels/flaps.
21. Perform 5A mission get-ahead tasks-
  - a. Remove launch restraints from Node 1 starboard midbay panels; and
  - b. Set-up wireless antenna assembly.
22. Perform mission 5A get-ahead tasks for general access or future maintenance-
  - a. Remove port and starboard alcove shear panels;
  - b. Remove launch restraints from Node 1 port and zenith midbay panels;
  - c. Remove launch restraints for FGB dust collector replacement; and
  - d. Remove launch restraints for FGB heat exchanger filter replacement.
23. Perform reboost maneuver to raise ISS to 213 nmi.

### **SATELLITE DE APLICACIONES/CIENTIFICO-A**

The Satellite de Aplicaciones/Cientifico-A (SAC-A) was successfully deployed by the crew on flight day 11. This marks the first deployment of an Argentinean satellite, which was built by the Argentinean National Commission of Space Activities (CONAE). Following ejection from the Orbiter, the solar arrays on this non-recoverable satellite deployed nominally. Subsequent ground station acquisitions indicated nominal performance of the satellite. The satellite is predicted to have a 6- to 9-month lifetime based on the ejection attitude. During its lifetime, the satellite will test various new

technologies including differential global positioning system (DGPS), a charge-coupled device (CCD) camera, silicon solar cells, a whale tracker and a magnetometer.

### **MIGHTYSAT**

The MightySat satellite was successfully deployed on flight day 12. The satellite functioned properly, and the first contacts with the satellite indicate that the antennas were not negatively impacted from the incidental contact during the first EVA. Four advanced technologies are to be demonstrated during the satellite's lifetime. They are composite structure, advanced solar cells, advanced electronics and a shock device.

A few minutes after the nominal deployment of the satellite, the crew reported spotting a small cylindrical object drifting out of the satellite's canister. Upon closer inspection, the crew described the object as a cylinder 1½ inches in length, hollow on one end with two holes 180 degrees apart on the cylinder. Review of the downlinked video and the crew comments lead to the tentative conclusion that the object was one of the two debris shields for the internal bolt cutters. This shield is normally tethered to the ejection system by wire.

### **IMAX CARGO BAY CAMERA**

The IMAX cargo bay camera (ICBC) performed nominally throughout the mission. However, only 67 percent of the planned objectives for the system was accomplished. This condition resulted from the scenes being required during periods of darkness when photography could not be performed with satisfactory results. A discussion of the ICBC activities is contained in the following paragraphs.

All four planned scenes of the Node 1 grapple and installation were completed. Only one of the four scenes of the FGB activities was completed. The one scene completed was of the FGB-to-Node 1 mating. The remaining scenes all occurred in darkness and could not be completed. One of the missed scenes was of the FGB grapple, a major objective for the ICBC on this flight. The crew was able to film two additional scenes of their choice and provide some coverage of the FGB operations.

The two scenes planned to be completed during the second EVA - early communications equipment installation and sunshade installation - were successfully accomplished. The three scenes planned for the third EVA - EVA stowage bag installation, APAS cable disconnection and stowage and TORU antenna operations - were accomplished. High film usage during these scenes resulted in the decision by the IMAX team to delete two other planned scenes, which were FGB docking ring inspection/handrail installation and the Simplified Aid for EVA Rescue (SAFER) operations.

The one planned scene of the undocking was not accomplished because of darkness. As a result, the remaining 60 to 80 seconds of film were exposed in two Earth observation scenes on flight day 12.

## **GET-AWAY SPECIAL**

The Get-Away Special (GAS) G-093 investigation entitled Vortex Ring Transit Experiment (VORTEX) was activated as planned on flight day 1 approximately 4 hours 29 minutes after launch. After approximately 9.5 hours of operation, the GAS experiment canister was deactivated. This action brought to a close the GAS activities for the STS-88 mission.

## **SPACE EXPERIMENT MODULE**

The Space Experiment Module-07 (SEM-07) housed various passive experiments from schools ranging from the Kindergarten level to the University level. Seven modules were provided by teachers and their schools participating in the NASA Educational Workshop for Mathematics, Science and Technology teachers (NEWMAST) Program. The various experiments contained in the SEM-07 are discussed in the following paragraphs.

The "Mariposa Express" experiment compared the growth of butterfly garden seeds exposed to the space environment to the control sample on the ground. This experiment was sponsored by Lyme School of Lyme, Vermont, and the Thomas J. Quirk Middle School of Hartford, Connecticut. Results of these experiments will be available from those educational institutions.

The "Snap-Crackle-Pop" experiment consisted of three individual passive experiments. The first experiment studied the volume and porousness of bread baked with dry inactive yeast that had been exposed to the space environment. The second experiment studied the effects of the launch and space environment on the longevity and intensity of light bulbs. The third experiment examined the appearance, weight, volume and popping time of different types of popcorn exposed to the space environment. These experiments were sponsored by the Norwood Jr. High School, Norwood Massachusetts; Thayer Academy, Braintree Massachusetts; Dennis-Yarmouth Regional High School, South Yarmouth, Massachusetts; and Woodstock Academy, Woodstock, New York. Results of these experiments may be obtained from those educational institutions.

The "A Nutty Idea" experiment studied the effects of microgravity and temperature extremes on various brands of peanut butter. Students are microscopically examining samples as well as measuring viscosity and conducting qualitative visual, spread-ability, and aroma tests of the samples. The experiment was sponsored by the F. H. Tuttle Middle School, South Burlington, Vermont, and The Gilbert School, Winsted, Connecticut. Results may be obtained from those educational institutions.

The "Bubble Laboratory Adds Science and Technology " (BLAST) and "Silly Putty Longevity and Applicability Testing" (SPLAT) experiments were conducted by the Oakcrest High School, Mays Landing, New Jersey; and William Pen High School, York, Pennsylvania. The BLAST experiment examined the effects of the launch and space environment on bubble longevity, size and quantity. SPLAT studied the effects of the space environment such as texture and composition, elasticity, image transfer capability and bounce-ability of silly putty. Results of the experiments may be obtained from the educational institutions cited previously in this paragraph.

The Maine Agricultural Industry NEWMAST Experiment (MAINE) consisted of two experiments concerning pine tree seeds and water quality. The first passive experiment studied the effects of the space environment (microgravity, radiation, and extreme temperatures) on the germination and growth of pine tree seeds. The second experiment examined water samples for standard quality test parameters such as pH, hardness, dissolved oxygen levels and carbon dioxide levels. These experiments were sponsored by the Maine School Administration District 54; Brewer School District, and Maine Indian Education, and the results may be obtained from those schools.

The "Growing Mold Together" experiment studied mold growth on common fresh foods exposed to the space environment versus those on Earth. Eleven vials contained food initially contaminated with mold, and the second 11 vials contained fresh foods. This experiment was sponsored by the Horntown Educational Learning Project (HELP), Horntown, Virginia, and results may be obtained from that institution.

The "Effects of Space Travel on Soil Micro-Structure: Redistribution of Mineral Species and Organics" experiment was to determine the effect of space travel on soil micro-structure by investigating the redistribution of minerals and organic matter in constructed soils. The context of this experiment was to evaluate the impact of variable g forces and the space environment on the structure of soils and the ultimate implications that this redistribution might have for horticulture in space. This experiment was sponsored by the first through third grades of Accomack County Schools TAG and the Virginia Institute of Marine Science (VIMS), College of William and Mary, Wachapreague, Virginia. Results may be obtained from those institutions.

The "Space Science and Technology Collaboration" investigation consisted of two passive experiments. The first experiment contained solar voltaic cells to investigate available solar energy. The second experiment contained vials of sand that were representative of all 24 NEWMAST teachers and their students. The students studied sand composition, density, and magnetic properties of sand before and after the space flight. These experiments were sponsored by the Spartanburg High School, Spartanburg, North Carolina, and North Greene High School, Greeneville, Tennessee. These schools may provide data on the results of the experiments.

The Summer High School Apprenticeship Research Program (SHARP) experiments were sponsored by the students of the NASA Space Scholars Club, and these students studied the effect of the space environment on various sample such as water-based paint, gelatin, chlorophyll, magnets, seeds, film and computer disks. The SHARP students may provide information on the results of this experiment.

The "Effects of Space Travel on 22 ALNICO Cylindrical Magnets" experiment studied the effects of the Earth's magnetic field and the space environment on 11 vials of the Alnico magnets. The students will examine the magnetic field shape and strength. This experiment was sponsored by the Harbor Creek High School, Harbor Creek, Pennsylvania, and the Arsenal Middle School, Pittsburgh, Pennsylvania. The results of this experiment may be obtained from those educational institutions.

The "Getting to the Heart of the Matter" experiment observed the effects of the space environment on the behavior and density of various liquids. A density column experiment was performed on four liquids (corn oil, tinted blue water, glycerin and brown

corn syrup). Mass, volume, and calculated densities were compared before and after the flight. A second experiment with vials containing water and delrin beads was performed as a vertical sorting experiment. These experiments were sponsored by the Betsy Ross Arts Magnet School of Connecticut; Woodland High School of New York; Saugerties High School of New York; Bethpage High School of New York; Elizabethport Catholic School of New Jersey; GlenRidge High School of New Jersey; and Neptune Middle School of New Jersey. Results of those experiments may be obtained from these educational institutions.

### **SHUTTLE IONOSPHERIC MODIFICATION WITH PULSED LOCAL EXHAUST**

The Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) experiment opportunity over the Jicamarca, Peru, station was completed on flight day 11. The OMS-7 engine firing had a duration of 9.92 seconds and was performed with the vehicle 90 degrees to the Orbiter's velocity vector nose (nose toward radar site, plume away from site).

The firing for the SIMPLEX experiment occurred during a period of strong "Spread-F" when the F-region was filled with natural irregularities. The Jicamarca radar recorded scatter from the Orbiter and from the irregularities. The data were taken for a period of 2 hours before and after the engine firing. Analysis at the University of Illinois and the Naval Research Laboratory will determine if the firing had any affect on the irregularities. This study is of interest because the equatorial Spread-F irregularities can disrupt and degrade satellite communication channels and GPS navigation signals.

## **VEHICLE PERFORMANCE**

### **SOLID ROCKET BOOSTERS**

All Solid Rocket Booster (SRB) systems performed nominally with no in-flight anomalies identified from the review of the data. The SRB countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operational Maintenance Requirements and Specifications Document (OMRSD) violations occurred.

During the countdown, the heated ground purge in the SRB aft skirts that is used to maintain the case/nozzle joint temperatures within the required LCC ranges was on the low range until switching to the high range at T-15 minutes.

STS-88 was the second flight for the aft skirt doubler brackets. These aluminum brackets were designed to increase the factor of safety of the holddown post weld from 1.28 to greater than 1.4. Strain gages mounted on the aft skirts verified that the brackets functioned as designed and did increase the factor of safety to greater than 1.4.

Evaluation of the thrust vector controller (TVC) data showed that the TVC subsystem responded as expected to the SSME trim modifications. These modifications decreased the angle between the SSME and SRB thrust vectors during the first stage of operation. The SRB thrust vectors were trimmed to maintain moment balance. This trimming of the SRB thrust vectors resulted in the TVC actuator positions being outside of their experience base during certain specific time frames. The overall actuator position experience base was not exceeded, only certain areas of the time specific (second by second) experience base were expanded.

Both SRB's were separated from the External Tank (ET) at approximately liftoff plus 123.764 seconds. Reports from the recovery area indicated that all deceleration subsystems performed nominally. The SRB's were towed to Port Canaveral and returned to Kennedy Space Center (KSC) for inspection, disassembly and refurbishment.

