

STS-110 SPACE SHUTTLE MISSION REPORT

June 2002



**National Aeronautics and
Space Administration**

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

NOTE

The STS-110 Space Shuttle Mission Report was prepared from inputs received from the responsible Space Shuttle Program offices as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

Kenneth L. Brown
281-483-3891

Orbiter and Subsystems

James Yeager, MSFC
256-544-3963

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

Anne M. Patterson
281-483-3367

Payloads/Experiments

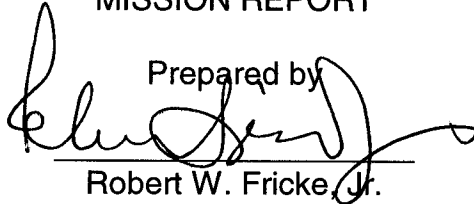
Fred A. Ouellette
281-483-0770

FCE and GFE

STS-110
SPACE SHUTTLE

MISSION REPORT

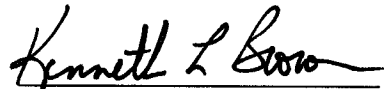
Prepared by



Robert W. Fricke, Jr.

LMSO/Mission Evaluation Room Support Section

Approved by



Kenneth L. Brown

STS-110 Lead Mission Evaluation Room Manager
Space Shuttle Vehicle Engineering Office



Ralph R. Roe, Jr.

Manager, Space Shuttle Vehicle Engineering Office



Ronald D. Dittmore

Space Shuttle Program Manager

Prepared by

Lockheed Martin Space Operations
for the

Space Shuttle Vehicle Engineering Office

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

May 2002

STS-110 Table of Contents

<u>Title</u>	<u>Page</u>
<u>INTRODUCTION</u>	1
<u>MISSION SUMMARY</u>	2
<u>PAYLOADS AND EXPERIMENTS</u>	10
<u>SUMMARY</u>	10
<u>INTERNATIONAL SPACE STATION OPERATIONS</u>	10
<u>Starboard Zero Truss</u>	10
<u>Transfer Activities</u>	10
<u>Nominal Tasks Completed</u>	11
<u>Real-Time Tasks Additions</u>	12
<u>Tasks Not Performed</u>	12
<u>SECONDARY PAYLOADS</u>	12
<u>Ram Firing Observation</u>	12
<u>Shuttle Ionospheric Modification with Pulsed Exhaust</u>	12
<u>VEHICLE PERFORMANCE</u>	13
<u>LAUNCH DELAY</u>	13
<u>SOLID ROCKET BOOSTERS</u>	13
<u>REUSABLE SOLID ROCKET MOTORS</u>	13
<u>EXTERNAL TANK</u>	14
<u>SPACE SHUTTLE MAIN ENGINES</u>	15
<u>SHUTTLE RANGE SAFETY SYSTEM</u>	16
<u>ORBITER SUBSYSTEMS PERFORMANCE</u>	16
<u>Main Propulsion Subsystem</u>	16
<u>Reaction Control Subsystem</u>	16
<u>Orbital Maneuvering Subsystem</u>	20
<u>Power Reactant Storage and Distribution Subsystem</u>	21
<u>Fuel Cell Powerplant Subsystem</u>	21
<u>Auxiliary Power Unit Subsystem</u>	22
<u>Hydraulics/Water Spray Boiler Subsystem</u>	23
<u>Electrical Power Distribution and Control Subsystem</u>	23
<u>Orbiter Docking System</u>	23
<u>Atmospheric Revitalization Pressure Control Subsystem</u>	24
<u>Atmospheric Revitalization Subsystem</u>	25
<u>Active Thermal Control Subsystem</u>	26
<u>Supply and Waste Water Subsystem</u>	27
<u>Waste Collection Subsystem</u>	28
<u>Smoke Detection and Fire Suppression Subsystem</u> ..	28
<u>Flight Data Subsystem</u>	28
<u>Flight Control Subsystem</u>	28
<u>Flight Software</u>	28
<u>Displays and Controls Subsystem</u>	28
<u>Communications and Tracking Subsystem</u>	29
<u>Operational Instrumentation/Modular Auxiliary Data System</u>	29

STS-110 Table of Contents

<u>Title</u>	<u>Page</u>
<u>Structures and Mechanical Subsystems</u>	30
<u>Integrated Aerodynamics, Heating and Thermal Interfaces</u>	31
<u>Thermal Control Subsystem</u>	31
<u>Aerothermodynamics</u>	31
<u>Thermal Protection Subsystem and Windows</u>	32
<u>Gas Sample Analysis</u>	33
<u>EXTRAVEHICULAR ACTIVITY</u>	34
<u>REMOTE MANIPULATOR SYSTEM</u>	37
<u>GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT</u>	38
<u>POSTLAUNCH PAD INSPECTION</u>	39
<u>DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES</u>	40
<u>DEVELOPMENT TEST OBJECTIVES</u>	40
<u>DETAILED SUPPLEMENTARY OBJECTIVES</u>	40
<u>PHOTOGRAPHY AND TELEVISION ANALYSIS</u>	42

List of Tables and Appendixes

<u>TABLE I - STS-108 SEQUENCE OF EVENTS</u>	43
<u>TABLE II - SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST</u>	46
<u>A - DOCUMENT SOURCES</u>	A-1
<u>B - ACRONYMS AND ABBREVIATIONS</u>	B-1

INTRODUCTION

The Space Transportation System (STS) -110 Space Shuttle Program Mission Report presents a discussion of the Orbiter and the activities of the mission, as well as presenting 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 one-hundred and ninth mission of the Space Shuttle Program. The STS-110 flight was the thirteenth flight to the International Space Station (ISS). STS-110 was the eighty-fourth mission since the return to flight, and the twenty-fifth flight of the OV-104 (Atlantis) vehicle. STS-110 was also the first flight in which all three SSMEs were of the Block II design.

The flight vehicle consisted of the Orbiter vehicle (OV) -104 Orbiter; an ET that was the fifteenth Super Lightweight Tank (SLWT), which was designated ET-114; three Block II SSMEs that were designated as S/Ns 2048, 2051 and 2045 in positions 1, 2 and 3 respectively; and two SRBs that were designated BI112. The two RSRMs were designated RSRM-85 with one installed in each SRB. The individual RSRM serial numbers were 360W085A for the left SRB and 360W085B for the right SRB.

The primary objective of the STS-110 mission was the delivery and integration of the 8A launch package (LP) to the orbiting ISS Stage Utilization Flight (UF) -1. The LP consisted of a Integrated Truss Segment (ITS) Starboard Zero (SO) with the Mobile Transporter (MT), powered and unpowered ISS utilization payloads, extravehicular activity (EVA) tools and equipment, Portable Computer System (PCS) items, critical spares, photo/television (TV) and water-transfer equipment. The middeck return complement included power and unpowered ISS utilization payloads transferred from the ISS. The Shuttle Ionospheric Modification with Pulsed Exhaust (SIMPLEX) and the ram burn observation (RAMBO) payload objectives were met during the deorbit maneuver when a suitable target became available.

The STS-110 flight was planned as an 11-day, mission with only the two contingency days that were available for weather avoidance for landing or other Orbiter contingency operations. The sequence of mission events is shown in Table I, and the Orbiter In-Flight Anomaly List is shown in Table II.

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

The seven crewmembers that were on the STS-110 mission consisted of Michael J. Bloomfield, Lt. Col, U. S. Air Force, Commander; Stephen N. Frick, CDR, U. S. Navy, Pilot; Rex J. Walheim, Lt. Col., U. S. Air Force, Mission Specialist 1; and Ellen Ochoa, Ph. D., Civilian, Mission Specialist 2; Lee M. E. Morin, Captain, U. S. Navy, Mission Specialist 3; Jerry L. Ross, Colonel (Retired), U. S. Air Force, Mission Specialist 4; and Steven L. Smith, Civilian, Mission Specialist 5.

STS-110 was the seventh space flight for Mission Specialist 4, the fourth space flight for the Mission Specialist 2 and Mission Specialist 5, the third space flight for the Shuttle Commander, and the first space flight for the Pilot, Mission Specialist 1 and Mission Specialist 3.

MISSION SUMMARY

The launch of the STS-110 mission was successfully completed after a 4-minute 47-second hold at T-5 minutes because of three data glitches in the front-end processor (FEP) that provides vehicle data to the Launch Control Center at KSC. Eleven seconds remained in the launch window at the time of launch, which occurred at 098:20:44:18.983 G.m.t. (4:44 p.m. e.d.t. on April 8, 2002).

The launch was originally scheduled for April 4. However, early in the External Tank (ET) hydrogen loading while operating in the fast-fill mode, a hydrogen leak was detected in the mobile launch platform piping and the countdown was stopped. The inspection revealed that the 16-inch hydrogen vent line had a 1/8-inch wide crack in a weld and repairs were made. A three-day delay in launch resulted from this failure.

An orbital maneuvering subsystem (OMS) assist maneuver was performed following Solid Rocket Booster (SRB) separation. The maneuver was initiated at 098:20:46:32 G.m.t. (00:00:02:13 MET) and was 76.4 seconds in duration.

The OMS 2 maneuver was performed at 098:21:23:03 G.m.t. (00:00:38:44 MET) and was 63.2 seconds in duration. The differential velocity (ΔV) was 96.0 ft/sec, and the orbit was 85.0 by 124.0 nautical miles (nmi) following the maneuver. The OMS performed satisfactorily throughout the maneuver.

The payload bay doors were opened as planned at 098:22:40:32 G.m.t. (00:01:56:13 MET). All voltages were nominal, and the motors opened the doors in nominal dual-motor time.

At 098:21:10:41 G.m.t. (00:00:26:22 MET), integrated display processor (IDP) 2 annunciated a single buffer overflow error (Flight Problem STS-110-V-04). This error is reported when more display data are received from a general-purpose computer (GPC) than can be processed in one cycle. Thirty-four seconds later, at 098:21:11:15 G.m.t. (00:00:26:56 MET), IDP 2 annunciated built-in test equipment (BITE) messages indicating that the IDP experienced errors when accessing its mass storage unit (MSU). The BITE fail message cleared 55 seconds later. The most probable cause of these errors is a glitch on the small computer system interface (SCSI) control line during MSU access. Recurrence of this event had a very low likelihood of repeating during the remainder of the mission. The event has a finite time-out recovery of less than 1 minute. There was no mission impact.

As a means of saving propellant, the NC1 and NC2 maneuvers were deleted and the ΔV that was to be imparted to the vehicle was combined into the NH maneuver that was performed by the OMS.

Checkout of the remote manipulator system (RMS), extravehicular mobility units (EMUs) and rendezvous tools was completed. All equipment was ready to support the planned extravehicular activities (EVAs).

At 099:12:03 G.m.t. (00:15:18 MET), the sequential still video (SSV) was locked up on decommutator 2, and the ground was seeing only color bars. Shortly thereafter, a test pattern was routed to SSV spare 1 and the crew selected "IN SEL" to NTSC and the color bars were still being seen on the ground (should have been the test pattern). The

ground had the crew power cycle the SSV and this produced no new results on the ground. The crew performed additional troubleshooting and determined that the "IN SEL" knob was loose and was therefore not moving the switch. The screw was tightened and the SSV power was recycled once again. After again selecting the 'IN SEL' to NTSC, a test pattern was seen on the ground. The hardware will be returned to JSC for troubleshooting.

During the NC3 rendezvous maneuver, primary reaction control subsystem (RCS) thruster L1A failed off when first commanded to fire and was auto-deselected by RCS redundancy management (RM) (Flight Problem STS-110-V-01). The reaction jet driver (RJD) output was nominal, however, the chamber pressure reached only 20-psia prior to the thruster being deselected. The thruster did not leak propellant following the fail-off. The thruster injector temperatures indicated at least some propellant flow through each (fuel and oxidizer) pilot-operated valve. The thruster remained deselected for the remainder of the flight.

The RMS was powered up at 099:14:36 G.m.t. (00:17:52 MET), and the RMS checkout was performed. The checkout was completed at 099:15:27 G.m.t. (00:18:43 MET), and no anomalies were detected. The single/direct-drive switch override was performed during RMS power-up to minimize the use of that switch. The functions of the single/direct-drive switch were transferred to the proceed/stop switch. The override was performed because of concerns over the cycle life of the single/direct-drive switch. Following the checkout, the RMS was used to perform a survey of the payload bay. The survey was started at 099:17:00 G.m.t. (00:20:16 MET) and was concluded when the RMS was cradled at 099:17:40 G.m.t. (00:20:56 MET).

The Orbiter docking system (ODS) was powered on at 099:19:00 G.m.t. (00:22:16 MET) as planned and the ring extension was completed nominally. The ODS was ready for rendezvous and docking operations.

The trajectory control sensor (TCS) operated nominally during the checkout and was ready to support rendezvous and docking.

At approximately 100:11:15 G.m.t. (01:14:31 MET), primary RCS thruster F1D exhibited low chamber pressure (Pc) during three consecutive 80-millisecond pulses (Flight Problem STS-110-V-02). These low-Pc pulses occurred approximately 20 minutes after a nominal 160-msec pulse. Prior to this nominal pulse, a fourth low-Pc 80-msec pulse was discovered in a review of the data. The maximum Pc during the four anomalous pulses was approximately 65 psia (nominal Pc is approximately 150 psia). The Pc was high enough that RM did not declare the thruster failed-off and deselect it. The crew reprioritized F1D to priority 2 to prevent further firings. To determine if this was an instrumentation problem, Orbiter acceleration rates during the firings were evaluated. This evaluation concluded that the rates were low indicating that F1D did not produce full thrust.

During the rendezvous, the Ku-band RADAR system acquired the International Space Station (ISS) at 100:13:05 G.m.t. (01:16:21 MET) at a range of 141,000 ft. (approximately 23.5 nautical miles). At 100:15:15 G.m.t. (01:18:31 MET), at a range of 630 ft, the Ku-band system was placed in the communications mode. The performance of the Ku-band system was nominal.

The table on the following page shows the maneuvers that were performed to complete the rendezvous with the ISS.

RENDEZVOUS MANEUVERS

Maneuver	Time G.m.t./MET	ΔV ft/sec	Firing time Sec	Orbit nmi,
NC3 (+X RCS)	099:21:17:13 01:00:32:54	4.5	19.7	84.9 by 122.3
NH (OMS-3) (dual OMS)	100:11:28:11.8 01:14:43:52.9	218.1	140.1	115.4 by 210.1
NC4 (OMS-4) (dual OMS)	100:12:11:48.4 01:15:27:29.5	146.6	92.4	198.0 by 210.8
NCC (Multi-axis RCS)	100:12:47:56 01:16:03:37	2.7	-	198.0 by 210.3
Ti (Left OMS)	100:13:45:37.6 01:17:01:18.7	10.5	13.2	203.0 by 211.4
MC1 (RCS)	100:14:05:40 01:17:21:21	0.4	-	203.0 by 211.4
MC-2 (not required)	-	-	-	-
MC-3 (RCS)	100:14:54:08.8 01:18:09:49.9	2.6	11.0	204.3 by 211.2
MC-4 (RCS)	100:15:04:08.8 01:18:19:49.9	2.0	8.8	204.0 by 211.3

The ODS performed nominally throughout capture, ring retraction, and hook closure. The ODS captured the ISS at approximately 100:16:04 G.m.t. (01:19:20 MET). The modified docking ring retraction procedure, which was developed to eliminate the potential for stuck high-energy dampers (HEDs), was used for the first time. The procedure retracts the ring for 10 seconds, then stops and extends for 5 seconds prior to completing the retraction process. No issues with ring misalignment were encountered. The hook-position indicator, which had been intermittent on the previous two missions, worked nominally. Hook gang 1 drive time was 2 minutes, 22 seconds, and hook gang 2 drive time was 2 minutes, 12 seconds.

