

# **STS-98 SPACE SHUTTLE MISSION REPORT**

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April 2001



**National Aeronautics and  
Space Administration**

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

## NOTE

The STS-98 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.

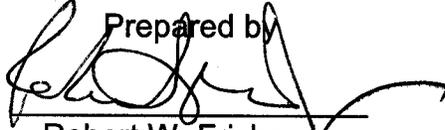
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STS-98

SPACE SHUTTLE

MISSION REPORT

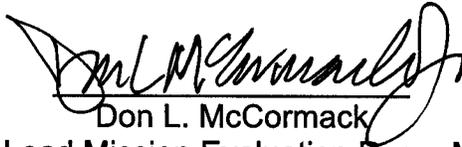
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## INTRODUCTION

The Space Transportation System (STS)-98 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during the mission. The STS-98 flight was the seventh mission to the International Space Station (ISS) to perform maintenance and logistics tasks.

The STS-98 report also summarizes the activities of the STS-98 mission, and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this one-hundred and second mission of the Space Shuttle Program. STS-98 was the seventy-seventh flight since the return to flight, and the twenty-third flight of the OV-104 (Atlantis) vehicle. This flight delivered the U. S. Laboratory (Destiny) to the ISS.

The flight vehicle consisted of the OV-104 Orbiter; an ET, which was the tenth Super Lightweight Tank (SLWT), and it was designated ET-106; three Block IIA SSMEs that were designated as S/Ns 2052, 2044, and 2047 in positions 1, 2, and 3, respectively; and two SRBs that were designated B1105. The two RSRMs were designated RSRM-77 with one installed in each SRB. The individual RSRMs were designated as 360W077A for the left SRB and 360W077B for the right SRB.

The primary objective of the STS-98 flight was to deliver and berth the 5A launch package (LP), the United States Laboratory Destiny, to the Node 1 forward common berthing mechanism (CBM), relocate the pressurized mating adapter (PMA) 2 to the U. S. Laboratory forward CBM, deliver and install a spare Orbital Replacement Unit (ORU), and deploy the P6 early external active thermal control system (EEATCS) aft and starboard radiators. After docking with PMA 3 at the Node 1 nadir port, three days of scheduled extravehicular activity (EVA) were performed using the Shuttle remote manipulator system (RMS).

The STS-98 flight was planned as a 10-day, plus 2-contingency-day flight, of which six days would be spent docked to the ISS. The two contingency days were available for bad weather avoidance for landing or other Orbiter contingency operations. The sequence of mission events is shown in Table I, and the Orbiter In-Flight Anomaly List is shown in Table II.

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

The five-person crew of the STS-98 flight consisted of Kenneth D. Cockrell, Civilian, Commander; Mark L. Polansky, Civilian, Pilot; Robert L. Curbeam, CDR., U. S. Navy, Mission Specialist 1; Marsha S. Ivins, Civilian, Mission Specialist 2, and Thomas D. Jones, Ph. D., Mission Specialist 3. STS-98 was the fifth space flight for Mission Specialist 2, the fourth space flight for the Commander and Mission Specialist 3; the second space flight for Mission Specialist 1 and the first space flight for the Pilot.

## MISSION SUMMARY

The STS-98 mission, to deliver the United States Laboratory to the International Space Station (ISS), was successfully launched with one unscheduled hold extension during the countdown. The T minus 9-minute hold was extended 1 minute 14 seconds and the cause of this extension is discussed in the following paragraph. The time of launch was 038:23:13:01.990 G.m.t. (February 7, 2001).

The launch delay occurred because of a concern with an aft main bus C current indication recorded in ground telemetry at the Kennedy Space Center (KSC). Coming out of the T-20 minute hold, the two readings (ground and vehicle) for aft main bus C disagreed with each other when the ground power was reduced to load up the fuel cells. KSC personnel were concerned that a problem existed with the Orbiter, possibly a data problem from multiplexer/demultiplexer (MDM) Orbiter Aft (OA) 1, but a review of vehicle data gave the flight team in the Mission Control Center at Houston and the launch team at KSC the confidence that the problem did not exist in the Orbiter and the launch could proceed. A teleconference was conducted the following day and a faulty hardware interface module (HIM) card that biased the ground reading was identified as the reason for the disparate data.

This mission was the first flight of the OI 28 software that included an automated firing of the forward primary reaction control subsystem (RCS) up-firing thrusters for approximately 2.02 seconds. The firing was programmed to occur during the Solid Rocket Booster (SRB) separation sequence and it was intended to change the flow pattern of the SRB separation motors. The intent of the resultant change in the flow pattern was to eliminate the hazing that occurs when the exhaust from the booster separation motors impacts the forward-facing Orbiter windows. This firing occurred but the crew reported debris on the forward-facing windows. The extent of the debris as well as comparisons with previous flight experience will be determined during postflight inspections. Initial indications are that the degree of window hazing is significantly reduced.

The evaluation of the vehicle performance was made using vehicle acceleration and preflight propulsion prediction data. The average flight-derived engine specific impulse ( $I_{sp}$ ) was 452.9 seconds as compared to the Space Shuttle main engine (SSME) tag value of 452.2 seconds at the 104.5-percent power level.

The orbital maneuvering subsystem (OMS) assist maneuver was performed at 038:23:15:17.89 G.m.t. (00:00:02:16 MET) following SRB separation. The maneuver was 102.2 seconds in duration. The OMS 2 maneuver was performed at 038:23:56:47.49 G.m.t. (00:00:43:45.505 MET) and was 82.87 seconds in duration. The differential ( $\Delta V$ ) velocity ( $\Delta V$ ) for the OMS 2 maneuver was 126.6 ft/sec, and the resultant orbit was 110.2 by 175.1 nautical miles (nmi.).

The payload bay doors were opened at 039:01:00:58 G.m.t. (00:01:47:57 MET). All voltages were nominal and the motors opened the doors in nominal dual-motor time.

The LH<sub>2</sub> Engine 1 prevalue (PV4) open position indicator B failed off between liftoff and main engine cutoff (MECO). The indication went off at 038:23:15:43 G.m.t. (00:00:02:41 MET) and recovered at 038:23:17:47 G.m.t. (00:00:04:45 MET). After

completion of the LH<sub>2</sub> dump, the position indicator failed off again at 038:23:28:30 G.m.t (00:00:15:28 MET) (Flight Problem STS-98-V-01). The measurement subsequently recovered. The prevalves remained in the open position for the remainder of the mission, and the failure had no effect on MPS operations. Postflight troubleshooting was being performed as this report was being published.

Extravehicular mobility units (EMUs) 1 and 2 were checked out successfully. During the checkout of EMU 3, the oxygen (O<sub>2</sub>) tank pressure was 482 psia, which was well below the nominal range of 850 to 950 psia. The tank was repressurized, and the crew performed a leak check with the EMU 3 gloves and helmet installed. The crew reported the O<sub>2</sub> tank pressure was 829 psia, which is within expected specifications. It is believed that the oxygen actuator was inadvertently bumped out of position and this caused the pressure loss. EMU 3 was stowed and remained ready to be used if needed for the planned EVAs.

The successful checkout of the remote manipulator system (RMS), the Orbiter space vision system (OSVS), and the Orbiter docking system (ODS) were all completed nominally. A payload bay survey, using the RMS cameras, was performed beginning at 039:16:57 G.m.t. (00:17:43 MET). Upon completion of the survey, the arm was cradled and powered down at 039:17:35 G.m.t. (00:18:21 MET). During the checkout of the wireless video system (WVS), error messages were received. The crew performed troubleshooting and complete functionality of the WVS was recovered.

The following table shows the Orbiter maneuvers performed to complete the ISS rendezvous.

<b>Maneuver</b>	<b>Time, G.m.t./MET</b>	<b>ΔV, ft/sec</b>	<b>Firing time, sec</b>	<b>Orbit, nmi.</b>
NC (Dual OMS)	039:02:49:09 00:03:36:07	132.8	85.2	161.9 by 197.3
NC3 (Right engine)	039:23:17:55 01:00:04:53	8.2	10.8	165.7 by 198.0
NC-4 (Dual OMS)	040:12:46:48 01:13:33:46	21.6	14.2	178.5 by 197.9
NCC (Multi-axis RCS)	040:13:26:42 01:14:13:40	2.1	-	178.5 by 197.6
TI (Left OMS)	040:14:24:25 01:15:11:23	10.7	14.0	183.7 by 198.5
MC-1 (RCS)	040:14:44:24 01:15:31:22	0.4	2.0	187.3 by 198.4
MC-2 (RCS)	040:15:14:20 01:16:01:18	0.2	1.0	183.7 by 198.5
MC-3 (RCS)	040:15:31:20 01:16:18:18	0.7	2.0	184.0 x 198.4
MC-4 (RCS)	040:15:41:20 01:16:28:18	1.2	9.6	184.7 x 198.4

The Orbiter successfully docked with the ISS at 040:16:50:49 G.m.t. (01:17:37:47 MET). Cabin depressurization for the first extravehicular activity (EVA) started at

040:23:35:02 G.m.t (02:00:22 MET) and was completed at 040:23:52:02 G.m.t (02:00:39 MET) at a pressure of 10.35 psia.

A collision avoidance maneuver for the ISS was completed satisfactorily. The maneuver was initiated at 041:11:48:02 G.m.t. (02:12:35:00 MET). The maneuver consisted of four +X axis pulses of 4.64 seconds each. The total  $\Delta V$  was 2.5 ft/sec and the resulting orbit was 186.5 by 199.4 nmi. The maneuver raised the perigee approximately 1 nmi.

The RMS was powered up at 041:13:47 G.m.t. (02:14:34 MET). The RMS successfully grappled pressurized mating adapter (PMA) 2 on Node 1 at 041:14:12 G.m.t. (02:14:59 MET) and maneuvered PMA 2 to the Z1 truss pre-installation position at 041:16:00 G.m.t. (02:16:47 MET). PMA 2 was installed onto the Z1 truss at 041:17:00 G.m.t. (02:17:47 MET) and was ungrappled by the RMS. The U.S. Laboratory was grappled in the payload bay at 041:17:22 G.m.t. (02:18:00 MET) and unberthed. Following the pitch-around maneuver, the U. S. Laboratory was attached to Node 1 at 041:19:00 G.m.t. (02:19:47 MET). Nominal RMS operations continued throughout the EVA. The RMS cradle and power-down was completed at 041:21:32 G.m.t. (02:22:19 MET).

The airlock depressurization for the first EVA was initiated at 041:15:29 G.m.t. (02:16:16 MET) and was completed at 041:15:40 G.m.t (02:16:27 MET). The EVA began at 041:15:51 G.m.t. (02:16:36 MET) when the EMUs were transferred to internal battery power, and the EVA was completed 7 hours and 37 minutes later. There were no significant problems with the EMUs, EVA tools, WVS or the Space-to-Space Communications System (SSCS).

During the EVA, the EV2 crewmember was exposed to ammonia while attempting to mate the U.S. Laboratory ammonia umbilicals. In accordance with the Flight Rule concerning EMU decontamination during an EVA, the EV2 crewmember retrieved the hydrazine brush from the Node bag and moved into a position of Sun exposure. The EV1 crewmember used the brush on the EV2 crewmember's suit. The EV2 crewmember remained in sunlight for a 30-minute bake-out period while the EV1 crewmember completed the remaining tasks and began the cleanup activities. After both crewmembers entered the airlock, the Chemical Check/Decontamination procedure was performed. This procedure required a repressurization of the airlock to 5 psia with a 15-minute waiting period prior to depressurizing the airlock for a second time after which the airlock was pressurized. The intravehicular (IV) crewmembers also performed the required precautionary steps, which included donning the "quick-don" oxygen masks. The IV crewmembers did not notice any odors, and the crew compartment was pressurized to 13.38-psia after the EVA.

At the end of the first EVA, shortly after reaching 5.0 psia in the airlock, the EV 1 crewmember reported problems with his communication in both the receiving and transmitting. After configuring to hard-line mode, the EV 1 crewmember reported that his communications improved. The EV 1 crewmember replaced his communication carrier assembly (CCA) with a backup CCA for the second EVA.

The first ISS reboost maneuver, which lasted one hour, began at 042:17:13 G.m.t. (03:18:00 MET) by firing primary RCS thrusters L3A and R3A. The pulse widths were 160 msec with a period of 15.04 seconds between firings. The primary RCS thruster firings were interrupted six times for attitude maintenance using the vernier thrusters and

this limited the number of primary RCS pulses to 225. The aft down-firing vernier thrusters had a duty cycle of 2.4 seconds on and 12.6 seconds off. This was the first flight use of the automated reboost software.

The second ISS reboost maneuver, which lasted 2.5 hours, was started at 042:18:18 G.m.t (03:19:05 MET) by firing primary thrusters L3A and R3A. The pulse widths and period were the same as the first reboost maneuver. The aft down-firing primary thrusters, however, were used for attitude control and had a duty cycle of 0.08 second on and 9 seconds off. The two reboost maneuvers resulted in an altitude increase of 3.6 nmi. and the final orbit of 203.0 nmi. by 188.9 nmi.

The second ISS reboost maneuver was completed at 042:20:47 G.m.t. (003:21:31 MET), which was early by 2 minutes 2.5 seconds. The flight software community investigated the problem and formed the following conclusions. When automatic reboost maneuvers are commanded for durations greater than 4096 seconds, the actual duration will be noticeably shorter than requested. In the flight software, a timer is maintained which decrements by the period of execution every time the reboost module executes (every 80 ms) until the requested duration is achieved. Due to the loss of AP-101 scalar precision in the decrement operation, the time remaining decreases slightly more than 80 ms each cycle, and consequently triggers reboost termination earlier than expected. A workaround was used to enter a compensated maneuver time that resulted in the desired maneuver duration. Discrepancy Report (DR) 111600 has been opened against this condition

EVA 2 began at 043:15:58 G.m.t. (04:16:45 MET) when the EMUs were transferred to internal battery power. During EVA preparations, EMU 1 power was temporarily lost. The servicing and cooling umbilical (SCU) 1 signature was similar to an airlock power supply shutdown due to an open circuit (-0.13 amps, 0 volts). It was later determined from the crew that the SCU 1 was inadvertently disconnected. The crew reconnected the SCU and recycled the airlock power supply (ALPS). EVA preparations continued nominally. The EVA was completed in 6 hours 50 minutes. The EVA was performed nominally and the EVA tools, WVS and SSSCS performed as expected.