The postflight inspection of the SRB's revealed the hardware to be in excellent condition. Both frustums were in excellent condition, and no thermal protection system (TPS) was missing nor were any bonded/debonded areas noted during the inspection. For the first time in the Space Shuttle Program, no squawks or problem reports were recorded during the postflight assessment period.

### **REUSABLE SOLID ROCKET MOTORS**

The Reusable Solid Rocket Motors (RSRM's) performed as designed with no in-flight anomalies identified in the review of the data. Also, no LCC or OMRSD violations occurred during the countdown.

Power up and operation of all igniter and field joint heaters was accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. The aft skirt purge maintained the nozzle/case temperatures above the

minimum LCC limits. During the LCC time frame, the nozzle/case joint sensor temperatures ranged from 80 °F to 90 °F and 78 °F to 88 °F for the left and right motors, respectively. The calculated flex bearing mean bulk temperature was 83 °F.

Data indicate that the flight performance of both RSRM's was well within the allowable contract end item (CEI) performance envelopes and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was 75 °F at liftoff. The maximum trace shape variation of pressure versus time during the 62 to 80 second time frame was calculated to be 1.059 percent at 80 seconds for the left motor and -0.703 percent at 65 seconds for the right motor. These values were well within the 3.2 percent allowable limits.

In general, the RSRM hardware performed as expected during the flight. The RSRM assessment indicated that the hardware was in good condition and that no pocket/wash erosion was observed on either nozzle.

The propulsion performance is shown in the following table.

### RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 75 °F		Right motor, 75 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	65.26	64.90	65.31	65.19
I-60, 10 <sup>6</sup> lbf-sec	174.14	174.21	174.25	174.12
I-AT, 10 <sup>6</sup> lbf-sec	296.95	297.04	296.85	296.02
Vacuum Isp, lbf-sec/lbm	268.6	268.6	268.6	267.8
Burn rate, in/sec @ 60 °F at 625 psia	0.3660	0.3668	0.3663	0.3675
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	110.4	109.8	110.2	109.7
50 psia cue time	120.1	119.5	120.0	119.4
Action time <sup>b</sup>	122.2	121.7	122.1	122.0
Separation command	125.0	-----	125.0	-----
PMBT, °F	75	75	75	75
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	2.9	2.8	3.3
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		237.9	

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) subsystems performed satisfactorily and all flight objectives were satisfied. No in-flight anomalies were identified in the review of the data. No LCC or OMRSD violations were identified during the countdown.

All objectives and requirements associated with ET propellant loading were met. The ET loading and flight performance was satisfactory. Two loading cycles of the ET were required because of the launch scrub on December 3, 1998. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operations were monitored and all performed properly.

No unexpected ice/frost formations were observed on the ET during the countdown. There was no observed ice or frost on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen (LO<sub>2</sub>) and liquid hydrogen (LO<sub>2</sub>) feedlines, the pressurization brackets, and along the LH<sub>2</sub> protuberance air load (PAL) ramps were reported by the Ice/Frost Team. There was unexpected ice/frost on the intertank -Z axis for about 20 inches from the LO<sub>2</sub> tank-intertank flange, but due to its location it was acceptable for flight.

The ET thermal systems operated satisfactorily. The ET pressurization system functioned properly throughout engine start and the flight. The minimum LO<sub>2</sub> ullage pressure experienced during the ullage pressure slump was 13.94 psid.

The crew took photographs of the ET after separation using a 35mm camera and 400mm lens as well as videos of the ET. No evidence of any anomaly was noted in the review of this data. A more complete discussion of this data is contained in the Photographic and Video Data Analysis section of this report.

ET separation was nominal, and the ET entry and breakup occurred within the expected footprint. The postflight predicted ET intact impact point was approximately 48 nmi. downrange from the preflight prediction for STS-88.

## SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) data parameters indicated nominal performance during the countdown and flight when compared with data from previous flights. No LCC or OMRSD violations were identified in the data. No in-flight anomalies were noted in the data analysis. Engine "Ready" was achieved at the proper time, and engine start and thrust buildup were normal.

Flight data indicate that the SSME performance during mainstage, throttling, shutdown and propellant dump were normal. The high pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures were well within specification throughout the ascent. The engine  $I_{sp}$  was rated as 453.2 seconds based on trajectory data. Controller and software performance was satisfactory with no problems indicated. Space Shuttle main engine cutoff (MECO) occurred 502.151 seconds after liftoff.

SSME 1 experienced shifts in the high pressure fuel turbine discharge temperature. Channel B shifted up approximately 40 °R at engine start plus 220 seconds, and

channel A shifted downward approximately 20 °R at engine start plus 330 seconds. These shifts have no other corresponding engine parameter changes, thus indicating that powerhead coolant redistribution was the cause of the shift in temperature. The HPFTP will be inspected postflight to assure that there are no anomalies in the pump which could have contributed to these shifts.

The nozzle ablative had some missing pieces, but it appears to have protected the nozzle prior to it being blown off. The parts remaining showed some signs of heating with no indication of heating to the materials remaining in the areas where the ablative was missing. Ablative material was found on the body flap and it has been identified as a foreign object damage (FOD) concern. Efforts are being expended to better define the environment around the aft section of the Orbiter and the nozzle aft manifold both for heating and airflow. Effort is also continuing to define alternative materials to adhere the ablative that will survive the entry environment as well as the cryogenic environment that occurs during ascent. An increased understanding of the flow environment will assist in identifying a suitable adhesive.

### **SHUTTLE RANGE SAFETY SYSTEM**

The Shuttle range safety system (SRSS) performed satisfactorily throughout the first stage of flight. The SRSS has been disabled for the second stage of flight.

The SRSS closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed, and the system inhibits were turned off at the appropriate times. All SRSS data indicated that the system operated nominally throughout the countdown and flight.

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

### **ORBITER SUBSYSTEMS**

#### **Main Propulsion System**

The overall performance of the main propulsion system (MPS) was nominal. No in-flight anomalies were identified from the data review, and there were no LCC or OMRSD violations during the two countdowns. However, one OMRSD violation occurred during the turnaround operations for the second launch attempt. The MPS pneumatic bottle pressure exceeded the maximum allowable pressure when the tank was locked up after the drain operations. The tank was isolated at a temperature of approximately 25 °F. Subsequent warming to ambient temperature raised the pressure of the gaseous helium (GHe) within the isolated tank to 4563 psia before the interconnect valves were opened and the pressure was bled off. Waivers were approved for this condition.

Liquid hydrogen (LH<sub>2</sub>) loading operations were normal through chill-down, slow fill, fast fill, topping and replenish. LH<sub>2</sub> loading was stopped at the beginning of slow fill after ET pressurization. High moisture content in the Orbiter aft compartment was the cause of the stop flow. Loading was reinitiated after the conditions were corrected. Based on the analysis of the loading system data, the LH<sub>2</sub> load at the end of replenish was

231,370 lbm, compared to a planned loading of 231,404 lbm. The loading was well within the required MPS LH<sub>2</sub> loading requirement.

The LO<sub>2</sub> loading was accomplished with no stop flows or reverts. The analysis of the loading system data showed that the LO<sub>2</sub> load at the end of replenish was 1,388,412 lbm compared to the planned load of 1,389,928 lbm. Again, the accuracy of the load was well within the required MPS LO<sub>2</sub> loading requirement. Throughout the period of the countdown, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment was approximately 120 ppm. This level was measured shortly after the start of fast-fill, and the level compares favorably with previous data from this vehicle.

Ascent performance was satisfactory. Data indicate that the LO<sub>2</sub> and LH<sub>2</sub> pressurization systems performed as planned, and that all net positive suction pressure (NPSP) requirements were met throughout the countdown and flight. The minimum LO<sub>2</sub> ullage pressure experienced during the period of the ullage pressure slump was a nominal 13.94 psid.

### **Reaction Control Subsystem**

The overall performance of the reaction control subsystem (RCS) was nominal, and no LCC or OMRSD violations occurred. Two in-flight anomalies were identified from the data. Thruster R2D failed leak shortly after the second pulse of the RCS hot-fire, and the right RCS 1/2 tank isolation valves failed to close. These anomalies are discussed in later paragraphs of this section. These failures did not impact the successful completion of the mission.

During prelaunch operations shortly after the right aft RCS activation, when both the A and B helium isolation valves were opened, the right RCS fuel tank ullage pressure increased from the primary lock-up pressure to the secondary regulator lock-up pressure at a rate of about 8.5 psi/hr. This pressure rise indicated that either the A or B primary regulator, or a combination of the two, leaked between 15,000 and 20,000 scch, which is relatively high, compared to the maximum allowable of 600 scch. Analysis and tests determined that the right RCS fuel primary regulator was leaking. Consequently, early in the flight following the OMS-2 maneuver, the pressurization system was switched to the B regulator for the remainder of the flight. Postflight troubleshooting will be performed to determine the exact cause of the leakage.

Of the total propellants consumed by the RCS (6560.6 lbm), 1982.9 lbm were provided by the orbital maneuvering subsystem (OMS) during left-pod interconnect operations. The primary RCS had a total of 3900 firings, and a total firing time of 1206.72 seconds. The vernier RCS had a total of 19161 firings, and a total firing time of 27127.92 seconds. The RCS maneuvers performed during the mission are shown in the table on the following page.

Approximately two hours after the NC5 maneuver, the forward RCS was used to perform the NC5A maneuver, which was also a +X firing. The purpose of this firing was to avoid a collision with a Delta II rocket casing.

### RCS MANEUVERS

RCS Maneuver	Ignition Time, G.m.t./MET	Differential Velocity, ft/sec	Firing Time, seconds
Trim Maneuver for OMS-2	338:09:20:46 G.m.t. 00:00:45:12 MET	-	-
NPC	Canceled	N/A	N/A
NC-3	Canceled	N/A	N/A
NC-4	Canceled	N/A	N/A
NC-5	340:06:28:58 G.m.t. 01:21:53:24 MET	1.4	6.24
NC-5A (Collision Avoidance)	340:08:25:34 G.m.t. 01:23:50:00 MET	1.2	5
NH	Canceled	N/A	N/A
NCC	340:20:16:58 G.m.t. 02:11:41:24 MET	1.3	2.9
Midcourse Correction 1	340:21:31:30 G.m.t. 02:12:55:56 MET	0.5	2.3
Midcourse Correction 3	340:22:20:09 G.m.t. 02:13:44:35 MET	1.4	6.0
Midcourse Correction 4	340:22:31:00 G.m.t. 02:13:55:26 MET	2.4	10.5
ISS Reboost Maneuver	342:20:35:34 G.m.t. 04:12:00:00 MET	22 minutes 47 seconds (11 firings)	11.0
Separation after Undocking	347:21:48:00 G.m.t. 09:13:12:26 MET	5.0	20.5

The RCS was used to perform an ISS re-boost maneuver, and as a result, the vehicle was placed in a 215 by 211 nmi. orbit. The RCS performed satisfactorily throughout the maneuver.

The RCS hot-fire was performed, starting at 348:21:34 G.m.t. (10:12:59 MET). All primary RCS thrusters were fired, and thruster R2D was deselected as "failed leak" by the redundancy management (RM) system following its second pulse at 348:21:41:40 G.m.t. (10:13:06:06 MET) (Flight Problem STS-88-V-03). The fuel injector temperature dropped below the RM limit of 20 °F and reached a minimum temperature of 18.8 °F. The temperature recovered to nominal values immediately following the hot-fire pulses. This thruster was not used during the remainder of the flight.