The RMS was powered up at 100:17:21 G.m.t. (01:20:37 MET) and moved into the starboard zero (S0) truss-installation viewing position. It was positioned using the single-joint mode with the proceed/stop switch. Its performance was nominal.

At 100:21:19 G.m.t. (02:00:35 MET), the crew reported that the ODS hatch differential pressure (ΔP) gauge was indicating approximately -0.7 psid during the hatch-opening procedure. Other instrumentation was used to determine that the Orbiter and ISS were pressure equalized, and that no ΔP was across the hatch. The crew downlinked a picture of the gauge showing the bias.

The installation of the S0 truss onto the ISS was performed using the Space Station remote manipulator system (SSRMS). The Orbiter RMS was used as a camera platform and performed nominally during the S0 installation and the first EVA.

The first EVA was successfully completed with a total EVA time of 7 hours and 48 minutes. The EVA, which was conducted from the ISS airlock, was officially started when the EMUs were placed on internal battery power at 101:14:36 G.m.t. (02:17:52 MET). All planned tasks were successfully completed. The EVA concluded when repressurization of the airlock was initiated at 101:22:24 G.m.t. (03:01:40 MET).

Following the EVA, the EV1 crewmember reported that he was unable to drink any water from the disposable in-suit drink bag (DIDB). This problem will be evaluated postflight.

This is the first flight of the digital television (DTV) system that interfaced with and augmented the existing closed-circuit television (CCTV) system. During the setup of the DTV system for a public affairs event on flight day 1, the crew encountered problems while setting up the DTV system using the digital Sony PD100 camcorder as a digital-video input source. During troubleshooting efforts, the analog video signal from the camcorder was successfully downlinked through the DTV (utilizing a different PD100 connector output). In addition, the payload bay camera input has also been successfully transmitted through the DTV system. All other flight and ground DTV segments were successful. Testing on the ground identified a possible cause of the problem. It was suspected that there is a problem with the strain relief on the cable interface at the camcorder connector end. During flight day 10, additional troubleshooting was not successful.

The crew was not able to talk from the Orbiter flight deck to the ISS Robotics Workstation (RWS) on intercommunications (ICOM) B using a battery-powered speaker/microphone unit (BPSMU). The problem was identified during BPSMU operation when using the push-to-talk (PTT)/PTT mode of the audio terminal unit (ATU). The Orbiter flight-deck crewmember could hear the crewmember at the RWS. Troubleshooting, which included switching from the Commander's crew communications umbilical (CCU) to the Pilot's CCU and trying a different BPSMU, was unsuccessful. The crew then switched to PTT/HOT (hot microphone) on the ATU and ICOM was recovered. It is suspected that the problem is caused by a failure in the BPSMU/CCU adapter cable, of which there is only one onboard. The current flight configuration was acceptable for operations. Troubleshooting of the cable is planned when it is returned after the flight.

Beginning at approximately 103:03:09 G.m.t. (04:06:25 MET), the right main landing gear (RMLG) inboard tire pressure measurement 1 shifted to off-scale low (232 psia) over a 7-minute period. Pressure measurement 2 on the RMLG inboard tire continued to indicate the correct tire pressure. There was no mission impact.

Throughout the mission, leakage of the right RCS fuel system Helium regulators was monitored. Leakage of these regulators was seen on the previous flight of OV-104 and at the launch pad for this flight during Helium activation following propellant servicing. A one-flight waiver was approved to fly as-is. Early in the mission, after a high leak-rate was observed on the A-leg regulators, the system was reconfigured to the B-leg regulators. Although the leak-rate was lower on the B-leg regulators, the leak still resulted in the right RCS fuel tank pressure approaching the limit of 20-psi greater than the right RCS oxidizer tank. When the ΔP reached 15-psi, the B-leg regulators were also isolated. With the A- and B-leg Helium isolation valves closed, further fuel-tank pressure increases did not occur. No mission impact resulted from this condition.

The second EVA was successfully completed with a total EVA time of 7 hours and 30 minutes. Like the first EVA, this EVA was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 103:14:09 G.m.t. (04:17:25 MET). The EVA concluded when repressurization of the airlock was initiated at 103:21:39 G.m.t. (05:01:55 MET). The only problem noted during the EVA was the loss of biomedical data from the extravehicular (EV) 3 crewmember at 103:18:49 G.m.t. (04:22:05 MET). The data returned for about 10 minutes before it was lost for the remainder of the EVA. The crewmember reported that he did not recall if the electrodes had fallen off during the EVA; however, he indicated after EVA 4 that the

electrodes were still attached. Troubleshooting of the Orbiter biomedical system will occur during the turnaround activity following the flight.

The first reboost session was started at 103:22:44 G.m.t. (05:02:00 MET) when primary RCS thruster L3A was fired. The session lasted one hour, and used both primary and vernier RCS thrusters. The primary thruster pulse widths were 160 msec. The firing period was 12.16 seconds from start of one pulse firing until the next firing. The L3A and R3A thrusters alternated firings. Breaks for attitude maintenance limited the number of pulses to 141 pulses for each thruster. There were approximately five breaks for attitude maintenance, which was performed with the vernier thrusters. The aft down-firing vernier thrusters had an average duty cycle of 8.72-seconds on and 15.28 seconds off. RCS performance was nominal throughout the operation. The reboost resulted in an overall average altitude increase of 0.95 nmi for a final orbit of 212 by 205 nmi, and a ΔV of 3.2 ft/sec.

The third EVA was successfully completed with a total EVA time of 6 hours and 27 minutes. All tasks except the Shuttle Tool Transfer and the Airlock Spur Installation were completed. Like EVA 1 and 2, EVA 3 was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 104:13:48 G.m.t. (05:17:04 MET). The EVA concluded when repressurization of the ISS airlock was initiated at 104:20:15 G.m.t. (05:23:31 MET).

The second reboost session was started at 104:21:44 G.m.t. (06:01:00 MET) when primary RCS thruster L3A was fired. The session lasted one hour, and used both primary and vernier RCS thrusters. The primary thruster pulse widths were 160 msec. The firing period was 12.16 seconds from start of one pulse firing until the next firing. The L3A and R3A thrusters alternated firings. Breaks for attitude maintenance limited the number of pulses to 126 with L3A and 127 with R3A, totaling 233 pulses. There were approximately ten breaks for attitude maintenance, which was performed with the vernier thrusters. The aft down-firing vernier thrusters had an average duty cycle of 8.72-seconds on and 15.28 seconds off. RCS performance was nominal throughout the operation. The reboost resulted in an overall average altitude increase of 1.0 nmi for a final orbit of 212 by 206 nmi, and a ΔV of 3.4 ft/sec.

The fourth and final planned EVA of the mission was successfully completed with a total EVA time of 6 hours and 37 minutes. All planned tasks were completed. Like the first three EVAs, EVA 4 was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 106:14:29 G.m.t. (07:17:45 MET). The EVA concluded when repressurization of the ISS airlock was initiated at 106:21:06 G.m.t. (08:00:22 MET).

The third ISS reboost maneuver was initiated at 107:11:19:20 G.m.t. (08:14:35:01 MET) when RCS primary thrusters F5L, F5R, L5D and R5D were fired. The reboost maneuver lasted one hour. There was no predefined duty cycle as the thrusters were turned on and off as necessary to maintain the vehicle attitude within the 5-degree deadband. The reboost was performed in right OMS interconnect. The reboost maneuver resulted in a ΔV of 12.8 ft/sec and a final orbit of 213.8 by 206.3 nmi.

Meetings were held to discuss the management of primary RCS thruster F1D during the undocking and separation from the ISS. Since the failure mode of the thruster was not known, the decision was made to deselect the thruster for nominal undocking operations with the following exception. If primary RCS thruster F3D failed inside of the safe breakout range of the ISS (150 feet), thruster F1D would be reselected. Once the

breakout was completed, the thruster would again be deselected. The thruster remained deselected for the remainder of the mission.

Undocking from the ISS was completed with no anomalies. The ODS was powered up at 107:18:02 G.m.t. (08:21:18 MET), and undocking was completed at 107:18:31 G.m.t. (08:21:47 MET). The hook-8 individual position indication toggled very briefly at the start of hook opening, however, this signature has been seen on previous missions and is not considered an issue. Following undocking, the ODS was powered down 107:18:46 G.m.t. (08:22:02 MET).

Following the successful undocking of the Orbiter from the ISS, the initial ISS separation maneuver began with a +Z-axis pulse of primary RCS thrusters at 107:18:31:19 G.m.t. (08:21:47:00 MET). The ISS flyaround operations were nominal with the exception of the performance of primary RCS thruster F3L, which is discussed in the following paragraph. Final separation from the ISS was accomplished with an 11.7-second +X-axis pulse of primary RCS thrusters L3A and R3A at 107:20:15:45 G.m.t. (08:23:31:26 MET). The ΔV delivered was 3.0 ft/sec and the resulting orbit was 216.5 by 208.9 nmi.

During the ISS flyaround at 107:19:07:13 G.m.t. (08:22:23:54 MET), primary RCS thruster F3L experienced a low chamber pressure (Pc) of 65 psia on an 80-msec pulse (should have been approximately 150 psia) (Flight Problem STS-110-V-03). After an evaluation of the thruster pulse profile, it was agreed to watch its performance on subsequent pulses. Thruster F3L subsequently had a second low Pc of 68 psia during an 80-msec pulse at 107:19:31:55 G.m.t. (08:22:47:36 MET). After this pulse, the crew placed the thruster in last priority at 107:19:34:21 G.m.t. (08:22:50:02 MET). The thruster was deselected and was not fired for the remainder of the mission.

After undocking from the ISS, the trajectory control sensor (TCS) began tracking at 6.5 ft. from the ISS and continued to track to a range of 2662.5 ft. The performance of the TCS was nominal.

The Ku-band system was placed in the RADAR mode at 107:20:08 G.m.t. (08:23:24 MET) and acquired the ISS at a range of 400 ft. The radar maintained lock-on to the ISS during the latter part of the ISS flyaround and during the separation maneuver. The Ku-band system was placed in the communications mode at 107:20:21 G.m.t. (08:23:37 MET) at a range of 1617 ft.

Flight controllers reported that closed-circuit television (CCTV) camera B was not panning and tilting through its complete range of motion. Video downlinked from 106:22:35 G.m.t. (08:01:51 MET) to 106:22:44 G.m.t. (08:02:00 MET) indicates that the cable between the pan/tilt unit (PTU) and the camera/illuminator was not tethered in one of the two cable guides (the guide mounted on the PTU yoke). Investigation of prelaunch closeout photographs indicates that the cable guide on the yoke was installed "upside down", which may be the cause of the cable becoming disengaged. Camera B was still fully usable within the achievable pan-and-tilt range and there was no mission impact. Postflight troubleshooting is planned.

The flight control subsystem (FCS) checkout was performed satisfactorily using auxiliary power unit (APU) 1 to support the checkout with an APU start time of 108:12:04:55 G.m.t. (09:15:20:36 MET). The run time was 6 minutes, 24 seconds, and 17 pounds of fuel were used during the APU 1 operation. The total run time was too short to require the water spray boiler (WSB) to provide spray cooling. FCS, APU and hydraulics performance was nominal.

Following FCS checkout, the RCS hot-fire was performed. The hot-fire began at 108:13:08:23 G.m.t. (09:16:24:04 MET) and ended at 108:13:18:11 G.m.t. (09:17:23:52 MET). A review of thruster chamber-pressure data confirmed that all of the firings were satisfactory. Each thruster, with the exception of L1A, F1D, and F3L, which experienced anomalous performance earlier in the mission, and R1A, which was not fired for procedure simplicity, performed at least two pulses of 320-millisecond duration. R1A had fired previously in the mission with satisfactory performance.

A 10.1-second Shuttle Ionosphere Modification with Pulsed Local Exhaust (SIMPLEX) firing was performed using both OMS engines at 108:17:26:18.6 G.m.t. (09:20:41:59.6 MET). The ΔV was 18.2 ft/sec and the resulting orbit was 206.3 by 218.3 nmi.

The OMS 7 orbit-adjust maneuver was performed at 108:18:04:18 G.m.t. (09:21:19:59 MET) and was approximately 37 seconds in duration. The ΔV was 70 ft/sec, and the orbit was 218 by 166 nmi following the maneuver. The OMS performed satisfactorily throughout the maneuver.

The payload bay doors were closed and latched for the first KSC landing opportunity at 109:12:52:12 G.m.t. (10:16:07:54 MET). All payload bay door operations occurred in dual motor time.

When powering the payload bay floodlights for payload bay door closing, the mid main A bus current had a signature that was indicative of a 10-ampere remote power controller (RPC), which is current limited, being tripped. Floodlights 1 (forward port) and 6 (aft starboard) are powered from the mid main A bus. The crew did not report a problem with either of the floodlights. During the postlanding operations, floodlight 1 was noted to have a cracked lens. The floodlight was removed and replaced.

The deorbit maneuver for the first KSC landing opportunity, a two-engine straight-feed firing, was performed on orbit 170 at 109:15:18:59.21 G.m.t. (10:18:34:39.728 MET). The maneuver was 138.8 seconds in duration with a ΔV of 264.2 ft/sec.

During entry when deploying the air data probes at Mach 5.0, the left air data probe did not deploy initially when the crew moved the switch on panel C3 to the deploy position. The crew was called to verify that the switch was in the deploy position, and the switch was wiggled at which time the air data probe began to deploy. Once the air data probe was deployed, all data and motor times were nominal for the left probe.

Entry interface occurred at 109:15:55:25 G.m.t. (10:19:11:06 MET) and entry was completed satisfactorily. Main landing gear touchdown occurred on KSC concrete runway 33 at 109:16:26:58 G.m.t. (10:19:42:39 MET) on April 19, 2002. The drag chute was deployed at 109:16:27:00.1 G.m.t. The nose gear touchdown occurred at approximately 109:16:27:09 G.m.t. The drag chute was jettisoned at 109:16:27:42.4 G.m.t. Wheels stop occurred at 109:16:28:08 G.m.t. The rollout was normal in all respects. The flight duration was 10 days 19 hours 42 minutes 39 seconds. The APUs were shut down approximately 19 minutes and 25 seconds after landing.

Following landing and just prior to the transition to the operations (OPS) -9 mode change, several mid motor control assembly (MMCA) operational-status (OP STATS) bits came on and did not go off. There was no ac current increase to indicate any motors driving.

The six OP STATS were MMCA 1 OP STAT 1, MMCA 2 OP STATS 1 and 7, MMCA 3 OP STAT 4 and MMCA 4 OP STATS 1 and 5. At that time, the only common items found between the OP STATS were the vent doors, payload bay door motors and software. As a result of the cause not being found, the vent doors were left in the open position. In addition, the eight 3-phase ac power circuit breakers for the OP STATS were opened. The postflight data review indicates that all of the affected OP STATS were related to a switch for the starboard RMS retention latches. The starboard retention latches switch is a standard three-position switch with the latch position being down. If the switch had been accidentally bumped to the latch position, the six OP STATS would be activated. During postflight testing, KSC was able to reproduce the signature with the switch. Voice tapes were reviewed and it was verified that the switch was out of position.

