

# **STS-106 SPACE SHUTTLE MISSION REPORT**

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November 2000



**National Aeronautics and  
Space Administration**

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

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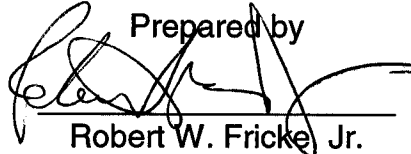
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STS-106

SPACE SHUTTLE

MISSION REPORT

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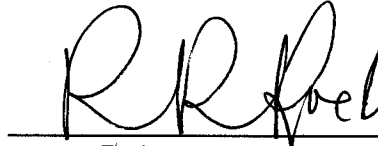
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## INTRODUCTION

The Space Transportation System (STS)-106 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified. The report also summarizes the activities of the STS-106 mission, and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this ninety-ninth mission of the Space Shuttle Program. STS-106 was the seventy-fourth flight since the return to flight, and the twenty-second flight of the OV-104 (Atlantis) vehicle. The STS-106 flight was the fourth mission to the International Space Station (ISS) to perform maintenance and logistics tasks.

The flight vehicle consisted of the OV-104 Orbiter; an ET, which was the seventh Super Lightweight Tank (SLWT), and it was designated ET-103; 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 B1102. The two RSRMs were designated RSRM-75 with one installed in each SRB. The individual RSRMs were designated as 360L075A for the left SRB and 360L075B for the right SRB.

The primary objectives of the STS-106 flight were to change the Zvezda [Service Module (SM)] from the launch to the flight configuration by installing six ground repressurization inlet caps, removing the fire extinguisher launch restraint bolts and activating the gas masks in the module for the Expedition 1 crew. In addition, the crew performed various logistics activities, which included unloading the Progress cargo vessel into the ISS and transferring equipment, supplies and water from the Space Shuttle to the ISS. The TORU docking unit and the aft docking probe were removed from the Zarya [Functional Cargo Block (FGB)] module. The crew replaced two batteries on the FGB, installed three batteries and associated electronic equipment on the SM, installed voltage converters in the SM and performed other electrical work in the SM. A spacewalk was performed to connect power, data and communication cables between the SM and the FGB, as well as install a magnetometer. A treadmill and related equipment was installed. Other tasks included taking air-monitoring measurements, monitoring the formaldehyde buildup, replacing three passive dosimeters and returning the three replaced units, as well as installing four passive dosimeters in the SM. Acoustic measurements were taken in the SM. The Space Integrated Global Positioning System/Inertial Navigation System (SIGI) was tested. The toilet facility was installed in the SM. Reboost maneuvers of the ISS as well as a fly-around of the ISS were performed. In addition, the secondary objectives of this flight were to perform the requirements for Space Experiment Module (SEM-08), Get-Away Special (GAS) Payload G-782, and Commercial Generic Bioprocessing Apparatus (CGBA).

The STS-106 flight was planned as a 11-day plus 1-day, plus 2-contingency-day flight. Consumables did allow the mission to be extended to the desired twelfth day. 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 seven-person crew of the STS-106 flight consisted of Terrence Wilcutt, Col., U. S. Marine Corps, Commander; Scott D. Altman, CDR, U. S. Navy, Pilot; Edward T. Lu, Ph. D., Civilian, Mission Specialist 1; Richard A. Mastracchio, Civilian, Mission Specialist 2, Daniel C. Burbank, Lt. Cdr., U. S. Coast Guard, Mission Specialist 3; Yuri I. Malenchenko, Col., Russian Air Force, Mission Specialist 4, and Boris V. Morukow, M.D., Ph. D., Civilian, Russian Cosmonaut, Mission Specialist 5. STS-106 was the fourth space flight for the Commander, the second space flight for Pilot and Mission Specialist 1, and the first space flight for Mission Specialist 2, Mission Specialist 3, and Mission Specialist 5. This was also the first space flight on the Space Shuttle for Mission Specialist 4; however, he had previously flown as Commander of Mir 16 to the Russian Mir Space Station.

## MISSION SUMMARY

The STS-106 mission was launched on a 51.6-degree inclination as planned at 252:12:45:47.008 G.m.t. (September 8, 2000, at 8:45 a.m. e.d.t.) with no unscheduled holds during the flawless countdown. The launch phase was nominal in all respects with no problems noted. The orbital maneuvering subsystem (OMS) Assist maneuver was performed during ascent at 252:12:47:59.12 G.m.t. (00:00:02:12 MET). The maneuver was 15.20 seconds in duration, and the OMS performed satisfactorily. Main engine cutoff (MECO) occurred at 252:12:54:13 G.m.t. (00:00:08:26 MET).

The OMS 1 maneuver was not required because of the nominal ascent trajectory. The OMS 2 maneuver was performed at 252:13:29:47.112 G.m.t. (00:00:44:00.1 MET). The OMS 2 maneuver was 53.60 seconds in duration and the differential velocity ( $\Delta V$ ) was 80.9 ft/sec. The orbit was 85 by 177 nautical miles (nmi.) following the maneuver.

A determination of vehicle performance was made using vehicle acceleration and preflight propulsion prediction data. The average flight-derived engine specific impulse was 453.0 seconds as compared to the SSME tag value of 452.21 seconds at the 104.5-percent level.

The payload bay doors were opened at 252:14:23:30 G.m.t. (00:01:37:43 MET). All voltages were nominal and the motors opened the doors within the nominal time.

During the review of high-rate ascent data, an electrical spike of approximately 60 amperes and 0.16-second duration was noted on aft main bus B and was also seen on all three fuel cell currents at 252:12:54:35.6 G.m.t. (00:00:08:48.6 MET) (Flight Problem STS-106-V-01). The event occurred approximately 4 seconds after External Tank (ET) separation. There was no reported loss of function as a result of the spike. A team was organized to determine the cause of the spike.

Several actions were completed in an effort to identify the cause of the spike. One of those actions was a list of the Orbiter equipment (functions) powered by the bus that was developed along with the criteria that could be used to exonerate functions as the potential cause of the spike. This analysis indicated that all but three functions could be exonerated. Those functions were ET 16-mm separation camera 2, the auxiliary power unit (APU) gas generator (GG) injector water B heaters, and the OMS crossfeed line B heaters. Data review indicated that the most probable source of the spike was in the ET 16-mm separation camera 2 circuit. During the postflight turnaround operations, the 15-ampere protective camera fuse in the aft power control assembly (APCA) 2 was found blown, and the camera was jammed with 68 feet of film.