During the postlanding RCS valve test, the right RCS ac motor valve 1/2 tank isolation valves talkback indication failed to indicate closed when commanded from the open to the closed position (Flight Problem STS-88-V-05). The crew reported that the talkback continued to indicate open. The switch was taken back to the open and then to the closed position with no change in either the talkback or the telemetered valve position indicators (VPI's). The analysis of the data indicates that the problem is either in the aft motor control assembly (MCA) no. 3, the cockpit switch, or the copper wire from the switch to the aft MCA no. 3. Tank isolation valves were closed via launch processing system (LPS) command, and the panel 7 talkback indicated closed; however, the VPI

did not indicate closed. Repeated valve cycling during the off-loading process had the same results.

### Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the flight, and no LCC or OMRSD violations occurred during the prelaunch operations. Two in-flight anomalies were recorded and these are discussed in the following paragraphs. The inlet pressures, chamber pressure and regeneration jacket temperature for both engines were at expected levels. The OMS firing times and propellant consumption were consistent with predictions, thereby verifying nominal performance. A total of 22308 lbm of OMS propellants were consumed during the mission, and of this total 1982.9 lbm were consumed by the RCS during the left OMS pod interconnect operations. The following table provides pertinent data concerning the OMS maneuvers performed.

**OMS Maneuvers**

Maneuver	Engine Configuration	Time, G.m.t./MET	Firing time, seconds	$\Delta V$ , ft/sec
Assist	Dual engine	338:08:37:48 G.m.t. 00:00:02:14 MET	102.2	N/A
OMS-2	Dual engine	338:09:19:15 G.m.t. 00:00:43:41 MET	66.8	102.6
OMS-3 (NC-1)	Left engine	338:12:25:40 G.m.t. 00:03:50:06 MET	14.0	10.7
OMS-4 (NC-4A)	Left engine	340:03:32:01 G.m.t. 01:18:56:27 MET	110.5	86.7
OMS-5 (NC-6)	Right engine	340:19:34:36 G.m.t. 02:10:59:02 MET	190.7	150.5
OMS-6 (TI)	Left engine	340:21:14:42 G.m.t. 02:12:39:08 MET	15.6	11.9
OMS-7 (Simplex)	Right engine	348:02:15:32 G.m.t. 09:17:39:58 MET	9.8	8.8
Deorbit	Dual engine	350:02:48:04 G.m.t. 11:18:12:30 MET	180.9	339.8

The OMS starboard keel web heater did not activate at 58 °F as it had on past missions while operating on system A, but the temperature continued to decrease to approximately 54 °F (Flight Problem STS-88-V-04). The port side keel web heater cycled five times while the starboard did not cycle at all. A review of all past flight data showed that 54 °F on this flight was the coldest temperature on-orbit for system A. When the starboard oxidizer tank temperature reached 70 °F, the heaters were switched to be B string to maintain the tank temperatures above 70 °F.

During the deorbit maneuver, the left OMS engine (S/N 109) bipropellant valve 1 exhibited a slow opening time of approximately 1 second (Flight Problem STS-88-V-06). This opening time was twice the length of time taken by previous firings (approximately 0.5 second). On the previous flight (STS-89), the valve opening time was faster at 0.4 second. The requirement for opening the valve is no more than 0.8 second. Also, the open position of the valve on this firing was 95 percent whereas, the open position

on previous firings was 98 percent. The closed position of the valve for the deorbit firing was 1.5 percent whereas, the closed position on previous firings was minus 2.1 percent. This engine will be removed and sent to White Sands Test Facility for failure investigation and repair.

The right OMS oxidizer and fuel as well as the left OMS oxidizer gaging systems performed satisfactorily. However, the left OMS fuel totalizer displayed anomalous behavior during each firing. The data evaluation indicates that the electronics module is not operating properly.

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

The power reactant storage and distribution (PRSD) subsystem performed nominally throughout the mission with no in-flight anomalies identified. There were no LCC violations noted during the prelaunch operations. The subsystem provided the fuel cells with 2780 lbm of oxygen and 350 lbm of hydrogen for the production of electricity. In addition, the environmental control and life support system (ECLSS) was supplied 196 lbm of oxygen. A 51-hour mission-extension capability existed at touchdown at the average mission power level of 14.2 kW, and at an extension-day power level of 11.7 kW, a 62-hour mission extension was available.

Two days prior to cryogenic tank loading was to occur, the oxygen tank 5 vac-ion pump output dropped to the lower limit of the telemetry measurement. The reading should have been greater than 91.7 percent. An OMRSD waiver was approved to fly with this condition as tests of the tank annulus vacuum produced nominal results and the prelaunch boil-off rates after cryogenic loading were nominal.

### **Fuel Cell Powerplant Subsystem**

Performance of the fuel cell powerplant subsystem was nominal throughout the STS-88 mission with no in-flight anomalies identified from the data. The average electrical power level and load for the mission was 14.2 kW and 466 amperes. The fuel cells produced 4025 kWh of electrical energy and 3130 lbm of by-product potable water while using 2780 lbm of oxygen and 350 lbm of hydrogen.

Four purges of the fuel cells were performed satisfactorily during the mission using both the automatic and manual systems. The actual fuel cell voltages at the end of the mission were 0.15 Vdc above predicted for fuel cell 1, 0.10 Vdc above predicted for fuel cell 2, and as predicted for fuel cell 3. The fuel cell operating times for the mission were 332 hours 51 minutes 43 seconds for fuel cell 1, 332 hours 13 minutes 8 seconds for fuel cell 2, and 331 hours 53 minutes 42 seconds for fuel cell 3.

The fuel cell monitoring system (FCMS) performed satisfactorily while monitoring individual cell voltages prelaunch, on-orbit and postlanding. All of the data were nominal with the exception of fuel cell 3, cells 5 and 6. The cell 5 voltage measurement was reading high and the cell 6 voltage was reading low. This same condition was present during the turnaround operations when tested. This condition did not cause any problem during the mission.

### Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed nominally with one in-flight anomaly noted in the data. This anomaly is discussed in a later paragraph. The following table provides data concerning the run times and fuel consumption of the APUs during the mission.

The APU 2 drain line pressure 1 and 2 decreased from approximately 15.5 psia prelaunch to 11.1 psia at 340:22:33 G.m.t. (02:13:58 MET) (Flight Problem STS-88-V-02). The drain line pressure reached 5.5 psia prior to entry. A similar decrease occurred during STS-89 and it was attributed to a slight leak of the relief valve. However, this is the first flight of a modification that added a burst disk between these pressure measurements and the relief valve. The data showed a small gaseous nitrogen (GN<sub>2</sub>) leak of 1.3 psi/day and as the mission progressed, the leak rate reduced to 0.5 psi/day. The leakage source for the system is unknown, but troubleshooting will be performed in an effort to isolate the cause of the leakage.

#### **APU RUN TIMES AND FUEL CONSUMPTION**

Flight phase	APU 1 (S/N 406)		APU 2 (S/N 203)		APU 3 (S/N 308)	
	(a) (b)		(a)		(a)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Scrub	09:12	28	09:12	30	09:13	28
Ascent	22:14	53	22:07	57	22:17	58
FCS checkout	05:51	18				
Entry <sup>a</sup>	61:23	110	87:28	173	61:29	131
Total	98:40	209	118:48	260	92:59	217

<sup>a</sup> APUs were shut down 17 minutes 01 seconds after landing.

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

APU 1 and hydraulic system 1 were selected for flight control system (FCS) checkout, and the checkout was nominal in all respects. APU 1 was operated for 5 minutes 49 seconds and fuel consumption for the APU was 18 lb.

### Hydraulics/Water Spray Boiler Subsystem

The overall performance of the hydraulics and WSB subsystem was nominal, except for the under-cooling condition that occurred during ascent. This problem is discussed in a following paragraph. No LCC or OMRSD violations occurred during the prelaunch operations, and no in-flight anomalies were noted.

At 337:08:53:42 G.m.t. (approximately liftoff minus 4½ minutes) during the final countdown for the planned launch on December 3, 1998, a master alarm was annunciated for a LCC violation and the countdown was held at that point. The hydraulic system 1 supply pressure B dropped to 1636 psia, well below the 2400-psia master-alarm trigger point, during transition from low pressure to normal pressure (Flight

Problem STS-88-V-07). The backup flight system (BFS) did not receive the fault message because the pressure recovered prior to the second data scan below the lower limit. Data analysis confirmed the expected switching valve operation, and confirmed that an insufficient flow demand did not cause the pressure drop. A review of the flight data indicated that the system 1 depressurization valve was momentarily energized at the time of the pressure drop. Troubleshooting and switch tests on the vehicle documented that the switch was more sensitive than the other two pump switches in that it requires less throw-travel to move from the low to the normal position; however, once the switch was properly locked in the norm position, it remained there. As a result, switch tease was determined to be the most likely cause of the momentary actuation of the depressurization valve. Proper remote power controller (RPC) operation with the switch in the normal-pressure position was verified on this vehicle during the STS-89 mission. Based on the results of the data evaluation and the vehicle tests, the decision was made to make no changes to the vehicle and fly as-is.

The hydraulic system and water spray boiler (WSB) performance was satisfactory during the FCS checkout. No drop in hydraulic pressure was observed when the hydraulic main pump switch was taken from low pressure to normal pressure. Because of the short run time of the APU, lubrication oil spray cooling was not required.

During ascent, the APU 2 lubrication oil return temperature reached approximately 296 °F before the crew switched WSB 2 from the A controller to the B controller. The lubrication oil outlet temperature reached 325 °F prior to the beginning of spraying, and the WSB used 0.6 lb of water (normal usage 2 to 3 lb). This under-cooling condition did not impact APU 2 operations during the remainder of the mission. For entry, APU 2/hydraulic system 2 was started at deorbit maneuver ignition minus 5 minutes using the A controller. The lubrication oil return temperature reached a nominal 247 °F at the start of spraying. At entry interface minus 13 minutes, the B controller was selected and nominal spray performance was noted until APU 2 was shut down postlanding. Both controllers were validated as operational hardware. The cause of the under-cooling behavior is believed to be ice forming on the WSB spray bars. This condition has been observed on numerous previous flight.

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

The electrical power distribution and control (EPDC) subsystem performed satisfactorily throughout the flight, and one in-flight anomaly (Flight Problem STS-88-V-05) may have been caused by the EPDC operation and it is discussed the Reaction Control Subsystem section of this report. All File IX in-flight checkout requirements were also met.

### **Orbiter Docking System**

The Orbiter Docking System (ODS) performed satisfactorily throughout the STS-88 mission. No in-flight anomalies were identified during the review and analysis of the data.

Node 1 was moved to the ODS pre-installation position. The first contact of the Orbiter docking ring by the pressurized mating adapter (PMA) 2 was at 339:23:44:43 G.m.t. (01:15:09:09 MET). At 339:23:45 G.m.t. (01:15:10 MET), a successful connection

between Node 1 and the ODS was confirmed. The ring retraction was completed at 339:23:50:01 G.m.t. (01:15:14:27 MET) and closing of the hook drive was completed at 339:23:52:25 G.m.t. (01:15:16:51 MET). The Node 1 installation was completed at 339:23:52 G.m.t. (01:15:17 MET) with all docking systems performing nominally.