PAYLOADS AND EXPERIMENTS

SUMMARY

Once the rendezvous and docking with the ISS was completed, the first of four extravehicular activities (EVAs) was performed that consisted of lifting the starboard zero (S0) Integrated Truss Segment (ITS) from the Orbiter cargo bay utilizing the Space Station remote manipulator system (SSRMS) and installing it on top of the ISS laboratory (Destiny). This flight marks the first time that all four mission EVA's originated from the ISS airlock. Cameras mounted on the Shuttle remote manipulator system (SRMS) provided assistance to the SSRMS operators during their robotic operations.

During the flight day (FD) 5 to FD10 docked operations, all preflight planned on-orbit task priorities were completed. Conservation of 4 LiOH canisters was accomplished by running Vozduk and CDRA on the ISS during the docked phase of the mission. Disposal of approximately 229 lb of old condensate water was completed. This condensate is equivalent to 113 days of humidity control onboard ISS, in concert with the Russian air conditioner (SKV/SRVK) condensate reclamation.

Undocking from the ISS vehicle was completed at 107:18:31 G.m.t. (08:21:47 MET). A fly-around of the ISS vehicle by the Shuttle was performed immediately following the undocking of the Shuttle from the ISS.

INTERNATIONAL SPACE STATION OPERATIONS

All of the planned mission objectives were completed successfully, including tasks that were added and completed during the flight. The EVAs were performed to transfer, install, configure and activate the starboard zero (S0) Truss and Mobile Transporter with the ISS. Additional EVA tasks that were accomplished included inserting the forward avionics umbilical tray-latching PIP pins and tying back the Multi-Layer Insulation (MLI) blanket around Global Positioning System (GPS) antenna 2 (Port/Zenith). Three Shuttle reboost maneuvers were performed, leaving the ISS vehicle in a 208 by 216 nmi orbit.

Starboard Zero Truss

The S0 Cargo Element, which consisted of the S0 Integrated Truss Segment (ITS) and the Mobile Transporter, was the sole hardware carried in the Shuttle's payload bay for the STS-110 mission. When deployed, this element constituted an addition of 26,716 lb to the ISS complex.

Transfer Activities

The total weight of the items transferred to the ISS is summarized as follows:

	<u>Planned, lb</u>	<u>Actual, lb</u>	<u>Percent</u>
S0 ITS to the ISS	26,716	26,716	100
Middeck Transfers to ISS	2,228	2,228	100
Transfers to Shuttle Middeck	2,450	2,607	106
Oxygen Transferred to Airlock High Pressure Tanks	130	146	112
Nitrogen Transfer to ISS	40	45	113
Water **	1,463	1,463	100

*First use of oxygen recharge compressor assembly (ORCA).

**14 Contingency Water Containers (CWC's) and 3 Payload Water Reservoirs (PWRs) of new water were transferred to the ISS.

Nominal Tasks Completed

The following list details the list on nominal tasks that were completed during the docked portion of the mission.

1. Rendezvous and dock with ISS;
2. Unberth S0 truss from the Shuttle payload bay, complete the minimum installation for S0 survival and install S0 on the load control assembly (LCA) using SSRMS;
3. Complete S0 installation;
4. Perform critical transfers;
5. Complete S0 activation and checkout;
6. Perform SSRMS power and data reconfiguration;
7. Transfer all planned ISS-powered Utilization middeck payloads to and from ISS;
8. Complete Mobile Transporter (MT) activation and configure for translation test;
9. Removed and stowed S0 keel pins and drag links;
10. Translate MT from launch site to first worksite;
11. Install CIDs S0-2B (7) and S0-4B (8) on S0.
12. Perform all remaining payload transfers to and from ISS.
13. Perform mission-specific transfers to and from ISS (crew provisions and supplies)
14. Perform ITCS fluid sampling and return all planned samples;
15. Release LCA capture interface and the Loads Release Mechanisms (LRMs);
16. Install Airlock Spur;
17. Remove MT-to-Mobile Base System (MBS) bolt debris covers;
18. Perform MT translation test in both directions to Worksites 4 & 5.
19. Deploy External Vehicle-Charged Particle Directional Spectrometer (EV-CPDS);
20. Assemble and deploy Crew and Equipment Translation Aid (CETA) lights;
21. Install MT CETA energy absorbers;
22. Activate and check out External Video Switch System (EVSWS)-1, -2, and -3;
23. Perform Get-Ahead Tasks;
24. Perform Main Bus Switching Unit (MBSU)/DDCU power-on test;
25. EVA tool maintenance and changeouts;
26. Perform Structural Dynamic Measurement System (SDMS) data take to verify signal conditioner unit (SCU) functionality;
27. Perform Station Development Test Objective (SDTO) 15004-U, ISS Control of Partial Pressure of Carbon Dioxide Levels in the Space Shuttle to Reduce lithium hydroxide (LiOH) Usage;
28. Perform Development Test Objective (DTO) 263, Reboost tuning;
29. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during Orbiter docking. (Assume performed based on negative reporting. Postflight review of data required);

30. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during SSRMS operations with S0. (Assume performed based on negative reporting. Postflight review of data required);
31. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during S0 installation. (Assume performed based on negative reporting. Postflight review of data required); and
32. Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during EVA activity. (Assume performed based on negative reporting. Postflight review of data required).

Real-Time Task Additions

The following list details the tasks that were added during the mission.

1. Carryover tasks from EVAs 1 and 2:
 - a. Inspect thermal shrouds where the port umbilical attaches to the S0 truss;
 - b. Insert the pip-pins into the latch on both the starboard and port avionics Trays; and
 - c. TUS-2 IUA Troubleshooting.
2. Tie down of the Global Positioning System (GPS) antenna shroud to reduce or eliminate interference;
3. Re-tighten the port avionics umbilical stanchion bolts and starboard avionics aft stanchion bolt; and
4. Take additional photographs of S0 aft laboratory tray.

Tasks Not Performed

The four tasks that were not performed are detailed in the following list.

1. Temporary stowage of the portable work platform (PWP);
2. Transfer of tools from ISS to the Orbiter for return;
3. Trace Gas Analyzer (TGA) tests were not completed because of a hardware anomaly; and
4. The LTA cables were not configured because the requirement was deleted during the mission. The crew performed the intent of the requirement as a part of the initial disconnect.

SECONDARY PAYLOADS

Ram Firing Observation

On flight day 10, the orbital maneuvering subsystem (OMS) deorbit maneuver was successfully observed by Ram Burn Observation (RAMBO) equipment.

Shuttle Ionospheric Modification with Pulsed Exhaust

The Shuttle Ionospheric Modification with Pulsed Exhaust (SIMPLEX) firing was successfully performed over the Millstone Hill radar facility on April 18, 2002 (flight day 11). The two-engine firing was 10.1 seconds in duration and the differential velocity was 18.2 ft/sec. The resulting orbit was 206.3 by 218.3 nmi.

VEHICLE PERFORMANCE

LAUNCH DELAY

The launch of the STS-110 mission was successfully completed after a 4-minute 47-second hold at T-5 minutes because of three data glitches in the front-end processor (FEP) that provides vehicle data to the Launch Control Center at KSC. Eleven seconds remained in the launch window at the time of launch, which occurred at 098:20:44:18.983 G.m.t. (4:44 p.m. e.d.t. on April 8, 2002).

The launch was originally scheduled for April 4. However, earlier on that day during External Tank (ET) hydrogen loading in the fast-fill mode, a hydrogen leak was detected in the mobile launch platform (MLP) piping and the count was stopped. The inspection revealed that the 16-inch hydrogen vent line had a 1/8-inch wide crack in a weld and repairs were made.

SOLID ROCKET BOOSTERS

Analysis of the Solid Rocket Booster (SRB) systems data indicated nominal performance of all SRB subsystems. The prelaunch countdown was normal and no SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements And Specifications Document (OMRSD) violations occurred. Likewise, no in-flight anomalies were identified in the evaluation of the data.

Both SRB's were recovered and returned to KSC for inspection, disassembly and refurbishment. The inspection revealed that both SRBs were in excellent condition. No anomalous SRB conditions were noted during the postflight operations.

REUSABLE SOLID ROCKET MOTORS

Data analysis of the flight performance of both reusable solid rocket motors (RSRMs) showed all parameters to be within the contract end item (CEI) specification limits, and the performance was typical of that observed on previous flights. The prelaunch countdown was normal and no RSRM LCC or OMRSD violations occurred. All RSRM temperatures were maintained within acceptable limits throughout the countdown.

No in-flight anomalies were identified from the analysis of the data. The maximum in-flight trace shape variation of pressure versus time during the 62- to 80-second time frame was calculated to be 2.05 percent at 66 seconds and 0.95 percent at 73 seconds for the left and right motor, respectively. These values were well within the 3.2 percent allowable limits.

Power application and operation of all field-joint heaters was accomplished routinely. Field-joint heaters operated for 12 hours 47 minutes during the final launch countdown and 19 hours 3 minute during the two launch countdowns. Power was applied to the heating elements an average of 44 percent of the time during the LCC time frame to maintain the field-joint temperatures in their normal operating range.

Power application and operation of all igniter-joint heaters was accomplished routinely. The igniter-joint heaters operated for 12 hours 32 minutes during the final launch countdown and 18 hours 48 minutes during the two launch countdowns. Power was

applied to the heating elements 60 percent of the time during the LCC time frame to maintain the igniter-joint temperatures in their normal operating range.

Reconstructed motor performance parameters adjusted to a 60 °F propellant mean bulk temperature (PMBT) are shown in table 1. The predicted PMBT at launch was calculated to be 69 °F. The predicted and actual propulsion systems performance is shown in the RSRM Propulsion Performance (Table 2). The delivered burn rates were 0.3686 and 0.3696 in/sec for the left and right motors, respectively.

TABLE 1.- MOTOR PERFORMANCE PARAMETERS

Parameter	CEI Specification Limit (60 °F)	Left Motor Delivered	Right Motor Delivered
Web time, seconds	105.4 – 116.7	111.0	110.3
Action time, seconds	115.2 – 131.2	122.0	122.5
Head end pressure, psia	847.9 – 965.7	909.2	910.5
Maximum sea level thrust, MLbf	2.88 – 3.26	3.08	3.07
Web time average pressure, psia	629.9 – 700.5	667.1	669.2
Web time average vacuum thrust, MLbf	2.46 – 2.74	2.61	2.62
Web time total impulse, MLbf sec	285.8 – 291.6	289.9	289.0
Action time impulse, MLbf seconds	293.7 – 299.7	297.2	296.9
ISP average delivered, Lbf sec/Lbm	266.5 – 270.3	268.8	268.7
Separation Command Time, seconds		123.4	123.4
Loaded propellant weight, Lbm,	>1103750	1106180	1105923

Note: All times referenced to liftoff time (when chamber pressure reaches 563.5 psia),

The heated, ground-supplied, aft skirt purges maintained the case/nozzle joint and flex bearing temperatures within the required LCC ranges. The purge was activated five times during the time of recorded data. Two aft-skirt purge-activations were performed during the final countdown and both lasted for a total of 12 hours and 7 minutes. It was necessary to activate the aft-skirt purge to maintain the nozzle-case joint temperatures above the minimum LCC temperature, but the purge was not required to thermally condition the flex bearing above the minimum required temperature of 60 °F. During the LCC time frame, the nozzle/case joint temperatures were nominal and ranged from 82 °F to 90 °F on both motors. The final flex bearing mean bulk temperature (FBMBT) was determined to be 84 °F.

EXTERNAL TANK

All External Tank (ET) objectives and requirements were met during the propellant loading and flight operations. No significant oxygen or hydrogen leakage concentrations were detected in the intertank. All ET electrical equipment and instrumentation operated satisfactorily. Purge and heater operations were also nominal. No ET LCC or OMRSD violations occurred.

STS-110 was the first flight of a full cluster (3) of Block II Space Shuttle main engines (SSME) and as a result, the Block II engine-start requirements raised the gaseous Helium (GHe) pre-pressurization limits and control band by 5.2 psia. The new range is from 46.1 to 48.0 psia. The Helium-burst trigger point was also raised to 47.0 psia.

TABLE 2.- RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 74 °F		Right motor, 74 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	>64.88	65.28	65.03	65.17
I-60, 10 ⁶ lbf-sec	173.97	175.43	174.29	174.92
I-AT, 10 ⁶ lbf-sec	297.02	297.46	296.95	297.12
Vacuum Isp, lbf-sec/lbm	268.5	268.9	268.5	268.7
Burn rate, in/sec @ 60 °F At 625 psia	0.3675	0.3686	0.3681	0.3696
Event times, seconds ^a				
Ignition interval	0.232	N/A	0.232	N/A
Web time ^b	110.0	109.9	109.8	109.2
50 psia cue time	120.1	118.8	119.8	118.7
Action time ^b	122.3	120.9	122.1	121.4
Separation command	124.5	123.4	124.5	123.4
PMBT, °F	69	69	69	69
Maximum ignition rise rate, psia/10 ms	90.8	N/A	90.8	N/A
Decay time, seconds (59.4 psia to 85 K)	3.1	2.9	3.1	3.6
Tailoff Imbalance Impulse Differential	Predicted N/A		Actual 586.8	

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

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

^b Referenced to liftoff time (ignition interval).

During prelaunch operations, the Ice/Frost Red team reported normal intertank cracks in the first and second valleys; the longest being about 10 to 12 inches. Cracking on the -Y vertical strut was also normal. There were no changes in the cracks from the first tanking.

The pressurization systems functioned properly throughout engine start and flight. The minimum liquid oxygen (LO₂) ullage pressure experienced during the ullage pressure slump was 13.7 psid.

The postflight analysis of the ET impact point showed the impact to be 78 nautical miles (nmi) uprange from the preflight predicted impact point.

SPACE SHUTTLE MAIN ENGINES

Prelaunch operations of the Space Shuttle main engines (SSMEs) were smooth with no LCC or OMSRD violations noted. STS-110 was the first flight of a full cluster of the Block II engines, and this flight marks the transition to using all Block II engines on future flights.

The ignition confirm limits and mainstage redline margins were satisfactory. All Interface Control Document (ICD) start and shutdown transient requirements were met. Engine performance during start, mainstage, and shutdown was nominal and as predicted. Engine cutoff times were 509.87, 510.01 and 510.13 seconds for SSMEs 1, 2, and 3,

respectively. Controller and software performance was satisfactory with no anomalies. No in-flight anomalies were identified from the review of the data.

The flight-derived specific impulse (I_{sp}) was 453.0 seconds as compared to an SSME tag value of 451.81 at the 104.5 power level.

Main engine cutoff (MECO) occurred 506.5 seconds after SRB ignition. The commanded maximum dynamic pressure (max q) throttle-down was a one-step throttle-down to 72 percent.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. During the SRSS closed-loop ground tests, the ground integrated-receiver-decoder (IRD) processed only three of the four commands. However, the flight IRDs processed 4 of 4 arm commands. Additional testing resulted in all arm commands being passed by both the ground and flight IRDs

All SRSS safe and arm (S&A) devices were armed and system inhibits were turned off at appropriate times. The system operated as expected 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 PERFORMANCE

Main Propulsion Subsystem

The overall performance of the main propulsion subsystem (MPS) was as expected. No problems occurred during the liquid hydrogen (LH_2) and liquid oxygen (LO_2) loading. Likewise, no OMRSD or LCC violations occurred during the countdown. No in-flight anomalies were identified during evaluation of the data.