During the post-insertion star tracker activation at 252:14:42:00 G.m.t. (00:01:56:13 MET), the -Z star tracker annunciated a Power Supply Fail built in test equipment (BITE) indication, along with a Tracker Fail BITE and a Magnitude Error BITE (Flight Problem STS-106-V-02). The star tracker was not bypassed and it showed signs of off-nominal operation (no target suppression or bright object indications while pointed at the lit earth). The BITE indications cleared simultaneously without any action from the crew. A self-test was performed. The self-test failed with indications that the bright object sensor/shutter-close functions were not operating. The star tracker was powered off to prevent possible sunlight damage during subsequent maneuvers.



On flight day (FD) 2, the -Z star tracker was activated during a scheduled inertial measurement unit (IMU) alignment and similar BITE indications were again observed. The star tracker was powered down for the remainder of the mission. The Commander's heads up display (HUD) was calibrated and verified to ensure a backup was available for IMU alignments. The -Y star tracker performed nominally throughout the mission and there was no mission impact from the loss of the -Z star tracker.

The following table shows the maneuvers that were performed to complete the rendezvous with the International Space Station (ISS).

#### RENDEZVOUS MANEUVERS

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Firing time, sec	Orbit, nmi.
NC-1 (OMS)	252:16:30:22.9 00:03:44:35.9	121.3	78.6	152.1 X 178.3
NC-2 (OMS)	253:04:45:56.7 00:17:00:09.7	24.7	38.8	160.9 X 190.4
NC-3 (RCS)	253:11:36:53 00:22:51:06	3.2	13.3	162 X 191
NC (OMS)	254:01:26:31 01:12:40:44	48.7	31.4	186 x 196
NCC (RCS)	254:02:00:52 01:13:15:05	0.9	-	185.7 x 196.1
TI (OMS)	254:02:58:33 01:14:12:46	9.3	10.6	187.2 x 198.5
MC-1 (RCS)	254:03:18:32 01:14:32:45	0.7	3.0	187.1 x 198.5
MC-2 (RCS)	254:03:51:14 01:15:05:27	0.8	4.0	187.0 x 198.7
MC-3 (RCS)	254:04:08:15 01:15:22:28	1.0	3.0	187.0 x 198.7
MC-4 (RCS)	254:04:18:14 01:15:32:27	2.5	7.0	187.1 x 199.5

The extravehicular mobility unit (EMU) checkout was performed and three good EMU's were verified ready for the scheduled extravehicular activity (EVA). The checkout involved communications testing between the three EMUs (EV3, EV2 and EV1), the Space-to-Space Orbiter Radio (SSOR) and the Mission Control Center (MCC). Audio between EV3 and MCC was broken during the first set of checkouts. The cause of the broken communications was believed to be the result of poor microphone placement causing intermittent voice-operated transmission (VOX) and was corrected during subsequent voice checks. The space-to-space communications system (SSCS) checks were successfully completed and verified ready to support the EVA.

During the previous flight of the SSCS, some problems were noted in the SSCS operation. During this mission, the overall performance of the SSCS was nominal with good audio quality, and no network upsets or frame synchronization dropouts were noted.

The remote manipulator system (RMS) was powered up at 253:06:32:00 G.m.t (00:17:46:13 MET) for the start of RMS checkout. The checkout, which included testing of the end effector, was completed successfully at 253:07:00 G.m.t. (00:18:14:13 MET). The RMS was then used to perform a payload bay survey. The RMS was powered down at 253:08:28:00 G.m.t. (00:19:42:13 MET).

The Orbiter Docking System (ODS) docking ring extension was completed satisfactorily in preparation of the docking with the ISS.

The crew reported that upon initially applying power to the ODS centerline camera, the camera failed to power up (Flight Problem STS-106-V-05). The crew switched from the primary to the backup harness assembly, and the camera was successfully powered up. No other problems with powering the camera were reported.

Following power up of the ODS centerline camera, the crew reported that the centerline camera crosshair was slightly misaligned in the X-axis. This condition was evaluated and it was determined that docking could be accomplished using the nominal procedures without any corrective action.

The Ku-Band radar acquired the ISS at 254:02:13 G.m.t (01:13:27 MET) at a range of 145,000 feet (approximately 24 nmi.) and tracked the ISS to a range of 320 feet when the Ku-Band was placed in the Communications mode to provide downlink television of the docking. The performance of the Orbiter trajectory control sensor (TCS) in support of the docking with the ISS was nominal.

The Orbiter/ISS capture occurred at 254:05:51:16 G.m.t. (01:17:05:29 MET). Docking ring retraction started at 254:05:57:37 G.m.t. (01:17:11:50 MET) and was completed 4 minutes 39 seconds later. Hook closure was activated at 254:06:02:03 G.m.t. (01:17:16:16 MET) and was completed approximately 2 minutes 22 seconds later. The ODS performance was nominal.

During ring retraction, a brief period of ring misalignment was observed. The misalignment was caused by a lag in the command and the physical disengagement of high-energy damper (HED) 3. Residual structural loads can cause the lag, which can result in ring misalignment during retraction. Once all of the HEDs physically disengaged, the ring went back into alignment. Docking simulations were used to duplicate the ring misalignment that was observed in flight. This behavior is an inherent characteristic of the docking mechanism due to the HED clutch design. It is understood and not considered to be a problem.

Following the rendezvous and docking, the crew reported that a damaged advanced flexible reusable surface insulation (AFRSI) thermal blanket was observed on the top of the left OMS pod. The RMS was used to provide video, which was recorded for analysis. From the video, it was determined that the trailing edge of an AFRSI blanket had a tear approximately 4 inches long and 1 inch wide. The AFRSI blanket was identified and repair history indicated that this blanket had a fabric patch repair installed at that location. Thermal analysis of the damage site determined that the maximum temperature on a nominal entry would not exceed 500 °F. It was determined that no structural damage would occur given that with a maximum outer mold line temperature of 500 °F, the presence of the inner mold line fabric and the bondline room temperature vulcanizing (RTV) adhesive alone is sufficient to prevent structural over-temperature.

Also, aerodynamic loading that could lead to further blanket damage does not occur until after the peak heating period.

The planned EVA was completed in 6 hours and 14 minutes. The EVA was successful in that all planned tasks were completed satisfactorily, and the EVA was completed 16 minutes ahead of the planned schedule. All EMU systems and EVA tools performed nominally, and no anomalies or problems were noted.

All RMS operations were nominal during activities prior to the EVA and during the EVA.