Prior to airlock repressurization following EVA 2, the EV 2 crewmember's left-side CCA earphone audio dropped out. In addition, after removing his CCA, the EV 1 crewmember reported small puddles of water had accumulated around the inside of each earmuff. The EV 2 crewmember used his backup CCA for EVA 3.

The RMS was powered up and un-cradled at 043:15:14 G.m.t. (04:16:00 MET) to support the second EVA. PMA 2, which was mated to the Z1 truss, was grappled and demated at 043:15:37:12 G.m.t. (04:16:24:10 MET). PMA 2 was positioned in the pre-installation position at the U. S. Laboratory forward common berthing mechanism (CBM) location at 043:16:55 G.m.t. (04:17:41:58 MET) and then was successfully berthed to the U. S. Laboratory at 043:17:30:25 G.m.t. (04:18:17:23 MET). After releasing PMA 2, the RMS provided EVA support. The RMS was parked in the pre-cradled position in preparation for a radiator survey that was performed during flight day 7.

During the mating of PMA 2 to the U. S. Laboratory, the bay-9 keel-camera failed. Closure of the circuit breaker was verified, and no current spikes were noted in the data. It was verified that the bus that provides power to the camera was functional. The camera was not required for the remainder of the mission.

The third ISS reboost maneuver, which lasted four hours, began at 044:15:53:02 G.m.t. (05:16:40:00 MET) by firing primary RCS thrusters L3A and R3A. The pulse widths were 160 msec with a period of 15.04 seconds between firings. Attitude maintenance was performed with the primary aft down-firing thrusters, which had a duty cycle of 0.08 second on and 9.0 seconds off.

The fourth ISS reboost maneuver, which lasted one hour, started at 044:20:06:02 G.m.t (05:20:53:00 MET) by firing RCS thrusters L3A and R3A. The pulse widths and period were the same as reboost maneuver 3. Attitude maintenance limited the number of pulses to 210. The aft down-firing vernier thrusters were used for attitude control and had a duty cycle of 2.4 seconds on and 12.6 seconds off. The total  $\Delta V$  from the two maneuvers (third and fourth) was 17.7 ft/sec. The two maneuvers resulted in an altitude increase of 5.0 nmi. and a final orbit of 206.5 nmi. by 193.7 nmi.

The RMS performed the P6 radiator survey starting at 044:22:49 G.m.t (05:23:36 MET). Only two survey positions were completed. The ISS starboard radiator was surveyed at 044:22:57 G.m.t. (05:23:44 MET) and the ISS aft radiator was surveyed at 045:00:04 G.m.t. (06:00:51 MET). The RMS was left in the pre-cradled position for flight day 8 activities.

Airlock depressurization for the third EVA started at 045:14:30 G.m.t. (06:15:17 MET) and was completed at 045:14:42 G.m.t. (06:15:29 MET). EVA 3 began at 045:14:48 G.m.t. (06:15:35 MET) when the EMUs were transferred to internal battery power. The EVA was completed in 5 hours 25 minutes. The EVA was performed nominally and the EMU's, EVA tools, WVS and SSCS performed as expected.

The RMS supported the EVA 3 tasks; SVS target inspection, and inspection of P6 starboard radiator. The RMS was de-selected at 045:20:12 G.m.t. (06:20:59 MET).

The fifth ISS reboost maneuver, which lasted one hour, started at 045:23:08 G.m.t (06:23:55 MET) by firing RCS primary thrusters L3A and R3A. The thruster pulse widths were 160 msec with a firing period of 15.04 seconds. Attitude maintenance activities limited the number of pulses to 208. The aft down-firing vernier thrusters were used for attitude control and had a duty cycle of 2.4 seconds on and 12.6 seconds off. The reboost maneuver resulted in an altitude increase of 1.4 nmi. and a total  $\Delta V$  of 4.9 ft/sec. The orbit as a result of this maneuver was 206 by 195 nmi.

The sixth ISS reboost maneuver commenced at 046:15:23 G.m.t. (07:16:10 MET) by firing primary RCS thrusters L3A and R3A. The reboost maneuver was performed in straight feed and lasted 1 hour and 22 minutes. The +X axis primary thruster pulse widths were 160 ms with a firing period of 15.04 seconds between firings. Attitude maintenance was performed with the primary aft down-firing thrusters. While performing attitude maintenance, the aft down-firing primary thrusters had an average duty cycle of 0.08 second on and 9 seconds off. The reboost resulted in a final orbit of 209.4 by 195.5 nmi. and a total  $\Delta V$  of 4.4 ft/sec.

The seventh, and final, ISS reboost maneuver began at 046:16:56 G.m.t. (07:17:43 MET) by firing primary RCS thrusters L3A and R3A. This maneuver was performed in right OMS interconnect and lasted approximately 3 hours and 41 minutes. The pulse widths, period, and attitude maintenance were the same as for the sixth

reboost maneuver. The reboost maneuver resulted in a final orbit of 212.5 by 199.2 nmi., and a total  $\Delta V$  of 11.9 ft/sec was imparted to the vehicle. Overall, the seven ISS reboost maneuvers along with the collision avoidance maneuver raised the ISS altitude approximately 15 nmi.

The Orbiter performed a repressurization of the ISS. The pressure was raised to 14.82 psia.

In preparation for undocking, the ODS hatch was closed and vestibule depressurization was begun at 047:13:22 G.m.t. (08:14:08:58 MET). Undocking occurred at 047:14:06 G.m.t. (08:14:53 MET) and ISS separation was initiated 2 minutes later with a +Z pulse of the primary RCS. A one-half revolution flyaround the ISS was performed prior to final separation from the ISS. The final separation maneuver was initiated at 047:14:48:18 G.m.t. (08:15:35:16 MET), with a 12.64 second, -X axis pulse of primary RCS thrusters F1F and F3F. The resultant  $\Delta V$  was 3.5 ft/sec.

The flight control system (FCS) checkout was performed nominally, with no problems identified. Auxiliary power unit (APU) 1 was used to support the checkout, with a start time of 048:14:39:52 G.m.t. (09:15:26:50 MET). The run time was 6 minutes, 6 seconds, and 16 pounds of fuel were used during the APU operation. APU performance was nominal and the total run time was too short to require the water spray boiler (WSB) to provide spray cooling.

The primary RCS hot-fire was not performed because each of the 38 primary RCS thrusters was fired during the course of the mission. This "passive" hot-fire, which saves propellant, was accomplished by re-prioritizing the thrusters. The vernier manifold valve test, a normal part of the RCS hot-fire test, was successfully performed.

A minus X-axis RCS orbit-adjust maneuver was performed at 048:20:59:02.29 G.m.t. (09:21:45:00.29 MET). The firing resulted in a orbit of 195.4 by 211.2 nmi., and a total  $\Delta V$  of 4.8 ft/sec was imparted to the vehicle.

The payload bay doors were closed and latched for the nominal end of mission landing opportunities at 049:14:08:23 G.m.t. (10:14:55:21 MET).

Both KSC landing opportunities for the planned landing day were waived because of excessive crosswinds, and the mission was extended 24 hours. The payload bay doors were reopened at 049:18:01:02 G.m.t. (10:18:48:00 MET).

The payload bay doors were closed and latched for the nominal end-of-mission plus 1 day landing opportunities at 050:15:06:08 G.m.t. (11:15:53:06 MET). Both of the nominal-end-mission plus 1 day KSC landing opportunities were waived because of excessive crosswinds, and the mission was extended 24 hours. The payload bay doors were reopened at 050:18:24:46 G.m.t. (11:19:11:44 MET).

The payload bay doors were closed and latched for the end-of-mission plus 2 day landing opportunities at 051:15:20:52 G.m.t. (12:16:07:50 MET). Both KSC landing opportunities on the second extension day were waived, and the decision was made to land at Edwards Air Force Base (EAFB) at the next opportunity.

The deorbit maneuver for the first EAFB landing opportunity on the second extension day, a two-engine straight-feed firing, was performed on orbit 202 at 051:19:27:20 G.m.t. (12:20:14:18 MET). The maneuver was 165.6 seconds in duration with a  $\Delta V$  of 317.9 ft/sec.

During entry, the Commander and Pilot observed a runway misalignment with their heads-up display (HUD). The Pilot's HUD was about 600 feet to the right of the runway and the Commander's HUD was about 300 feet to the right of the runway (Flight Problem STS-98-V-02). This condition did not impact entry operations.

Entry interface occurred at 051:20:01:46 G.m.t. (12:20:47:44 MET), and entry was completed satisfactorily. Main landing gear touchdown occurred on EAFB concrete runway 22 at 051:20:33:06 G.m.t. (12:21:20:04 MET) on February 20, 2001. The drag chute was deployed at 051:20:33:08 G.m.t. The nose gear touchdown occurred at 051:20:33:17 G.m.t. The drag chute was jettisoned at 051:20:33:36 G.m.t. Wheels stop occurred at 051:20:34:02 G.m.t. The rollout was normal in all respects. The flight duration was 12 days 21 hours 20 minutes 04 seconds. The APU's were shut down 15 minutes 17 seconds after landing.

## PAYLOADS AND EXPERIMENTS

This seventh U. S. mission to the International Space Station (ISS) delivered the first (U. S. Laboratory Destiny) of six planned research modules that will be added to the ISS. The U. S. Laboratory will serve as the command and control center for the entire complex. Following a flawless rendezvous and docking at pressurized mating adapter (PMA) 3, the crew successfully removed PMA 2 from Node 1 of the ISS, installed the U. S. Laboratory on Node 1, reinstalled PMA-2 on the forward common berthing mechanism (CBM) of the laboratory and performed three successful extravehicular activities (EVAs). The crew also completed seven ISS reboost maneuvers and a collision avoidance maneuver, raising the overall ISS altitude by approximately 15 nautical miles.

## **TRANSFER OPERATIONS**

The crew successfully completed all transfer operations including real-time additions and deletions to the transfer plans. The transfer operations included a total of 109 items moved to the ISS and 57 items moved to the Orbiter for return. The approximate weight of the items transferred is shown in the following table.

Type	Transfer to ISS, lb	Transfer to Orbiter, lb
Dry cargo (Intravehicular)	3036	843
U. S. Laboratory	29866	-
External (Extravehicular)	368	29
Total	33,270	872

## **TASK PERFORMANCE**

### Nominal Tasks

A listing of the 39 nominal tasks assigned to the mission is listed as follows.

1. Rendezvous and dock Orbiter to PMA 3;
2. Demate PMA 2 from Node 1 forward CBM and mate to Z1 truss manual berthing mechanism (MBM);
3. Install U. S. Laboratory to Node 1 forward CBM;
4. Connect U. S. Laboratory heater umbilical to Node 1;
5. Demate PMA 2 from Z1 MBM and mate to U. S. Laboratory forward CBM;
6. Deploy starboard early external active thermal control system (EEATCS) radiator (6A mission preparatory task);
7. Activate U. S. Laboratory core systems;
8. Install six circuit interrupt devices (CID's);
9. Activate and checkout U. S. guidance, navigation and control (GN&C) system;
10. Activate and checkout the high-rate S-Band antenna;
11. Stow radio frequency group (S-Band antenna and support assembly) critical spare on Z1 truss;
12. Perform Service Module software load and integrate the onboard computer system;
13. Transfer and return cargo and utilization equipment from the middeck to the ISS;

14. Activate and checkout control moment gyroscopes (CMG's) with handover of attitude control to U. S. GN&C system;
15. Install U. S. Laboratory power and data grapple fixture (PDGF) and video signal converter (VSC) (6A mission preparatory task);
16. Connect U. S. Laboratory/PMA 2 umbilicals;
17. Remove 15.250 to 17.250 Gigahertz (Ku-Band) space to ground antenna (SGANT) gimbal lock flight support equipment (FSE) and multilayer insulation (5A.1 mission preparatory task)
18. Remove U. S. Laboratory window cover and install laboratory window shutter mechanism (WSM) and gearbox;
19. Remove and replace Node nadir hatch cover and remove PMA 3 to Node 1 CBM ground straps (5A.1 mission preparatory task);
20. Remove six U. S. Laboratory charcoal filters and replace with high efficiency particulate accumulator (HEPA) filters;
21. Remove four Node 1 charcoal filters and replace with U. S. Laboratory charcoal filters;
22. Install atmospheric control system non-propulsive vent;
23. Install EVA worksite and translation aids on U. S. Laboratory (5A.1 mission preparatory task);
24. Vent Z1 truss utility jumpers;
25. Install U. S. Laboratory trunnion pin thermal covers;
26. Perform IMAX 3D operations for filming of 5A mission activities in Russian and U. S. segments;
27. Install internal thermal control system coolant sampling tool and take a sample of mid-temperature and low-temperature coolant;
28. Perform Development Test Objective (DTO) 263, Shuttle Automatic Reboost Tuning (discussed in DTO section of this report);
29. Accomplish Solar Array 4-bar linkage inspection;
30. Activate, checkout and leak-test PMA 2;
31. Perform DTO 261, ISS on-orbit loads validation (data collection during reboost and U. S. Laboratory berthing only);
32. Inspect U. S. Laboratory portable fire extinguishers (PFE's), inspect portable breathing apparatus (PBA) and reconfigure for on-orbit use;
33. Reposition, activate and checkout the U. S. Laboratory atmospheric revitalization system (ARS) rack and reposition air velocity closeout (AVCO);
34. Install condensate tank T connection modification kit;
35. Deploy one of the zero-g stowage racks in the U. S. Laboratory;
36. Retrieve adjustable equipment tether from Z1 truss clevis tray and return to the ground;
37. Perform DTO 675 incapacitated EVA crewmember translation;
38. ISS reboost maneuvers; and
39. Orbiter flyaround of the ISS.