The ODS valves were used during the docked operation and for EVAs and the valves performed nominally. After the PMA 2 and Node 1 module were installed on the ODS, the vestibule was pressurized in 2-psi steps with a 5-minute hold between steps to protect the A-pass hatch from losing pressure. The ODS upper hatch equalization valve screen was taped to minimize the flow rate during vestibule pressurization. After the vestibule was pressurized and the leak check was complete, the Orbiter/PMA 2/Node 1 pressures were equalized at 11.84 psia. The Orbiter was then isolated and depressurized to 10.2 psia in preparation for the planned EVAs. After the second EVA, the Orbiter/ISS stack (PMA 2, Node 1, PMA-1 and FGB) pressures were equalized at 13.03 psia and then the pressure was raised to 15.0 psia in preparation for the planned activities in the ISS. The vestibule depressurization valves were used to depressurize the vestibule and PMA 2 to space prior to undocking from the ISS.

To verify successful connectivity and control of the PMA 1 docking mechanism through the ODS and PMA 2, a PMA 1 docking ring extend-and-retract cycle was successfully performed.

Undocking from the ISS was initiated at 347:20:24:34 G.m.t. (09:11:49:00 MET) followed by the fly-around inspection of the ISS.

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

The primary and alternate atmospheric revitalization pressure control subsystems (ARPCS) operated satisfactorily throughout the flight.

After the vestibule was pressurized and the leak check was complete, the Orbiter/PMA 2/Node 1 pressures were equalized at 11.84 psia. The crew compartment was depressurized to 10.2 psia on three occasions to pre-breathe the two crewmembers who were to perform the extravehicular activities (EVAs). The cabin depressurization began at 339:01:33 G.m.t. (00:16:00 MET) and was completed approximately 30 minutes later with the cabin pressure stabilized at 10.25 psia. Following the second EVA, the Orbiter/ISS stack was pressurized to 14.7 psia using the Orbiter 14.7 psia repressurization procedure, and then to 15.0 psia using oxygen. Before undocking, leak checks were performed on the ISS. The FGB and Node 1 were left at 15.0 psia and 13.8 psia, respectively.

The cabin was repressurized to 14.7 psia following the third EVA and starting at 348:00:07 G.m.t. (09:15:32 MET) as no additional EVA's were planned.

#### **Atmospheric Revitalization Subsystem**

The atmospheric revitalization subsystem (ARS) performed nominally for this mission.

At 341:00:14 G.m.t. (02:15:39 MET), the cabin air temperature peaked at 84.6 °F, while the cabin pressure was at 10.2 psia. This temperature at this cabin pressure violates

the avionics-life certification operating temperature limit of 80 °F when cabin pressure is at 10.2 psia. In addition, flight rule 9-75 addresses the temperature protection for the inertial measurement unit (IMU) from an over-temperature condition. The crew used a portable onboard meter to measure the temperature on the middeck location of the air inlet for the IMUs. The temperature was 76 °F using the portable meter.

The PPCO<sub>2</sub> peaked at 3.5 mmHg on flight day 1 when the cabin pressure was 14.7 psia. During the 10.2 psia cabin pressure operations, the PPCO<sub>2</sub> peaked at 3.8 mmHg. PPCO<sub>2</sub> concentrations averaged a nominal level of 1.94 mmHg throughout the duration of the flight.

### **Active Thermal Control Subsystem**

The active thermal control subsystem (ATCS) operation was satisfactory throughout the mission. No in-flight anomalies were identified from the data analysis.

Ascent performance was nominal. Radiator flow was initiated at 338:09:06 G.m.t. (00:01:31 MET) and the payload bay doors were fully open approximately 9 minutes later. The radiators were not deployed on this flight. The FES was inhibited several times during the flight to support payload operations.

The radiator cold-soak prior to entry resulted in cooling being provided throughout entry. The radiators started to lose control two minutes after landing and the temperature continued to climb until landing plus four minutes when ammonia boiler system (ABS) A was activated. System A provided cooling for 41 minutes until the tank pressure blew-down. An additional 13 minutes of cooling was required using system B before external cooling was activated.

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

The supply water and waste management system performed nominally throughout the mission. All in-flight checkout were completed with satisfactory results prior to the end of the mission.

Prior to launch, a higher-than-normal level of bacteria was detected in the potable water system. Samples taken three day prior to launch contained 154 colony forming unit (CFU's) per ml, and the specification allows a maximum of 100 CFU's per ml. The bacteria were of a type that had been seen before and were not considered harmful. A waiver was approved based on the rationale that tank A would be drained down to 25-percent prelaunch and then refilled with fuel cell water, which contains 3 to 4 ppm of iodine. Also, the crew performed additional flushes through the galley needle prior to consuming the water.

Upon installing the galley iodine removal assembly (GIRA) hose at approximately 338:13:45 G.m.t. (00:05:00 MET), the crew found an incompatible connection between the activated carbon ion exchange (ACTEX) cartridge and the ACTEX hose assembly (Flight Problem STS-88-V-08). This problem is discussed in greater detail in the Government Furnished Equipment/Flight Crew Equipment section of this report.

Supply water was managed through the use of the flash evaporator system (FES) and the water dump system. Three supply water dumps were made at a nominal average dump rate of 1.47 percent/minute (2.42 lb/min). The supply water dump line was maintained between 71.9 °F and 101.3 °F throughout the mission with the operation of the line heater.

The supply water tank B quantity sensor exhibited a few dropouts near the end of the mission. The condition did not impact mission operations.

Waste water was gathered at about the predicted rate. Three waste water dumps were completed at an average dump rate of 1.82 percent/minute (3.00 lb/min). The waste water dump line temperature was maintained between 53.0 °F and 77.8 °F throughout the mission.

The vacuum vent line temperature was maintained between 57.6 °F and 81.6 °F.

### **Waste Collection Subsystem**

The waste collection subsystem (WCS) performed nominally during STS-88. When the compaction procedure was attempted on flight day 12, however, the compactor did not sweep the full arc and compactor operations were ceased. The vanes did not move across the transport tube and did not impede further nominal operation. Postflight analysis of the system did not reveal any malfunctions of the WCS or the compactor system. The compaction procedure is normally performed on flight day 8 or 9. It is suspected that attempting it later in the flight resulted in more frozen material than the design allows for during compaction, and the specified torque setting was not sufficient to move the material and complete the cycle. WCS training and flight operations personnel have been advised to emphasize the flight day 8 or 9 window-of-opportunity for compactor operations to remain within the hardware design limits.

### **Airlock Support System**

The active airlock support system monitor parameters indicated normal operation throughout the flight during which three EVAs were performed. The external airlock water line heaters were configured to the B heater string before EVA 1 and the C heater string was also turned on for the EVAs to prevent hot and cold conditions in the water lines.

The nominal airlock repressurization following EVA 1 began at 342:05:30 G.m.t. (03:20:55 MET). A very successful 7 hour and 21 minute EVA was completed.

A nominal airlock repressurization following the second EVA occurred at 344:03:35 G.m.t. (05:19:00 MET) to successfully conclude the 7-hour 2-minute EVA.

A nominal Orbiter airlock depressurization in preparation for the third EVA began at 346:20:17 G.m.t. (08:11:41 MET). A very successful third EVA was concluded after 6 hours and 59 minutes with a nominal airlock repressurization.

Exposure of the airlock booster fan to a vacuum was a subject of discussion during the mission. A one-flight certification deviation was approved, allowing the fan to be

exposed to vacuum conditions during the third EVA. Following the EVA, the fan started under normal current loads as a data comparison to pre-exposure to vacuum starting conditions. Current trace amplitude versus time comparisons indicated that all three phases, thus the fan had not changed after exposure to a vacuum.

Depressurization of the airlock vestibule was completed nominally with the performance of a successful leak check at 347:06:04 G.m.t. (08:21:29 MET).

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

The smoke detection system performed satisfactorily and showed no indications of smoke generation during the mission. Use of the fire suppression system was not required.

### **Flight Data Subsystem**

The flight data system performed satisfactorily throughout the mission. The Global Positioning System (GPS) had five autonomous resets (tilts), all of which had a normal recovery. The GPS performance was nominal during ascent and entry.

The inertial measurement units (IMU's) performed satisfactorily throughout the mission. The preflight calibrations performed during the scrub and launch day countdowns resulted in good calibrations of the IMU parameters. As a result, only one adjustment of the IMU accelerometer compensations was required for two of the IMU's. The third required no adjustment required for the third unit. Also, no drift compensations were required for any of the IMU's.

### **Flight Software**

The overall performance of the flight software was satisfactory. Two minor issues were noted during the mission and were resolved with no impact to the mission.

The first issue arose when general purpose computer (GPC) 3 was taken from standby to run to become the third guidance, navigation and control (GNC) computer in a three-GPC redundant set in preparation for the final rendezvous activities. A negative duty-cycle percentage (-2 percent) was noted for this computer, and since this same GPC had an initial program load (IPL) anomaly during the prelaunch activities, a decision was made to remove GPC 3 from the redundant set. GPC 3 and GPC 1 were dumped to the ground for analysis. As a result, it was determined that the negative duty cycle was the result of the normal initialization processing, and the GPC was found ready to support the remainder of the mission. No anomalous operation was noted from this computer during the remainder of the mission. This negative duty cycle has no adverse effects on the flight software, and its only manifestation is in the downlist.

The second issue was noted when using the systems management (SM) GPC to point the Ku-band antenna while operating in the GPC Designate mode. The roll and pitch pointing angle data for Tracking and Data Relay Satellite (TDRS) East failed to update for approximately 30 seconds. In this mode, the Ku-band system operates in an open-loop mode and does not track the forward link. The open-loop mode requires the roll-pitch angles to be within 1.5 degrees (total error) to maintain lock on the TDRS. This

total error was exceeded, and the loss of the angle update caused an approximate 3 to 4 second loss of return link communications. An analysis of the flight software algorithms, which format the data for transfer to the SM GPC, revealed a protection singularity in which the computations of the Euler angles are suspended when the yaw angle approaches  $\pm 90$  degrees. As a result, static values for roll, pitch and yaw are transferred to the SM GPC. The occurrence of this condition is rare, but when it occurs while in the GPC Designate Mode, it can cause a temporary loss of lock as witnessed in this instance.

### **Flight Control System**

The flight control system performance was nominal throughout the mission. On-orbit flight control system performance during payload-extended operations was also nominal. There were no known violations of the flight control constraints. The data analysis indicates that the preflight mass property and structural model accuracy's were within the requirements. No dynamic interaction stability concerns were observed.

Three OMS maneuvers were performed while the Node 1 was attached to the Orbiter Docking System. The maneuvers were performed with only one engine, as planned, and residuals were small after each maneuver.

Mated vehicle rotational control was nominal. Both the local vertical local horizontal (LVLH) and inertial attitudes were used successfully. Likewise, the mated vehicle reboost maneuver was successfully completed. The crew commanded 11 +X axis primary RCS firings of 5 seconds each to increase the orbit semi-major axis approximately 3 nmi. However, during the first two firings of the reboost maneuver, attitude excursions were larger than expected by approximately 7 degrees. This condition was caused by an error in the pitch rate when beginning the reboost procedure. A second reboost maneuver, originally planned for flight day 7, was not required since the targeted altitude increase was achieved with the first reboost maneuver.