As a result of the energy gains realized from the on-time liftoff, the flawless FD 3 rendezvous and docking as well as the conservation steps taken during the first four days of the mission, the decision was made to extend the mission from 11 to 12 days.

On FD 5, the crew ingressed the ISS and began transfer operations. During the docked operations, all preflight planned on-orbit task priorities were completed, including over 5399 lb of EVA and intravehicular (IVA) transfers from the Shuttle to the ISS and approximately 3000 lb of hardware transferred from the Progress to the ISS. In addition, 22 additional tasks were requested and completed.

The first of the ISS reboost maneuvers was initiated at 255:12:28:47 G.m.t. (02:23:43:00 MET) when reaction control subsystem (RCS) thrusters L1A and R1A were fired. There were a total of 36 +X primary-RCS-thruster reboost pulses with vernier-RCS-thruster attitude adjustments. The aft down-firing vernier-RCS thrusters had an average duty cycle of 60 seconds on and 40 seconds off. There were no thermal violations during the reboost maneuver, and the propellant usage was as expected. The  $\Delta V$  delivered was 11 ft/sec, and the final orbit was 201 by 191 nmi, an altitude increase of approximately 3.2 nmi.

At 256:00:35 G.m.t (03:11:49 MET) during Orbiter space vision system (OSVS) operations, the camera C iris was commanded closed but failed to close entirely. Partial closure was observed when commanded. After a series of ground commands, it was determined that the camera was usable, though it may be difficult to command, and should not affect the mission. The preliminary analysis of the videotape from this camera indicated that a problem might exist in the lens mechanism. The camera continued to operate for the remainder of the mission.

A blurred or fuzzy image was noted in the video downlinked from camera B. The blurred image was noted in the center of the lens. There was no mission impact.

At 256:12:04 G.m.t. (03:23:18 MET), the fuel cell 1 hydrogen flowmeter failed off-scale low. Monitoring of other fuel cell parameters provided sufficient insight to verify nominal health of the fuel cell. The flowmeter failure did not impact the mission.

The second ISS reboost maneuver was initiated at 258:06:13:17 G.m.t. (05:17:27:30 MET) when RCS thrusters L1A and R1A were fired. The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.2 nmi. The  $\Delta V$  delivered was 11.4 ft/sec and the final orbit was 203.4 by 195.3 nmi.

At approximately 258:22:27 G.m.t. (06:09:41 MET), a defective tape segment on operations recorder 1 track 2 at a tape location of 65-percent to 67-percent was detected. The data recording consistently dropped out for about 2 seconds at the affected segment. Further testing revealed that most tracks on the recorder tape had the same problem in the 61- to 68-percent region of the tape. For the remainder of the mission, whenever possible, operations recorder 2 was used as the loss-of-signal (LOS) recorder. However, when operations recorder 1 had to be used, the affected region of the tape was not used.

The third ISS reboost maneuver was initiated at 259:06:45:47 G.m.t. (06:18:00:00 MET) when RCS thrusters L1A and R1A were fired. The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.4 nmi. The  $\Delta V$  delivered was 11.4 ft/sec and the final orbit was 206.3 by 199.2 nmi.

The fourth and final ISS reboost maneuver was initiated at 261:03:25:47 G.m.t. (08:14:40:00 MET) when RCS thrusters L1A and R1A were fired. The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.3 nmi. The  $\Delta V$  delivered was 11.6 ft/sec and the final orbit was 208.6 by 203.8 nmi. The orbit of the ISS was raised approximately 13 nmi. by the four reboost maneuvers.

Undocking from the ISS was performed satisfactorily at 262:03:46 G.m.t. (09:15:00 MET). The initial separation from the ISS for the flyaround was initiated at 262:03:46:05 G.m.t. (09:15:00:18 MET) with a low Z-axis pulse of the Orbiter primary RCS. The initial separation from the ISS, the two-lap flyaround of the ISS, and the final separation from the ISS were all performed nominally. The final separation maneuver from the ISS was initiated at 262:05:34:26 G.m.t. (09:16:48:39 MET) using primary RCS thrusters L1A and R1A for 1.5 seconds resulting in a  $\Delta V$  of 3.0 ft/sec.

Normally, auxiliary power unit (APU) 1 is selected for flight control system (FCS) checkout; however, APU 3 was selected to accommodate the repositioning of the right Space Shuttle main engine (SSME) given that it was two pulse count modulation (PCM) counts away from the 2-degree step limit for repositioning. APU 3 was started at 263:01:57:43 G.m.t. (10:13:11:56 MET) and completed at 263:02:06:12 G.m.t. (10:13:20:25 MET) with a run-time of 8 minutes 29 seconds and approximately 16 lbm of fuel used. Thrust vector control (TVC) isolation valve 3 was opened for approximately 45 seconds and then closed to support SSME repositioning. Hydraulic, water spray boiler (WSB), FCS and APU performance on system 3 was nominal. APU lubrication oil spray cooling was required and approximately 0.28 lb of water was consumed. The APU lubrication oil return temperature was approximately 261 °F when spraying commenced.

On STS-101, during the secondary actuator check portion of FCS checkout, the speedbrake channel 3 secondary differential pressure ( $\Delta P$ ) exhibited an approximate 1.7-second delay when the positive stimulus was applied. The channel bypassed nominally during the negative stimulus portion of the test. As a result, during the STS-106 FCS checkout, the negative stimulus was run first and the test was repeated in each

direction. Performing the negative stimulus first was intended to determine whether the performance was dependent on the direction of the initial stimulus. The stimulus was repeated to confirm that the servo-valve responded properly in both directions after the first stimulus. The speedbrake channel 3 bypassed nominally during each portion of the test.

The RCS hot fire was performed at 263:03:06:00 G.m.t (10:14:20:13 MET) and ended at 263:03:12:00 G.m.t. (10:14:26:13 MET). All of the thrusters were fired at least twice for at least 0.480-second and each one demonstrated nominal performance. Prior to the hot fire, 23 of the 38 thrusters had been fired during the mission.

The payload bay doors were closed and latched for landing at 264:04:14:41 G.m.t. (11:15:28:54 MET). The deorbit maneuver for the first Kennedy Space Center (KSC) landing opportunity, a two-engine straight feed firing, was performed on orbit 185 at 264:06:50:07.3 G.m.t. (11:18:04:20.3 MET). The maneuver was 197.8 seconds in duration with a  $\Delta V$  of 340.1 ft/sec.