#### **Real-Time Additional Tasks**

1. Perform RMS survey of ISS thermal radiators and Service Module (SM) solar arrays;
2. Z1 truss Ammonia jumper connector inspection and cap installation during EVA;
3. PMA 2 P613 connector inspection and remate during EVA;
4. Inspect treadmill vibration isolation system (TVIS) cable fatigue and CPA connector interface damage;

5. Perform Node 1 to U. S. Laboratory S-Band cable connector back shell re-clock;
6. Carbon dioxide removal assembly troubleshooting; and
7. Perform RMS survey of Orbiter OMS pods and vertical stabilizer tiles.

#### **Assigned Tasks Not Performed**

1. Carbon dioxide removal assembly activation was not performed as planned due to a failed pump;
2. Emergency egress lights test was not performed as planned;
3. Radiation area monitors were not deployed as planned;
4. Dummy receptacle change-out was not performed as planned;
5. Aft hatch closure closeout was not completed as planned;
6. Internal wireless instrumentation system (IWIS) activation in the U. S. Laboratory was not performed as planned;
7. ARE rack K-bar installation was not completed as planned;
8. Node 1 and Russian segment video of stowage survey was not performed as planned; and
9. Articulated portable foot restraint (APFR) thermal shield removal not performed as planned.

All of these tasks except the APFR thermal shield removal will be performed by the Expedition 1 crewmembers.

#### **Real-Time Shuttle-to-ISS Transfer Changes**

1. Swap battery-powered speaker/microphone unit (BPSMU) with bad one from the ISS;
2. Orbiter Communications Adapter components;
3. MUT handrail end effector not transferred;
4. Substituted a V10 for a Camcorder;
5. Deerskin gloves;
6. Sunglasses;
7. Goggles;
8. Transferred only one of three ISS desk plates;
9. In-Flight Maintenance kit piece parts and tools;
10. Kapton tape;
11. General paper; and
12. Four 24-inch/22 gauge jumpers.

#### **Real-Time ISS to Shuttle Transfer Changes**

1. Did not return the four CPA's removed from the Node 1 forward hatch as planned because of a connector problem with the Node 1 nadir CPA;
2. Did not transfer nine empty contingency water containers (CWC's)
3. Did not transfer the dummy power supplies;
4. Left four connector caps on ISS;
5. Did not transfer all five IMAX film cans. The unused film was left on the ISS;
6. Transferred two PCBM alignment guides;
7. Transferred PFE neck launch restraints;
8. Transferred knee braces;
9. Transferred PTAB; and

10. Transferred predock-collected Russian Segment air samples.

### **ISS Hardware Anomalies Affecting Task Completion**

Five ISS anomalies were encountered during the flight and these affected task completion in the associated areas.

1. Carbon Dioxide Removal Assembly pump failure;
2. Treadmill Vibration Isolation System hardware problems;
3. Node 1 nadir CPA connector damage;
4. S-Band cable connection clocking; and
5. SASA connector O-ring came off of hardware.

## **VEHICLE PERFORMANCE**

### **LAUNCH DELAY**

Rollout of the STS-98 vehicle was originally planned for December 14, 2000; however, a postflight STS-97 Solid Rocket Booster (SRB) in-flight anomaly (STS-97-B-001) investigation and subsequent inspection, testing and repair/replacement delayed the rollout until January 3, 2001. The anomaly investigation resulted in an extensive examination of SRB flight cables as well as cables in inventory, and a flight cable in the watertight, reusable (WTR) system tunnel was found to have a severed conductor. These cables could not be inspected or tested on the launch pad, consequently, the vehicle was rolled back to the Vehicle Assembly Building (VAB) on January 19, 2001. Upon return to the VAB, the 36 system tunnel WTR cables were both X-rayed inspected and flex continuity tested. The vehicle was rolled out to the launch pad on January 26, 2001.

### **SOLID ROCKET BOOSTERS**

All Solid Rocket Booster (SRB) systems performed as expected. The prelaunch countdown was normal and no SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements And Specifications Document (OMRSD) violations occurred. No in-flight anomalies were identified from the evaluation of the data.

Power-up and operation of all igniter and field joint heaters were accomplished routinely. The heated, ground-supplied aft-skirt purges maintained the case/nozzle joint and flexible bearing temperatures within the required LCC ranges. These purges were in high-flow throughout the countdown

With the exception of the failed thrust vector controller (TVC) gas generator (GG) bed primary temperature measurement for the right SRB rock auxiliary power unit (APU), all SRB subsystems performed nominally during the prelaunch testing and launch countdown. The backup measurement to the GG bed temperature was also erratic. Inspection of the APU and its cabling during the postflight assessment failed to reveal a cause for the erratic operation. Detailed troubleshooting will take place at the APU vendor facility.

Both SRB's were successfully separated from the vehicle at approximately T+125.3 seconds. Radar tracking indicated a normal descent and splash down. All 48 sea water activated release (SWAR) links (8 links per parachute) fired satisfactorily.

Both SRB's were recovered and returned to KSC for inspection, disassembly and refurbishment.

### **REUSABLE SOLID ROCKET MOTORS**

All Reusable Solid Rocket Motor (RSRM) systems performed satisfactorily during the countdown and the ascent phase of the mission. No LCC or OMRSD violations occurred during the countdown phase. No in-flight anomalies were identified during the review of the data. All RSRM temperatures were maintained within acceptable limits throughout the countdown.

Data indicate that the flight performance of both RSRM's was within the allowable performance envelopes, and was typical of the performance observed on previous flights. The predicted propellant mean bulk temperature (PMBT) was 61 °F. Delivered burn rates were 0.3682 and 0.3680 inch/second for the left and right motors, respectively. The maximum trace shape variation of pressure versus time during the 62 to 80 second time frame was calculated to be 1.062 percent at 80 seconds on the left motor and 1.025 percent at 72 seconds on the right motor. Both of these values were within the 3.2 percent allowable limits. A comparison of the predicted and actual propulsion system performance is shown in the following table.

### RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 68 °F		Right motor, 68 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	65.75	65.59	65.80	65.58
I-60, 10 <sup>6</sup> lbf-sec	175.90	174.78	176.03	175.51
I-AT, 10 <sup>6</sup> lbf-sec	297.15	296.64	297.30	297.64
Vacuum Isp, lbf-sec/lbm	268.5	268.0	268.5	268.8
Burn rate, in/sec @ 60 °F at 625 psia	0.3706	0.3696	0.3706	0.3700
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	108.7	109.1	108.6	109.1
50 psia cue time	118.7	119.3	118.7	118.9
Action time <sup>b</sup>	120.9	121.5	120.9	121.4
Separation command	123.1	123.7	123.1	123.3
PMBT, °F	68	68	68	68
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	304	3.1	3.6
Tailoff Imbalance Impulse	Predicted		Actual	
differential, Klbf-sec	N/A		513.4	

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

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

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

The launch pad environment showed ambient temperatures between 62 °F and 70 °F during the LCC time frame of the countdown. Field joint heaters operated for 13 hours 32 minutes during the final launch countdown. Power was applied to the heating elements 47 percent of the time during the LCC time frame. All field joint heaters operated nominally throughout the countdown.

The igniter joint heaters operated for 18 hours 36 minutes during the final launch countdown. The igniter heaters were activated prior to L-18 hours because the ambient temperature was less 55 °F. Power was applied to the heating elements 66 percent of the time to keep the igniter joints within their normal operating range.

The aft skirt purge was activated four times during the 69 hours of recorded data for a total of 20 hours 58 minutes. The activation time during the final countdown was 12 hours 47 minutes. It was necessary to activate the aft skirt purge to maintain the nozzle/case joint temperatures above the minimum LCC temperature. The purge was also necessary to thermally condition the flex bearing. During the LCC time frame, the nozzle/case joint sensor temperatures ranged from 75 to 85 °F on both motors. The final flexible bearing mean bulk temperature was determined to be 80 °F.

All ground environmental instrumentation (GEI) and operational flight instrumentation performed within established requirements. All available data were recorded, transmitted and analyzed without incident.

### **EXTERNAL TANK**

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

The ET ullage temperature measurement failed off-scale high during topping. This measurement is not required for launch, drain and safing. The documentation for the measurement failure was dispositioned as no constraint to launch.

The observed thermal protection system (TPS) cracks were acceptable. Crack growths and additions during loading were acceptable. All ice conditions were acceptable. Later in the count, a greater than usual ice/frost formation was observed on the ground umbilical carrier plate (GUCP) and extending onto the adjacent foam. A thermal, stress and potential debris assessment eliminated any concern for this condition.

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

ET separation was performed and since it occurred within expected tolerances, entry and break-up occurred within the expected footprint approximately 67 miles downrange from the preflight predicted impact point.

### **SPACE SHUTTLE MAIN ENGINES**

The prelaunch operation for the Space Shuttle main engines (SSME's) was satisfactory. The SSME's performed satisfactorily throughout ascent with no in-flight anomalies identified from the data. The flight-derived specific impulse ( $I_{sp}$ ) was 0.7 second higher than predicted. The Block IIA engines, which were on this vehicle, have typically delivered approximately 0.8 second higher  $I_{sp}$  than predicted from ground testing.

Main engine cutoff (MECO) occurred 503.08 seconds after SRB ignition. The commanded maximum dynamic pressure (Max  $Q\alpha$ ) throttle-down was in a single throttle step to 72 percent.

## SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits 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 SUBSYSTEM PERFORMANCE

### Main Propulsion Subsystem

The main propulsion system (MPS) operated satisfactorily, and no LCC or OMRSD violations occurred during the launch countdown and flight. One in-flight anomaly was identified from the evaluation of the data. That anomaly is discussed in a later paragraph in this section.

No significant hazardous gas concentrations were detected prior to liftoff. The maximum hydrogen concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fast-fill, was 184 ppm (corrected for mass spectrometer drift). This compares favorably with previous data for this vehicle.

The LH<sub>2</sub> ullage temperature sensor exhibited an erratic signature coincident with the LH<sub>2</sub> tank venting and then failed off-scale high. Other measurements associated with multiplexer/demultiplexer (MDM) Orbiter aft (OA) 3 card 4 were reviewed and no anomalies were noted. The measurement is criticality 3 and therefore, had no impact on tanking or flight operations. Orbiter wiring was tested during the postflight turnaround activities and no anomalies were found. Therefore, the failure cause is assumed to have been the transducer.

The LH<sub>2</sub> Engine 1 prevalue (PV4) open position indicator B failed off between liftoff and main engine cutoff (MECO). The indication went off at 038:23:15:43 G.m.t. (00:00:02:41 MET) and recovered at 038:23:17:47 G.m.t. (00:00:04:45 MET). After completion of the LH<sub>2</sub> dump, the position indicator failed off again at 038:23:28:38 G.m.t. (00:00:15:36 MET) (Flight Problem STS-98-V-01). The measurement subsequently recovered at 039:02:51:55 G.m.t. The prevalues go to the open position for the dump and remain there for the rest of the mission. Since the LH<sub>2</sub> prevalues have redundant position indicators, the valve was verified open by the open position indicator A, and the failure had no effect on MPS operations. Postflight troubleshooting was being performed as this report was being published.

The gaseous oxygen (GO<sub>2</sub>) 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 liquid oxygen (LO<sub>2</sub>) and liquid hydrogen (LH<sub>2</sub>) pressurization systems performed as planned. Engine inlet net positive suction pressure (NPSP) requirements were met throughout the flight. All three flow-control valves performed nominally, and all pneumatic valve cycles were within the timing requirements.

Helium system performance for the SSME and pneumatic Helium systems was nominal. Entry Helium usage was 59.6 lbm, which is within the requirements.

### Reaction Control Subsystem

The reaction control subsystem (RCS) performed satisfactorily throughout the mission. No in-flight anomalies were noted in the evaluation of the data. STS-98 was the first flight in which RCS-to-RCS crossfeed to balance propellant was established using the master crossfeed switch. Because of propellant quantity concerns, the RCS thruster hot-fire test was performed passively. This was accomplished by changing thruster priorities as required to ensure that all thrusters were fired during the mission prior to entry.

The RCS was used to perform 16 translation firings in support of the rendezvous with the ISS, a collision avoidance maneuver and seven RCS reboost maneuvers. The overall altitude increase delivered during the eight separate maneuvers was approximately 15.4 nmi. Only one minor problem was noted during the mission and that concerned thruster L5D. The valve temperature for this thruster most likely exceeded the limit of 200 °F during a non-use period following the first reboost maneuver. The following table reflects the maneuvers performed to complete the rendezvous with the ISS.

#### RCS RENDEZVOUS MANEUVERS

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Firing time, sec	Orbit, nmi.
NC-4 (-X Trim)	040:12:47:02 01:13:34:00	N/A	0.48	-
NCC (Multi-axis RCS)	040:13:26:42 01:14:13:40	2.1	-	178.5 x 197.6
MC-1 (RCS)	040:14:44:24 01:15:31:22	0.4	2.0	187.3 x 198.4
MC-2 (RCS)	040:15:14:20 01:16:01:18	0.2	1.0	183.7 x 198.5
MC-3 (RCS)	040:15:31:20 01:16:18:18	0.7	2.0	184.0 x 198.4
MC-4 (RCS)	040:15:41:20 01:16:28:18	1.2	9.6	184.7 x 198.4
Collision avoidance	041:11:48:02 02:12:35:00	2.5	Four +X axis 4.64-second pulses	186.5 x 199.4

This mission was the first flight of the OI-28 software that included an automated firing of the forward primary reaction control subsystem (RCS) up-firing thrusters for approximately 2.02 seconds. The firing was programmed to occur during the Solid Rocket Booster (SRB) separation sequence and it was intended to change the flow pattern of the SRB separation motors. The intent of the resultant change in the flow pattern was to eliminate the hazing that occurs when the exhaust from the booster separation motors impacts the forward-facing Orbiter windows. This firing occurred at 038:23:13:G.m.t. (00:00:02:04.52 MET) and was terminated 2.08 seconds later. RCS

thrusters F1U, F2U and F3U were fired during the maneuver. The crew reported debris on the forward-facing windows: however, postflight assessments indicate that the windows are clearer than observed in the previous flights.

RCS thruster L3D has set a new record for the most pulses on a thruster during a single flight. The thruster was fired 2941 pulses compared with the previous high of 2092 pulses on the STS-92 mission.