A larger-than-expected pitch rate was noted at the beginning of the reboost maneuver. This rate resulted from the procedure calls for the initial rotational hand controller (RHC) commands to be performed in digital autopilot (DAP) A mode that loads a rotational pulse of 0.002 degrees per second (deg/sec) instead of the correct DAP B mode that uses a pulse size of 0.02 deg/sec. Had the second reboost maneuver been required, a recommendation was made to modify the procedures to use DAP B mode.

### **Displays and Control Subsystem**

While performing EVA 1 operations, the crew reported that the aft starboard, forward starboard, and mid port payload bay floodlights had failed off. All payload bay floodlights were turned on at 341:20:53 G.m.t. (03:12:18 MET). The aft and forward starboard payload bay floodlights failed off at 341:22:26 G.m.t. (03:13:51 MET). The mid port floodlight failed off at 342:01:56 G.m.t. (03:17:21 MET). Power was removed from the failed lights. These floodlights are a modified assembly which also included a modified ballast. During the mission, the most probable cause of the floodlight failures was believed to be a cracked lamp based on the lack of arcing in the lamp assembly and the lack of any indication of an RPC trip, which is indicative of a failed transistor driver in the ballast. Ground troubleshooting that was performed at KSC has

determined that the bulb was cracked. The cracked lamp failure was attributed to the difference of the coefficient of thermal expansion between the tungsten electrode and the fused silica glass.

The aft port payload bay floodlight failed to illuminate at 347:04:55 G.m.t. (08:20:20 MET) as noted in the mid main bus C data. The crew verified that the floodlight was failed and turned the power off to the light.

At 347:22:05 G.m.t. (09:13:30 MET), the crew reported that the forward port payload bay floodlight was flashing, and this condition was also observed on the downlink video. The floodlight was declared failed and turned off. During payload bay door closure, all floodlights were turned on for troubleshooting to document the signature on the bus current while turning on each floodlight. The forward port floodlight operated normally and was left on for door-closure illumination.

During the postflight debriefings, the crew reported that the parameter select and value select thumb wheels on caution and warning panel R13U were very stiff. The crew also stated that the switches were very sticky and difficult to actuate. Postflight testing that was performed at KSC determined that the tenth digit on the value select push-button switch was somewhat stiff to movement. The OMRSD does allow some hesitation in the plunger. Discussions with the crew and their support personnel resulted in an agreement that the switches were acceptable in the as-is condition.

### **Communications and Tracking Subsystems**

At 339:02:04 G.m.t. (00:17:29 MET), the crew reported a binding condition with the payload bay closed circuit television (CCTV) camera B pan drive mechanism. In the fast pan/tilt rate, camera B failed to pan the required 90 degrees (Flight Problem STS-88-V-01). The binding did not appear to repeat when the camera was operated in the SLOW pan/tilt rate. As a result, camera B was not used for Orbiter Space Vision System (OSVS) checkout, and was left in an acceptable pan position to support upcoming berthing operations. On flight day 8 at 345:01:16 G.m.t. (06:16:41 MET), additional troubleshooting was performed. The camera appeared to experience binding during fast-rate operation. When the binding occurred, the camera moved sluggishly or stopped moving altogether. When the camera was panned using the slow-rate operation, binding appeared not to occur. Video of camera B was taken using camera C and that data was used for analysis of the problem.

At approximately 340:03:46 G.m.t. (01:19:11 MET), the crew reported a problem was experienced with the cable which allows the ODS audio/video cables to connect directly with a crewman communications umbilical (CCU) for audio. This cable was to be used only in this application. As a result, this condition did not impact any future operations during this mission. Postflight troubleshooting was required to determine the cause of the problem.

The Ku-band radar acquired the FGB at a range of 144,000 feet (24 nmi.) and tracked the FGB to a range of 450 feet when the Ku-band was placed back into the communication mode.

### Operational Instrumentation/Modular Auxiliary Data System

One of the two pressure sensors for the right inboard main landing gear tire failed off-scale low at 344:21:53 G.m.t. (06:13:18 MET). The loss of the measurement did not impact the mission as the redundant measurement was still operating properly.

### Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. The landing and braking parameters for this flight are shown in the following table.

#### LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	3290.7	196.6	-2.3	N/A
Nose gear touchdown	6038.3	157.7	N/A	-5.20
Brake initiation speed		151.8 knots		
Brake-on time		36.04 seconds		
Rollout distance		11612 feet		
Rollout time		47.78 seconds		
Runway		15 (Concrete) KSC		
Orbiter weight at landing		201606.1 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	1637	Left-hand inboard	30.33	
Left-hand inboard 3	1637			
Left-hand outboard 2	1575	Left-hand outboard	29.45	
Left-hand outboard 4	1575			
Right-hand inboard 1	1975	Right-hand inboard	33.34	
Right-hand inboard 3	1975			
Right-hand outboard 2	1829	Right-hand outboard	30.26	
Right-hand outboard 4	1829			

The main landing gear tires were reported to be in reasonably good condition for a landing on the KSC concrete runway.

The ET/Orbiter separation devices (EO-1, EO-2, and EO-3) functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. The EO-2 fitting retainer springs were in the nominal configuration while the spherical washer and retainer springs in the EO-3 fitting were offset/displaced. A total of three clips were missing from EO-2 and EO-3. Virtually no umbilical closeout foam or white room temperature vulcanizing material adhered to the umbilical plate near the LH<sub>2</sub> recirculation line disconnect.

As a result of the unresolved drag parachute anomaly on STS-95, the drag parachute was not deployed during the landing operations. As this report was being completed, the resolution for the drag chute anomaly is still being evaluated.

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

The prelaunch thermal interface purges were normal with no problems noted. The ascent aerodynamic and plume heating was normal. The entry aerodynamic heating on the SSME nozzles was also normal. The acreage heating on the vehicle was typical. Minor localized heating was indicated by localized tile slumping on the carrier panel tiles just outboard of the chin panel.

### **Thermal Control Subsystem**

The thermal control subsystem (TCS) performance was satisfactory for the STS-88 mission. All TCS temperatures were maintained within acceptable limits.

Because of the concern of freezing the external water line on the airlock, an operational plan was developed and successfully implemented to prevent the freezing. This plan maintained a higher thermostat set point for the system C external airlock water line heater. This plan was able to protect the water line from both the cold and hot issues of the external water line.

The starboard keel web thermostat failed off during the top-Earth, tail on the velocity vector attitude. The A heater had cycled 24 times at 58 °F or above, followed by the temperature lowering to 54 °F with no cycle, consequently, heater system B was selected and it worked nominally for the remainder of the mission.

### **Aerothermodynamics**

Data indicate that a normal symmetrical transition occurred. Aileron data, wing skin temperature and yaw thruster firings were all normal. Skin temperature rise indicates a turbulent to laminar flow transition time of 1290 seconds. No protruding AMES gap fillers were reported.

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

The thermal protection subsystem (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was normal based on structural temperature rise data. MADS data showed transition from turbulent to laminar flow occurred at Mach 6.4, which was 1290 seconds after entry interface and was symmetric.

The Orbiter TPS sustained a total of 116 damage sites (hits) during the mission. Of this total, 25 had a major dimension of 1-inch or larger. The total does not include the numerous damage sites on the base heat shield that are attributed to SSME vibration/acoustics, exhaust plume recirculation, and the flame arrestment sparkler system. A comparison of these numbers to 71 missions of similar configuration indicates that the total number of sites was near the average and the number of sites greater than 1-inch was greater than the cumulative mission average. The following table provides the data for the total number of damage sites on the STS-95 Orbiter.

**TPS DAMAGE SITES**

<b>Orbiter Surfaces</b>	<b>Hits &gt; 1 Inch</b>	<b>Total Hits</b>
Lower Surface	21	80
Upper Surface	0	4
Right Side	0	4
Left Side	0	3
Right OMS Pod	1	5
Left OMS Pod	1	4
Window Area	2	15
<b>Total</b>	<b>25</b>	<b>116</b>

Most of the lower surface damage was concentrated between the nose landing gear and main landing gear wheel wells on both the left and right chines although the predominant number of damage sites occurred on the right side. The outboard damage sites on the chines follow a similar location/damage pattern that has been documented on STS-86, -87, -89, -90, -91, and -95, though the pattern was not as symmetric as on previous flights. It should also be noted that this is the third flight of the super light weight tank (SLWT). A comparison of Orbiter lower surface tile damage statistics since STS-86 is shown in the table on the following page.

The initial evaluation indicates that no lower surface tiles will be scrapped as a result of debris damage. The largest lower surface tile damage site, located on the right chine, measured 4.5 inches long by 1.125 inches wide by 0.125 inch deep. The deepest lower surface tile damage site measured 0.5 inch deep and was located on the right chine.

The damage sites around and aft of the LH<sub>2</sub> and LO<sub>2</sub> ET/Orbiter umbilicals were much less than usual. This damage is usually caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream. Typical amounts of damage occurred on the base heat shield. All SSME dome-mounted heat shield (DMHS) closeout blankets were in excellent condition with the exception of frayed, torn, and missing material on the SSME 3 blanket between the 9:00 and 11:00 o'clock position.

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

<b>Parameter</b>	<b>STS -86</b>	<b>STS -87</b>	<b>STS -89</b>	<b>STS -90</b>	<b>STS -91</b>	<b>STS -95</b>	<b>STS -88</b>
Lower surface total hits	100	244	95	76	145	139	80
Lower surface hits > 1 in.	27	109	38	11	45	42	21
Longest damage site, in.	7	15	2.8	3.0	3.0	4.0	4.5
Deepest damage site, in.	0.4	1.5	0.2	0.25	0.5	0.4	0.5

No unusual damage was detected on the leading edges of the OMS pods and vertical stabilizer.

Hazing and streaking of the forward-facing windows was moderate. Damage sites on the window perimeter tiles were much less than usual in quantity and size.

## EXTRAVEHICULAR OPERATIONS

The extravehicular activity (EVA) hardware performed satisfactorily throughout the mission and EVA operations were very successful with many tasks being completed that were to be completed on future mission EVA's.

The extravehicular mobility unit (EMU) checkout was performed at 339:06:19:36 G.m.t. (00:21:44:02 MET). All three suits performed nominally and were ready for the planned EVA's.

EVA 1 officially began when battery power was selected on the EMUs at 341:22:09 G.m.t. (03:13:34 MET). The foot restraint installation to the RMS striker bar was performed at 341:22:55 G.m.t. (03:14:20 MET). All objectives of EVA 1 were successfully completed, and the Zarya module and Unity module cable interfaces were verified with no anomalies noted. Another task completed during EVA 1 was the inspection of the undeployed TORU antennas on the Zarya module. From the inspection, it was determined that the antenna pyrotechnics have fired, but the antennas did not deploy.

At approximately 342:00:34 G.m.t. (03:16:59 MET), a slide-wire carrier became loose from the EV1 crewmember and floated away. At approximately 342:03:15 G.m.t. (03:18:40 MET), a work-site interface (WIF) socket and a retractable tether also became loose from the EV1 crewmember. Both of these items floated away from the Orbiter and ISS and caused no impact hazard.

The nominal airlock repressurization following EVA 1 began at 342:05:30 G.m.t. (03:20:55 MET), and the EMUs performed nominally during the entire EVA. A very successful 7 hour and 21 minute EVA was completed. Water recharging of the EMUs was completed at 342:07:07 G.m.t. (03:22:32 MET) in preparation for the next EVA, and the EMU battery recharging began at 342:07:40 G.m.t. (03:23:05 MET). EVA 1 was performed using only the RCS vernier thrusters for attitude control.