During the operations (OPS) 301 major mode vent door close operations, the left vent doors 8 and 9 close microswitch 2 failed to annunciate (Flight Problem STS-106-V-04). As a result, drive motor 2 came on and remained on until the software terminated operation after approximately 10 seconds. The close microswitch 2 performed nominally later during the OPS 304 major mode transition. During the post-landing vent door purge positioning command, the left vent door 8 and 9 purge microswitch 1 did not annunciate. This caused the drive motors to drive the left-hand doors to the closed position rather than the purge position. This problem did not impact the entry or post-landing operations, since the doors were in the correct position during entry and the right-hand doors were placed in the purge position post-landing.

Entry interface occurred at 264:07:25:01.3 G.m.t. (11:18:39:14.3 MET), and entry was completed satisfactorily. Main landing gear touchdown occurred on Shuttle Landing Facility (SLF) concrete runway 15 at 264:07:56:43.9 G.m.t. (11:19:10:56.9 MET) on September 20, 2000, at 3:56 a.m. e.d.t. The drag chute was deployed at 264:07:56:46.0 G.m.t. The nose gear touchdown occurred at 264:07:56:51.8 G.m.t. The drag chute was jettisoned at 264:07:57:23.3 G.m.t. Wheels stop occurred at 264:07:58:02.1 G.m.t. The rollout was normal in all respects. The flight duration was 11 days 19 hours 10 minutes 56 seconds. The APUs were shut down 22 minutes 10 seconds after landing.

The microwave scanning beam landing system (MSBLS) 2 initially locked on in range for a few seconds, and then lost lock for the remainder of the landing (Flight Problem STS-106-V-03). The unit provided nominal azimuth and elevation data during landing operations. The other MSBLS units operated satisfactorily in providing nominal range, azimuth and elevation data. This problem did not impact the landing operations.

## PAYLOADS AND EXPERIMENTS

On FD 5, the crew ingressed the ISS and began transfer operations. During the docked operations, all of the planned mission objectives (48 tasks) were completed successfully, plus an additional 22 tasks that were added and completed during the flight. These tasks resulted in 5399 lb of EVA and intravehicular (IVA) transfers from the Shuttle to the ISS and approximately 3000 lb of hardware transferred from the Progress to the ISS. The change-out of two of the Functional Cargo Block (FGB) battery systems was completed, and the FGB was left with all six-battery-block systems functioning nominally. Three Service Module (SM) battery-blocks were installed to complete the full SM set of battery systems. Seven of the eight SM battery block systems were functioning nominally when the crew undocked from the ISS. In addition, all of the ISS maintenance activities were successfully accomplished. The FGB electrical system was restored to full operation and all of the FGB limited-life items were replaced, and as a result, extended functionality of the systems is provided. The crew quarters were prepared for the arrival of the Mission 2R crew.

Several risk mitigation (RM) activities were performed that will provide future ISS flexibility for the nominal assembly sequence and for contingency planning. One extravehicular activity (EVA) was performed with all objectives accomplished. These included connecting cables between the FGB and the SM to provide power, data, and video communications. The orbit of the ISS was raised approximately 13.1 nmi. to the desired altitude via four Orbiter reaction control subsystem (RCS) reboost maneuvers, and this has preserved ISS propellants in preparation for the next (STS-92) mission. The ISS vehicle was left in a 208 by 204 nmi. orbit and should be in a 206 by 203 nmi. orbit for the STS-92 mission. The ISS Development Test Objective (DTO) 700-21 [Space Integrated Global Positioning System/Inertial Navigation System (SIGI) Operational Attitude Readiness (SOAR) was conducted, completing 100-percent of its pre-docked and docked activities.

In addition to all of the planned mission objectives, several objectives were completed for future missions that will allow those flights to dedicate more IVA and EVA time to their mission objectives. The ISS evaluation of this mission was that the mission was a total success. The total transferred weight is summarized as follows:

1. Shuttle to ISS – 5399 lb (includes 780 lb of drinking water);
2. ISS to Shuttle – 948 lb;
3. Weight increase to ISS – 4451 lb; and
4. Progress to ISS – 1300 lb of equipment (excess packing material and trash were reloaded into Progress).

There were 48 prioritized tasks approved for the STS-106 mission. Only 30 of these tasks could be scheduled during the preflight planning on an 11-day flight in the available on-orbit crew time. However, with the addition of the twelfth day and the efficiency of the crew operations, all of the original 48 approved tasks were completed as well as 22 additional tasks.

## **SPACEHAB**

The Spacehab Logistics Double Module (LDM) is 20-feet long, 14-feet wide and 11.2-feet high, and is a pressurized aluminum module that is carried in the Orbiter cargo bay. The Spacehab is connected to the Orbiter middeck by an access tunnel.

The LDM was designed to augment the Shuttle's middeck. The double module has a total cargo capacity of 10,000 lb and contains the systems necessary to support crewmembers, such as ventilation, lighting and limited power.

The Spacehab systems operated nominally for the mission duration. Versatility of the Spacehab stowage system proved to be invaluable for transition of cargo between the Orbiter and the ISS. A total of 4399 lb (101-percent of pre-planned) were transferred from the Spacehab to the ISS, and 789 lb (107-percent of pre-planned) were transferred from the ISS back to the Spacehab.

## **MIDDECK PAYLOADS**

### **Commercial Generic Bioprocessing Apparatus**

The Commercial Generic Bioprocessing Apparatus (CGBA) has experiments that explore the ways biological processes are affected by microgravity. Scientists also plan to use the CGBA to investigate growing human tissue for use in surgical procedures such as skin grafts and organ transports and in developing medicines.

The CGBA performed nominally throughout the mission. Its operation was monitored daily by the crew performing status checks. The results of this payload will be reported in other documentation.

### **Protein Crystal Growth Enhanced Gaseous Nitrogen Dewar**

The primary purpose of the Enhanced Gaseous Nitrogen (EGN) Dewar experiment was to demonstrate a low-cost platform for conducting a large number of experiments to determine the optimum conditions for growing large, high-quality protein crystals in space. The EGN Dewar was transferred to the ISS where the crystals will continue to grow until the package is returned to Earth on the next Shuttle mission.

## **CARGO BAY PAYLOADS**

### **Integrated Cargo Carrier**

The Integrated Cargo Carrier (ICC) is mounted in the cargo bay and expands the Orbiter's capability to transport cargo. The ICC is 8-feet long, 15-feet wide and 10-inches thick. The ICC is designed to carry 6000 lb of cargo.

The ICC performed satisfactorily in carrying logistics that were deployed during the EVA.