A total of 4929.6 lbm propellants (3000 - oxidizer, 1929.6 - fuel) were used from the RCS during the rendezvous mission with the International Space Station. In addition, a total of 3350.4 lbm of the orbital maneuvering subsystem (OMS) propellants were used by the RCS during interconnect operations. The primary RCS thrusters had 12958 firings and a total firing time of approximately 1911.46 seconds. The vernier RCS thrusters had 11928 firings and a total firing time of 25247.68 seconds.

The first ISS reboost maneuver, which lasted one hour, began at 042:17:13 G.m.t. (03:18:00 MET) by firing primary +X axis RCS thrusters L3A and R3A. The pulse widths were 160 msec with a period of 15.04 seconds between firings. The primary RCS thruster firings were interrupted six times for attitude maintenance using the vernier thrusters and this limited the number of primary RCS pulses to 225. The aft down-firing vernier thrusters had a duty cycle of 2.4 seconds on and 12.6 seconds off. This was the first flight use of the automated reboost software.

The second ISS reboost maneuver, which lasted 2.5 hours, was started at 042:18:18 G.m.t (03:19:05 MET) by firing +X axis RCS primary thrusters L3A and R3A. The pulse widths and period were the same as the first reboost maneuver. The aft down-firing primary thrusters, however, were used for attitude control in roll and yaw and had a duty cycle of 0.08 second on and 9 seconds off. The two reboost maneuvers resulted in a  $\Delta V$  of 12 ft/sec, an altitude increase of 3.6 nmi., and the final orbit of 203.0 nmi. by 188.9 nmi.

The second ISS reboost maneuver was completed at 042:20:47 G.m.t. (003:21:31 MET), which was early by 2 minutes 2.5 seconds. The flight software community investigated the problem and formed the following conclusions. When automatic reboost maneuvers are commanded for durations greater than 4096 seconds, the actual duration will be noticeably shorter than requested. In the flight software, a timer is maintained which decrements by the period of execution every time the reboost module executes (every 80 ms) until the requested duration is achieved. Due to the loss of AP-101 scalar precision in the decrement operation, the time remaining decreases slightly more than 80 ms each cycle, and consequently triggers reboost termination earlier than expected. A workaround was used to enter a compensated maneuver time that resulted in the desired maneuver duration.

The third ISS reboost maneuver, which lasted four hours, began at 044:15:53:02 G.m.t. (05:16:40:00 MET) by firing primary +X axis RCS thrusters L3A and R3A. The pulse widths were 160 msec with a period of 15.04 seconds between firings. Attitude maintenance was performed with the primary aft down-firing thrusters, which had a duty cycle of 0.08 second on and 9.0 seconds off.

The fourth ISS reboost maneuver, which lasted one hour, started at 044:20:06:02 G.m.t (05:20:53:00 MET) by firing +X axis RCS thrusters L3A and R3A. The pulse widths and

period were the same as reboost maneuver 3. Attitude maintenance limited the number of pulses to 210. The aft down-firing vernier thrusters were used for attitude control and had a duty cycle of 2.4 seconds on and 12.6 seconds off. The total  $\Delta V$  from the two maneuvers was 17.7 ft/sec. The two maneuvers resulted in an altitude increase of 5.0 nmi. and a final orbit of 206.5 nmi. by 193.7 nmi.

The fifth ISS reboost maneuver, which lasted one hour, started at 045:23:08:03 G.m.t (06:23:55:01 MET) by firing +X axis RCS primary thrusters L3A and R3A. The thruster pulse widths were 160 msec with a firing period of 15.04 seconds. Attitude maintenance activities limited the number of pulses to 208. The aft down-firing vernier thrusters were used for attitude control and had a duty cycle of 2.4 seconds on and 12.6 seconds off. The reboost maneuver resulted in an altitude increase of 1.4 nmi. and a total  $\Delta V$  of 4.9 ft/sec. The orbit as a result of this maneuver was 208.7 by 195.1 nmi.

The sixth ISS reboost maneuver, which lasted 1.25 hours, commenced at 046:15:23:13.4 G.m.t. (07:16:10:11.2 MET) by firing primary +X axis RCS thrusters L3A and R3A. The reboost maneuver was performed in straight feed. The primary thruster pulse widths were 160 ms with a firing period of 15.04 seconds between firings. Attitude maintenance was performed with the primary aft down-firing thrusters. While performing attitude maintenance, the aft down-firing primary thrusters had an average duty cycle of 0.08 second on and 9 seconds off. RCS performance was nominal. The reboost resulted in a final orbit of 209.4 by 195.5 nmi. and a total  $\Delta V$  of 4.4 ft/sec.

The seventh, and final, ISS reboost maneuver began at 046:16:56 G.m.t. (07:17:43 MET) by firing primary +X-axis RCS thrusters L3A and R3A. This maneuver was performed in right OMS interconnect and lasted approximately 3 hours and 41 minutes. The pulse widths, period, and attitude maintenance were the same as for the sixth reboost maneuver. RCS performance was nominal. The reboost maneuver resulted in a final orbit of 213.3 by 199.8 nmi., and a total  $\Delta V$  of 11.9 ft/sec was imparted to the vehicle.

Undocking occurred at 047:14:08:31 G.m.t. (08:14:55:29 MET) and ISS separation was initiated 2 minutes later with a +Z pulse of the primary RCS. A one-half revolution flyaround the ISS was performed prior to final separation from the ISS. The final separation maneuver was initiated at 047:14:48:18 G.m.t. (08:15:35:16 MET), with a 12.64 second, -X axis pulse of primary RCS thrusters F1F and F3F. The resultant  $\Delta V$  was 3.5 ft/sec.

The primary RCS hot-fire was not performed because each of the 38 primary RCS thrusters was fired during the course of the mission. This "passive" hot-fire, which saves propellant, was accomplished by re-prioritizing the thrusters. The vernier manifold valve test, a normal part of the RCS hot-fire test, was successfully performed.

A minus X-axis RCS orbit-adjust maneuver was performed at 048:20:59:02.29 G.m.t. (09:21:45:00.29 MET). The firing was 19.52 seconds in duration and resulted in a orbit of 195.4 by 211.2 nmi., and a total  $\Delta V$  of 4.8 ft/sec was imparted to the vehicle.

### Orbital Maneuvering Subsystem

The orbital maneuvering subsystem (OMS) performed satisfactorily throughout the mission. No in-flight anomalies were identified from the evaluation of the data. The OMS inlet pressures, chamber pressures and regeneration jacket temperatures for both engines were as predicted, verifying nominal engine performance. All OMS maneuvers were performed accurately, and OMS operation was nominal during all the maneuvers.

The deorbit maneuver for the first EAFB landing opportunity on the second extension day, a two-engine straight-feed firing, was performed on orbit 202.

A total of 21247 lbm (13209 - oxidizer and 8038 lbm - fuel) of OMS propellants were consumed during the mission. Of this total, the OMS provided 3350.4 lbm of propellants to the RCS during interconnect operations.

The following table lists the OMS maneuvers performed during the flight.

**OMS Maneuvers**

<b>Maneuver</b>	<b>Time, G.m.t./MET</b>	<b><math>\Delta V</math>, ft/sec</b>	<b>Firing time, sec</b>	<b>Orbit, nmi.</b>
Assist Maneuver (Both engines)	038:23:15:17 00:00:02:15	-	102.2	-
OMS-2 (Both engines)	038:23:56:47 00:00:43:45	126.6	82.8	110.2 x 175.1
OMS-3 (Both engines)	039:02:49:09 00:03:36:09	132.8	85.2	161.9 x 197.3
OMS-4 (Right engine)	039:23:17:55 01:00:04:53	8.2	10.8	165.7 x 198.0
NC-4 (Both engines)	040:12:46:47 01:13:33:45	21.6	14.2	178.5 x 197.9
TI (Left engine)	040:14:24:25 01:15:11:23	10.7	14.0	183.7 x 198.5
Deorbit (Both engines)	051:19:27:20 12:20:14:18	317.9	164.2	-

Following the 14-second oxidizer totalizer integration period at the start of the OMS assist firing, the left OMS oxidizer total output reading went off-scale high and remained there until the start of the OMS-2 firing. The left OMS oxidizer total output gave correct values on all left OMS engine firings following the assist firing.

The left fuel total quantity dropped to 45 percent after the 14-second integration period at the start of the OMS-2 firing. It remained there until the start of the deorbit firing after which it decremented in its usual manner.

The deorbit maneuver for the first EAFB landing opportunity on the second extension day, a two-engine straight-feed firing, was performed on orbit 202.

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

The power reactant storage and distribution (PRSD) subsystem performance was nominal throughout the STS-98 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. The PRSD subsystem supplied the fuel cells with 2981 lbm of oxygen and 375 lbm of hydrogen for the production of 4356 kW of electrical energy. In addition, the environmental control and life support system (ECLSS) was supplied 203 lbm of oxygen for life support.

During the prelaunch preparations, the oxygen cryogenic load sample indicated a total impurity level in excess of the 110 ppm specification. The level was 144 ppm. A signed waiver approved that impurity level for flight because no constraint to more frequent fuel cell purges was identified. There was no observable effect on the fuel cell performance due to the out-of-specification impurity level in the oxygen. The performance levels and performance degradation of the fuel cells was the same for the previous flight of this vehicle as well as this flight.

The Orbiter landed with 737 lbm of oxygen and 83 lbm of hydrogen remaining in the PRSD subsystem. A 47-hour mission extension capability existed at landing, based on the PRSD oxygen (limiting reactant) tank landing quantities and an average power level of 14.2 kW. At an extension-day power level of 12.1 kW, a 55-hour mission extension capability was available.

## **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 14.1 kW and 457 amperes. The fuel cells produced 3357 lbm of potable water and 4356 kWh of electrical energy while using 2981 lbm of oxygen and 375 lbm of hydrogen.

Six purges of the fuel cells were performed, all of which achieved nominal results. The actual fuel cell voltages at the end of the mission were 0.3 V above the predicted for fuel cell 1, 0.17 volt above predicted for fuel cell 2, and 0.3 V 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 1.1 V for fuel cell 1, 0.9 V for fuel cell 2, and 1.4 V 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 4.5 days of the mission. The B system was selected at that time and it operated for the remainder of the mission.

There was no observable effect on fuel cell performance because of the out-of-specification impurity level in the prelaunch oxygen sample. A waiver approved the oxygen for this flight because there was no restriction of fuel cell purges.

The fuel cell monitoring system (FCMS) was used to monitor individual cell voltages during the prelaunch period as well as during the mission and after landing. Full-rate on-orbit data were recorded for 12 minutes during the mission. No problems were identified

from the analysis of the data. All of the cell performance monitor (CPM) values remained stable throughout the mission.

The fuel cell 2 stack exit temperature fault detection and annunciation (FDA) lower limit was decreased from 190 °F to 185 °F to prevent a potential alarm. The fuel cell 2 load decreased to near 3 kW, which caused the temperature to decrease to 191 °F. The SM alert lower limit for fuel cell stack exit temperature varies according to the power level; at

less than 3.5 kW, the lower limit is 180 °F. For power levels between 3.5 kW and 7.5 kW, the lower limit is 190 °F.

### Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performance was nominal throughout the STS-98 mission. No in-flight anomalies were identified during the review of the data. 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)		APU 2 (S/N 303)		APU 3 (S/N 409)	
	(a) (b) Time, Min:sec	Fuel consumption, lb	(a) Time, Min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	19:18	45	19:43	48	20:04	51
FCS checkout	06:06	16				
Entry <sup>a</sup>	59:25	104	86:17	151	59:49	118
Total	84:49	165	106:00	199	79:53	169

<sup>a</sup> APUs were shut down 15 minutes 17 seconds after landing.

The flight control system (FCS) checkout was performed nominally, with no problems identified. APU 1 was used to support the checkout, with a run time was 6 minutes, 6 seconds, and a fuel consumption of 16 pounds during the APU operation. APU performance was nominal and the total run time was too short to require the water spray boiler (WSB) to provide spray cooling.

The APU 3 exhaust gas temperature (EGT) 1 was erratic during ascent. The APU 3 EGT 1 and 2 measurements were also erratic during entry.

### Hydraulics/Water Spray Boiler Subsystem

The hydraulics/WSB subsystem performed satisfactorily throughout the mission. No in-flight anomalies were identified from the analysis of the data. STS-98 was the fifth flight in which the new WSB water additive (PGME) was used to preclude ascent freeze-ups and the third flight on this vehicle. (OV-104). The additive was loaded into WSB system 3 core only during the turnaround flow at KSC.

One minor item was noted following ascent when the hydraulic system 2 priority valve reseal pressure was 2649 psia, but it should have been no less than 2675 psia. The reseal value was only slightly less than the File IX specification requirement. During the

two previous flights of this vehicle, the system 2 also exhibited a similar lock-up pressure. Ground checkouts and test of system 2 following the two previous flights have shown lockup pressures that were above the minimum File IX requirement.

During the last Orbiter Maintenance Down Period (OMDP) of this vehicle, the bootstrap accumulators were changed from the earlier piston design to the new bellows type and the position of the pressure transducer was moved from the GN<sub>2</sub> side of the system to the hydraulic fluid side. It is now believed that the bellows accumulator modification has altered the pressure signature observed during priority valve crack and reseal, resulting in lower reseal pressures than were observed with the piston-type accumulator. The hydraulic system engineering community is assessing the dynamics of the accumulator design change to determine if a corresponding OMRSD File IX change is required. Since this behavior has not impacted system operations and system performance has remained consistent for three flights, and since a change to the in-flight checkout requirement is under consideration, it has been determined that further ground testing is not required.

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

The electrical power distribution and control (EPDC) subsystem performed nominally throughout the mission. No in-flight anomalies were identified from the data analysis.

The launch delay occurred because of a concern with an aft main bus C current indication recorded in ground telemetry at the Kennedy Space Center (KSC). Coming out of the T-20 minute hold, the two readings (ground and vehicle) for aft main bus C disagreed with each other when the ground power was reduced to load up the fuel cells. KSC personnel were concerned that a problem existed with the Orbiter, possibly a data problem from multiplexer/demultiplexer (MDM) Orbiter Aft (OA) 1, but a review of vehicle data gave the flight team in the Mission Control Center at Houston and the launch team at KSC the confidence that the problem did not exist in the Orbiter and the launch could proceed. A teleconference was conducted the following day and a faulty hardware interface module (HIM) card that biased the ground reading was identified as the reason for the disparate data.