EVA 2 officially began when battery power was selected on the EMU's at 343:20:33 G.m.t. (05:11:58 MET). A nominal ODS depressurization in preparation for the EVA occurred at 343:20:13 G.m.t. (05:11:38 MET). All objectives of EVA 2 were successfully completed. An additional task completed on EVA 2 was the deployment of one of the Zarya module TORU antennas. The second TORU antenna was deployed during EVA 3. At approximately 344:00:52 G.m.t. (05:16:17 MET), a trunnion pin cover separated and floated away, thus only three of the four covers were installed on Node 1. A new cover will be fabricated and installation of the fourth cover is planned for STS-96 (flight 2A.1). The EMUs performed nominally during the entire EVA. A nominal airlock repressurization following the EVA occurred at 344:03:35 G.m.t. (05:19:00 MET) to successfully conclude the 7-hour 2-minute EVA.

EVA 3 officially began when the EMU's were set to battery power at 346:20:33 G.m.t. (08:11:57 MET). A nominal Orbiter airlock depressurization in preparation for the EVA began at 346:20:17 G.m.t. (08:11:41 MET). The RMS was repowered at 346:19:51 G.m.t. (08:11:15 MET) to support the EVA. All objectives of EVA 3 were successfully completed, including the deployment of the second Zarya TORU antenna.

The evaluation of the USA Simplified Aid for EVA Rescue (SAFER) which took place during this EVA achieved approximately 50 percent of its objectives due to uncertainties concerning the amount of gaseous nitrogen (GN<sub>2</sub>) propellant that remained. The EMU's performed nominally during the entire EVA. A nominal airlock repressurization following EVA 3 occurred at 347:03:32 G.m.t. (08:18:56 MET) to successfully conclude the 6-hour 59-minute EVA. EMU water recharges were not performed and an additional EVA was not required. The 20-hour EMU battery recharge was initiated at 347:04:15 G.m.t. (08:19:40 MET). The recharge on the pistol grip tool batteries and the EMU helmet light batteries was initiated at 347:04:22 G.m.t. (08:19:47 MET).

Depressurization of the airlock vestibule was completed nominally with the performance of a successful leak check at 347:06:04 G.m.t. (08:21:29 MET).

## **REMOTE MANIPULATOR SYSTEM OPERATION**

The remote manipulator system (RMS) performance was very satisfactory throughout the mission. No in-flight anomalies were noted during the mission.

The primary task of the RMS was to assemble the first International Space Station (ISS) element. This task included the unberthing and attachment of Unity Node 1 to the Orbiter Docking System (ODS), followed by the capture of the Russian Zarya (FGB) module. After FGB capture, it would be mated to the Unity Node 1 pressurized mating adapter (PMA 1). In addition, the RMS was used to support over 21 hours of extravehicular activity (EVA) on three different flight days.

Power was applied to the RMS at 339:02:09 G.m.t. (00:17:33:26 MET). The RMS checkout was completed successfully followed by a payload bay survey. The arm was then powered down and cradled, latched and placed in the temperature-monitor mode. All RMS operations were nominal.

The RMS was repowered at 339:21:20 G.m.t. (01:12:45 MET), and the arm was maneuvered from its pre-cradle position to the Node 1 pre-grapple position. Node 1 was grappled by the RMS at 339:22:05 G.m.t. (01:13:30 MET). The RMS was used to unberth and move Node 1 to the Orbiter docking system (ODS) pre-installation position. At 339:23:42 G.m.t. (01:15:07 MET), with four inches of separation between Node 1 and the ODS, the RMS was switched into the test mode. At 339:23:43 G.m.t. (01:14:58 MET), the automatic brakes were inhibited by general purpose computer (GPC) command. At that time, the RMS was in a "limp" configuration and the Orbiter primary reaction control subsystem (RCS) thrusters were fired to complete the mating of Node 1 and the ODS. The first contact of the Orbiter docking ring by pressurized mating adapter (PMA) 2 was at 339:23:44:43 G.m.t. (01:15:09:09 MET). At 339:23:45 G.m.t. (01:15:10 MET), a successful connection between Node 1 and the ODS was confirmed. The ring retraction was completed at 339:23:50:01 G.m.t. (01:15:14:27 MET) and closing of the hook drive was completed at 339:23:52:25 G.m.t. (01:15:16:51 MET). The Node 1 installation was completed at 339:23:52 G.m.t. (01:15:17 MET) with all docking systems performing nominally. The RMS was ungrappled from Node 1 at 340:00:10 G.m.t. (01:15:45 MET). The RMS was then maneuvered to the PMA 1 interface survey position. RMS Node 1 operations were completed, and the RMS was powered down at 340:02:36 G.m.t. (01:18:01MET). The arm was cradled, latched and placed in the temperature-monitor mode.

The RMS was repowered at 340:19:55 G.m.t. (02:11:20 MET) and was maneuvered from its pre-cradle position to the Functional Cargo Block (FGB) poise-for-capture position at 340:21:26 G.m.t. (02:12:51 MET). The FGB was grappled by the RMS at 340:23:48 G.m.t. (02:15:13 MET). The RMS was used to maneuver the FGB to the FGB/Node 1 pre-installation position. The RMS FGB pre-installation operations were completed followed by survey operations using the RMS cameras. To alleviate alignment problems during final docking of the FGB, it was necessary for the RMS to ungrapple the FGB. This prevented minor forces that are generated by the arm from pushing the FGB out of alignment.

The OSVS was used as a confirming cue along with the RMS digital data and camera displays for FGB alignment with the Node. The crew reported that when it OSVS was operating, the OSVS data agreed to within one-half inch of the RMS digital information. Overall, the crew stated that the OSVS was not an acceptable means for berthing the Zarya to the Unity.

The RMS was repowered at 341:20:58 G.m.t. (03:12:23 MET) and maneuvered to the EVA egress position. A nominal ODS depressurization was completed in preparation for EVA 1.

The RMS successfully supported the EVA 1 activities and power was removed at 342:05:38 G.m.t. (03:21:03 MET). All arm operations were nominal. The RMS was cradled, latched and placed in the temperature-monitor mode until required for the second EVA.

The RMS was repowered at 343:19:48 G.m.t. (05:11:13 MET) to support EVA 2. Following the second EVA, the RMS was used to perform a survey of OSVS targets. Power was removed from the RMS at 344:05:49 G.m.t. (05:21:15 MET).

The RMS was repowered at 356:19:51 G.m.t. (08:11:16 MET) to support the third EVA. Following the third EVA, the RMS was used to perform a survey of OSVS targets and the Simplified Aid for EVA Rescue (SAFER) Development Test Objective (DTO). The RMS was cradled and latched at 347:05:56 G.m.t. (08:21:20 MET). Power was removed from the RMS as no more RMS activities were planned or required for this mission.

## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The overall performance of the Government Furnished Equipment/Flight Crew Equipment (GFE/FCE) was satisfactory. The two in-flight anomalies and the minor problems that were encountered are discussed in the following paragraph.

At 339:02:04 G.m.t. (00:17:29 MET), the crew reported a binding condition with the payload bay closed circuit television (CCTV) camera B pan drive mechanism (Flight Problem STS-88-V-01). In the fast pan/tilt rate, camera B failed to pan the required 90 degrees. The binding did not appear to repeat when the camera was operated in the SLOW pan/tilt rate. As a result, camera B was not used for Orbiter Space Vision System (OSVS) checkout, and was left in an acceptable pan position to support upcoming berthing operations. On flight day 8 at 345:01:16 G.m.t. (06:16:41 MET), additional troubleshooting was performed. The camera appeared to experience binding during fast-rate operation. When the binding occurred, the camera moved sluggishly or stopped moving altogether. When the camera was panned using the slow-rate operation, binding appeared not to occur. Video of camera B was taken using camera C and that data will be used for analysis of the problem.

Checkout was performed only on CCTV camera C with the OSVS because of a possible problem with the camera B pan-and-tilt operation. The checkout was nominal. Docking ring extension was successfully completed at 339:09:31:54.9 G.m.t. (01:00:56:20 MET). Activation of Orbiter interface units (OIU's) 1 and 2 was performed, and the OIU's performed nominally.

At approximately 340:07:13 G.m.t. (01:22:36 MET), the crew reported that one of the five pistol grip tool batteries would not recharge. The battery was tried in other charger locations without success. At 340:20:11 G.m.t. (02:10:36 MET), the crew reported that the battery (s/n 1004) could be charged and it would be used it as a spare. The condition did not impact EVA operations.

The performance of the trajectory control sensor (TCS) in support of the International Space Station (ISS) docking was nominal. Two units were used. Initial indications were that the units or cabling were switched. An investigation will be made of this condition following the flight. TCS unit 1 acquired the target at about 4600 feet. TCS unit 2 acquired the target at about 4300 feet. Both units tracked solidly in the pulse mode. Both units tracked the target to docking with only one retroreflector switch-over for each unit, as expected. Both units were powered down following the docking.

The lights on panel A7 which indicate that payload bay camera B, an intensified television camera (ITVC), failed to illuminate. This condition is a known problem with this black-and-white camera as the data from the camera are interleaved in the video stream and the video switching unit (VSU) cannot always synchronize on these data. The history has shown that this condition occurs approximately 1/3 of the time, and a camera power-cycle usually clears the problem. However, in this case, the power was cycled numerous times and the problem did not clear. A later power cycle did clear the problem, and the camera was left on for the remainder of the mission.

Upon installing the galley iodine removal assembly (GIRA) hose at approximately 338:13:45 G.m.t. (00:05:00 MET), the crew found an incompatible connection between the activated carbon ion exchange (ACTEX) cartridge and the ACTEX hose assembly (Flight Problem STS-88-V-08). The ACTEX hose assembly was built with a ¼ inch male quick disconnect (QD) instead of the nominal ¼ inch female QD. An in-flight maintenance (IFM) procedure was performed that replaced the male quick disconnect (QD) at the end of the ACTEX hose with a female QD from a hose that was a part of the contingency hose and cable kit. The GIRA operated properly thereafter.

## **CARGO INTEGRATION**

The analysis of data for the cargo integration hardware revealed satisfactory operation of all hardware with no in-flight anomalies noted.

## **POSTLAUNCH PAD INSPECTION**

The postlaunch inspection of the launch pad showed that the damage appeared to be minimal. No flight hardware was found during the inspection.

Data showed an Orbiter liftoff lateral acceleration of 0.10g, which is below the threshold (0.14g) for stud hang ups. Overall, the holddown posts exhibited the usual amount of damage from a launch. The tail service masts (TSM's) appeared undamaged and the bonnets were closed properly. The GH<sub>2</sub> vent line was latched in the eighth tooth of the eight tooth latching mechanism. Debris damage was minimal on the fixed service structure.

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

### **DEVELOPMENT TEST OBJECTIVES**

#### **DTO 257 - Structural Dynamics Model Validation**

Data were taken for this Development Test Objective (DTO) on flight day 4 following the berthing of the Functional Cargo Block (FGB). The analysis of the data showed that the results were well within the preflight predictions. This analysis was given to the flight control team prior to the reboost maneuver on flight day 6.

#### **DTO 689 - USA Simplified Aid for EVA Rescue**

The evaluation of the USA Simplified Aid for EVA Rescue (SAFER) which took place at the end of the third EVA achieved approximately 50 percent of its objectives due to uncertainties concerning the amount of gaseous nitrogen (GN<sub>2</sub>) propellant that remained. The performance of the DTO was cut short as a result of the propellant indications. However, the crew confirmed later in the flight that adequate propellants did remain and that an indication error may have occurred. A postflight analysis of this DTO and the propellant indications will be performed.