### **Get-Away Special 782**

The Get-Away Special (GAS) 782 payload (known as ARIA 1 to its sponsors) was an educational project to give elementary and high school students in the St. Louis, Mo. area an opportunity to be involved in hands-on space science. More than 300 students participated in this experiment.

This experiment was completely passive and did not require any power or crew interaction. The payload is self-contained within a standard-sealed 2.5 cubic foot GAS canister. There were no on-orbit operations associated with this payload. The results of this payload will be reported in other documentation.

### **Space Experiment Module**

A total of 13 experiments were flown on this eighth flight of the Space Experiment Module (SEM). The SEM is flown by NASA to provide increased access to space for students from kindergarten through college age. NASA provides the experiment modules or containers, which are placed in a standard 5-cubic-foot GAS canister in the cargo bay.

Since the first SEM flight in 1996, tens of thousands of students have flown experiments in space that they have created, designed and built with the help of teachers or mentors.

This experiment was completely passive and did not require any power or crew interaction. The results of this payload will be reported in other documentation.



## VEHICLE PERFORMANCE

### **SOLID ROCKET BOOSTERS**

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

Both SRBs were successfully separated from the vehicle at approximately T+ 123 seconds. Radar tracking indicated a normal descent to the splashdown in the Atlantic Ocean. Two of the 48 sea-water-activated release (SWAR) mechanisms failed to release its parachute riser upon contact with the sea-water. The failure mode for both SWARs was a failure of the primer to initiate the main pyrotechnic charge.

The postflight inspection of the launch complex revealed that both aft-skirt gaseous nitrogen (GN<sub>2</sub>) purge lines [Government furnished equipment (GFE)] were damaged. The left SRB side was severed and was found on the launch surface near the main launch platform (MLP) post no. 6. The right SRB side purge line was broken, but it remained attached by the flexible line braided shield. The time of occurrence was after liftoff plus 2 seconds as evidenced by the liftoff films.

Both SRBs were recovered and returned to the Port from where both SRBs were transported to Hangar AF for inspection and disassembly. The most significant finding of the inspection was that the enhanced data acquisition system (EDAS) failed to activate because of a broken battery-lead cable conductor.

No debonding of the thermal protection system on the frustums was found. All eight booster separation motor (BSM) heat shield covers had fully opened at SRB separation as evidenced by cover contact marks on the nozzles. However, numerous covers and attach rings had been bent by parachute riser entanglement. The left forward cover on the right-hand frustum had been pulled from the attach ring by the risers.

There were no areas of debonding thermal protection subsystem (TPS) or missing TPS on the forward skirts. The closeouts for the field joint protection system and the system tunnel covers were generally in good condition with no areas of debonding observed. The aft skirt external surface TPS was in good condition.

The holddown post debris containment system appeared to have functioned normally. There was no broaching of stud holes. No stud hang-ups were expected, as the lateral acceleration value at liftoff was 0.09 g.

### **REUSABLE SOLID ROCKET MOTORS**

All Reusable Solid Rocket Motor (RSRM) systems performed as expected. The prelaunch countdown was nominal and no LCC or OMRSD violations occurred, nor were any in-flight anomalies identified. Data indicate that the flight performance of both RSRMs was well within the allowable performance envelopes, and were typical of the performance observed on previous flights. The RSRM postflight assessment indicated

that the hardware was in good condition. The RSRM sections were disassembled and returned to the vendor for reuse.

The motor performance parameters for this flight were within the contract end item (CEI) limits. Propulsion system performance is shown in the following table. The calculated propellant mean bulk temperature at liftoff was 81 °F. The maximum trace shape variation of pressure versus time during the 62-80 second time frame was nominal and calculated to be 0.91 percent at 69.5 seconds (left motor) and 0.58 percent at 72.5 seconds (right motor).

### RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 81 °F		Right motor, 81 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	65.82	66.35	65.74	66.56
I-60, 10 <sup>6</sup> lbf-sec	176.07	176.97	175.89	177.49
I-AT, 10 <sup>6</sup> lbf-sec	297.28	296.70	297.15	297.09
Vacuum Isp, lbf-sec/lbm	268.6	268.1	268.6	268.6
Burn rate, in/sec @ 60 °F at 625 psia	0.3675	0.3695	0.3674	0.3700
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	108.6	107.8	108.7	107.6
50 psia cue time	118.6	117.6	118.7	117.6
Action time <sup>b</sup>	120.8	120.0	120.9	119.7
Separation command	123.1	123.1	123.1	123.1
PMBT, °F	81	81	81	81
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	3.3	3.1	2.9
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		541.2	

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).

Power up and operation of all igniter and field joint heaters were accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. The igniter joint heaters operated for 13 hours 31 minutes during the countdown. Power was applied to the heating elements for 39 percent of the time during the LCC time frame to keep the igniter joints in their normal operating range. The field joint heaters operated for 13 hours 40 minutes during the launch countdown. Power was applied for 25 percent of the time during the LCC time frame. All field joint heaters operated as expected.

The heated, ground-supplied, aft skirt purges was activated twice during the launch countdown for a total of 9 hours 50 minutes. This was necessary to maintain the

case/nozzle joint temperatures above the LCC minimum temperature. The final flexible bearing mean bulk temperature was 83 °F.

### **EXTERNAL TANK**

All objectives and requirements of the External Tank (ET) 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 and OMRSD violations occurred during the countdown.

All ice conditions as well as observed TPS cracks were acceptable. The crack growths and additions as a result of the three propellant loading scrubs and final launch loading were acceptable.

The pressurization systems functioned properly throughout engine start and flight. The minimum liquid oxygen (LO<sub>2</sub>) ullage pressure slump was a nominal 13.8 psid.

ET separation was confirmed. Entry and breakup of the ET was nominal.

### **SPACE SHUTTLE MAIN ENGINES**

The Space Shuttle main engines (SSMEs) performed nominally throughout the flight with no anomalies noted. Prelaunch operations went smoothly except that the intermediate seal purge pressure indicated possible icing in the gaseous nitrogen (GN<sub>2</sub>) system. This condition was controlled by a preplanned contingency of using the high-flow helium purge. No SSME LCC or OMRSD violations occurred during the countdown.

All Interface Control Document (ICD) start and shutdown transient requirements were met. Engine performance during start, main stage, and shutdown was nominal and as predicted. The shutdown times for the three engines were 511.46, 511.58 and 511.68 seconds for SSMEs 1, 2, and 3, respectively.