### **Orbiter Docking System**

The Orbiter Docking System (ODS) performed satisfactorily throughout the mission. No in-flight anomalies were identified from the review of the data. The active system monitor parameters indicated normal outputs throughout the duration of the flight.

The Orbiter successfully docked with the ISS at 040:16:50:49 G.m.t. (01:17:37:47 MET). The Orbiter was docked at the pressurized mating adapter (PMA) 3 docking station followed by the ISS pressurizing the vestibule and leak checks that were nominal.

As a result of the ammonia spill contacting a crewmember during the first EVA, a Chemical Check/Decontamination procedure was implemented. The airlock was pressurized to 5-psia to remove any ammonia remaining on the crewmembers suit. The airlock was then depressurized after 15 minutes followed by the airlock then being repressurized nominally and equalized with cabin pressure for hatch opening.

During the airlock depressurization for the third EVA, the crew realized that the equalization valve on the airlock-to-cabin hatch was left open. Consequently, the depressurization was terminated and the valve was closed. The valve was open for less than one minute. Airlock depressurization was then resumed and completed nominally.

The vestibule depressurization valves were opened at 047:13:22 G.m.t. (08:14:08:58 MET) to depressurize the vestibule to vacuum before undocking. During the vestibule leak check, the vestibule depressurization valves were found open about 10 minutes into the leak check when the valves should have been closed for 30 minutes. The valves were then closed and the leak check was restarted and completed with no problems noted. Undocking occurred at 047:14:06 G.m.t. (08:14:53 MET).

The external airlock waterline heater reconfiguration from strings 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. The active system monitor parameters indicated normal output throughout the duration of the flight.

The cabin regulator inlet valves were shut and the cabin pressure was allowed to bleed down prior to the first depressurization to 10.2-psia. The hatches between the ISS and the Orbiter were opened at 040:19:02 G.m.t. (01:19:49 MET) and subsequently closed at 040:23:26 G.m.t. (02:00:13 MET). The first 10.2-psia depressurization to support the first extravehicular activity (EVA) was initiated at 040:23:35 G.m.t. (02:00:22 MET). Pressure was maintained at 10.2-psia until after the first EVA. Cabin pressure was increased to 13.4-psia prior to equalization with the ISS. The Orbiter cabin pressure was equalized with the ISS at 041:15:36 G.m.t. (03:02:34 MET) at 14.1 psia. After ingressing the U. S. Laboratory module, the cabin and ISS were repressurized to 14.7 psia.

In preparation for the second EVA, the hatches with the ISS were closed, and the second depressurization to 10.2-psia began at 042:22:45 G.m.t. (03:23:32 MET). The Orbiter cabin pressure was maintained at 10.43 psia to support the second and third EVA. After the third EVA, the Orbiter cabin pressure was returned to 14.7 psia. The cabin was equalized with the ISS and the hatches to the ISS were opened at 045:22:45 G.m.t. (06:23:34 MET). The repressurization of the Orbiter/ISS stack, using oxygen, was performed at 046:21:46 G.m.t. (07:22:33 MET). The pressure was raised to 14.82 psia. The hatches to the ISS were closed at 047:12:07 G.m.t. (08:12:54 MET). Normal operation of the ARPCS was used for the remainder of the mission.

### **Atmospheric Revitalization Subsystem**

The atmospheric revitalization subsystem (ARS) system performed nominally through the duration of the flight.

During the postflight turnaround operations from the previous flight, the Orbiter ARS was modified to improve the flow of air to the ISS. This revision implemented the beneath-the-floor ducting modification, which in turn deleted the above-the-floor ducting that was used on previous ISS missions. This above-the-floor ducting measured 106 inches in

length by 4 inches in diameter. The modification placed an orifice in the supply air ducting upstream of the forward middeck venturi location. The purpose of the orifice is to maintain the proper air-flow balance to the cabin air system, while providing the ISS with a minimum of 43 cubic feet per minute of conditioned air. In addition, the middeck air intake was relocated from near the 576-bulkhead hatch location to 51 inches forward into the mid-deck. The STS-96 crew had reported stagnant air in the Node of the ISS. On STS-97, the initial flight after implementing the changes, the crews' response was positive, stating the air quality in the ISS had improved. Consequently, the beneath-the-floor ducting was incorporated into the vehicles to be flown on all future ISS flights.

During the launch phase, the crew compartment temperature peaked to 74.5 °F at approximately 35 minutes and 40 seconds into the flight. Cabin humidity peaked to 38.8 percent 18 minutes and 12 seconds into the flight.

During the first EVA when the crew was mating an ammonia-cooling quick disconnect (QD) used for cooling the U. S. Laboratory, the QD released a small amount of ammonia, which contacted the suit of a crewmember. The non-EVA crewmembers initiated the Chemical Check/Decontamination procedures. At the time of the incident, the cabin humidity was 19.6 percent, which is fairly dry. The Medical operations and crew contamination personnel were contacted and stated that ammonia is very soluble in water and recommended increasing cabin humidity prior to the crew ingress. At 041:21:51 G.m.t. (02:22:38 MET) water coolant loop 1 was powered on and cabin humidity was successfully increased to 26 percent. At 041:23:57 G.m.t. (03:00:44 MET), the cabin temperature controller 1 was powered off and the crew pinned the cabin temperature control valve in the full heat-exchanger flow position. Water coolant loop 1 and the cabin temperature controller remained in this configuration until after crew ingress at which time the crew reported that there was no indication of ammonia contamination.

At 047:01:03 G.m.t. (08:01:50 MET), the partial pressure of carbon dioxide (ppCO<sub>2</sub>) peaked to 2.74 mmHg while cabin pressure was at 14.7 psia. During 10.2-psia cabin pressure operations, the ppCO<sub>2</sub> peaked to 2.42 mmHg for a short duration. The ppCO<sub>2</sub> averaged 1.75-mmHg for the duration of the flight. This was quite low, but the STS-98 crew of 5 had a lower metabolic production rate than the crew of 5 on STS-97. This was confirmed by comparing to STS-97 wastewater production rate (excluding periods of condensate separation on STS-97) and the ppCO<sub>2</sub> production rate.

Cabin Humidity averaged 30.0 percent for the flight. The peak cabin humidity was 51 percent, and it occurred during a water coolant loop cycle on flight day 11 during the second landing opportunity.

During the landing phase of the flight, the heat exchanger outlet temperature peaked to 57.4° F 14 minutes after wheel stop, with the cabin air temperature peaking to 70.5 °F 33 minutes 50 seconds after wheel stop. The cabin humidity peaked near 52.8-percent approximately 15 minutes 50 seconds after wheel stop.

### **Active Thermal Control Subsystem**

The active thermal control subsystem (ATCS) performed nominally for the STS-98 mission. During ascent, a very minimal amount of pre-evaporative cooling was observed. The pre-evaporative cooling resulted in a 1 to 2 °F reduction in the flash

evaporator system (FES) outlet temperature, an indication that there was very little condensate in the FES cores.

During the post-orbital-insertion period, an unexpected temperature signature was observed at the high-load FES outlet. This condition occurred about 10 minutes after radiator flow was initiated at 039:00:40 G.m.t. (00:01:27 MET). After the radiator flow controllers were configured from the bypass to the flow position, the FES controllers were switched from primary A command to primary B command in preparation for the joining tanks A and B together. The high-load FES core was still enabled (meaning the FES was still in full-up mode). Placing of the FES in the primary B command allowed the FES to draw water from tanks C and D while tanks A and B were collecting water that was to be put in contingency water containers (CWCs) and transferred to the ISS. As Freon began to flow through the radiators, the inlet temperatures to the high-load FES dropped from an average of 87 °F to 60 °F. The FES, in primary B full-up mode, began to sense low enough heat loads at this time to force the high load FES to go into standby. This occurs by design when the mid-point temperature drops below approximately 43 °F. The topper handled the entire heat load for eight minutes after the high-load evaporator went into standby. At approximately 039:00:49 G.m.t. (00:01:37 MET), nine minutes after radiator flow was initiated, the radiator outlet began to warm up from 60 °F because the panels were still not exposed to space. This forced the high-load FES to activate about 2 minutes later, resulting in the first unexpected transient behavior that showed up as a FES outlet temperature spike to 51.7 °F. The abrupt rise to 51.7 °F and cool-down to about 39 °F was caused by the FES pulse-rate resetting to zero Hz when the high-load FES was activated by the controller. As the radiators sent gradually warming Freon (63 to 65 °F) to the FES, the FES outlet temperature exhibited a second unexpected transient. The beginning of the second transient was the result of the high-load FES going back to standby (topper FES operations only) because of the unstable FES operation in this temperature range when the mid-point temperature drops below 43 °F. This is a normal event for the high-load FES. However, it was unexpected because this condition has been experienced in only one flight (STS-60) when the duration between initiating radiator flow and the opening of the PLB doors was as long as was experienced during this flight (about 28 minutes). In this instance, as soon as the high-load FES went to standby, the FES mid-point temperature exceeded 62 °F because the inlet temperature was above 62 °F, and the high-load FES again came out of standby. This is the cause of the slight perturbation in the FES outlet temperature shortly after the beginning of the second unexpected transient. The FES controller then established proper control at approximately 39 °F with stable full-up FES operation (both topper and high-load operation).

The unstable FES operation just described has been documented to occur at low heat loads of this range (inlet temperatures of 65 °F through 88 °F). These low-heat load instabilities for a full-up FES were documented in vacuum-chamber tests conducted in 1978. After the second spike, the FES inlet temperatures (from the radiators) had warmed enough to allow the high-load FES to maintain stability. No other unexpected conditions were observed after this incident. The PLB doors were opened at approximately 39/00:55 GMT (00:01:42 MET).

The latest record found that was similar to this situation was a reported anomaly on STS-60 (OV-103) in which the FES shut down due to the combination of a midpoint sensor thermal lag and an 18-minute delay in opening the PLB doors after radiator flow

initiation. The STS-60 post-insertion FES inlet-temperature profile was similar to STS-98; however, a midpoint sensor thermal lag of the STS-60 FES unit prevented the FES from adequately dealing with the low-heat loads. The STS-60 FES shut down 14 minutes after radiator-flow initiation.

Five FES water dumps were performed in this flight. The FES was using the primary B controller from post-insertion through 047:15:09 G.m.t. (08:15:56 MET). The first four FES water dumps were performed using the primary B controller.

There were two 24-hour deorbit delays and FES checkouts were performed prior to each deorbit delay. The third deorbit attempt had a 2 hour 31 minute radiator coldsoak and also involved a FES checkout. The last coldsoak produced radiator-panel outlet-temperatures that were in the low 70 °F range.

Radiator flow was initiated at 051:20:20 G.m.t. (12:21:07 MET) or about 12 minutes before landing. Postlanding, the radiators were placed at high setpoint only seconds before the ammonia boiler system was activated at 051:20:45 G.m.t. using the primary A controller. Because adequate temperatures were produced by the coldsoak, there was no need to use the system B ammonia tank. The radiators were placed in normal position at 051:21:31 G.m.t. along with ammonia system A deactivation. Ground cooling was initiated about 4 minutes later. The ammonia system B secondary controller was not required, but was available if required.

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

The supply water and waste water systems performed nominally throughout the mission.

Supply water was managed through the use of the FES, water transfer to the ISS and the overboard dump system. Five FES water dumps were performed during the mission. Two supply-water nozzle dumps were performed at a nominal dump rate of 1.68 percent (2.77 lb/min). The line heater maintained the supply water dump line temperature between 69 °F and 92 °F throughout the mission.

Ten contingency water containers (CWCs) were filled and transferred to the ISS, for a total of 998.8 lb. Five of the CWCs transferred were potable water and five were technical water. During the CWC fills, it was observed that the fill rate was lower than expected. Calculated average fill rate was 87 lb/hr compared to the 106 lb/hr fill-rate observed during STS-106. This low flow-rate was no impact to the mission; however, it resulted in a longer period of time to fill the CWCs.

Five waste water dumps were performed at an average rate of 1.91 percent/minute (3.15 lb/min). The waste water dump line temperature was maintained between 57 °F and 72 °F throughout the mission.

The vacuum vent line temperature was maintained between 58.6 °F and 75 °F.

### **Waste Collection Subsystem**

The waste collection subsystem (WCS) performed satisfactorily throughout the mission. The crew noted no anomalous performance.

Solid urine pre-treat assembly (SUPA) was manifested on STS-98, however, it was not implemented because of unknown contamination that was discovered during STS-97 postflight WCS inspection. The SUPA was implemented on STS-97. It is not known if the Oxone used in the SUPA assembly is a contributor to the formation of the unknown contamination.

### **Airlock Support System**

The airlock support system performed satisfactorily throughout the STS-98 mission. Three extravehicular activities were completed and the airlock support system met all requirements.

### **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 throughout the mission. No in-flight anomalies were noted in the evaluation of the data.

The inertial measurement units (IMUs) performed satisfactorily throughout the mission. Onboard IMU compensations were performed the second day of the flight, and the drift compensations were updated on the ninth day of flight. The compensations that were updated reflected less than one sigma errors in the IMU values that were updated. The entry guidance, navigation and control performance was nominal. The navigation sensor data were incorporated into the onboard navigation state vector at the expected region of operations. All sensor measurement residuals and residual ratios were nominal with no navigation edit operations observed.

One item of note was the heads-up display (HUD) runway overlay misalignment observed during the approach and landing phase (Flight Problem STS-98-V-02). Analysis of the onboard navigation state vector as well as various guidance data have exonerated the navigation system as the source of the misalignment. The current investigation has concentrated on the HUD hardware calibration/installation.

### **Flight Software**

The flight software performed as expected during the mission. One item of note occurred during the mission and is discussed in the paragraph after the next.