The maximum hydrogen concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fast fill, was 170 ppm. This level compares favorably with previous data from this vehicle.

The gaseous oxygen (GO_2) fixed-orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely matched the actual ET ullage pressure measurements. Data indicate that the LO_2 and LH_2 pressurization systems performed as planned. The engine inlet net positive suction pressure requirements were met throughout the flight. All three flow-control valves performed nominally. Also, all pneumatic valve cycles performed within the timing requirements. The Helium system performance for the SSME and pneumatic Helium systems were nominal. Entry Helium usage was 57.8 lbm, which is within the requirements.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed acceptably throughout the mission. A total of 10 maneuvers, which included three 60-minute reboost period that raised the altitude of the International Space Station (ISS) approximately four nmi, were completed satisfactorily. Three in-flight anomalies were identified during the mission and these are discussed later in this section of the report. These anomalies did not impact the successful completion of the planned mission.

A total of 4888.9 lbm propellants (3031.5 lbm - oxidizer, 1857.4 lbm - fuel) were used from the RCS during the mission. A total of 1191.7 lbm of orbital maneuvering subsystem (OMS) propellants were also used by the RCS during the mission. The primary RCS thrusters had 3752 firings and a total firing time of approximately 941.44 seconds. The vernier RCS thrusters had 10,591 firings and a total firing time of 32,970.96 seconds.

The RCS window protect maneuver was initiated at 098:20:46:21.4 G.m.t. (00:00:02:03.4 MET and was terminated 2.08 seconds later. This maneuver provided a method of protecting the windows of the Orbiter from booster separation motor exhaust products. This maneuver results in improved clarity during the mission and a reduction in the turnaround effort following the mission.

The ET Photographic maneuver was cancelled as well as the NC1, NC2 and NPC maneuvers.

The following table shows the significant RCS maneuvers that were performed during the mission.

RCS MANEUVERS

Maneuver	Time, G.m.t./MET	ΔV , ft/sec	Firing time, sec	Orbit, nmi
NC3 (+X)	099:21:17:13.1 01:00:32:54.1	4.5	19.7	84.9 by 122.3
NCC (Multi-axis)	100:12:47:56 01:16:03:37	2.7	N/A	198.0 by 210.3
MC1	100:14:05:40 01:17:21:21	0.4	2.6	203.0 by 211.4
Out of Plane Null	100:14:26:52.3 01:17:42:34.3	N/A	N/A	N/A
MC-2 (not required)	-	-	-	-
MC-3	100:14:54:08.8 01:18:09:49.9	2.6	11.0	204.3 by 211.2
MC-4	100:15:04:08.8 01:18:19:49.9	2.0	8.8	204.0 by 211.3
Reboost 1	103:22:44:31.6 05:02:00:13.6	3.4	1 hour	205 by 212
Reboost 2	104:21:44:20 06:01:00:02	3.4	1 hour	206 by 212
Reboost 3	107:11:19:20.1 08:14:35:02.1	12.8	1 hour	206.3 by 213.8
Final Separation from ISS	107:20:15:45 08:23:31:27	3	11.7	208.9 by 216.5

During the NC3 rendezvous maneuver, primary RCS thruster L1A failed off when first commanded to fire. The chamber pressure (Pc) continued to rise during the attempted pulse and reached a maximum of 20 psia. The redundancy management (RM) auto-deselected the thruster because the thruster failed to reach the minimum threshold pressure (approximately 26 psia) within the allotted time of 320 msec (Flight Problem STS-110-V-01). The reaction jet driver (RJD) output was nominal. The thruster injector

temperatures and chamber pressure indicate at least some propellant flow through each (fuel and oxidizer) pilot-operated valve and suggest a problem with the thruster pilot valve. The thruster did not leak propellant following the fail-off. The thruster remained deselected for the remainder of the flight. This thruster along with all the thrusters in that manifold will be replaced during the postflight turnaround activities.

At approximately 100:11:15 G.m.t. (01:14:31 MET) during the rendezvous with the ISS, primary RCS thruster F1D exhibited low Pc during three consecutive 80-millisecond pulses (Flight Problem STS-110-V-02). These low-Pc pulses occurred approximately 20 minutes after a nominal 160-msec pulse. Prior to this nominal pulse, a fourth low-Pc 80-msec pulse was discovered in a review of the data. The maximum Pc during the four anomalous pulses was approximately 65 psia (nominal Pc is approximately 150 psia). The Pc was high enough that RM did not declare the thruster failed-off and deselect it. The crew reprioritized F1D to priority 2 to prevent further firings. To determine if this was an instrumentation problem, Orbiter acceleration rates during the firings were evaluated. This evaluation concluded that the rates were low indicating that F1D did not produce full thrust.

Meetings were held later in the mission to discuss the management of primary RCS thruster F1D during the undocking and separation from the ISS. Since the failure mode of the thruster was unknown, the decision was made to deselect the thruster for nominal undocking operations with the following exception. If primary RCS thruster F3D failed inside of a safe breakout range of the ISS (150 feet), thruster F1D would be reselected. Once the breakout was completed, the thruster would again be deselected. The thruster remained deselected for the remainder of the mission and did not impact the mission or its objectives. Postflight inspection of the F1D thruster revealed residue from incomplete combustion all over the chamber wall, as well as the fuel injectors and acoustic cavities. This thruster will be replaced along with all thrusters in that manifold.

Throughout the mission, leakage of the right RCS fuel system Helium regulators was monitored. Leakage of these regulators was seen on the previous flight of OV-104 and at the launch pad for this flight during Helium activation following propellant servicing. A one-flight waiver was approved to fly as-is. Early in the mission, after a high leak-rate (approximately 4000 scch) was observed on the A-leg regulators, the system was reconfigured to the B-leg regulators. Although the leak-rate was lower on the B-leg regulators (2700 scch), the leak still resulted in the right RCS fuel tank pressure approaching the limit of 20-psi greater than the right RCS oxidizer tank. When the differential pressure reached 15-psi, the B-leg regulators were also isolated. With the A- and B-leg Helium isolation valves closed, further fuel-tank pressure increases did not occur. No mission impact occurred from the leakage or the actions taken to stop the leakage. The A-leg pressure regulator will be replaced during turnaround operations and replacement of the B-leg fuel pressure regulator has been recommended.

The first reboost session lasted one hour, and used both primary and vernier RCS thrusters. The primary thruster pulse widths were 160 msec. The firing period was 12.16 seconds from start of one pulse firing until the next firing. The L3A and R3A thrusters alternated firings. Breaks for attitude maintenance limited the number of pulses to 141 pulses for each thruster. There were approximately five breaks for attitude maintenance, which was performed with the verniers. The aft down-firing vernier thrusters had an average duty cycle of 8.72-seconds on and 15.28 seconds off. RCS performance was nominal throughout the operation. This maneuver was performed in left OMS interconnect with the Helium regulators in the auto mode.

The second reboost session lasted one hour, and used both primary and vernier RCS thrusters. The primary thruster pulse widths were 160 msec. The firing period was 12.16 seconds from start of one pulse firing until the next firing. The L3A and R3A thrusters alternated firings. Breaks for attitude maintenance limited the number of pulses to 126 with the L3A thruster and 127 with the R3A thruster, thus totaling 233 pulses. There were approximately ten breaks for attitude maintenance, which was performed with the vernier thrusters. The aft down-firing vernier thrusters had an average duty cycle of 8.72-seconds on and 15.28 seconds off. RCS performance was nominal throughout the maneuver. This maneuver was performed in the RCS-straight feed mode.

The third ISS reboost maneuver also lasted one hour. There was no predefined duty cycle as the thrusters were turned on and off as necessary to maintain the vehicle attitude within the 5-degree deadband. The reboost was performed in right OMS interconnect.

Following the successful undocking of the Orbiter from the ISS, the initial ISS separation maneuver began with a +Z-axis pulse of primary RCS thrusters at 107:18:31:19 G.m.t. (08:21:47:00 MET). The ISS flyaround operations were nominal with the exception of the performance of primary RCS thruster F3L, which is discussed in the following paragraph. Final separation from the ISS was accomplished with the primary RCS thrusters at 107:20:15:45 G.m.t. (08:23:31:26 MET).

During the ISS flyaround at 107:19:07:13 G.m.t. (08:22:22:54 MET), it was noted that primary RCS thruster F3L had a low Pc of 64.7 psia on an 80-msec pulse (should have been approximately 150 psia) (Flight Problem STS-110-V-03). After evaluation of the thruster pulse profile, it was agreed to watch its performance on subsequent pulses. Thruster F3L subsequently had a second low Pc of 68.5 psia during an 80-msec pulse at 107:19:31:55 G.m.t. (08:22:47:36 MET). After this pulse, the crew placed the thruster in last priority at 107:19:34:21 G.m.t. (08:22:50:02 MET). The thruster was deselected later and was not fired for the remainder of the mission. The thruster along with all thrusters in the same manifold will be replaced during postflight turnaround operations.

The following table shows how the attitude control of the combined ISS and Orbiter were shared during the docked operations.

Control Responsibility	Start, G.m.t.	End, G.m.t	Elapsed Time, DD:HH:MM	Comments
ISS	100:17:13:14	102:12:43:14	01:23:30:00	Initial handoff to ISS
Orbiter	102:12:43:14	102:15:17:50	00:02:34:36	Water dumps
ISS	102:15:17:50	103:21:19:10	01:06:01:20	
Orbiter	103:21:19:10	104:00:18:57	00:02:59:47	Reboost maneuver 1
ISS	104:00:18:57	104:09:59:47	00:09:40:50	
Orbiter	104:09:59:47	104:12:48:31	00:02:48:44	Waste water dumps
ISS	104:12:48:31	104:20:55:29	00:08:06:58	
Orbiter	104:20:55:29	104:23:22:39	00:02:27:10	Reboost maneuver 2
ISS	104:23:22:39	107:10:27:24	02:11:04:45	
Orbiter	107:10:27:24	107:12:56:41	00:02:29:17	Reboost maneuver 3 and water dumps
ISS	107:12:56:41	107:17:35:02	00:04:38:21	ISS control until undocking

The attitude control during docked operations for the ISS was 6 days 13 hours 52 minutes and 14 seconds, and the Orbiter controlled the attitude for 14 hours 19 minutes 44 seconds.

The RCS hot-fire began at 108:13:08:23 G.m.t. (09:16:24:05 MET) and was satisfactorily completed approximately 10 minutes later. All RCS thrusters were fired at least twice and for at least 0.320 seconds on each pulse with the following exceptions. Thruster R1A was not hot-fired for simplicity of the amended test procedure. There was no issue with firing that thruster as it had been fired previously during the mission. Thrusters L1A, F1D and F3L were not fired because of their previous unsatisfactory performances earlier in the mission. No failures or fail-leaks were detected during the hot-fire exercise. In addition, the manifold 5 leak test was also performed satisfactorily.

Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the mission. There were no LCC or OMRSD violations during the countdown. A total of eight maneuvers were performed during the mission. No in-flight anomalies were identified during the data review. The following table shows the OMS maneuvers that were performed during the mission.

OMS MANEUVERS

Maneuver	Time, G.m.t./MET	ΔV , ft/sec	Firing time, sec	Orbit, nmi,
OMS Assist (Dual OMS)	098:20:46:32,6 00:00:02:13.6	-	76.3	-
OMS-2 (Dual OMS)	098:21:23:03 00:00:38:44	96.0	63.2	85.0 by 124.0
NH (OMS-3) (Dual OMS)	100:11:28:11.8 01:14:43:52.9	218.1	140.1	115.4 by 210.1
NC4 (OMS_4) (Dual OMS)	100:12:11:48.4 01:15:27:29.5	146.6	92.4	203.0 by 211.4
Ti (OMS-5) (Left OMS)	100:13:45:37.6 01:17:01:18.7	10.5	13.2	203.0 by 211.4
OMS-6 (Dual OMS)	108:17:26:18.6 09:20:41:59.6	18.2	10.1	206.3 by 218.3
OMS-7 (Dual OMS)	108:18:04:18 09:21:19:59	69.9	38	218 by 166
Deorbit (Dual OMS)	109:15:18:58.6 10:18:34:39.7	264.2	138.8	-

A total of 23,309 lbm (14,579 lbm - oxidizer and 8730 lbm - fuel) of OMS propellants were consumed during the mission. A total of 1191.7 lbm of OMS propellants were provided during interconnect operations to the RCS. As a means of saving propellant, the NC1, NC2 and NPC maneuvers were deleted and the ΔV that was to be imparted to the vehicle was combined into the NH maneuver that was performed by the OMS.

Two problems were identified during the mission and these were:

1. The left fuel total quantity showed an approximately 45-percent drop at the start of the OMS assist maneuver. The measurement did not correct itself until the deorbit maneuver when the fuel level dropped low enough for the totalizer to update from the aft probe; and

2. The right OMS Helium regulator steady-state performance appeared to be lower than expected.

The deorbit maneuver for the first KSC landing opportunity on orbit 170 was performed satisfactorily.

Power Reactant Storage and Distribution

The power reactant storage and distribution (PRSD) subsystem performance was nominal throughout the STS-110 mission. No LCC or OMRSD violations occurred during the countdown and mission, and no in-flight anomalies were noted during the analysis of the data. All File IX requirements were satisfied during the mission.

The PRSD subsystem supplied the fuel cells with 2416 lbm of oxygen and 304 lbm of hydrogen for the production of 3521 kWh of electrical energy. In addition, the environmental control and life support system (ECLSS) was supplied 243 lbm of oxygen for life support. The average power level for the mission was 13.6 kW. A 103-hour mission extension was possible at the average power level with the reactants remaining at landing, and at extension day power level of 12.1 kW, a 113-hour mission extension was possible.

PRSD tanks 4 and 5 were depleted to residual quantities during the mission. The Orbiter landed with 1297 lbm of oxygen and 154 pounds of hydrogen remaining.

Hydrogen tank 3 had a vacuum annulus indication of 0 percent. Most past indications of 0 percent have been attributed to a failed converter output signal in earlier model converters. A waiver was written that deferred corrective action until the next flight of this Orbiter and STS-110 was flown in the as-is condition. The boil-off rate on hydrogen tank 3 was 0.053 lbm/hr and the average for the five hydrogen tanks was 0.052 lbm/hr, which indicates that the tank had not lost the vacuum in the annulus.

During the long periods of low vehicle acceleration while on-orbit, the fluid in oxygen tanks 1, 3, 4 and 5 stratified at various times. When the fluid destratified after RCS thruster firings, the corresponding pressure drop and quantity increase was observed. In all cases, the fluid remained in the single-phase region.

During the mission, approximately 140 lbm of oxygen was transferred from the PRSD system to the ISS's high-pressure oxygen tanks. A transfer line was used along with the oxygen recharge compressor assembly (ORCA).

Fuel Cell Powerplant Subsystem

The overall performance of the fuel cell powerplant (FCP) subsystem was nominal during the mission. There were no OMRSD or LCC violations, nor were any in-flight anomalies found during the analysis of the data. The average power level and load was 13.6 kW and 442 amperes. The fuel cells produced 2720 lbm of potable water and 3521 kWh of electrical energy while using 2416 lbm of oxygen and 304 lbm of hydrogen.

Four purges of the fuel cells were performed, all of which achieved nominal results. The fuel cell reactant purge system operated nominally in both the automatic and manual modes.