The preliminary, flight-derived, specific impulse ( $I_{sp}$ ) was 0.8-second (453-seconds) higher than predicted. The block IIA engines have typically delivered approximately 0.8-second higher flight  $I_{sp}$  than predicted from ground testing.

Main engine cutoff (MECO) occurred 505.1 seconds after SRB ignition. This cutoff was 1.5 seconds later than predicted. The commanded maximum dynamic pressure (max  $q\alpha$ ) throttle down was made in two steps (98 percent and 72 percent). A single throttle step down to 72 percent was predicted.

### **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 turned off at the appropriate times. The system operated as planned throughout the countdown and flight. As planned, the SRB S&A devices were safed and SRB system power was removed prior to SRB separation.

## **ORBITER SUBSYSTEM PERFORMANCE**

### **Main Propulsion Subsystem**

The main propulsion subsystem (MPS) performed nominally throughout the countdown and flight. There were no prelaunch LCC or OMRSD violations, nor were there any anomalies identified from the review and analysis of the data. Also, there was not any significant hazardous gas concentrations 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 200 ppm uncorrected. This level compares favorably with previous data from this vehicle.

During the stable replenish operations of loading no. 3, the ground personnel recognized that the 100-percent liquid-level sensor 1 had failed wet and the control logic was switched to the 100-percent sensor 2. Loss of the single liquid-level sensor had no effect on the loading, drain or ascent operations. These two sensors are used for loading control only and have no criticality during ascent. Postflight, a checkout of the Orbiter portion of the sensor electrical system was performed and no anomalies were found. The issue was closed as an unexplained anomaly with the most probable cause being a failure of the ET sensor.

The gaseous oxygen (GO<sub>2</sub>) fixed orifice pressurization system performed as predicted. The reconstructed data from the engine and MPS parameters closely matched the actual ET ullage pressure measurements.

All three flow control valves (FCVs) performed nominally. Also, all pneumatic valve cycles performed within flow requirements.

Data indicate that the LO<sub>2</sub> and LH<sub>2</sub> pressurization systems performed as planned, and the engine inlet net positive suction pressure (NPSP) requirements were met throughout the flight. Liquid oxygen residuals were approximately 6500 lbm, which was lower than expected.

Helium system performance for the SSME and pneumatic systems was slightly above nominal. Entry helium usage was 60.7 lbm, which failed the OMRSD File IX requirement. The increased usage is being attributed to higher-density helium. The extended dwell time of the Orbiter payload bay and aft compartment in the shadow of the ISS caused the starting temperature of the helium to be 20 to 30 °F colder than normal. Evaluation of this condition by Kennedy Space Center (KSC) personnel is continuing.

### **Reaction Control Subsystem**

The reaction control subsystem (RCS) performed satisfactorily throughout the mission. No LCC or OMRSD violations were noted prior to launch, and no failures of problems were noted during the countdown. No in-flight anomalies were noted during the data review and analysis. The table on the following page lists pertinent data concerning the RCS rendezvous maneuvers.

A total of 5206.5 lbm propellants (3206.4 - oxidizer, 2000.1 - fuel) were used from the RCS during the rendezvous mission with the International Space Station. In addition,

6386 lbm of the orbital maneuvering subsystem (OMS) propellants were used by the RCS during interconnect operations. The primary RCS thrusters had 4484 firings and a total firing time of approximately 1289.2 seconds. The vernier RCS thrusters had 24962 firings and a total firing time of 71679.68 seconds.

### RCS RENDEZVOUS MANEUVERS

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Firing time, sec	Orbit, nmi.
NC-3 (RCS)	253:11:36:53 00:22:51:06	3.2	13.3	162 X 191
NC (RCS trim)	254:01:26:31.3 01:12:40:44.3	-	0.5	-
NCC (RCS)	254:02:00:52 01:13:15:05	0.9	-	185.7 x 196.1
TI (RCS trim)	254:02:58:33.3 01:14:12:46.3	-	0.5	-
MC-1 (RCS)	254:03:18:32 01:14:32:45	0.7	3.0	187.1 x 198.5
MC-2 (RCS)	254:03:51:14 01:15:05:27	0.8	4.0	187.0 x 198.7
MC-3 (RCS)	254:04:08:15 01:15:22:28	1.0	3.0	187.0 x 198.7
MC-4 (RCS)	254:04:18:14 01:15:32:27	2.5	7.0	187.1 x 199.5

The first of three planned ISS reboost maneuvers was initiated at 255:12:28:47 G.m.t. (02:23:43:00 MET) when RCS thrusters L1A and R1A were fired. There were a total of 36 +X primary-RCS-thruster reboost pulses with vernier-RCS-thruster attitude adjustments. The aft down-firing vernier-RCS thrusters had an average duty cycle of 60 seconds on and 40 seconds off. There were no thermal violations during the reboost maneuver, and the propellant usage was as expected. The differential velocity ( $\Delta V$ ) delivered was 11 ft/sec, and the final orbit was 201 by 191 nmi, an altitude increase of approximately 3.2 nmi.

The second ISS reboost maneuver was initiated at 258:06:13:17 G.m.t. (05:17:27:30 MET) when RCS thrusters L1A and R1A were fired. The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.2 nmi. The  $\Delta V$  delivered was 11.4 ft/sec and the final orbit was 203.4 by 195.3 nmi.

The third ISS reboost maneuver was initiated at 259:06:45:47 G.m.t. (06:18:00:00 MET) when RCS thrusters L1A and R1A were fired. The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.4 nmi. The  $\Delta V$  delivered was 11.4 ft/sec and the final orbit was 206.3 by 199.2 nmi.

The fourth ISS reboost maneuver, which was added during the mission, was initiated at 261:03:25:47 G.m.t. (08:14:40:00 MET) when RCS thrusters L1A and R1A were fired.

The maneuver consisted of 36 +X primary-RCS-thruster pulses. The aft down-firing vernier thrusters had an average duty cycle of 60 seconds on and 40 seconds off. The reboost maneuver resulted in an average altitude increase of 3.3 nmi. The  $\Delta V$  delivered was 11.6 ft/sec and the final orbit was 208.6 by 203.8 nmi.

The ISS separation maneuver was performed at 262:05:34:26 G.m.t. (09:16:48:39 MET). The maneuver duration was 1.5 seconds with a  $\Delta V$  of 3 ft/sec.

The RCS hot fire was performed at 263:03:06:00 G.m.t (10:14:20:13 MET) and ended at 263:03:12:00 G.m.t. (10:14:26:13 MET). All of the thrusters were fired at least twice for at least 0.480-second and each one demonstrated nominal performance. Prior to the hot fire, 23 of the 38 thrusters had been fired during the mission.