This mission was the first flight of the OI 28 software that included an automated firing of the forward primary reaction control subsystem (RCS) up-firing thrusters for approximately 2.02 seconds. The firing was programmed to occur during the Solid Rocket Booster (SRB) separation sequence and it was intended to change the flow pattern of the SRB separation motors. The intent of the resultant change in the flow pattern was to eliminate the hazing that occurs when the exhaust from the booster separation motors impacts the forward-facing Orbiter windows. This firing occurred but the crew reported debris on the forward-facing windows. The extent of the debris as well as comparisons with previous flight experience will be determined during postflight

inspections. Initial indications are that the degree of window hazing is significantly reduced.

The second ISS reboost maneuver was completed at 042:20:47 G.m.t. (003:21:31 MET), which was early by 2 minutes 2.5 seconds. The flight software community investigated the problem and formed the following conclusions. When automatic reboost maneuvers are commanded for durations greater than 4096 seconds, the actual duration will be noticeably shorter than requested. In the flight software, a timer is maintained which decrements by the period of execution every time the reboost module executes (every 80 ms) until the requested duration is achieved. Due to the loss of AP-101 scalar precision in the decrement operation, the time remaining decreases slightly more than 80 ms each cycle and consequently triggers reboost termination earlier than expected. A workaround was used to enter a compensated maneuver time that resulted in the desired maneuver duration.

### **Flight Control Subsystem**

The flight control subsystem performed satisfactorily. No in-flight anomalies or hardware problems were evidenced during the mission.

### **Displays and Control Subsystem**

The displays and control subsystem (D&C) performed nominally throughout the mission. One of the payload bay floodlights failed to illuminate near the end of the mission and it is discussed in the following paragraphs.

At approximately 049:14:00 G.m.t. (10:14:47 MET), the crew activated the payload bay floodlights for payload-bay-door closure and the mid-main C bus current data exhibited a signature indicative of a 10-ampere remote power controller (RPC) trip. It was suspected that either the mid-starboard or aft-port payload bay floodlight had failed. With the payload bay doors closed, the crew was able to confirm that the mid-starboard floodlight was failed off, and as a result, the light was not used for the remainder of the mission.

The OV-104 floodlight electronics assemblies (FEA's) are modified and have a current output of 1.3 amperes. FEA 2 provides power to the mid-starboard floodlight. The main bus current measurements point to the most probable cause for the loss of the mid-starboard floodlight to be a failed ballast B in FEA 2. Another possible cause is corona arcing in the floodlight assembly; however, the current signature traces are not consistent with arcing. FEA 2 was issued to OV-104 in 1996 in support of flight 16, and has successfully supported 7 missions prior to STS-98. Troubleshooting will be performed during the scheduled turnaround activities.

### **Communications and Tracking Subsystem**

The communications and tracking subsystem performed nominally during the mission. A minor problem was noted in the Ku-band system, and it is discussed in the following paragraphs.

During the rendezvous with the ISS at 040:14:28:41 G.m.t. (01:15:15:39 MET), immediately after the transfer injection (TI) rendezvous maneuver was performed, the

Ku-band antenna steering mode was changed from Auto-track to general purpose computer (GPC) acquisition (ACQ). After the change, it was noted that the elevation angle, which had been agreeing to within 0.5 degree with the designated angle, appeared to have about a 2-degree bias. The actual elevation angle was about 2 degrees greater than the designated angle. This condition continued for about 18 minutes, until 2 minutes after the midcourse correction (MC) 1 maneuver. At that time, the Ku-band antenna broke track and immediately reacquired with the ISS with the 2-degree bias gone. Apparently the reacquisition eliminated the bias. This condition did temporarily affect the rendezvous navigation state and the calculated MC 2 maneuver ignition time of ignition.

A detailed circuit analysis was performed on the Ku-band hardware. The failure signature suggests that the Ku-band electronic assembly -2 (EA-2) may have generated the angle offset error. The range and angle-rate data, which was observed to be noisy, is generated within the EA-2. The EA-2 unit has been installed in OV-104 since the STS-27 mission. Analysis continues in an effort to determine the cause of this problem.

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

The operational instrumentation/modular auxiliary data system performed satisfactorily throughout the mission. No in-flight anomalies were noted in the review of the data. Minor data problems were experienced with other Orbiter subsystems and these are reported in the subsystem discussion.

### **Structures and Mechanical Subsystems**

The structures and mechanical subsystems performed satisfactorily throughout the mission. No in-flight anomalies were identified in the data. The landing and braking parameters are shown in the following table.

The payload bay doors were opened at 039:01:00:58 G.m.t. (00:01:47:57 MET). All voltages were nominal and the motors opened the doors in nominal dual-motor time.

The landing gear tires were reported to be in good condition. There was no ply undercutting on the main landing gear doors. No debris was found beneath the LO<sub>2</sub> and LH<sub>2</sub> umbilicals after the umbilical doors were opened.

No flight hardware was found during the postlanding walkdown of the runway. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing and line-cutter pyrotechnic devices were expended.

The OMRSD File IX requirement for the payload bay door drive system was not satisfied during door closure for the nominal (NEOM) landing opportunity. The requirement verifies that the starboard payload bay door closes nominally within 63 seconds with both drive motors running. The time of operation is determined by observation of ac bus currents corresponding to the motor operation. During STS-98, when the payload bay doors were closed for entry, the starboard door total run time was 66.76 seconds on ac bus 1 and 66.88 seconds on ac bus 2. This behavior arises from thermal effects on the door panels that causes an increase in door length along the centerline. As a result, the door panels must be moved back into appropriate positions during closing, thus requiring

### LANDING AND BRAKING PARAMETERS

Parameter	From Threshold, Ft	Speed, Keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2094.8	211.6	-1.05	N/A
Nose gear touchdown	5641.7	143.4	N/A	-5.08
Brake initiation speed		71.5 knots		
Brake-on time		21.5 seconds		
Rollout distance		7963.8 feet		
Rollout time		56.88 seconds		
Runway		22 (Concrete) EAFB		
Orbiter weight at landing		197,580 5 lb		
Brake sensor Location	Peak Pressure, Psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	799.2	Left-hand inboard	7.71	
Left-hand inboard 3	799.2			
Left-hand outboard 2	767.3	Left-hand outboard	5.66	
Left-hand outboard 4	767.3			
Right-hand inboard 1	936.7	Right-hand inboard	7.17	
Right-hand inboard 3	936.7			
Right-hand outboard 2	946.3	Right-hand outboard	4.31	
Right-hand outboard 4	946.3			

additional effort and longer door drive and latch actuator run times. At the time of this door closing, the port bending effect temperature (BET) was 99 °F and the starboard BET was 85 °F. Typical BETs are generally lower, in the 60 °F to 70 °F range. When the NEOM and EOM +1 landings were waived off, the two additional door closings were nominal. The BETs were slightly lower for the second and third payload bay door closings, but the door were only open for approximately 24 hours, thus limiting the amount of time for the door to become thermally distorted. This behavior has been observed on several previous flights. Since the condition is understood, no additional ground checkout during the flow is recommended.

The payload bay doors were closed and latched for the nominal end-of-mission (NEOM) landing opportunities at 049:14:08:23 G.m.t. (10:14:55:21 MET). Both KSC landing opportunities for the planned landing day were waived because of excessive crosswinds, and the mission was extended 24 hours. The payload bay doors were reopened at 049:18:01:02 G.m.t. (10:18:48:00 MET). The payload bay doors were closed and latched for the NEOM + 1 day landing opportunities at 050:15:06:08 G.m.t. (11:15:53:06 MET). Both of the NEOM + 1 day KSC landing opportunities were waived because of excessive crosswinds, and the mission was extended an additional 24 hours. The payload bay doors were reopened at 050:18:24:46 G.m.t. (11:19:11:44 MET). The payload bay doors were closed and latched for the NEOM + 2 day landing opportunities at 051:15:20:52 G.m.t. (12:16:07:50 MET). Both KSC landing opportunities on the second extension day were waived, and the decision was made to land at Edwards Air Force Base (EAFB) at the next opportunity.

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

The prelaunch thermal interface purges were normal with no problems noted. Likewise, the ascent aerodynamic heating and plume heating was nominal with no problems noted. The entry aerodynamic heating on the SSME nozzles was also normal with no bluing of the closure metal noted during the postflight inspection.

### **Thermal Control Subsystem**

The thermal control subsystem performed nominally. All temperatures were maintained within nominal limits. The heaters operated nominally and the temperatures and entry interface as well as the main landing gear tire pressures were within acceptable limits.

The crossfeed line on this vehicle has a history of cycling in a higher temperature range than the other vehicles in the fleet. As a result, the fault detection and annunciation (FDA) limits were raised to prevent nuisance alarms.

A total of seven reboost maneuvers were performed during the mission, requiring a total of 13.93 hours of thruster operation. Temperatures were maintained, for the most part, within the established limits. Additionally, three EVA's were performed and the external airlock service-line heater performance was nominal. The A string heaters were used for the first EVA, and the B heaters were used for EVA's 2 and 3. The C heaters were not required for the Orbiter attitudes flown.

### **Aerothermodynamics**

Wing structural temperature and yaw thruster firings both show indicate symmetric transition. Wing maximum temperature data were nominal, but the temperature rise was higher than nominal.

The acreage heating was normal. The entry was with a light vehicle entering from a high inclination orbit.

Local heating was nominal. No unusual thermal damage has been reported.

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

The thermal protection subsystem (TPS) performed satisfactorily. Entry heating was normal based on lower-surface structural temperature response data. Boundary layer transition from laminar flow to turbulent flow occurred 1192 seconds after entry interface (EI).

The postlanding inspection of the Orbiter TPS identified a total of 102 impacts of which 13 had a major dimension of 1-inch or larger. The distribution of these impacts on the vehicle is shown in the table on the following page. This total does not include the numerous damage sites on the base heat shield that are attributed to the flame arrestment sparkler system, SSME vibration/acoustics and exhaust plume recirculation.

The Orbiter lower surface sustained 73 hits of which 8 had a major dimension of 1-inch or larger. Approximately 24 damage sites (three larger than 1-inch) were located in the area from the nose landing gear to the main landing gear wheel wells. The amount and

size of the damage in this region was less than average. ET intertank TPS venting modifications continue to have a reducing effect on both the quantity and size of the damage sites.

### TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	8	73
Upper Surface	1	5
Window Area	3	18
Right Side	1	1
Left Side	0	3
Right OMS Pod	0	2
Left OMS Pod	0	0
Total	13	102

Numerous damage sites around the LH<sub>2</sub> ET/Orbiter umbilical were most likely caused by pieces of the umbilical purge barrier flapping in the airstream and contacting tiles before pulling loose and falling aft.

The largest damage site on the lower surface was located just aft and outboard of the nose landing gear door, and it measured 2.5 inches long by 2 inches wide by 0.25 inch deep. Slight erosion was observed at this and an adjacent damage site. Imbedded in a third damage site in this area was a fibrous material believed to be Ames gap filler. The second largest damage site on the lower surface was located on the left-hand inboard elevon and measured 2 inches long by 1.5 inches wide by 0.5 inch deep. The damage site showed indications of thermal erosion.

### COMPARISON OF LOWER SURFACE DAMAGE SITE DATA FROM LAST TEN FLIGHTS

Parameter	STS -91	STS -95	STS -88	STS -96	STS -93	STS -103	STS -101	STS -92	STS -97	STS -98
Lower surface total hits	145	139	80	160	161	84	70	86	78	73
Lower surface Hits > 1 in.	45	42	21	66	42	13	19	14	10	8
Longest damage Site, in.	3.0	4.0	4.5	4.0	6.0	1.5	8	2	3	3
Deepest damage Site, in.	0.5	0.4	0.5	0.5	0.5	0.25	0.75	0.75	0.5	0.5

Only two small hits were noted on the left OMS pod. However, two adjoining edges of the advanced flexible reusable surface insulation (AFRSI) blanket near the leading edge

of the left OMS pod were observed to be loose and frayed. There were no debris hits on the right OMS pod. There were no mission tiles or blankets from the left OMS pod that would coincide with the debris observed near the OMS pod prior to SRB separation. There were no tiles or blankets missing from the vertical tail. The vertical tail leading-edge damage site observed during on-orbit operations had not changed significantly. Its size was 2 inches long by 3 inches wide by 0.25 inch deep. The damage site appeared to have an impact residue embedded in it, and it was removed for analysis.

This was the first flight using the forward up-firing RCS thruster plumes to help prevent the SRB booster separation motor particulate impingement on the windows during SRB separation. Window hazing appeared to be less than normal. Streaks were observed on forward-facing windows 3 and 4. The streaks are believed to be room temperature vulcanizing (RTV) adhesive that was used to bond the paper covers to the Orbiter forward RCS thruster nozzle exits. It was also noted that an AFRSI blanket was slightly protruding from the area immediately aft of the up-firing thrusters in the forward RCS.

A total of 18 impact damage sites were observed on the window perimeter tiles with 3 of the sites having a major dimension of one-inch or greater. These damage sites are a result of impact by forward RCS paper covers with RTV adhesive on the back.

The tile damage on the base heat shield was typical. All SSME dome heat shield closeout blankets were in excellent condition with the exception of SSME 1 closeout blanket, which was torn at the seven o'clock position..

### **Gas Sample Analysis**

The STS-98 mission was a successful flight for the gas sample bottles. The hardware provided six excellent gas samples. The data obtained during ascent in the gas sample bottle system was all in the acceptable range; however, the hydrogen content in bottle 6 was 2 percent. That value is much higher than observed for a number of previous flights. All six bottle-pressures were in the expected range. The oxygen data was within the bands of error as determined by the argon measurement, and the amount detected can be attributed to air.

STS-98 was the first for four of the bottles and the second flight for two these bottles. New pyrotechnic valves were installed in the reprocessed bottles after the bottles were thoroughly cleaned by the vendor. The two reprocessed bottles were submitted to the same cleaning and vacuum processing cycle as when the bottles were new.

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

## EXTRAVEHICULAR OPERATIONS

All three extravehicular activities (EVAs) were successfully executed. All planned EVA tasks were completed on or ahead of schedule with the exception of the Z1 truss-to-U. S. Laboratory fluid umbilicals and the PCA vent installation. There were no hardware anomalies that significantly impacted the EVA tasks.