The actual fuel cell voltages at the end of the mission were 0.1 Vdc above the predicted for fuel cell 1, 0.2 Vdc above predicted for fuel cell 2, and 0.15 Vdc above the predicted for fuel cell 3. The voltage margin above the minimum performance curve at 200 amperes at the end of the mission was 0.9 Vdc for fuel cell 1, 0.9 Vdc for fuel cell 2, and 1.2 Vdc for fuel cell 3.

The overall thermal performance of the fuel cell water relief, water line, and reactant purge heater systems was normal. System A was used during the countdown, ascent and through approximately 6½ days of the mission for the water relief and water line systems. The B system was selected at that time and it operated nominally in both the automatic and manual modes for the remainder of the mission.

The fuel cell monitoring system (FCMS) was used to monitor individual cell voltages during prelaunch, on-orbit and postlanding operations. Full-rate data were recorded for 12 minutes beginning at 099:20:39 G.m.t. (00:23:55 MET) and all of the cell voltages were nominal.

All fuel cell in-flight checkout requirements were met except for the fuel cells 1, 2 and 3 water-relief-valve heater-test for system B. This requirement was not completed because the environment was not cold enough to activate the B heater.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performance was nominal throughout the mission. No in-flight anomalies were identified during the evaluation of the data. All in-flight checkout requirements were completed satisfactorily.

The following table presents the APU run times and fuel consumption for the mission.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 405) (a) (b)		APU 2 (S/N 303) (a)		APU 3 (S/N 409) (a)	
	Time, Min:sec	Fuel consumption, lb	Time, Min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	19:32	43	19:56	44	20:14	49
FCS checkout	6:24	16				
Entry ^a	63:44	109	92:22	144	63:54	117
Total	89:40	168	112:18	188	84:08	166

^a APUs were shut down 19 minutes 25 seconds after landing.

^b APU 1 was used for the FCS checkout.

The flight control subsystem (FCS) checkout was performed satisfactorily using APU 1 to support the checkout with an APU start time of 108:12:04:55 G.m.t. (09:15:20:36 MET). The total run time was too short to require the WSB to provide spray cooling. The APU and hydraulics performance was nominal.

The only problem noted occurred following landing and after APU shutdown. The gearbox gaseous nitrogen (GN₂) pressure measurement and gas generator bed temperature dropped out when the controller switch was turned off. These measurements are powered from the controller power switch as well as from the gas generator/fuel pump heater switch. The measurements should have continued to be

active until the heater switch was turned off. KSC will perform troubleshooting to determine the cause of this problem.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/WSB subsystem performed satisfactorily throughout the mission. STS-110 was the first flight of the OV-104 vehicle with the water additive, Propylene Glycol Monomethyl Ether (PGME), added to all three WSBs. No overcooling or undercooling conditions were noted in the data. Spray cooling was noted at 58 and 85 seconds after MECO on systems 1 and 2, respectively. System 3 began spray cooling 18 seconds prior to MECO. This was the first occurrence of spray cooling prior to MECO since the PGME was added to the APUs.

There were no unexpected decreases in reservoir quantity, indicating that the systems had no gross leakage. Priority valve checks at APU activation were all well below the 1-second specification.

STS-110 was the first flight of the OI-29 software, which incorporates the lower circulation pump thermal limits on all three hydraulic systems. The use of the new lower limits reduces circulation pump operation to save cryogenics consumables during the docked phase of the mission. There were a total of four circulation pump operations during the mission.

The APU/HYD system 1 was selected for FCS checkout. Hydraulic system 1 operation was nominal.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed nominally throughout the mission with the exception of the floodlight problem that is discussed in the following paragraph. All File IX in-flight checkout requirements were completed satisfactorily. Likewise, no in-flight anomalies were identified in the evaluation of the data.

When powering the floodlights for payload bay door closing, mid-main A current had a signature that was indicative of a 10-ampere remote power controller (RPC) that current-limited and tripped. Floodlights 1 and 6 are powered from that bus. The crew did not report a problem with any of the floodlights. During postlanding inspection of the lights, the forward port floodlight was found to have a crack.

Orbiter Docking System

The Orbiter docking system (ODS) was powered on at 099:19:00 G.m.t. (00:22:16 MET) as planned and the ring extension was completed nominally. The ODS was ready for rendezvous and docking operations. The Orbiter docked and opened hatches with the ISS at 099:17:10 G.m.t. (01:20:26 MET).

The ODS performed nominally throughout capture, ring retraction, and hook closure. The ODS captured the ISS at approximately 100:16:04 G.m.t. (01:19:20 MET). The modified docking ring retraction procedure, which was developed to eliminate the potential for stuck high-energy dampers (HEDs), was used for the first time. The procedure retracts the ring for 10 seconds, then stops and extends for 5 seconds prior to completing the retraction process. No issues with ring misalignment were encountered.

The hook-position indicator, which had been intermittent on the previous two missions, worked nominally. Hook gang 1 drive time was 2 minutes, 22 seconds, and hook gang 2 drive time was 2 minutes, 12 seconds.

The ODS valves were used during the docked operation. The Orbiter was docked to the ISS pressurized mating adapter 2 (PMA 2) and the vestibule was pressurized from the ISS. The vestibule leak check performed after docking showed nominal results.

At 100:21:19 G.m.t. (02:00:35 MET), the crew reported that the ODS hatch differential pressure (ΔP) gauge was indicating approximately -0.7 psid during the hatch-opening procedure. Other instrumentation was used to determine that the Orbiter and ISS were pressure equalized with no ΔP across the hatch. The crew downlinked a picture of the gauge showing the bias. On flight day 10 after undocking, the crew reported that the gauge was reading about 18 to 19 psid. The cabin pressure at that time was 14.66 psia with a vacuum on the other side of the hatch. Review of the OMRSD revealed that the calibration requirement is ± 1.0 psid, and the gauge was calibrated during the Orbiter Major Modification (OMM) period. This condition did not impact the successful completion of the mission.

The vestibule depressurization valves were used to depressurize the vestibule to vacuum before undocking, and the pre-undocking vestibule leak check was nominal.

Undocking from the ISS was completed with no anomalies. The ODS was powered up at 107:18:02 G.m.t. (08:21:18 MET), and undocking was completed at 107:18:31 G.m.t. (08:21:47 MET). The hook-8 individual position indication toggled very briefly at the start of hook opening, however, this signature has been seen on previous missions and was not an issue. Following undocking, the ODS was powered down 107:18:46 G.m.t. (08:22:02 MET).

The external airlock waterline heater reconfiguration from string A heaters to String B heaters was performed as part of the in-flight checkout. String C heaters were not required.

Atmospheric Revitalization Pressure Control Subsystem

The atmospheric revitalization pressure control subsystem (ARPCS) performed normally throughout the duration of the flight. To minimize the use of consumables and maintain pressure for gas transfer to the ISS, the 14.7-psia cabin regulators were left off after orbital insertion. The Orbiter docked and opened hatches with the ISS at 099:17:10 G.m.t. (01:20:26 MET).

All EVA's on this mission were performed from the ISS Airlock. Due to the large amount of oxygen exhausted into the cabin atmosphere during the ISS prebreathing procedure, cabin pressure during the docked period was maintained by the introduction of the oxygen from the ISS prebreathing system.

During the docked period, approximately 143.8 lbm of oxygen and 37 lbm of nitrogen were transferred to the ISS tanks via the transfer lines. Prior to undocking, a repressurization of the entire stack to a pressure of 14.7 psia was performed. After this, normal pressure control was maintained for the remainder of the flight.

After undocking, the PCS 2 was placed in service and a full switchover was observed on this system. The active system monitor parameters indicated a normal output throughout the duration of the flight.

Atmospheric Revitalization Subsystem

The atmospheric revitalization subsystem (ARS) system performed nominally throughout the duration of the flight and the highlights of the mission are presented.

The 75.5 °F cabin air temperature at launch was 0.5 degree cooler than the preflight predicted temperature of 76 °F provided through the STS-110 ECLSS/Payload Thermal Compatibility Verification Analysis. The 75.5 °F exceeded the flight-rule limit of 75 °F air temperature for the launch phase. Cabin temperature climbed to 79 °F two-hours and forty-one minutes after launch, which was the highest indicated cabin temperature during the mission.

The partial pressure of carbon dioxide (ppCO₂) peaked at an indicated sensor value of 5.14 mmHg at 102:21:57G.m.t. (04:01:1 MET). The peak occurred during joint operations with the Orbiter and International Space Station hatch-interface open. This peak occurred during the pre-sleep activity of flight day 4. During the docked phase of the mission, both the CDRA and Vozdukh were operational, with Vozdukh operating in MODE 5. In this operational mode, the service module ppCO₂ reading averaged 2.5-mmHg ppCO₂, while the Orbiter cabin ppCO₂ averaged approximately 3.0-mmHg ppCO₂. The ppCO₂ reading from the U. S. Laboratory was not available for STS-110. The preflight ppCO₂ analysis predicted peaks above 6.0-mmHg ppCO₂ on two different occasions, the first occurring at approximately 4 days into the mission and the second at approximately 7 days into the mission. The cabin ppCO₂ did actually peak on these two days; however, the cabin ppCO₂ peaked at values of 5.14 mmHg and 5.02 mmHg ppCO₂, respectively.

From the lithium hydroxide (LiOH) cue card change-out schedule, a total of 25 LiOH canisters were expended during the flight. Of this total, eight canisters were transferred from the ISS LiOH canister stockpile.

The floodlight coldplate temperature location on the 576 bulkhead indicated the temperature averaged approximately 70 °F during the mission, decreasing to a minimum temperature of 67.5 °F.

The ARS file IX requirements included the checkout of the secondary cabin temperature controller and the checkout of the primary water coolant loop (WCL) 1 actuator and its response to temperature. The WCL 1 bypass valve functional checkout was successfully performed at 109:11:25 G.m.t. (10:14:41 MET).

Approximately mid-way through the flight, the crew performed the cabin temperature controller reconfiguration by unpinning the linkage on controller 1 and pinning the linkage on controller 2. During this time, the cabin temperature selector was positioned to the full-bypass position, which drives the temperature controller away from the full heat exchanger flow. This reduces the force on the linkage and subsequently reduces the amount of force required for crewman to remove and install the linkage pit pin. The flight continued flawlessly on the secondary controller for the remainder of the flight.

During the launch phase, the crew compartment temperature was 75.5 °F at launch and continued to climb until it stabilized to 79.1 °F at 2 hours and 41 minutes into the flight.

At launch, the cabin humidity was 38.4 percent and peaked to 43 percent at 4 minutes and 24 seconds after launch. The heat exchanger outlet air temperature peaked to 69.77 °F at approximately 2 minutes 54 seconds into the flight.

During the on-orbit phase of the mission, the cabin temperature averaged 76 °F. The Orbiter cabin temperature during the docked portion of the mission had temperature swings from a low of 75.5 °F to a high of 77 °F. The ppCO₂ peaked at an indicated ppCO₂ reading of 5.14 mmHg during the docked phase of the mission and 4.9 mmHg ppCO₂ during the non-docked phase of the mission..

Cabin humidity averaged 32.5 percent for the flight, peaking to 42.8 percent during crew deorbit preparation period of flight day 11.

During the landing phase of the flight, the heat exchanger outlet temperature peaked to 60.19 °F at 8 minutes and 12 seconds after wheel stop, with the cabin air temperature peaking at 73.4 °F at 51 minutes and 12 seconds after wheel stop. The temperature at landing was 71.2 °F, well below the 75-degree cabin air-temperature limit. The cabin humidity peaked near 45.2 percent approximately 10 minutes and 26 seconds after wheel stop.

Active Thermal Control Subsystem

The active thermal control subsystem (ATCS) performed satisfactorily throughout the mission. No in-flight anomalies were identified during the flight or the data review.

During ascent, at about 1 minute and 33 seconds after liftoff, pre-evaporative cooling occurred resulting in a drop in the flash evaporator system (FES) outlet temperatures from 83.7 °F to about 69 °F. This amount of pre-evaporative cooling is within history and was not unexpected. The amount of pre-evaporative cooling had no impact on the mission. The FES duct temperatures were nominal.

At about 098:22:10 G.m.t. (00:01:26 MET), the FES controller was switched from primary A command to primary B command after the supply water system was configured to interconnect tanks C and D. These tanks would supply water through the feedline B system. This allowed for water to accumulate in tanks A and B for eventual transfer to the ISS in contingency water containers (CWCs) and Payload Water Reservoirs (PWRs) while still retaining the FES cooling capability that was required for the duration of the warmer-attitude phases of the mission. The FES was inhibited at 100:16:47 G.m.t. (01:20:03 MET) to increase the net water gain for the water transfer. At 107:12:13 G.m.t. (08:15:29 MET), after the water transfer was completed, the FES primary A command was reactivated at 108:17:33 G.m.t. (09:20:49 MET). A FES water dump using the primary A command was performed from 108:17:33 G.m.t. (09:20:49 MET) through 108:21:58 G.m.t. (10:01:12 MET).

On entry day, the radiator coldsoak was begun at 109:11:24 G.m.t. (10:14:40 MET) and ended one hour later with the initiation of the radiator bypass/FES checkout. The radiator bypass/FES checkout produced nominal results and required seven minutes to perform after which the FES was configured to the primary B controller in full-up mode.

The payload bay doors were closed at about 109:12:49:49 G.m.t. (10:16:05:30 MET). The radiators were never deployed for this mission. Thirty-seven minutes after the payload bay doors were closed, the FES was configured from primary B command to primary B general-purpose computer (GPC) control in preparation for entry. The

radiators were configured for radiator flow at 109:16:15 G.m.t. (10:19:31 MET), which was about 12 minutes before touchdown.

Approximately 109:16:30 G.m.t., three minutes after touchdown, the radiator flow control assemblies were switched from normal setpoint control to high setpoint control in preparation for the ammonia boiler system (ABS) activation. Five minutes later, the ABS primary B GPC controller was enabled to begin cooling. The ABS B cooled to a FES outlet of about 36.7 °F. The ammonia tank B began blowdown at 109:20:57 G.m.t., signaling the depletion of the ammonia tank. Two minutes later, the ABS primary B GPC controller was inhibited and the primary A GPC controller was enabled. By this time, the ground support crew was ready to initiate ground support equipment (GSE) cooling resulting in the primary A GPC being deactivated after approximately two minutes of operation.

Supply and Waste Water Subsystem

The supply water and waste Management systems performed nominally throughout the mission and all of the scheduled in-flight checkout requirements were satisfied. Supply water was managed through the use of the FES, water transfer to the ISS and the overboard nozzle-dump system. One supply-water-nozzle dump was performed at a nominal dump rate of 1.69 percent per minute (2.78 lb/min). The line heater maintained the supply water dump line temperature between 71 °F and 91 °F throughout the mission.

Three wastewater nozzle dumps from the waste tank were made at an average rate of 2.02 percent per minute (3.3 lb/min). During this mission, two CWCs of ISS-Laboratory condensate, two PWRs containing expired iodinated water (certified wet life on orbit is 278 days) and three CWCs of Shuttle-condensate were nominally dumped through the wastewater dump nozzle.