#### **DTO 700-14 - Miniature Air-to-Ground Receiver-Global Positioning System**

The Miniature Air-to-Ground Receiver (MAGR) for the Global Positioning System (GPS) operated nominally throughout the mission, although at least one "tilt" was observed in the down-listed data. Occasional "tilts" are expected with the current receiver firmware. Data that were recorded on the payload and ground support computer (PGSC) were used in the postflight analysis of the MAGR performance.

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

The Space Integrated Global Positioning System/Inertial Navigation System (SIGI) operated nominally. Analysis of the first data set down-linked indicated satisfactory performance; however, the second data set appeared to have a corrupted file within the data. These data were not lost, as that data were also recorded on the PGSC onboard the vehicle and were retrieved postflight. In troubleshooting this problem, it was found that the card in the PGSC that transfers the data to the Orbiter communications adapter (OCA) had some bad sectors. This problem was resolved with the substitution of another board in the computer (not used during the on-orbit phase) for the bad card, and the PGSC software was reinitialized to continue on-orbit data collection.

#### **DTO 847 - Solid State Tracker Size Limitation**

This Solid State Tracker Size Limitation DTO was performed during the separation maneuver from the International Space Station (ISS). The data will be analyzed in the postflight time period. Results of this DTO may be obtained from the sponsor.

## **DETAILED SUPPLEMENTARY OBJECTIVES**

### **DSO 331 - Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion**

Data were collected from two crewmembers prior to the deorbit preparations and data were provided from that time through landing. The results of this Detailed Supplementary Objective (DSO) may be obtained from the sponsor of this DSO.

### **DSO 496 - Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance**

Data were collected for this DSO during the preflight and postflight time periods. The results of this experiment may be obtained from the sponsor of this DSO.

### **DSO 497 - Effects of Microgravity of Cell Mediated Immunity and Reactivation of Latent Viral Infections**

Data were collected for this DSO during the preflight and postflight time periods. The results of this experiment may be obtained from the sponsor of this DSO.

### **DSO 904 - Assessment of Human Factors**

Data were collected for this DSO during the preflight and postflight time periods. The results of this experiment may be obtained from the sponsor of this DSO.

## **PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

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

The launch photography films and the videos were reviewed by KSC, MSFC, and JSC. No anomalous vehicle-related conditions were noted in any of the photography or videos.

Two rolls of 16 mm umbilical well film and one roll of 35 mm umbilical well film were reviewed. On this mission, a +X axis translation maneuver was performed to facilitate the imaging of the ET with the umbilical well cameras. However, due to total darkness at the time of ET separation, both the 16 mm and 35 mm film was unusable for that portion of the evaluation.

The left SRB separation was visible on the 16 mm films because of the light from the SRBs, and the separation appeared normal. Numerous light-colored pieces of debris (insulation) and dark debris (charred insulation), which were considered typical, were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter liquid hydrogen umbilical electrical cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. No anomalous conditions were noted from the film review.

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

The STS-88 crew photographed the External Tank (TPS) using a 35mm camera and a video camera. A total of 36 photographs were taken with the 35mm camera, and all were of excellent quality. This imagery is useful in the continuing investigation into the sources of Orbiter tile damage. The analysis of the film led to the following conclusions.

1. No evidence of ET venting can be seen (photographs as well as video of ET). As a result, the tumble rate of the ET was very small ( $< 1$  deg/sec).
2. The normal SRB separation burn scars and aerodynamic-heating marks were observed on the +Y and -Y sides of the intertank and nose TPS of the ET.
3. The first 16 photographs of the ET were silhouetted due to the Sun light incidence angle. This resulted in large areas of the ET being in the dark shadow regions.
4. Views of the ET +Z, -Y, -Z, and +Y sides were acquired including the +Y and -Y thrust panels.
5. No damage is visible on the intertank surrounding the thrust panel regions of the ET, nor was any significant damage noted on the -Y and +Y thrust panels.

Enhancements were made of 10 of the photographs to bring out the details of the thrust panels. Analysis of these enhancement photographs further confirmed that no damage is visible on these panels.

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

The landing was on runway 15 at the KSC Shuttle Landing Facility, and the videos of landing were reviewed. Observations from the review show the touchdown to be normal. No in-flight anomalies were noted in the review.

**TABLE I.- STS-88 SEQUENCE OF EVENTS**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	338:08:30:44.912 338:08:30:46.588 338:08:30:48.070
SRB HPU Activation <sup>a</sup>	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	338:08:35:05.969 338:08:35:06.129 338:08:35:06.299 338:08:35:06.449
Main Propulsion System Start <sup>a</sup>	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	338:08:35:27.458 338:08:35:27.577 338:08:35:27.717
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	338:08:35:34.019
Throttle up to 104/104.5 Percent Thrust <sup>ab</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	338:08:35:38.185 338:08:35:38.188 338:08:35:38.198
Throttle down to 72 Percent Thrust	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	338:08:36:13.866 338:08:36:13.868 338:08:36:13.878
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	338:08:36:24
Throttle up to 104/104.5 Percent Thrust <sup>ab</sup>	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	338:08:36:25.226 338:08:36:25.228 338:08:36:25.239
Both RSRM's Chamber Pressure at 50 psi <sup>a</sup>	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	338:08:37:33.259 338:08:37:33.379
End RSRM <sup>a</sup> Action <sup>a</sup> Time	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	338:08:37:35.959 338:08:37:36.279
SRB Physical Separation <sup>a</sup>	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	338:08:37:37.779 338:08:37:37.779
SRB Separation Command	SRB separation command flag	338:08:37:38
OMS Assist Maneuver Ignition	Right Engine Bi-Prop Valve Position Left Engine Bi-Prop Valve Position	338:08:37:48.0 338:08:37:48.1
OMS Assist Maneuver Cutoff	Left Engine Bi-Prop Valve Position Right Engine Bi-Prop Valve Position	338:08:39:30.5 338:08:39:30.6
Throttle Down for 3g Acceleration <sup>a</sup>	ME-1 command accepted ME-2 command accepted ME-3 command accepted	338:08:42:54.808 338:08:42:54.832 338:08:42:54.833
3g Acceleration	Total load factor	338:08:42:54.8
Throttle Down to 67 Percent Thrust <sup>a</sup>	ME-1 command accepted ME-2 command accepted ME-3 command accepted	338:08:43:49.850 338:08:43:49.873 338:08:43:49.874
ET Separation	ET separation command flag	338:08:44:16

<sup>a</sup>MSFC supplied data

<sup>b</sup>SSME 1 is a Block 1A engine with a nominal power level of 104 percent.

**TABLE I.- STS-88 SEQUENCE OF EVENTS  
(Continued)**

Event	Description	Actual time, G.m.t.
SSME Shutdown <sup>a</sup>	ME-1 command accepted	338:08:43:56.170
	ME-2 command accepted	338:08:43:56.193
	ME-3 command accepted	338:08:43:56.194
MECO	MECO command flag	338:08:43:57
	MECO confirm flag	338:08:43:58
APU Deactivation	APU-2 GG chamber pressure	338:08:52:51.166
	APU 1 GG chamber pressure	338:08:52:56.393
	APU 3 GG chamber pressure	338:08:53:01.539
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	338:09:19:15.7
	Right engine bi-prop valve position	338:09:19:15.8
OMS-2 Cutoff	Left engine bi-prop valve position	338:09:20:22.9
	Right engine bi-prop valve position	338:09:20:23.0
Payload Bay Doors (PLBDs) Open	PLBD right open 1	338:10:14:57
	PLBD left open 1	338:10:16:17
OMS-3 Ignition	Left engine bi-prop valve position	338:
	Right engine bi-prop valve position	338:
OMS-3 Cutoff	Left engine bi-prop valve position	338:
	Right engine bi-prop valve position	338:
Cabin Depressurization to (10.2 psi)	Cabin pressure	339:02:02:13
<b>PMA-1/Node 1 Operations</b>		
Payload Grapple	Payload captured	339:21:54:19 ?
Payload Unberthed	Payload select 1 latch 4B release ind.	339:22:08:10
Ring Capture	Capture	339:23:44:43
Payload Docked	Docking ring final position	339:23:52:40
Payload Ungrappled	Payload captured	340:00:09:30
OMS-4 Ignition	Left engine bi-prop valve position	340:03:32:02.0
	Right engine bi-prop valve position	N/A
OMS-4 Cutoff	Left engine bi-prop valve position	340:03:33:52.8
	Right engine bi-prop valve position	N/A
OMS-5 Ignition	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	340:19:34:37.5
OMS-5 Cutoff	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	340:19:37:48.5
OMS-6 Ignition	Left engine bi-prop valve position	340:21:14:42.2
	Right engine bi-prop valve position	N/A
OMS-6 Cutoff	Left engine bi-prop valve position	340:21:14:58.0
	Right engine bi-prop valve position	N/A
FGB Grapple	Payload captured	340:23:47:02
FGB Ungrapple	Payload released	341:02:43:52
Airlock Depressurized - EVA 1	EMU battery activation	341:22:09
Airlock Repressurized - EVA 1	Start Airlock Repressurization	342:05:30
International Space Station RCS Reboost Maneuver		
	Start End	Selected RCS thrusters firing Selected RCS thrusters not firing
		342:20:35:34 342:20:58:21

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

Event	Description	Actual time, G.m.t.
Airlock Depressurized - EVA 2	EMU battery activation	343:19:48
Airlock Repressurized - EVA 2	Start Airlock Repressurization	344:03:35
Airlock Depressurized - EVA 3	EMU battery activation	346:20:17
Airlock Repressurized - EVA 3	Start Airlock Repressurization	347:03:32
Undocking	Undocking complete	347:20:24:34
Cabin Repressurization	Cabin pressure	348:00:07
OMS-7 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 348:02:15:32.3
OMS-7 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 348:02:15:42.1
Flight Control System Checkout APU Start APU Stop	APU 1 GG chamber pressure APU 1 GG chamber pressure	348:20:45:40.093 348:20:51.28.623
Payload Bay Door Closure	PLBD left close 1 PLBD right close 1	350:00:11:14 350:00:13:19
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	350:02:43:03.646 350:03:09:04.713 350:03:09:06.405
Deorbit Burn Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	350:02:48:04.3 350:02:48:04.4
Deorbit Burn Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	350:02:51:05.5 350:02:51:05:6
Entry Interface (400K feet)	Current orbital altitude above	350:03:22:01
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	350:03:46:53
Main Landing Gear Contact	RGA pitch rate	350:03:53:32
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels RH main landing gear weight on wheels	350:03:53:33 350:03:53:34
Nose Landing Gear Contact	NLG RH tire pressure 1	350:03:53:38
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	350:03:53:38
Wheel Stop	Velocity with respect to runway	350:03:54:16
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	350:04:10:23.913 350:04:10:29.126 350:04:10:32.979