Extravehicular mobility units (EMUs) 1 and 2 were checked out successfully. During the checkout of EMU 3, the oxygen (O<sub>2</sub>) tank pressure was 482 psia, which was well below the nominal range of 850 to 950 psia. The tank was repressurized, and the crew performed a leak check with the EMU 3 gloves and helmet installed. The crew reported the O<sub>2</sub> tank pressure was 829 psia, which is within expected specifications. It is believed that the oxygen actuator was inadvertently bumped out of position and this caused the pressure loss. EMU 3 was stowed and remained ready to be used if needed for the planned EVAs.

Cabin depressurization for the first EVA started at 040:23:35:02 G.m.t (02:00:22 MET) and was completed at 040:23:52:02 G.m.t (02:00:39 MET) at a pressure of 10.35 psia.

The airlock depressurization for the first EVA was initiated at 041:15:29 G.m.t (02:16:16 MET) and was completed at 041:15:40 G.m.t (02:16:27 MET). The EVA began at 041:15:51 G.m.t (02:16:36 MET) when the EMUs were transferred to internal battery power, and the EVA was completed 7 hours and 33 minutes later. The EMUs and tools performed nominally.

During the EVA, one of the male quick-disconnects (QDs) on the U jumper at the Z1 truss (Z1 truss to U. S. Laboratory fluid umbilical) leaked ammonia when the fluid jumper was disconnected. The leak was stopped when the sister umbilical QD was disconnected from the Z1 truss, thus eliminating the source of the ammonia. The EV2 crewmember was exposed to ammonia during the leak. Because of the leak, the fluid umbilical task was delayed to allow the Mission Control Center (MCC) time to evaluate the situation and to allow the ammonia ice on the QD to sublime before connecting it to the U. S. Laboratory. All four QDs were successfully connected. In accordance with the Flight Rule, the EMU decontamination procedures (i.e. brushing, bake-out, repressurization/depressurization cycle of the airlock and cabin air scrubbing) were executed with satisfactory results. The intravehicular (IV) crewmembers also performed the required precautionary steps, which included donning the "quick-don" oxygen masks. The IV crewmembers did not notice any odors, and the crew compartment was pressurized to 13.38-psia after the EVA. This activity delayed the U. S. Laboratory activation and crew sleep by 2 ½ hours, but did not significantly impact the mission. After both crewmembers entered the airlock, the Chemical Check/Decontamination procedure was performed. This procedure required a repressurization of the airlock to 5 psia with a 15-minute waiting period prior to depressurizing the airlock for a second time after which the airlock was pressurized.

At the end of the first EVA, shortly after reaching 5.0 psia in the airlock, the EV 1 crewmember reported problems with his communication in both the receiving and transmitting. After configuring to hard-line mode, the EV 1 crewmember reported that

his communications improved. The EV 1 crewmember replaced his communication carrier assembly (CCA) with a backup CCA for the second EVA.

EVA 2 began at 043:15:58 G.m.t. (04:16:45 MET) when the EMUs were transferred to internal battery power. During EVA preparations, EMU 1 power was temporarily lost. The servicing and cooling umbilical (SCU) 1 signature was similar to an airlock power supply shutdown due to an open circuit (-0.13 amps, 0 volts). It was later determined from the crew that the SCU 1 was inadvertently disconnected. The crew reconnected the SCU and recycled the airlock power supply (ALPS). EVA preparations continued nominally. The EVA was completed in 6 hours 50 minutes. The EVA was performed nominally and the EVA tools, WVS and space-to-space communication system (SSCS) performed as expected.

During EVA 2, the crew discovered that the pressure control assembly (PCA) vent flange had 3/8-inch bolts instead of 5/16 inch bolts as expected. Removal of the flange and installation of the vent were delayed to allow time for ground evaluation. Following the evaluation, the crew was directed to obtain a 3/8-inch socket from the Node stowage bag and the task was successfully completed. Also, two EVA 3 tasks plus several get-ahead tasks were completed.

Prior to airlock repressurization following EVA 2, the EV 2 crewmember's left-side CCA earphone audio dropped out. In addition, after removing his CCA, the EV 1 crewmember reported small puddles of water had accumulated around the inside of each earmuff. The EV 2 crewmember used his backup CCA for EVA 3.

Airlock depressurization for the third EVA started at 045:14:30 G.m.t. (06:15:17 MET) and was completed at 045:14:42 G.m.t. (06:15:29 MET). EVA 3 began at 045:14:48 G.m.t. (06:15:35 MET) when the EMUs were transferred to internal battery power. The EVA was completed in 5 hours 25 minutes. The EVA was performed nominally and the EMU's, EVA tools, WVS and SSCS performed as expected.

All planned EVA 3 tasks were successfully accomplished. These were:

1. Transfer spare S-Band Antenna Support Assembly (SASA);
2. Removal of starboard radiator winches;
3. PMA 2-to-U. S. Laboratory umbilical cleanup; and
4. Development Test Objective (DTO) 675 (Incapacitated Crewmember Translation Demonstration).

Several get-ahead tasks for future mission EVAs were accomplished during the third EVA. Additionally, the inspection and photography of the QD (which leaked during the first EVA), and the de-mating, inspection and re-mating of the P613 electrical connector (with the partially failed bail observed during EVA 2) was performed during EVA 3. All planned EVA tasks for the STS-98 mission were successfully completed.

Several EVA hardware items were transferred to the ISS for future flights. Transferred items include the following:

1. One EMU to be used during the following three ISS missions (5A.1, 6A, and 7A);
2. Ammonia vent tool; and
3. Fluid line anchor patch hardware and trace gas analyzer that were used for repairing external leaks in fluid lines.

## REMOTE MANIPULATOR SYSTEM

The remote manipulator system (RMS) performed nominally on this 59<sup>th</sup> flight of the RMS during the Space Shuttle Program. The major tasks for the RMS were the relocation of PMA 2, installation of the U. S. Laboratory (Destiny) on to the International Space Station (ISS), and support three extravehicular activities (EVA's). All of the planned activities were successfully completed.

The successful checkout of the RMS was completed nominally. A payload bay survey, using the RMS cameras, was performed beginning at 039:16:57 G.m.t. (00:17:43 MET). Upon completion of the survey, the arm was cradled and powered down at 039:17:35 G.m.t. (00:18:21 MET).

The RMS was powered up at 041:13:47 G.m.t. (02:14:34 MET). The RMS successfully grappled pressurized mating adapter (PMA) 2 on Node 1 at 041:14:12 G.m.t. (02:14:59 MET) and maneuvered PMA 2 to the Z1 truss pre-installation position at 041:16:00 G.m.t. (02:16:47 MET). PMA 2 was installed onto the Z1 truss at 041:17:00 G.m.t. (02:17:47 MET) and was ungrappled by the RMS. The U.S. Laboratory was grappled in the payload bay at 041:17:22 G.m.t. (02:18:00 MET) and unberthed. Following the pitch-around maneuver, the U. S. Laboratory was attached to Node 1 at 041:19:00 G.m.t. (02:19:47 MET). Nominal RMS operations continued throughout the EVA. The RMS cradle and power-down was completed at 041:21:32 G.m.t. (02:22:19 MET).

The RMS was powered up and un-cradled at 043:15:14 G.m.t. (04:16:00 MET) to support the second EVA. PMA 2, which was mated to the Z1 truss, was grappled and demated at 043:15:37:12 G.m.t. (04:16:24:10 MET). PMA 2 was positioned in the pre-installation position at the U. S. Laboratory location at 043:16:55 G.m.t. (04:17:41:58 MET) and then was successfully berthed to the U. S. Laboratory at 043:17:30:25 G.m.t. (04:18:17:23 MET). After releasing PMA 2, the RMS provided EVA support. The RMS was parked in the pre-cradled position in preparation for a radiator survey that was performed during flight day 7.

The RMS performed the P6 radiator survey starting at 044:22:49 G.m.t. (05:23:36 MET). Only two survey positions were completed. The ISS starboard radiator was surveyed at 044:22:57 G.m.t. (05:23:44 MET) and the ISS aft radiator was surveyed at 045:00:04 G.m.t. (06:00:51 MET). The RMS was left in the pre-cradled position for flight day 8 activities.

The RMS supported the EVA 3 tasks; SVS target inspection, and inspection of P6 starboard radiator. The RMS was de-selected at 045:20:12 G.m.t. (06:20:59 MET).

## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The Shuttle PD100 digital camcorder was brought to the ISS U. S. Laboratory module for use on flight day 5. The camcorder was producing a poor quality video. The downlink image was reversed with apparent bad synchronization information and was unusable. The problem appears to be with the ground connection inside the multi-pin video/audio input/output (I/O) connector on the camcorder. The camcorder was stored for the remainder of the flight.

Prior to airlock repressurization following EVA 2, the EV 2 crewmember's left-side CCA earphone audio dropped out. In addition, after removing his CCA, the EV 1 crewmember reported small puddles of water had accumulated around the inside of each ear muff. The EV 2 crewmember used his backup CCA for EVA 3.

During the mating of PMA 2 to the U. S. Laboratory, the bay-9 keel-camera failed. This keel camera is a Videospection camera, which has the 156 white-light emitting diode (LED) illuminator. The circuit breaker was found closed, and no current spikes were noted in the data. It was verified that the bus that provides power to the camera was functional. Since a workaround procedure was available and this camera was not required for the remainder of the mission, no on-orbit troubleshooting was performed. However, the crew was asked to power up aft power control unit (APCU) 1 to verify the integrity of the cabin payload bus. The power-up of the APCU was successfully completed.

While setting up the Proshare system for a private medical conference (PMC) video-conference, the crew reported that the video from the mini camera would not consistently display on the Proshare local video window. When the crew wiggled the cable at the mini camera connector end, the video would appear for a short time, but when the crew released the cable, the video would again disappear. Later video conferences used the camcorder for the video input to the Proshare PGSC.

At 048:00:59 G.m.t. (09:01:46 MET), the crew reported that the ergometer "power ref" switch had stopped working. This switch is used to control the level of resistance of the ergometer during exercise. The crew said that they were still able to control resistance manually.

The crew reported that a warning was received from the Autocheck program on the Proshare payload and general purpose computer (PGSC) that several of the hardware settings were not in the normal flight configuration. The Autocheck program prompted the crew, asking if AutoXD should be run in an attempt to fix this problem. Yes was selected and the Autocheck was unsuccessful in correcting the error. After a number of other corrective procedures were run without success, the hard drive of the PGSC was exchanged with the backup PGSC hard drive. The AutoXD procedure was run again and the PGSC returned to normal operation. The PGSC was returned to JSC for troubleshooting.

The crew reported that the SpOC update floppy diskette could not be read with the RPOP PGSC floppy drive. The problem could be with the floppy diskette or the floppy drive. This problem did not impact operations because the updates are sent to the RPOP PGSC using the network. The SpOC update floppy diskette is used for

contingency, if the network were to fail. Also, all of the PGSC's have a floppy drive that could be used as a backup to the RPOP PGSC. Troubleshooting was performed at JSC during the postflight turnaround period.

## **CARGO INTEGRATION**

Integration hardware performance was nominal throughout the mission.

## POSTLAUNCH LAUNCH PAD INSPECTION

The postlaunch inspection of the main launch platform (MLP) -2, Launch Pad A, Fixed Service Structure and Rotating Service Structure was successfully completed approximately 14 hours after the launch. No flight hardware was found. The inspection was delayed because the bus (4A) dropped out immediately after launch. This loss resulted in the launch of four MLP hardware interface modules (HIM's).

The Orbiter liftoff lateral acceleration data to predict stud hang-ups indicated that a hang-up had not occurred. Also, no signs of stud hang-ups were detected in the visual inspection of the four south posts. Erosion was typical for the north posts. Erosion was typical for the north posts. The hold down post (HDP) 6 shoe shim material was debonded from the right-hand side. North holddown post blast covers and the T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt gaseous nitrogen purge lines were intact, however, the protective tape layering was partially eroded.

The LO<sub>2</sub> and LH<sub>2</sub> tail service masts (TSM's) appeared undamaged and the bonnets were closed properly. The MLP deck was in generally good shape.

The GH<sub>2</sub> vent line latched in the number eight tooth of the latching mechanism. The ground umbilical carrier plate (GUCP) 7-inch quick disconnect (QD) sealing surface exhibited no damage.

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 vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Large pieces of roofing material came off from the top of the power sub-station building just west of the pad apron. This material impacted a trailer near the launch pad, causing major damage to the trailer.

Overall, the damage to the FSS/RSS and Main Launch Platform appeared to be minimal. Minimal debris was noted of the pad apron and FSS.

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

### **DEVELOPMENT TEST OBJECTIVES**

**DTO 261 - International Space Station On-Orbit Load Verification** - The International Space Station (ISS) On-Orbit Loads Verification test was successful in collecting structural dynamics data for load model validation and postflight load reconstructions. The internal wireless instrumentation system (IWIS) performed well, providing Node acceleration data and strain measurement data for the reboost and U. S. Laboratory installation events. All data files were downlinked and were found to be complete. The Shuttle video data were successfully recorded, and these data showed both the U. S. Photovoltaic tip responses as well as the starboard and forward electrical power system (EPS) radiator tip responses during reboost. The postflight assessment of the data is underway.

**DTO 263 - Shuttle Automatic Reboost Tuning** - The Shuttle automatic reboost was successfully performed with no changes to the procedure. Prior to the reboost, the reboost tuning Development Test Objective (DTO) was performed. The test firing was performed in accordance with the procedure and no anomalies occurred. The structural dynamics from the test firing were measured by the Shuttle inertial measurement units (IMU's), as planned. The quality of the data was good and the data allowed determination of the primary pitch natural frequency of the mated Shuttle and ISS. Postflight assessment of the data is in work.

**DTO 675 - Incapacitated EVA Crewmember Translation** - The incapacitated EVA crewmember translation DTO was successfully performed on flight day 8. Data from this exercise are being evaluated during the postflight period.

**DTO 700-14 - Single String Global Positioning System** - The DTO configuration of a miniature air-to-ground receiver (MAGR) Global Positioning System (GPS) without a payload and general support computer (PGSC) was successfully performed on flight day 10 and 11. Data are being evaluated during the postflight period.