As a result of condensate separation/collection, three CWCs of Shuttle Condensate have been filled and dumped overboard through the wastewater dump nozzle. The waste dump isolation valve was closed prior to connecting the PWR (S/N 1003) into the waste Cross-Tie quick disconnect (QD) to prevent back flow from the waste tank. However, the PWR containing iodinated water was connected to the wastewater cross tie QD prior to closing the waste dump isolation valve and about 5 lbm of urine from the waste tank was introduced into the PWR. Cabin pressure was at 14.7 psia during the condensate CWC and PWR dumps. The wastewater dump line temperature was maintained between 55 and 74 °F throughout the mission. Vacuum vent line temperature was maintained between 58 °F and 75 °F.

Fourteen CWCs were filled with technical water and transferred to the ISS, for a total of 1396.6 lb. Calculated average fill rate was 107 lb/hr. In addition, three PWRs of iodinated water total quantity (in three) 68 lb were filled to support future ISS EVAs and were transferred to ISS.

Waste Collection Subsystem

The waste management subsystem performed satisfactorily throughout the mission.

Smoke Detection and Fire Suppression Subsystem

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

Flight Data Subsystem

The flight data subsystem performed nominally with only one problem occurring during the mission. There was no mission impact from this problem.

At 098:21:10:41 G.m.t. (00:00:26:22 MET), integrated display processor (IDP) 2 announced a single buffer overflow error (Flight Problem STS-110-V-04). This error is reported when more display data are received from a GPC than can be processed in one cycle. Thirty-four seconds later, at 098:21:11:15 G.m.t (00:00:26:56 MET), IDP 2 announced built-in test equipment (BITE) messages indicating that the IDP experienced errors when accessing its mass storage unit (MSU). The BITE fail message cleared 55 seconds later. The most probable cause of these errors is a glitch on the small computer system interface (SCSI) control line during MSU access. Recurrence of this event had a very low likelihood of repeating during the remainder of the mission. The event has a finite time-out recovery of less than 1 minute. Postflight troubleshooting will be performed to determine the status of the MSU.

Inertial measurement unit (IMU) performance was nominal throughout the flight. IMU accelerometer compensations were adjusted once on each IMU during the flight. No drift compensations were required during the flight. This ship-set of IMUs is acceptable for the next flight.

Flight Control Subsystem

The flight control subsystem (FCS) performed nominally throughout the mission with no in-flight anomalies identified during the evaluation of the data.

The FCS checkout was performed satisfactorily using APU 1 to support the checkout with an APU start time of 108:12:04:55 G.m.t. (09:15:20:36 MET). The run time was 6 minutes, 24 seconds. FCS performance was nominal.

Flight Software

STS-110 was the first flight of the OI-29 software. No in-flight anomalies or significant problems were noted in this version of the software.

Displays and Controls Subsystem

The displays and controls subsystem performed nominally during the STS-110 mission. When powering the payload bay floodlights for payload bay door closing, the mid main A bus current had a signature that was indicative of a 10-ampere RPC, which is current limited, being tripped. Floodlights 1 (forward port) and 6 (aft starboard) are powered from the mid main A bus. The crew did not report a problem with either of the

floodlights; however, the floodlights were checked out during the postlanding operations and one was found cracked.

Following landing and just prior to the transition to the operations (OPS) -9 mode change, several mid motor control assembly (MMCA) operational-status (OP STATS) bits came on and did not go off. There was no ac current increase to indicate any motors driving. The postflight data review indicates that all of the affected OP STATS were related to a switch for starboard RMS retention latches. The starboard retention latches switch is a standard three-position switch with the latch position being down. If the switch was accidentally bumped to the latch position, the six OP STATS would be activated. During postflight testing, KSC was able to reproduce the signature with the switch. Voice tapes were reviewed to verify the switch position.

Communications and Tracking Subsystem

The communications and tracking subsystem performed satisfactorily, although a number of minor problems occurred. However, none of these problems impacted the successful completion of the planned mission.

During the rendezvous, the Ku-band RADAR system acquired the ISS at 100:13:05 G.m.t. (01:16:21 MET) at a range of 141,000 ft. (approximately 23.5 nmi.). At 100:15:15 G.m.t. (01:18:31 MET), at a range of 630 ft, the Ku-band system was placed in the communications mode. The performance of the Ku-band system was nominal.

The crew was not able to talk from the Orbiter flight deck to the ISS Robotics Workstation (RWS) on intercommunications (ICOM) B using a battery-powered speaker/microphone unit (BPSMU). The problem was identified during BPSMU operation when using the push-to-talk (PTT)/PTT mode of the audio terminal unit (ATU). The Orbiter flight-deck crewmember could hear the crewmember at the RWS. Troubleshooting, which included switching from the Commander's crew communications umbilical (CCU) to the Pilot's CCU and trying a different BPSMU, was unsuccessful. The crew then switched to PTT/HOT (hot microphone) on the ATU and ICOM was recovered. It is suspected that the problem is caused by a failure in the BPSMU/CCU adapter cable, of which there is only one onboard. The flight configuration was accepted for operations. Troubleshooting of the cable was performed.

The Ku-band system was placed in the RADAR mode at 107:20:08 G.m.t. (08:23:24 MET) and acquired the ISS at a range of 400 ft. The radar maintained lock-on the ISS during the latter part of the ISS flyaround and during the separation maneuver. The Ku-band system was placed in the communications mode at 107:20:21 G.m.t. (08:23:37 MET) at a range of 1617 ft.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation (OI) system/modular auxiliary data system (MADS) performed satisfactorily throughout the mission. A minor problem that was identified is discussed in the following paragraph.

Beginning at approximately 103:03:09 G.m.t. (04:06:25 MET), the right main landing gear (RMLG) inboard tire pressure measurement 1 shifted to off-scale low (232 psia) over a 7-minute period. Pressure measurement 2 on the RMLG inboard tire continued to indicate the correct tire pressure. At 106:22:15:05 G.m.t. (08:01:30:46 MET), the pressure measurement returned indicating 334.1 psia. This measurement returned at

approximately the same temperature at which the measurement went off-scale-low. There was no mission impact. Postflight troubleshooting of this measurement sensor and wiring will be performed.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily. No significant problems were noted during the mission. One minor problem is discussed in the following paragraph.

During entry when deploying the air data probes at Mach 5.0, the left air data probe did not deploy initially when the crew moved the switch on panel C3 to the deploy position. The crew was called to verify that the switch was in the deploy position, and the switch was wiggled at which time the air data probe began to deploy. Once the air data probe was deployed, all data and motor times were nominal for the left probe.

LANDING PARAMETERS

Parameter	From Threshold, ft	Speed, Keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	3128.0	192.3	-2.81	N/A
Nose gear touchdown	6354.7	137.2	N/A	-5.11
Brake initiation speed		67.9 keas		
Brake-on time		33.74 seconds		
Rollout distance		9628.7 feet		
Rollout time		69.94 seconds		
Runway		33 (Concrete) KSC		
Orbiter weight at landing		201,895.3 lb		
Brake sensor Location	Peak Pressure, Psia	Brake assembly		Gross energy, million ft-lb
Left-hand inboard 1	686.3	Left-hand inboard		8.73
Left-hand inboard 3	686.3			
Left-hand outboard 2	578.4	Left-hand outboard		6.77
Left-hand outboard 4	578.4			
Right-hand inboard 1	720.6	Right-hand inboard		9.45
Right-hand inboard 3	720.6			
Right-hand outboard 2	769.6	Right-hand outboard		11.87
Right-hand outboard 4	769.6			

The payload bay doors were opened as planned at 098:22:40:32 G.m.t. (00:01:56:13 MET). All voltages were nominal, and the motors opened the doors in nominal dual-motor time.

The payload bay doors were closed and latched for the first KSC landing opportunity at 109:12:52:12 G.m.t. (10:16:07:54 MET). All payload bay door close and latch operations occurred in dual motor time.

Main landing gear touchdown occurred on KSC concrete runway 33 at 109:16:27:03 G.m.t. (10:19:42:44 MET) on April 19, 2002. The drag chute was deployed

at 109:16:27:00 G.m.t. The nose gear touchdown occurred at approximately 109:16:27:09 G.m.t. The drag chute was jettisoned at 109:16:27:42 G.m.t. Wheels stop occurred at 109:16:28:08 G.m.t. All mechanical functions occurred as planned.

The post-landing walkdown of runway 33 was performed immediately after landing and no foreign object damage (FOD) or flight hardware, other than the drogue parachute components, were found on the runway.

Integrated Aerodynamics, Heating and Thermal Interfaces

The prelaunch thermal interface purges were normal with no problems noted. Likewise, the ascent aerodynamic heating and plume heating were nominal with no problems noted. The entry aerodynamic heating on the SSME nozzles had evidence of higher heating (metal had a bluish discoloration due to outgassing or oxidization). A hardness test was conducted and the results showed that the nozzle material met the hardness test requirements. The discoloration was later polished out with "Scotchbrite".

Thermal Control Subsystem

The thermal control subsystem (TCS) maintained temperatures within limits throughout the STS-110 mission. No significant problems or in-flight anomalies were noted in the review of the data. Some concerns were brought up during the mission that are listed as follows:

1. Beginning at approximately 103:03:09 G.m.t. (04:06:25 MET), the right main landing gear (RMLG) inboard tire pressure measurement 1 shifted to off-scale low (232 psia). The second pressure measurement on the RMLG inboard tire continued to indicate the correct tire pressure. Later in the mission when the temperature warmed, the pressure measurement began again indicating 334.1 psia.
2. The port OMS oxidizer drain panel temperature dropped prior to rendezvous with the ISS. An evaluation of the data showed that the drop in temperature was caused by attitude changes of the vehicle.
3. On this first flight for oxygen being transferred to the ISS, the oxygen flow could be seen in the external airlock oxygen line temperature. This caused the temperature of the potable water line to rise, resulting in the thermostat in zone 2 being inhibited. While on the B thermostat, the oxygen transfer did not affect the zone 2 heaters. Future missions will require the B or C thermostat during future transfer operations.

Aerothermodynamics

Structural thermocouple temperature data, aileron deflection data, and yaw thruster firings all indicated an asymmetric drag around Mach 10.6. This drag data are associated with the onset of asymmetric transition from laminar flow to turbulent flow. However, wing structural temperature-rise data did not indicate asymmetric boundary layer transition.

The acreage heating data indicate that the vehicle experienced normal entry heating. Structural temperature data are within the range expected for this type of mission. The upper surface structural temperature data indicate higher heating on the starboard side,

with the exception of the OMS pod in which the left pod was much higher than the right pod. All data reviewed are within the flight experience of this vehicle.

Local heating was also normal.

Thermal Protection Subsystem and Windows

The thermal protection subsystem (TPS) performed satisfactorily. The postlanding inspection of the Orbiter TPS identified a total of 110 damage sites of which 22 had a major dimension of 1-inch or larger. This 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. The distribution of these impacts on the vehicle is shown in the following table.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	18	70
Upper Surface	0	0
Window Area	4	34
Right Side	0	6
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	0	0
Total	18	110

The Orbiter lower surface sustained 70 damage sites of which 18 had a major dimension of 1-inch or larger. The majority of the hits (30 damage sites with 11 larger than 1-inch in length) were located in the area between the nose landing gear and the main landing gear wheel wells. Approximately 15 of the lower surface damage sites were located around the LH₂ umbilical area. Most of these damage sites around the External Tank/Orbiter were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

A comparison of lower surface damage sites for the previous 10 flights is shown in the following table.

COMPARISON OF LOWER SURFACE DAMAGE SITE DATA FROM LAST TEN FLIGHTS

Parameter	STS-92	STS-97	STS-98	STS-102	STS-100	STS-104	STS-105	STS-108	STS-109	STS-110
Lower surface, total hits	86	78	73	44	42	108	144	95	63	70
Lower surface, hits > 1 in.	14	10	8	10	4	4	25	22	14	18
Longest damage site, in.	2.0	3.0	3.0	1.0	2.5	4.5	5	8.0	3.5	3.5
Deepest damage site, in.	0.75	0.5	0.5	0.12	0.12	0.25	0.06	0.37	0.12	0.62

Gap filler material was found protruding from between tiles on the left-hand pod eyeball area.

Typical amounts of tile damage occurred on the base heat shield. All SSME dome heat shield closeout blankets were in good condition.

A total of 34 damage sites, with 4 having one dimension greater than one inch, were identified on the window perimeter tiles. The hazing and streaking of the forward-facing windows appeared to be heavier than normal. There is one window ding, ¼ -inch in diameter, approximately at the center of window 2.

In summary, the total number of Orbiter TPS damage sites and the number of sites that were 1-inch or larger were within the established family. The potential identification of debris damage sources for this mission will be based on laboratory analysis of the Orbiter postlanding microchemical samples, inspection of the recovered SRB components, film analysis and aerodynamic debris particle trajectory analysis. The results will be published in the STS-110 Debris/Ice/TPS Assessment and Integrated Photographic Analysis report.

Gas Sample Analysis

The analysis of the gas samples contained in the six bottles showed the samples to be acceptable and within the nominal range for percentage of hydrogen.

The analysis was performed using an AeroVac Mass Spectrometer and the backup analysis was accomplished using a new Finnegan 9001 Gas Chromatograph with Discharge Ionization Detection.

The table showing the data measured from the bottles is presented in the Shuttle Flight Data and In-Flight Anomaly List (JSC 19413). This document may be accessed on the Space Shuttle Vehicle Engineering Office home page under the MER heading.

EXTRAVEHICULAR ACTIVITY

All planned and almost all of the get-ahead extravehicular activity (EVA) tasks were completed during the four EVAs. The official length of the four EVAs was 28 hours 22 minutes, which is record for a single ISS mission.

EMU checkout was completed with all three units performing nominally. The EMUs were ready to support the four scheduled extravehicular activities (EVAs).

FIRST EXTRAVEHICULAR ACTIVITY

The first EVA was successfully completed with a total EVA time of 7 hours and 48 minutes. The EVA, which was conducted from the ISS airlock, was officially started when the EMUs were placed on internal battery power at 101:14:36 G.m.t. (02:17:52 MET). The following list details the tasks performed during the first EVA.

1. Installation of the port and starboard forward module-to-truss (MTS) struts;
2. Installation of forward and port avionics umbilical trays and all planned connections made;
3. Deployment of Starboard Zero (SO) aft laboratory tray and all planned connections made;
4. Completed nominal SO activation and verified that all EVA-made connections were functional; and
5. Installation of Mobile Transporter (MT) and Zenith TUS, and MT systems activated.

The crewmembers encountered some problems during the first EVA and these are detailed in the following list.

1. Some bolts required a higher torque than expected, and alternate operations and settings of the various EVA tools was necessary;
2. Forward avionics umbilical trays, aft starboard and forward and aft port stanchion bolts were not driven the full length. Re-torqueing of these bolts was planned for the fourth EVA;
3. The SO aft laboratory tray required excessive force to be deployed; however, the tray was successfully deployed and latched using a crewmember on each side of the tray;
4. Extra time was required to resolve problems because some of the strut bolts had excessive torque; and
5. Problems with the starboard and port avionics tray stanchion bolts and deployment of the aft laboratory tray resulted in the EVA lasted longer than planned; consequently the installation of CIDs 7 and 8 was deferred to the third EVA.

The EVA was concluded when repressurization of the airlock was initiated at 101:22:24 G.m.t. (03:01:40 MET). Following the EVA, the EV1 crewmember reported that he was unable to drink any water from the disposable in-suit drink bag (DIDB). This problem will be evaluated postflight.