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

No.	Title	Reference	Comments
STS-88-V-01	Camera B Pan Drive Anomaly	338:02:04 G.m.t. 00:00:17:28 MET IPR 99V-0007	<p>At approximately 339:02:04 G.m.t., the crew reported a binding problem with the Camera B pan drive. The crew first attempted to pan Camera B from 'directed at Camera C' to an alignment directed at Camera A (pan left). This process was repeated with the same results when trying to pan. Camera C was activated to view Camera B activities, but no cable-related binding was apparent. Binding occurred only at high rate only and not at low rate. Camera B video operations were good but panning operations were being minimized. On flight day 8, troubleshooting was performed on Camera B and the binding at the fast pan rate was again experienced. At the slow rate, the camera was able to pan. Video was taken while troubleshooting this problem. This camera experienced a similar problem during the STS-88 flow operations while preparing for flight.</p> <p>KSC: Troubleshooting of the problem will be performed prior to removal of the camera for its return to JSC.</p>
STS-88-V-02	APU 2 Drain Line Pressure Decrease	340:22:33 G.m.t. 02:13:57 MET CAR 88RF08 IPR 99V-0002	<p>APU 2 Drain Line Pressure Measurement 1 and 2 decreased from approximately 15.5 psia to 11.1 psia in a 60 hour period that began at liftoff. A similar decrease occurred during STS-89 that was attributed to a slight leak of the relief valve. However, this is the first flight of the burst disk located between these pressure measurements and the relief valve. The data show initially a small GN<sub>2</sub> leak of 1.3 psi/day with the decay rate decreasing to 0.5 psi/day.</p> <p>KSC: A postflight troubleshooting plan has been developed and was being implemented as this report was written.</p>
STS-88-V-03	RCS Thruster R2D Failed Leak	348:21:41 G.m.t. 10:13:06 MET CAR 88RF09 ROP1-28-1153	<p>During the RCS Hot-Fire test, RCS thruster R2D was declared failed leak by the redundancy management (RM) due to evaporative cooling. The fuel injector temperature dropped below the RM limit of 20 °F and reached a minimum of 18.8 °F. The temperature recovered to nominal immediately following the hot-fire pulses. The RCS thruster was deselected and remained so for the duration of the flight.</p> <p>KSC: Troubleshooting was performed and the thruster was replaced along with the other thrusters on that manifold.</p>
STS-88-V-04	OMS Pod Starboard Keel Web Heater Failed Off.	348:13:44 G.m.t. 10:05:08 MET CAR 88RF10 IPR 99V-0012	<p>The RP01 pod starboard keel web heater cycled consistently on system A at a low point of 58 °F on STS-88 and previous missions. At 348:13:44 G.m.t., the heater did not activate at 58 °F and the temperature continued to decrease to 54 °F. The attitude was mostly -ZLV -XVV at a low beta angle so the heating was fairly symmetric for both pods. The port side keel web heater cycled five times while the starboard heater did not cycle at all. A data review showed that the 54 °F was the coldest on-orbit for while using system A heater. The starboard oxidizer tank reached 70 °F; consequently the starboard heaters were switched to system B to maintain the tank temperatures above 70 °F.</p> <p>KSC: Troubleshooting will be performed in an effort to isolate the anomaly.</p>

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

No.	Title	Reference	Comments
STS-88-V-05	Right RCS 1/2 Tank Isolation Valves Failed to Close	350:04:26 G.m.t. 11:19:50 MET CAR 88RF11 IPR 99V-0010	<p>During the postlanding RCS and OMS valve test, the right RCS ac motor valve 1/2 tank isolation valves talkback indication failed to indicate closed when commanded from the open to the closed position. The crew reported that the talkback remained indicating open. The switch was taken back to the open and then to the closed position with no change of either the talkback or the telemetered valve position indicators (VPI's). The preliminary analysis of the data indicates that the problem is either in the aft motor control assembly (MCA) no. 3, the cockpit switch, or the copper wire from the switch to the aft MCA no. 3. Tank isolation valves were closed via launch processing system (LPS) command, and the panel 7 talkback indicated closed; however, the VPI did not indicate closed. Repeated valve cycling during the off-loading process had the same results.</p> <p>KSC: Troubleshooting will be performed.</p>
STS-88-V-06	Left OMS Engine Bipropellant Valve 1 Slow with Reduced Travel	350:02:48:04 G.m.t. 11:18:12:30 MET CAR 99RF12	<p>During the deorbit maneuver, the left OMS engine (S/N 109) bipropellant valve 1 exhibited a slow opening time of approximately 1 second. This opening time was twice the length of time taken by previous firings (approximately 0.5 second). On the previous flight (STS-89), the valve opening time was faster at 0.4 second. The requirement for opening the valve is no more than 0.8 second. Also, the open position of the valve on this firing was 95 percent whereas, the open position on previous firings was 98 percent. The closed position of the valve for the deorbit firing was 1.5 percent whereas, the closed position on previous firings was minus 2.1 percent.</p> <p>KSC: Postflight troubleshooting will be performed. Replacement of the engine may also be required.</p>
STS-88-V-07	Pressure Fluctuation in Hydraulic System 1	337:08:53:42 G.m.t. Prelaunch CAR 88RF13 IPR 88V-0165 PR V070-5-A0007	<p>Approximately 4 1/2 minutes prior to liftoff during the final countdown for the December launch, a master alarm was annunciated for a Launch Commit Criteria (LCC) violation and the countdown was held at that point. The hydraulic system 1 supply pressure B dropped to 1636 psia, well below the 2400 psia master alarm trigger point, during transition from low pressure to normal pressure. The backup flight system (BFS) did not receive the fault message because the pressure recovered prior to the second data scan of the telemetered measurement. Data analysis confirmed the expected switching valve operation, as well as confirming an insufficient flow demand had not caused the pressure drop. A review of the flight data indicated that the system 1 depressurization valve was momentarily energized at the time of the pressure drop. Troubleshooting and switch tests on the vehicle documented that switch tease was the most likely cause of the momentary actuation of the depressurization valve. The troubleshooting also showed that the depressurization switch had good stability in the normal pressure position. Proper remote power controller (RPC) operation with the switch in the normal pressure position was verified during the STS-89 mission. Based on the results of the data evaluation and the vehicle tests, the decision was made to make no changes to the vehicle and fly as-is for the second STS-88 launch attempt.</p>

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

No.	Title	Reference	Comments
STS-88-V-07 (Continued)	Pressure Fluctuation in Hydraulic System 1 (Continued)	(Continued)	KSC: Since the switch was found to be position sensitive, troubleshooting was scheduled for the switch with the possibility of replacement of the switch.
STS-88-V-08	ACTEX Hose Wrong Connector	338:13:45 G.m.t. 00:04:30 MET PR DR BM8333135	<p>Upon the installation of the Galley Iodine Removal Assembly (GIRA) hardware, the crew discovered an incompatible connection between the Activated Carbon Ion Exchange (ACTEX) cartridge and the ACTEX hose assembly. The ACTEX hose assembly was built with a ¼ inch male quick disconnect (QD) per the drawing. The ACTEX cartridge was assembled correctly, and all labels were correct.</p> <p>An in-flight maintenance (IFM) procedure was developed to replace the male QD with a female QD from the Red-Red hose, which was a part of the contingency hose and cable kit. The IFM was performed on flight day 2 and the system operated nominally thereafter.</p> <p>KSC: No action required.</p>

## DOCUMENT SOURCES

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

1. Flight Requirements Document
2. Public Affairs Press Kit
3. Customer Support Room (CSR) Daily Science Reports, and Final CSR Report
4. Mission Evaluation Room (MER) Daily Reports
5. MER Mission Summary Report
6. MER Problem Tracking List
7. MER Event Times
8. Subsystem Manager Reports/Inputs
9. MOD Systems Anomaly List
10. MSFC Flash Report
11. MSFC Event Times
12. MSFC Interim Report
13. Crew Debriefing comments
14. Shuttle Operational Data Book
15. STS-88 Summary of Significant Events
16. Contractor Reports of Subsystem Operation

## ACRONYMS AND ABBREVIATIONS

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

ABS	ammonia boiler system
ACTEX	activated carbon ion exchange
AMTEC	Alkali Metal Thermal-to-Electric Converter
APAS	Androgynous Peripheral Attachment System
APCU	assembly power converter unit
APDS	Androgynous Peripheral Docking System
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
AWCS	Automated Water Cartridge System
BFS	backup flight system
BLAST	Bubble Laboratory Adds Science and Technology
CBM	common berthing mechanism
CCD	charge-coupled device
CCTV	closed circuit television
CCU	crewman communication umbilical
CE	Cargo Element
CEI	contract end item
CFU	colony forming units
c.g.	center of gravity
CONAE	Argentinean National Commission of Space Activities
CPM	cell performance monitor
DGPS	differential Global Positioning System
DMHS	dome-mounted heat shield
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
$\Delta V$	differential velocity
ECLSS	Environmental Control and Life Support System
EMU	extravehicular mobility unit
EO	ET/Orbiter
EPDC	electrical power distribution and control
e.s.t.	eastern standard time
ET	External Tank
EVA	extravehicular activity
FCE	flight crew equipment
FCMS	fuel cell monitoring system
FCS	flight control system
FEA	floodlight electronic assembly
FES	flash evaporator system
FGB	Functional Cargo Block
ft/sec	feet per second
g	gravity
GAS	Get-Away Special

GFE	Government furnished equipment
G.m.t.	Greenwich mean time
GN <sub>2</sub>	gaseous nitrogen
GNC	guidance, navigation and control
GO <sub>2</sub>	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
HELP	Horntown Educational Learning Project
Hg	Mercury
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
ICBC	IMAX cargo bay camera
ICD	Interface Control Document
IFM	in-flight maintenance
IMU	inertial measurement unit
IPL	initial program load
I <sub>sp</sub>	specific impulse
ISS	International Space Station
ITVC	intensified television camera
JSC	Johnson Space Center
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LH <sub>2</sub>	liquid hydrogen
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO <sub>2</sub>	liquid oxygen
LP	Launch Package
MADS	Modular Auxiliary Data System
MAGR	miniature airborne GPS receiver
MAINE	Maine Agricultural Industry NEWMAS <sup>T</sup> Experiment
MCC	Mission Control Center/midcourse correction (maneuver)
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MET	mission elapsed time
ml	milliliter
mm	millimeter
MPS	main propulsion system
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NEWMAS <sup>T</sup>	NASA Educational Workshop for Mathematics, Science and Technology
nmi.	nautical mile
NPC	rendezvous maneuver
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OCA	Orbiter Communications Adapter
ODS	Orbiter docking system

OIU	Orbiter interface unit
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OSVS	Orbiter Space Vision System
PAL	protuberance air load
PGSC	payload and general support computer
PMA	pressurized mating adapter
PMBT	propellant mean bulk temperature
ppm	parts per million
PPCO <sub>2</sub>	partial pressure carbon dioxide
PRSD	power reactant storage and distribution
psi	pound per square inch
psia	pound per square inch absolute
QD	quick disconnect
RCS	reaction control subsystem
RMS	Remote Manipulator System
RPC	remote power controller
RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAC-A	Satellite de Aplicaciones/Centifico-A
SAFER	Simplified Aid for EVA Rescue
SEM-7	Space Experiment Module-7
SHARP	Summer High School Apprenticeship Research Program
SIGI	Space Integrated Global Positioning System/Inertial Navigation System
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SLF	Shuttle Landing Facility
SM	systems management
S/N	serial number
SPLAT	Silly Putty Longevity and Applicability Test
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulator System
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
TCS	trajectory control sensor/thermal control system
TI	terminal phase initiation (rendezvous maneuver)
TPS	thermal protection system/subsystem
TSM	tail service mast
Vdc	Volts direct current
VIMS	Virginia Institute of Marine Science
VORTEX	Vortex Ring Transit Experiment
VSU	video switching unit
WCS	waste collection system
WIF	work-site interface
WSB	water spray boiler