**DTO 805 - Crosswind Landing Performance** - This DTO of opportunity was not performed because crosswinds were not of the magnitude required.

### **DETAILED SUPPLEMENTARY OBJECTIVES**

**DSO 496 - Individual Susceptibility to Post Spaceflight Orthostatic Intolerance** - This Detailed Supplementary Objective (DSO) was performed during the preflight and postflight periods. Evaluation of the data and the results will be published in separate documentation.

**DSO 498 - Spaceflight and Immune Function** - This Detailed Supplementary Objective (DSO) was performed during the preflight and postflight periods. Evaluation of the data and the results will be published in separate documentation.

**DSO 802 - Educational Activities** - The activities in support of this DSO were performed on flight day 9.

## **PHOTOGRAPHY AND TELEVISION ANALYSIS**

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

A total of 43 high-speed 16mm films, large format 35mm tracking films and videos were reviewed. The review of the launch photography isolated three significant items, which are as follows:

1. Several pieces of light-colored debris (at least five or six) were seen near the Orbiter left wing and port orbital maneuvering subsystem (OMS) pod approximately 4.5 seconds prior to Solid Rocket Booster (SRB) separation. Two pieces of debris, one on the right side of the vertical stabilizer and one on the left side of the vertical stabilizer, were seen moving in an +Y and -Y direction, respectively, away from the vehicle at 3.4 seconds prior to SRB separation. This debris may have been associated with the tile damage to the leading edge of the vertical stabilizer seen on the flight day 1 video.
2. Similar to STS-97, body flap motion was very apparent during the first stage of ascent.

Neither of these observations had any effect of the mission.

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

No on-orbit photography or videos were analyzed. The normal photography of the External Tank (ET) was not obtained because the vehicle was in darkness at the time of ET separation.

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

Six videos and seven films of landing were received and screened. No significant findings or anomalies were noted in the approach, landing, and rollout video and film views screened. All observations were nominal.

**TABLE I.- STS-98 SEQUENCE OF EVENTS**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	038:23:08:11.091 038:23:08:12.157 038:23:08:13.028
SRB HPU Activation <sup>a</sup>	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	038:23:12:33.990 038:23:12:34.150 038:23:12:34.310 038:23:12:34.470
Main Propulsion System Start <sup>a</sup>	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	038:23:12:55.430 038:23:12:55.559 038:23:12:55.674
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	038:23:13:01.990
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	038:23:13:06.019 038:23:13:06.034 038:23:13:06.050
Throttle down to 72 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	038:23:13:35.139 038:23:13:35.154 038:23:13:35.170
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	038:23:13:48.739 038:23:13:48.754 038:23:13:48.770
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	038:23:14:05
Both RSRM's Chamber Pressure at 50 psi <sup>a</sup>	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	038:23:15:02.07 038:23:15:02.43
End RSRM <sup>a</sup> Action <sup>a</sup> Time	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	038:23:15:05.20 038:23:15:05.60
SRB Physical Separation <sup>a</sup>	LH rate APU turbine speed - LOS	038:23:15:07.55
SRB Separation Command	SRB separation command flag	038:23:15:08
OMS Assist Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	038:23:15:17.7 038:23:15:17.8
OMS Assist Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	038:23:17:00.1 038:23:17:00.4
Throttle Down for 3g Acceleration <sup>a</sup>	ME-3 command accepted ME-2 command accepted ME-1 command accepted	038:23:20:22.654 038:23:20:22.664 038:23:20:22.674
3g Acceleration	Total load factor	038:23:20:59.1
Throttle Down to 67 Percent Thrust <sup>a</sup>	ME-3 command accepted ME-2 command accepted ME-1 command accepted	038:23:21:18.655 038:23:21:18.664 038:23:21:18.674
SSME Shutdown <sup>a</sup>	ME-3 command accepted ME-2 command accepted ME-1 command accepted	038:23:21:25.095 038:23:21:25.104 038:23:21:25.114

<sup>a</sup>MSFC supplied data

**TABLE I.- STS-98 SEQUENCE OF EVENTS  
(Continued)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
MECO	MECO command flag MECO confirm flag	038:23:21:25 038:23:21:27
ET Separation	ET separation command flag	038:23:21:44
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	038:23:37:25.842 038:23:27:52.026 038:23:28:14.969
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	038:23:56:47.5 038:23:56:47.6
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	038:23:58:10.4 038:23:58:10.5
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	039:00:59:42 039:01:00:59
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	039:02:49:09.4 039:02:49:09.5
OMS-3 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	039:02:50:34.8 039:02:50:35.1
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	040:12:46:47.6 040:12:46:47.7
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	040:12:47:02.0 040:12:47:02.1
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	040:14:24:25.2 N/A
OMS-5 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	040:14:24:39.4 N/A
Initial ISS Contact	Initial contact	040:16:14:03
Docking with ISS	Docking ring final position	040:17:00:00
Cabin Depressurization (end)	Cabin pressure	040:23:53:24
Debris Avoidance Maneuver	As reported	041:11:48:02
PMA 2 Grappled	Payload captured	041:14:12:16
Airlock Depressurization (end)	Airlock differential pressure no. 1	041:15:45:50
Begin First Extravehicular Activity	Airlock differential pressure no. 1	041:15:51:00
PMA 2 Ungrappled	Payload released	041:17:09:44
U. S. Laboratory Grapple	Payload captured	041:17:22:23
U. S. Laboratory Ungrappled	Payload released	041:20:40:49
End First Extravehicular Activity	Airlock differential pressure no. 1	041:23:28:00
Cabin Re-pressurization	Cabin pressure	042:00:53:13
First Reboost Maneuver Start	As reported	042:17:13
Second Reboost Maneuver Start	As reported	042:18:18
Cabin Depressurization	Cabin pressure	042:23:02:33
PMA 2 Grappled	Payload captured	043:15:37:03

**TABLE I.- STS-98 SEQUENCE OF EVENTS  
(Continued)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
Begin Second Extravehicular Activity	Airlock differential pressure no. 1	043:15:59:00
PMA 2 Ungrappled	Payload released	043:17:43:42
End Second Extravehicular Activity	Airlock differential pressure no. 1	043:22:48:35
Third Reboost Maneuver Start	As reported	044:15:53:02
Fourth Reboost Maneuver Start	As reported	044:20:06:02
Begin Third Extravehicular Activity	Airlock differential pressure no. 1	045:14:48:00
End Third Extravehicular Activity	Airlock differential pressure no. 1	045:20:13:00
Cabin Repressurization	Cabin pressure	045:20:25:11
Fifth Reboost Maneuver Start	As reported	045:23:08:03
Sixth Reboost Maneuver Start	As reported	046:15:23:13
Seventh Reboost Maneuver Start	As reported	046:16:56:13
Undocking from ISS	Undock complete	047:14:06:00
Flight Control System Checkout		
APU Start	APU 1 GG chamber pressure	048:14:39:50.602
APU Stop	APU 1 GG chamber pressure	048:14:45:54.995
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	049:14:05:39 049:14:07:36
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	049:17:59:44 049:18:01:03
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	050:15:03:33 050:15:05:11
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	050:18:23:28 050:18:24:47
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	051:15:18:22 051:15:19:55
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	051:19:22:08.846 051:19:48:45.840 051:19:48:46.757
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	051:19:27:20.1 051:19:27:20.2
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	051:19:30:04.5 051:19:30:04.6
Entry Interface (400K feet)	Current orbital altitude above	051:20:01:46
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Management	Major mode change (305)	051:20:26:45
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	051:20:33:06 051:20:33:06
Drag Chute Deployment	Drag chute deploy 1 CP volts	051:20:33:08.2

**TABLE I.- STS-98 SEQUENCE OF EVENTS  
(Concluded)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
Main Landing Gear Weight on Wheels	LH MLG weight on wheels	051:20:33:13
	RH MLG weight on wheels	051:20:33:14
Nose Landing Gear Contact	NLG LH tire pressure 1	051:20:33:18
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	051:20:33:18
Drag Chute Jettison	Drag chute jettison 1 CP Volts	051:20:33:35.5
Wheel Stop	Velocity with respect to runway	051:20:34:02
APU Deactivation	APU-1 GG chamber pressure	051:20:48:09.201
	APU-2 GG chamber pressure	051:20:48:24.625
	APU-3 GG chamber pressure	051:20:48:33.778

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

No.	Title	Reference	Comments
STS-98-V-01	LH <sub>2</sub> Engine 1 Prevalve (PV4) Open Position Indicator B Failed Off	038:23:15:43 G.m.t. 00:00:02:041 MET	<p>The LH<sub>2</sub> engine 1 prevalve (PV4) open position indicator B failed off between liftoff and MECO. The indication went off at 038:23:15:43 G.m.t. (00:00:02:41 MET) and recovered 2 minutes 4 seconds later. After completion of the LH<sub>2</sub> dump, the position indicator failed off again at 038:23:28:30 G.m.t. (00:00:15:28 MET). The measurement subsequently recovered. The prevalves remained in the open position for the remainder of the mission, and this failure had no effect on MPS operations.</p> <p>KSC: Postflight troubleshooting will be performed during turnaround activities.</p> <p>During entry, both the Commander and Pilot observed a runway misalignment with their HUD. The Pilot's HUD was about 600 feet to the right of the runway and the Commander's HUD was about 300 feet to the right of the runway. At the crew debriefing, the Pilot stated that the misalignment was observable down to 7000 feet and was off by 400 feet.</p>
STS-98-V-02	Commander and Pilot HUD Misalignment	051:00:00:00 G.m.t. 12:00:46:58 MET	

## DOCUMENT SOURCES

In an attempt to define the official as well as the unofficial sources of data for the STS-98 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-98 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.

ACQ	acquisition
AFRSI	advanced flexible reusable surface insulation
ALPS	airlock power supply
APCU	aft power controller unit
APFR	articulated portable foot restraint
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
AVCO	air velocity closeout
BET	bending effect temperature
BPSMU	battery-powered speaker/microphone unit
CBM	common berthing mechanism
CCA	communications carrier assembly
CID	circuit interrupt device
CMG	control moment gyro
CPM	cell performance monitor
CSR	Customer Support Room
CWC	contingency water container
D&C	displays and controls
DR	Discrepancy Report
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
$\Delta V$	differential velocity
EAFB	Edwards Air Force Base
ECLSS	environmental control and life support system
EEATCS	Early External Active Thermal Control System
EGT	exhaust gas temperature
EI	entry interface
EMU	extravehicular mobility unit
EO	ET/Orbiter
EOM	end-of-mission
EPDC	electrical power distribution and control
EPS	Electrical Power System
e.s.t.	eastern standard time
ET	External Tank
EV1, EV2	extravehicular crewmember designations
EVA	extravehicular activity
FCE	flight crew equipment
FCMS	fuel cell monitoring system
FCP	fuel cell powerplant
FCS	flight control system/subsystem
FDA	fault detection and annunciation
FEA	floodlight electronic assembly

FES	flash evaporator system
FSE	flight support equipment
FSS	Fixed Service Structure
ft/sec	feet per second
GEI	ground environmental instrumentation
GFE	Government furnished equipment
GG	gas generator
G.m.t.	Greenwich mean time
GN&C	guidance navigation and control
GN <sub>2</sub>	gaseous nitrogen
GO <sub>2</sub>	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
GSE	ground support equipment
GUCP	ground umbilical carrier plate
HDP	holddown post
HEPA	high efficiency particulate accumulator
HIM	hardware interface module
HUD	heads-up display
IMAX	Camera system
IMU	inertial measurement unit
I/O	input/output
I <sub>sp</sub>	specific impulse
ISS	International Space Station
IV	intravehicular
IWIS	Internal Wireless Instrumentation System
JSC	Johnson Space Center
keas	knots estimated air speed
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LED	light emitting diode
LH <sub>2</sub>	liquid hydrogen
LMSO	Lockheed Martin Space Operations
LO <sub>2</sub>	liquid oxygen
LP	Launch Package
MAGR-S	Miniature Air to Ground Receiver-Shuttle
Max q <sub>α</sub>	maximum dynamic pressure
MBM	manual berthing mechanism
MC	midcourse correction (rendezvous maneuver)
MCC	Mission Control Center
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MET	mission elapsed time
MLP	Mobile Launch Platform
mmHg	millimeter mercury
MPS	main propulsion system

MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NC, NCC	circularization maneuver (rendezvous maneuver)
NC3, NC4	circularization maneuver (rendezvous maneuver)
NEOM	nominal end-of-mission
nmi.	nautical mile
NPSP	net positive suction pressure
O <sub>2</sub>	oxygen
OA	Orbiter Aft
ODS	Orbiter Docking System
OI	
OMDP	Orbiter Maintenance Down Period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
ORU	orbital replacement unit
OV	Orbiter Vehicle
PBA	portable breathing apparatus
PCA	pressure control assembly
PDGF	power and data grapple fixture
PFE	portable fire extinguisher
PGME	Propylene Glycol Monomethyl Ether
PGSC	payload and ground support computer
PMA	pressurized mating adapter
PMBT	propellant mean bulk temperature
PMC	private medical conference
ppCO <sub>2</sub>	partial pressure carbon dioxide
ppm	parts per million
PRSD	power reactant storage and distribution
psia	pound per square inch absolute
psid	pound per square inch differential
QD	quick disconnect
RCS	reaction control subsystem
RMS	Remote Manipulator System
RPC	remote power controller
RSRM	Reusable Solid Rocket Motor
RSS	rotating service structure
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SCU	service and cooling umbilical
SLF	Shuttle Landing Facility
SLWT	super lightweight tank
SM	service module
S/N	serial number
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSCS	Space-to-Space Communications System
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
SUPA	Solid Urine Pretreat Assembly

SWAR	Sea water activated release
TI	transfer initiation (rendezvous maneuver)
TPS	thermal protection system/subsystem
TVC	thrust vector controller
TVIS	treadmill vibration isolation system
TSM	tail service mast
V	Volts
VAB	Vehicle Assembly Building
WCS	waste collection system
WSB	water spray boiler
WSM	window shutter mechanism
WTR	watertight reusable
WVS	Wireless Video System