SECOND EXTRAVEHICULAR ACTIVITY

The second EVA was successfully completed with a total EVA time of 7 hours and 30 minutes. Like the first EVA, this EVA was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 103:14:09 G.m.t. (04:17:25 MET). The following list details the tasks completed during the second EVA.

1. Installed of two aft mobile transporter system struts;
2. Removed and stowed two keels and two drag links;
3. Installed Nadir TUS cable and activated the remaining MT systems;
4. Removed the DDCU thermal cover (bay 4/face 1); and
5. Installed the Airlock handrail.

The crewmembers encountered some problems during the second EVA and these are detailed in the following list.

1. Alternate operations and settings of the various EVA tools was necessary because some bolts required a higher torque than expected, and; and
2. Higher-than-expected torque was noted with the TUS/IUA safing bolt during MT TUS 2 installation. This bolt prevented the inadvertent actuation of the TUS cable-cutter during launch. A decision was made to defer further troubleshooting of this interface until the fourth EVA.

The EVA concluded when repressurization of the airlock was initiated at 103:21:39 G.m.t. (05:01:55 MET). The only problem noted during the EVA was the loss of biomedical data from the extravehicular (EV) 3 crewmember at 103:18:49 G.m.t. (04:22:05 MET). The data returned momentarily for about 10 minutes before it was lost for the remainder of the EVA. The crewmember reported that he did not recall if the electrodes had fallen off during the EVA; however, he indicated after EVA 4 that the electrodes were still attached. Troubleshooting of the Orbiter biomedical system will occur during the turnaround activity following the flight.

THIRD EXTRAVEHICULAR ACTIVITY

The third EVA was successfully completed with a total EVA time of 6 hours and 27 minutes. All tasks except the Shuttle tool transfer and the Airlock spur Installation were completed. Like EVA 1 and 2, EVA 3 was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 104:13:48 G.m.t. (05:17:04 MET). The following list details the tasks completed during the third EVA.

1. Installed and reconfigured the SSRMS cabling at Laboratory J300 and J400 panels, and released the LCA capture claw;
2. Transferred power, data and video from the Laboratory to SO resources;
3. Released all MT launch constraints;
4. Removed MT thermal covers;
5. Installed CIDs 7 and 8; and
6. Transferred Shuttle tools to temporary location on the SO truss.

Because of the extra time spent re-installing the J300/400 MMOD shields, the starboard SSAS RTL test and the airlock spur were deferred to the fourth EVA.

The third EVA concluded when repressurization of the ISS airlock was initiated at 104:20:15 G.m.t. (05:23:31 MET).

FOURTH EXTRAVEHICULAR ACTIVITY

The fourth and final planned EVA of the mission was successfully completed with a total EVA time of 6 hours and 37 minutes. All planned tasks were completed. Like the first three EVAs, EVA 4 was conducted from the ISS airlock and officially started when the EMUs were placed on internal battery power at 106:14:29 G.m.t. (07:17:45 MET). The following list details the tasks completed during the third EVA.

1. Completed starboard and port SSAS RTL tests that had been rescheduled to fourth EVA;
 2. Installed Node and U.S. Laboratory EVA lights;
 3. Installed Airlock spur. Task rescheduled from an earlier EVA;
 4. Released LCA bolts, which resulted in the entire truss load path being through the MTS struts and not the LCA;
 5. Performed part 1 and 2 of the trace gas analyzer tests. Experienced an anomaly during part 3 and operations were terminated;
 6. Actuated CIDs 7 and 8 in support of MBSU/DDCU checkout;
 7. Retorqued starboard and port avionics umbilical trays;
 8. Installed starboard and port avionic umbilical tray pip pins;
 9. Relocated the SO wedge-face articulated portable foot restraint (APFR) to P6 to support the Utilization Flight 2;
 10. Performed the P6 radiator photographic survey;
 11. Performed troubleshooting on the TUS-2 safing bolt;;
 12. Deployed the EV-CPDS;
 13. Installed starboard and port MT energy absorbers;
 14. Performed a video survey of the MT;
 15. Completed the tie-down of the GPS MLI blanket;
 16. Installed five SO on-orbit-installed handrails (OIHs);
 17. Performed the photographic survey of the GPS antenna;
 18. Performed the photographic survey of the P6 radiator, aft laboratory tray and "rats nest" area.
 19. Transferred Shuttle tools from temporary location to toolbox;
 20. Removed DDCU MLI for port wedge face;
 21. Assembled the portable work platform;
 22. Removed the MT/MBS nut covers; and
 23. Deployed the Node 1 swing arm. (This task had been deleted from the planned set of tasks because of the number of carry-over tasks that had been added.
- The crew was able to do all of the carry-over tasks and perform this task as well.

The TUS-2 safing bolt could not be removed properly. Based on the indications from EVA 2 and this EVA, it is possible that the cable cutter assembly may have engaged. Plans are to leave the system as is and possibly replace the hardware on a subsequent mission.

The EVA concluded when repressurization of the ISS airlock was initiated at 106:21:06 G.m.t. (08:00:22 MET).

REMOTE MANIPULATOR SYSTEM

The remote manipulator system (RMS) performed satisfactorily during this 66th flight of the RMS. No in-flight anomalies were identified in the review of the data.

During the prelaunch time frame, the review of switch cycle activity showed that the single/direct drive switch on the RMS displays and control (D&C) panel had exceeded its qualified life of 5000 cycles. As a result, a recommendation was made to transfer the single/direct drive switch functions to the auto sequence proceed/stop switch. The estimated life remaining on the latter switch was considerably more than the single/direct drive switch. Also the functions of the single/direct drive switch could be easily transferred from the onboard computers. The crew was notified of this new procedure and for most of the single-drive operations, and for most of the single-drive operations, the auto sequence proceed/stop switch was used to command the joints.

The RMS was powered up at 099:14:36 G.m.t (00:17:52 MET), and the RMS checkout was performed. The checkout was completed at 099:15:27 G.m.t. (00:18:43 MET), and no anomalies were detected. Following the checkout, the RMS was used to perform a survey of the payload bay. The survey was started at 099:17:00 G.m.t. (00:20:16 MET) and was concluded when the RMS was cradled at 099:17:40 G.m.t. (00:20:56 MET).

The RMS was powered up at 100:17:21 G.m.t. (01:20:37 MET) and moved into the starboard zero (S0) truss-installation viewing position. It was positioned using the single-joint mode with the proceed/stop switch. Its performance was nominal.

The installation of the S0 truss onto the ISS was performed using the Space Station remote manipulator system (SSRMS). The Orbiter RMS was used as a camera platform and performed nominally during the S0 installation and the first EVA.

The RMS was used in support of all the EVAs and the system performed satisfactorily.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The government furnished equipment/flight crew equipment (GFE/FCE) performed nominally with only minor problems, which are discussed in the following paragraphs.

At 099:12:03 G.m.t. (00:15:18 MET), the sequential still video (SSV) was locked up on decommutator 2, and the ground was seeing only color bars. Shortly thereafter, a test pattern was routed to SSV spare 1 and the crew selected "IN SEL" to NTSC and the color bars were still being seen on the ground (should have been the test pattern). The ground had the crew power cycle the SSV and this produced no new results on the ground. The crew performed additional troubleshooting and determined that the "IN SEL" knob was loose and was therefore not moving the switch. The screw was tightened and the SSV power was recycled once again. After again selecting the "IN SEL" to NTSC, a test pattern was seen on the ground. The hardware will be returned to JSC for troubleshooting.

This is the first flight of the digital television (DTV) system that interfaces with and augments the existing closed-circuit television (CCTV) system. During the setup of the DTV system for a public affairs event on flight day 1, the crew encountered problems while setting up the DTV system using the digital Sony PD100 camcorder as a digital-video input source. During troubleshooting efforts, the analog video signal from the camcorder was successfully downlinked through the DTV (utilizing a different PD100 connector output). In addition, the payload bay camera input was also successfully transmitted through the DTV system. All other flight and ground DTV segments were operating successfully. Testing on the ground identified a possible cause of the problem. It is suspected that there is a problem with the strain relief on the cable interface at the camcorder connector end. During flight day 10, additional troubleshooting was not successful. Troubleshooting of the cable and camera will be performed at JSC.

The trajectory control sensor (TCS) operated nominally during the rendezvous tools checkout. After undocking from the ISS, the TCS began tracking at 6.5 ft. from the ISS and continued to track to a range of 2662.5 ft. The performance of the TCS was nominal.

Flight controllers reported that closed-circuit television (CCTV) camera B was not panning and tilting through its complete range of motion. Video downlinked from 106:22:35 G.m.t. (08:01:51 MET) to 106:22:44 G.m.t. (08:02:00 MET) indicated that the cable between the pan/tilt unit (PTU) and the camera/illuminator was not tethered in one of the two cable guides (the guide mounted on the PTU yoke). Investigation of prelaunch closeout photographs indicated that the cable guide on the yoke was installed "upside down", which may be the cause of the cable becoming disengaged. Camera B was still fully usable within the achievable pan-and-tilt range and there was no mission impact. A postflight inspection of the cable tether will be performed.

POSTLAUNCH PAD INSPECTION

The postlaunch inspection of the mobile launch platform (MLP) -3, Launch Pad B flight service structure (FSS), and rotating service structure (RSS) was conducted from Launch + 1.75 to 3.75 hours. No flight hardware was found.

Orbiter lift-off lateral acceleration data used to predict stud hang-ups showed a value of 0.14g, which indicated that no SRB holddown stud hang-up had occurred. Evaluation of the MLP Zero-level was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for the north post with some evidence of missing room temperature vulcanizing (RTV) at the hold down post (HDP) haunch interface. The north holddown post blast covers and the T-0 umbilical exhibited minimal exhaust plume damage. Both SRB aft-skirt GN₂ purge lines were intact; however, the protective tape layering was partially eroded on both the right-hand side and the metal braid was exposed on the LH₂ purge line.

The LO₂ and LH₂ tail service masts (TSMs) appeared undamaged with both bonnets closed properly. The MLP deck was generally in good shape. All MLP deck communication connector caps were found intact and secured. The removable handrail on side 4 was partially displaced; the floor plate was missing one fastener and had one loose fastener still in place.

The GH₂ vent line latched on the fourth of eight teeth on the FSS latching mechanism. The vent line was displaced to the south and had contacted the north stabilizer rod. Inspection of the area showed no indication of the vent line having contacted the FSS. The ground umbilical carrier plate (GUCP) and 7-inch quick-disconnect (QD) probe had no damage; the poppet was observed to be intact. The deceleration cable was in its nominal configuration, and the vent-line blanket was sooted and torn.

The Orbiter access arm (OAA) appeared to be intact with no evidence of plume impingement. All slide-wire baskets were secured with no evidence of damage.

The gaseous oxygen (GO₂) vent arm, ducts and structure appeared to be in nominal shape with no evidence of plume damage.

Debris findings included:

- A. A loose clamp and fasteners were found on the FSS 235-foot level;
- B. A Z-shaped piece of metal panel flashing (9 feet by 4 inches) was found on the pad surface southwest near the RSS truck; and
- C. A metal object approximately 5 feet 8 inches by 3 inches (half round) that was believed to be the MLP flame hole panel batten was found in the north flame trench.

Overall damage to the pad appeared to be normal.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

DEVELOPMENT TEST OBJECTIVES

DTO 263 - Shuttle Automatic Reboost Tuning - DTO 264 was completed on flight day 3. The DTO data collection was completed with a single 160-msec firing of the L3A and R1a thrusters as well as associated vernier firings. Good quality data were recovered and processed. No updates to the Shuttle flight control for the reboost maneuvers were required.

DTO 700-14 - Single-String Global Positioning System without Payload and General Support Computer - The miniature air-to-ground receiver (MAGR) DTO 700-14 was completed successfully during the STS-110 mission. The crew reported MAGR payload and general support computer (PGSC) status each day, assuring that the PGSC was properly recording MAGR receiver data. All PGSC operations were completed on the day of entry when the crew made the final entry setup on the PGSC and stowed the PGSC in the special electromagnetic interference (EMI) shielded locker for entry. The PGSC continued to record MAGR data automatically through landing.

The MAGR operations (OPS) 3 test, the commanded self-test during flight control subsystem (FCS) checkout, and the OPS 2 test were all completed successfully. The commanded self test results show several "Fail" bits, but this was expected and did not effect the DTO operation. The "Fail" bits are actually the result of the Orbiter MAGR configuration and do not represent a fail or degraded condition.

Downlisted MAGR data was reviewed throughout the mission and nominal MAGR operation was reflected for the entire mission.

The entry and landing mission phase is most important for the DTO since MAGR will eventually replace the tactical air navigation (TACAN) equipment and become the primary navigation sensor for entry. Downlisted MAGR entry data will be evaluated real time and will also be used for post-mission analysis.

DTO 805 - Crosswind Landing Performance – (DTO of Opportunity) – Crosswind conditions during landing did not exist; therefore, this DTO was not performed.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 493 - Monitoring Latent Virus Reactivation and Shedding in Astronauts - Samples were acquired during the flight, and these samples will be assessed postflight. Results will be reported postflight.

DSO 496 - Individual Susceptibility to Post Spaceflight Orthostatic Intolerance – This DSO was not performed on this flight because adequate data to meet the requirements was collected during the STS-109 mission.

DSO 498 - Space Flight and Immune Functions – Samples were taken during preflight and postflight activities and the results will be published in separate documentation.

DSO 500 - Test of Midodrine as Countermeasure against Postflight Orthostatic Hypotension - Samples were taken from the crew preflight and postflight. The results for this process will be reported in separate documentation.

PHOTOGRAPHY AND TELEVISION ANALYSIS

The launch videos and films were reviewed and evaluated following the STS-110 launch. A total of 24 launch videos and 27 launch films were reviewed and no anomalous events or conditions were noted.

In addition, films from the new 35mm umbilical well camera, the 16mm umbilical camera as well as the hand-held 35mm and video cameras onboard the Orbiter provided good coverage of the ascent and ET after separation. No anomalous conditions were noted.

No anomalous events were noted in the review of the landing videos. All aspects of the landing appeared to be normal.

TABLE I.- STS-110 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	098:20:39:33.479 098:20:39:34.263 098:20:39:35.004
SRB HPU Activation ^a	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	098:20:43:50.953 098:20:43:51.113 098:20:43:51.273 098:20:43:51.433
Main Propulsion System Start ^a	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	098:20:44:12.431 098:20:44:12.552 098:20:44:12.669
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	098:20:44:18.983
Throttle up to 104.5 Percent Thrust ^a	ME-1 Command accepted ME-3 Command accepted ME-2 Command accepted	098:20:44:22.889 098:20:44:22.911 098:20:44:22.912
Throttle down to 72 Percent Thrust ^a	ME-1 Command accepted ME-3 Command accepted ME-2 Command accepted	098:20:44:51.050 098:20:44:51.071 098:20:44:51.073
Throttle up to 104.5 Percent Thrust ^a	ME-1 Command accepted ME-3 Command accepted ME-2 Command accepted	098:20:45:05.130 098:20:45:05.152 098:20:45:05.153
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	098:20:45:22
Both RSRM's Chamber Pressure at 50 psi ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	098:20:46:17.623 098:20:46:17.663
End RSRM ^a Action ^a Time	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	098:20:46:20:103 098:20:46:20.343
SRB Separation Command	SRB separation command flag	098:20:46:22
SRB Physical Separation ^a	LH rate APU turbine speed – LOS	098:20:46:22.347
OMS Assist Maneuver Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	098:20:46:32.6 098:20:46:32.6
OMS Assist Maneuver Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	098:20:47:49.0 098:20:47:49.0
Throttle Down for 3g Acceleration ^a	ME-1 command accepted ME-3 command accepted ME-2 command accepted	098:20:51:41.300 098:20:51:41.319 098:20:51:41.321
3g Acceleration	Total load factor	098:20:52:31.2
Throttle Down to 67 Percent Thrust ^a	ME-1 command accepted ME-3 command accepted ME-21 command accepted	098:20:52:36.021 098:20:52:36.040 098:20:52:36.042
SSME Shutdown ^a	ME-1 command accepted ME-3 command accepted ME-2 command accepted	098:20:52:42.542 098:20:52:42.560 098:20:52:42.562
MECO	MECO command flag MECO confirm flag	098:20:52:42 098:20:52:44
ET Separation	ET separation command flag	098:20:53:05

^aMSFC supplied data

**TABLE I.- STS-110 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	098:20:59:03.279 098:20:59:27.351 098:20:59:45.845
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	Not performed
OMS-2 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	098:21:23:04.0 098:21:23:04.0
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	098:21:24:07.2 098:21:24:07.4
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	098:22:39:14 098:22:40:33
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	100:11:28:12.3 100:11:28:12.4
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	100:11:30:32.5 100:11:30:32.5
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	100:12:11:48.9 100:12:11:49.0
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	100:12:13:21.7 100:12:13:21.7
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	100:13:45:38.1 N/A
OMS-5 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	100:13:45:51.5 N/A
Docking with ISS	Docking ring final position	100:16:04:30
Starboard Zero Truss Grapple	As reported	
Starboard Zero Truss Ungrapple	As reported	
ISS Airlock Depressurization (Begin First EVA)	As reported	101:14:36
ISS Airlock Repressurization (End First EVA)	As reported	101:22:24
ISS Airlock Depressurization (Begin Second EVA)	As reported	103:14:09
ISS Airlock Repressurization (End Second EVA)	As reported	103:21:39
First Reboost Maneuver (start)	As reported	103:22:44
ISS Airlock Depressurization (Begin Third EVA)	As reported	104:13:48
ISS Airlock Repressurization (End Third EVA)	As reported	104:20:15
Second Reboost Maneuver Start	As reported	104:21:44
ISS Airlock Depressurization (Begin Fourth EVA)	As reported	106:14:29
ISS Airlock Repressurization (End Fourth EVA)	As reported	106:21:06
Third Reboost Maneuver Start	As reported	107:11:19:20

**TABLE I.- STS-110 SEQUENCE OF EVENTS
(Concluded)**

Event	Description	Actual time, G.m.t.
Undocking from ISS	Undock complete	107:18:31:13
ISS Separation Maneuver (RCS)	As reported	107:18:31:19
Flight Control System Checkout		
APU Start	APU 1 GG chamber pressure	108:12:04:54.828
APU Stop	APU 1 GG chamber pressure	108:12:11:16.928
OMS-6 Ignition (SIMPLEX Maneuver)	Left engine bi-prop valve position Right engine bi-prop valve position	108:17:26:19.1 108:17:26:19.1
OMS-6 Cutoff (SIMPLEX Maneuver)	Left engine bi-prop valve position Right engine bi-prop valve position	108:17:26:29.5 108:17:26:29.5
OMS-7 Ignition (Orbit Adjust Maneuver)	Left engine bi-prop valve position Right engine bi-prop valve position	108:18:04:19.1 108:18:04:19.1
OMS-7 Cutoff (Orbit Adjust Maneuver)	Left engine bi-prop valve position Right engine bi-prop valve position	108:18:04:57.1 108:18:04:57.3
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	109:12:44:12 109:12:49:49
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	109:15:14:04.552 109:15:42:36.664 109:15:42:38.770
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	109:15:18:59.2 109:15:18:59.2
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	109:15:21:17.4 109:15:21:17.4
Entry Interface (400K feet)	Current orbital altitude above	109:15:55:25
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Management	Major mode change (305)	109:16:20:24
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	109:16:26:58 109:16:26:58
Main Landing Gear Weight on Wheels	LH MLG weight on wheels RH MLG weight on wheels	109:16:26:58 109:16:26:58
Drag Chute Deployment	Drag chute jettison 1 CP Volts	109:16:27:00.1
Nose Landing Gear Contact	NLG LH tire pressure 1	109:16:27:08
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	109:16:27:09
Drag Chute Jettison	Drag chute jettison 1 CP Volts	109:16:27:42.4
Wheel Stop	Velocity with respect to runway	109:16:28:08
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	109:16:46:19.008 109:16:46:24.402 109:16:46:30.844

TABLE II- STS-110 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-110-V-01	Primary RCS Thruster L1A Failed Off	099:21:18 G.m.t. 01:00:33 MET PR LP03-30-0733 SPR 110RF01	<p>During the NC-3 maneuver, primary RCS thruster L1A failed off when first commanded to fire and RCS redundancy management (RM) deselected the thruster. The thruster did not leak propellant following the fail-off. The thruster injector temperatures indicate at least some propellant flow through each (fuel and oxidizer) pilot-operated valve. The thruster remained deselected for the remainder of the flight.</p> <p>KSC: The thruster will be removed and replaced during the postflight turnaround activities. This replacement will also include all thrusters on the L1 manifold.</p>
STS-110-V-02	Low Chamber Pressure on Primary RCS Thruster F1D	100:11:15 G.m.t. 01:14:31 MET PR FRC4-26-0608 SPR 110RF02	<p>At approximately 100:11:15 G.m.t. (01:14:31 MET), primary RCS thruster F1D exhibited low chamber pressure (Pc) during three consecutive 80-msec pulses. These low-Pc pulses occurred approximately 20 minutes after a nominal 160-msec pulse. Prior to this nominal pulse, a fourth low-Pc 80-msec pulse was found in the data review. The maximum Pc during the anomalous pulses was approximately 65 psia (nominal Pc is approximately 150 psia). The Pc was high enough that the RM did not declare the thruster failed off and deselected it. The crew reprioritized thruster F1D to priority 2 to prevent further firings. To determine if this was an instrumentation problem. Orbiter acceleration rates during the firings were evaluated. The evaluation concluded that the rates were low indicating that F1D did not produce full thrust for all four suspect pulses.</p> <p>Since the failure mode of the thruster was unknown, the decision to deselect the thruster from nominal docking operations to end of mission with the following exception. If primary RCS thruster F3D failed inside of a safe breakout range of the ISS (150 feet) during undocking and separation, thruster F1D would be deselected. Once the breakout was completed, the thruster would again be deselected and would remain deselected for the remainder of the mission. During postflight troubleshooting, F1D inspection revealed residue from incomplete combustion all over the chamber wall, and also in the fuel injectors and acoustic cavities. A video borescope was performed and two wipe samples were taken.</p> <p>KSC: The thruster will be replaced during the postflight turnaround activities. This will include the replacement of all thrusters on the F1 manifold.</p>

TABLE II- STS-110 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-110-V-03	Low Chamber Pressure on Primary RCS Thruster F3L	107:19:07 G.m.t. 08:22:22 MET PR FRC-26-0609 SPR 110RF03	<p>During the ISS flyaround at 107:19:07:13 G.m.t. (08:22:22:54 MET), it was noted that primary RCS thruster F3L had a low chamber pressure (Pc) of 65 psia on an 80-msec pulse (should be approximately 150 psia). After evaluation of the thruster pulse profile, it was agreed to watch its performance on subsequent pulses. Thruster F3L subsequently had a second low PC of 68 psia during an 80-msec pulse at 107:19:31:55 G.m.t. (08:22:47:36 MET). After this pulse, the crew placed the thruster in last priority at 107:19:34:21 G.m.t. (08:22:50:03 MET). The thruster was deselected and not fired again during the mission.</p> <p>KSC: The thruster will be removed and replaced during the postflight turnaround activities. This replacement will also include the replacement of all thrusters on the F3 manifold.</p>
STS-110-V-04	MEDS IDP2 MSU BITE and FCW Overflow Error	098:21:10 G.m.t. 00:00:26:22 MET IPR 112V-0005 SPR 110RF03	<p>At 098:21:10:41 G.m.t., (00:00:26:22 MET), the integrated display processor (IDP) 2 annunciated a single buffer overflow error. This error is reported when more display data are received from a general purpose computer (GPC) than can be processed in one cycle. Thirty-four seconds later, at 098:21:11:15 G.m.t. (00:00:26:56 MET). ODP 2 annunciated built-in-test-equipment (BITE) messages indicating that the IDP experienced errors when accessing the mass storage unit (MSU). The BITE fail message cleared 55 seconds later.</p> <p>The most probable cause of these errors was a glitch in the SCSI control line during MSU access. Recurrence of this event has a very low likelihood of repeating during the remainder of the mission. The event has a finite time-out recovery of less than one minute. The MSU access during critical time-frames is unlikely. With the performance experienced thus far in the mission, there is not mission impact. Postflight testing included using the MEDS portable loader to retrieve a copy of the MSU error logs from IDP 2. The IDP 3 logs were also retrieved for comparison. The logs analyzed and reviewed by the vendor to determine if the unit will be removed or replaced.</p>

DOCUMENT SOURCES

In an attempt to define the official as well as the unofficial sources of data for the STS-110 Mission Report, the following list is provided.

1. Flight Requirements Document
2. Public Affairs Press Kit
3. Customer Support Room (CSR) Daily Reports and Final CSR Report
4. MER Daily Reports
5. MER Mission Summary Report
6. SSVEO In-Flight Anomaly List
7. MER Funny/Problem Tracking List
8. MER Event Times
9. Subsystem Manager Reports/Inputs
10. MOD Systems Anomaly List
11. MSFC Flash and Executive Summary Reports
12. MSFC Event Times
13. MSFC Interim Report
14. Crew Debriefing comments
15. Shuttle Operational Data Book
16. STS-110 Summary of Significant Events
17. Contractor Reports of Subsystem Operation

ACRONYMS AND ABBREVIATIONS

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

ABS	Ammonia Boiler System
APFR	Articulated portable foot restraint
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
ATU	audio terminal unit
BITE	built-in test equipment
BPSMU	battery-powered speaker/microphone unit
BSM	Booster Separation Motor
CCTV	closed-circuit television
CCU	crew communications unit
CDRA	carbon dioxide removal assembly
CEI	contract end item
CETA	crew and equipment translation aid
CID	computer interface device
CWC	contingency water container
DDCU	DC-to-DC converter unit
DIDB	disposable in-suit drink bag
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
DTV	Digital Television
ΔP	differential pressure
ΔV	differential velocity
ECLSS	environmental control and life support system
e.d.t.	eastern daylight time
EMI	electromagnetic interference
EMU	extravehicular mobility unit
EPDC	electrical power distribution and control
ET	External Tank
EV	extravehicular
EVA	extravehicular activity
EV-CPDS	External Vehicle-Charged Particle Directional Spectrometer
EVSWS	external video switch system
FCE	flight crew equipment
FCMS	fuel cell monitoring system
FCP	fuel cell powerplant
FCS	flight control system/subsystem
FD	flight day
FEP	front end processor
FES	flash evaporator system
FMBBT	flexible bearing mean bulk temperature
FOD	foreign object damage
FSS	Fixed Service Structure

ft	feet
ft/sec	feet per second
GFE	Government furnished equipment
G.m.t.	Greenwich mean time
GN ₂	gaseous nitrogen
GO ₂	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
GSE	ground support equipment
GUCP	ground umbilical carrier plate
HDP	hold-down post
HED	high-energy damper
ICD	Interface Control Document
ICOM	intercommunications
IDP	Integrated Display Processor
IMU	inertial measurement unit
In/sec	inch per second
IRD	integrated receiver-decoder
I _{sp}	specific impulse
ISS	International Space Station
ITCS	Internal thermal control system
ITS	Integrated Truss Segment
IUA	interface unit assembly
JSC	Johnson Space Center
keas	knots estimated air speed
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm/hr	pound per hour
lbm/min	pound per minute
lbm	pound mass
LCA	load control assembly
LCC	Launch Commit Criteria
LH ₂	liquid hydrogen
LiOH	lithium hydroxide
LMSO	Lockheed Martin Space Operations
LO ₂	liquid oxygen
LP	Launch Package
LRM	loads release mechanism
LTA	launch through activation
MADS	modular auxiliary data system
Max q α	maximum dynamic pressure
MBS	Mobile Base System
MBSU	main bus switching unit
MC	midcourse correction (rendezvous maneuver)
MCA	motor control assembly
MECO	main engine cutoff
MER	Mission Evaluation Room
MET	mission elapsed time
MLI	multi-layer insulation

MLP	Mobile Launch Platform
Mlbf	million pounds force
MMCA	mid motor control assembly
mmHg	millimeter mercury
MMOD	micrometeoroid/orbital debris
MPS	main propulsion system
msec	millisecond
MSU	mass memory storage unit
MT	Mobile Transporter
MTS	module-to-truss
NASA	National Aeronautics and Space Administration
NC1, NC2	circularization maneuvers (rendezvous maneuver)
NC3, NC4	circularization maneuvers (rendezvous maneuver)
NCC	rendezvous circularization maneuver
NH	height adjust maneuver
nmi	nautical mile
OAA	Orbiter Access Arm
ODS	Orbiter Docking System
OIH	on-orbit installed handrail
OMM	Orbiter Major Modification
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	Operations
OP-STAT	Operations-Status
ORCA	oxygen recharge compressor assembly
OV	Orbiter Vehicle
Pc	chamber pressure
PCS	pressure control system/portable computer system
PGME	Propylene Glycol Monomethyl Ether
PGSC	payload and general support computer
PMA	pressurized mating adapter
PMBT	propellant mean bulk temperature
ppCO ₂	partial pressure carbon dioxide
ppm	parts per million
PRSD	power reactant storage and distribution/Prototype Synchrotron Radiation Detector
psia	pound per square inch absolute
psid	pound per square inch differential
PTT	push-to-talk
PTU	pan/tilt unit
PWP	portable work platform
PWR	payload water reservoir
QD	quick disconnect
RAMBO	ram burn observations
RCS	reaction control subsystem
RJD	reaction jet driver
RM	redundancy management
RMLG	right main landing gear
RMS	Remote Manipulator System
RPC	remote power controller

RSRM	Reusable Solid Rocket Motor
RSS	rotating service structure/range safety system
RTL	responsible task leader
RTV	room temperature vulcanizing (material)
RWS	robotic work platform
S&A	safe and arm
SCSI	small computer system interface
SCU	signal conditioner unit
SDMS	structural dynamic measurement unit
SDTO	Station Development Test Objective
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SKV/SRVK	Russian air conditioner
SLWT	super lightweight tank
S/N	serial number
SO	starboard zero (truss)
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSAS	Solid Sorbent Air Sampler
SSME	Space Shuttle main engine
SRMS	Shuttle Remote Manipulator System
SSRMS	Space Station Remote Manipulator System
SSV	Sequential Still Video
STS	Space Transportation System
T-	time minus minutes to launch
TACAN	tactical air navigation
TCS	trajectory control sensor
TGA	trace gas analyzer
Ti	terminal initiation maneuver
TPS	thermal protection system/subsystem
TSM	tail service mast
TUS	trailing umbilical system
TV	television
UF	Utilization Flight
Vdc	Volts direct current
WCL	water coolant loop
WSB	water spray boiler