A total of four RCS master alarms occurred during the mission, all of which were explained as non-problems. These were:

1. RCS caution and warning light – Four thrusters were indicated as unavailable. The crew performed the required procedures and the thrusters were recovered.
2. Propellant thermal message – A thermal measurement exceeded the limit. This condition was temporary and was caused by a slug of warm propellant passing the thermal sensor on the crossfeed line. This condition has been seen on a previous flight of this vehicle and did not impact flight operations.
3. Forward MCA 2 inadvertent power-down – The RCS redundancy management (RM) annunciated a dilemma on forward RCS manifold 2. This problem was diagnosed as a switch bump that was corrected by the crew. Power was reapplied to the disabled thrusters, and the thrusters performed satisfactorily for the remainder of the mission.
4. Crossfeed propellant thermal alarm – This alarm was annunciated when the gimbal-crossfeed temperature-limit was exceeded by 0.5 °F. A hot slug of propellant is also suspected as the cause of this alarm. The temperature returned to normal levels after approximately 15 minutes. This problem did not impact the successful completion of the planned mission.

### **Orbital Maneuvering Subsystem**

The OMS performed satisfactorily throughout the mission. No LCC or OMRSD violations were noted during the prelaunch countdown. Likewise, no OMS in-flight anomalies were recorded during the mission. The OMS inlet pressures, chamber pressures and regeneration jacket temperatures for both engines were as predicted, verifying nominal engine performance.

A total of 22592 lbm (14137 – oxidizer and 8455 lbm – fuel) of OMS propellants were consumed during the mission. Of this total, the OMS provided 6386 lbm of propellants to the RCS during interconnect operations.

An OMS assist maneuver was performed during ascent at 252:12:47:59.12 G.m.t. (00:00:02:12 MET). The maneuver was 15.20 seconds in duration.

The OMS 1 maneuver was not required because of the nominal ascent trajectory. The OMS 2 maneuver was performed at 252:13:29:47.112 G.m.t. (00:00:44:00.1 MET). The

OMS 2 maneuver was 53.20 seconds in duration and the  $\Delta V$  was 80.9 ft/sec. The orbit was 85 by 177 nmi. following the maneuver. The OMS maneuvers performed in support of the rendezvous are shown in the following table.

At the end of the NC-1 OMS maneuver, the left OMS fuel total quantity went to 31.2 percent. This condition indicated an output of 0 percent from the forward compartment fuel probe. Similar behavior was seen on this gaging system during STS-71, -76, -81, -84, and -86. This failure had no mission impact. The OMS quantity measurement is criticality 3 and is primarily used during loading. The probe functioned nominally during the prior flight of this vehicle, STS-101, and during STS-106 preflight processing.

#### **OMS RENDEZVOUS MANEUVERS**

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Firing time, sec	Orbit, nmi.
NC-1 (OMS 3)	252:16:30:22 00:03:44:35	121.3	78.6	152.1 X 178.3
NC-2 (OMS 4)	253:04:45:56 00:17:00:09	24.7	38.8	160.9 X 190.4
NC (OMS 5)	254:01:26:31 01:12:40:44	48.7	31.4	186 x 196
TI (OMS 6)	254:02:58:33 01:14:12:46	9.3	10.6	187.2 x 198.5

The deorbit maneuver for the first KSC landing opportunity, a two-engine straight feed firing, was performed on orbit 185 at 264:06:50:07 G.m.t. (11:18:04:20 MET). The maneuver was 197.6 seconds in duration with a  $\Delta V$  of 340.1 ft/sec.

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

The power reactant storage and distribution (PRSD) subsystem performance was nominal during the STS-106 mission. No anomalies were found during the flight and postflight analysis of the data.

A total of 2881 lbm of oxygen and 363 lbm of hydrogen was furnished to the fuel cells for power generation and potable water production. In addition, the PRSD supplied 173 lbm of oxygen to the environmental control and life support system (ECLSS) for pressurization and crew breathing. A 57-hour mission extension was possible at the STS-106 average power level of 14.8 kW with the reactants remaining at landing. At extension-day power levels of 13.2 kW, a 64-hour mission extension was available.

The oxygen/hydrogen ( $O_2$  and  $H_2$ ) manifold isolation valves were cycled for the crew sleep periods, and this satisfied the OMRSD File IX in-flight checkout requirements.

#### **Fuel Cell Powerplant Subsystem**

The overall performance of the fuel cell powerplant (FCP) subsystem was nominal during the STS-106 mission, and there were no in-flight anomalies noted in the data. One problem was exhibited and it is discussed in a later paragraph in this section. The

average electrical power level and load was 14.8 kW and 483 amperes. The fuel cells produced 3244 lbm of potable water and 4204 kWh of electrical energy while using 2881 lbm of oxygen and 363 lbm of hydrogen.

Four purges of the fuel cells were performed during the mission. The actual fuel cell voltages at the end of the mission were 0.20 V above predicted for fuel cell 1, 0.25 V above predicted for fuel cell 2, and 0.20 V above 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 and 2, and 1.2 V for fuel cells 3.

The overall thermal performance of the fuel cell water relief, water line, and reactant purge heater systems was nominal. All of the water system heaters cycled to satisfy the in-flight checkout requirements. The fuel cell 2 and 3 alternate water line temperatures were erratic at various times, indicating a slight leakage past the check valves. This leakage had no impact on the successful completion of the planned mission.

At 256:12:04 G.m.t. (03:23:18 MET), the fuel cell 1 hydrogen flowmeter failed off-scale low. Monitoring of other fuel cell parameters provided sufficient insight to verify nominal health of the fuel cell. The flowmeter failure did not impact the mission.

The fuel cell monitoring system (FCMS) was used to monitor the individual cell voltages during prelaunch operations and at various times during the mission. Full-rate data were recorded for a 12-minute period early in the mission. These data showed that cells 81 and 82 of fuel cell 2 had erratic voltage readings. The connections for the individual cell voltage pins are not soldered in this fuel cell or fuel cell 1. This condition caused no concern for the operation of these two fuel cells.

### Auxiliary Power Unit Subsystem

The auxiliary power unit subsystem (APU) performed satisfactorily throughout the mission. There were no in-flight anomalies recorded during the operation of the APUs. The following table shows the run times and fuel consumption for the three APUs during the mission.

#### APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 310)		APU 2 (S/N 204)		APU 3 (S/N 404)	
	(a) (b) Time, Min:sec	Fuel consumption, lb	(a) Time, Min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	20:04	45	29:13	50	20:23	53
FCS checkout					08:29	21
Entry <sup>a</sup>	62:42	104	89:38	152	62:51	117
Total	82:46	149	109:51	202	91:43	191

<sup>a</sup> APUs were shut down 22 minutes 10 seconds after landing.

Normally, APU 1 is selected for flight control system (FCS) checkout; however, APU 3 was selected to accommodate the repositioning of the right SSME given that it was two



pulse count modulation (PCM) counts away from the 2-degree step limit for repositioning. APU 3 was started at 263:01:57:43 G.m.t. (10:13:11:56 MET) and shutdown was at 263:02:06:12 G.m.t (10:13:20:25 MET) with a run-time of 8 minutes 29 seconds and approximately 21 lbm of fuel used. Thrust vector control (TVC) isolation valve 3 was opened for approximately 45 seconds and then closed to support SSME repositioning. APU performance on system 3 was nominal. APU lubrication oil spray cooling was required and approximately 0.28 lb of water was consumed. The APU lubrication oil return temperature was approximately 261 °F when spraying commenced.

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

The overall hydraulics and WSB system performance was nominal during the mission. No in-flight anomalies were noted from the analysis of the data. STS-106 was the second of eight flights in which Propylene Glycol Monomethyl Ether (PGME) was used along with water as the core preload for the system 3 water spray boiler (WSB). This new additive performed as designed and no problems or anomalies of WSB 3 were noted. Although early indications of PGME appear very promising, six more flights are required before any firm conclusions can be drawn on the use of PGME in all three WSBs.

All three WSB systems displayed nominal steam-vent heater cycling during the prelaunch activities. The gaseous nitrogen (GN<sub>2</sub>) isolation valves were opened for the launch 90-minutes before liftoff. A "WSB Ready" indication was present from that time through liftoff. Circulation pump performance was nominal during the prelaunch time period.

During ascent, no over-cooling or under-cooling operations of the WSBs were noted, and the priority valve openings at APU activation were all within the one-second-specification limit.

A total of 83 circulation-pump runs were noted during the mission. A majority of these runs were for thermal conditioning of the rudder speed brake (RSB) power drive unit (PDU) and to a lesser extent, the elevon actuators. Circulation run-time was significantly reduced during the mission as a result of lowering the "on" and "off" temperatures of the hydraulic line sensors used in the circulation pump control logic. This was done to reduce electrical power usage by the circulation pumps in support of the effort to achieve an extra mission day.

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

The electrical power distribution and control (EPDC) subsystem performance was nominal during the mission. No in-flight anomalies or failures were noted during the mission. No abnormal conditions were identified except the one identified in the following paragraph.

During ascent, an electrical spike of approximately 60 amperes and 0.16-second duration was noted on aft main bus B and was also seen on all three fuel cell currents at 252:12:54:35.6 G.m.t. (00:00:08:48.6 MET) (Flight Problem STS-106-V-01). The event occurred approximately 4 seconds after ET separation. There was no reported loss of function as a result of the spike.

A list of the Orbiter equipment (functions) powered by the bus was developed along with the criteria that could be used to exonerate the functions as the potential cause of the spike. This analysis indicated that all but three functions could be exonerated. Those functions were ET 16-mm separation camera 2, the APU gas generator (GG) injector water B heaters, and the OMS crossfeed line B heaters. The ET camera was not powered for the remainder of the flight. There was no restriction on using the APU GG injector water B heaters, since power could not be removed from the suspect portion of the circuit. The APU B heaters were selected at 257:10:50 G.m.t. (04:22:05 MET) and the heaters performed nominally. That operation exonerated the APU heaters as a cause of the spike. The OMS crossfeed line B heaters were not to be powered for the remainder of the flight unless the A heaters failed or insight to the heater operation was lost. The OMS crossfeed B heaters were not powered during the remainder of the mission. Data review indicated that most probable source of the spike was in the ET 16-mm separation camera 2 circuit. During postlanding turnaround operations, the 15-ampere protective camera fuse in aft power control assembly (APCA) 2 was found blown, and the camera was jammed with 68 feet of film.

### **Orbiter Docking System**

The Orbiter Docking System (ODS) performed all of the required functions for docking and undocking in a satisfactory manner. The active system monitor parameters indicated normal outputs throughout the duration of the flight. The docking ring extension was completed satisfactorily at 253:10:40:45 G.m.t. (00:21:54:58 MET) in preparation of the docking with the ISS.

The crew reported that upon initially applying power to the ODS centerline camera in preparation for docking, the camera failed to power up (Flight Problem STS-106-V-05). The crew switched from the primary to the backup harness assembly, and the camera was successfully powered up. No other problems with powering the camera were reported.

Following power up of the ODS centerline camera, the crew reported that the centerline camera crosshair was slightly misaligned in the X-axis. This condition was evaluated and it was determined that docking could be accomplished using the nominal procedures without any corrective action.

The Orbiter/ISS capture occurred at 254:05:51:16.1 G.m.t. (01:17:05:29.1 MET). Docking ring retraction started at 254:05:57:37 G.m.t. (01:17:11:50 MET) and was completed 4 minutes 39 seconds later. Hook closure was activated at 254:06:02:03 G.m.t. (01:17:16:16 MET) and was completed approximately 2 minutes 22 seconds later.

During ring retraction, a brief period of ring misalignment was observed. The misalignment was caused by a lag in the command and the physical disengagement of high-energy damper (HED) 3. Residual structural loads can cause the lag, which can result in ring misalignment during retraction. Once all of the HEDs physically disengaged, the ring went back into alignment. Docking simulations were used to duplicate the ring misalignment that was observed in flight. This behavior is an inherent characteristic of the docking mechanism due to the HED clutch design. It is understood and not considered to be a problem.

The ODS pressurization valves were used during the docked operations and EVA to pressurize and depressurize the airlock as required.

After docking, the vestibule/pressurized mating adapter (PMA) 2 pressurization and leak check was performed. One equalization valve was configured to normal to pressurize the vestibule and PMA 2. The crew cycled the valve 10 times, 8 seconds on and 30 seconds off, to prevent the vestibule-to-PMA 2 hatch from "burping". The valve was left open after the tenth cycle to let the Orbiter, vestibule and PMA 2 pressures equalize. The valve was closed before airlock depressurization for the extravehicular activity (EVA). The vestibule depressurization valves were used to depressurize the vestibule and PMA 2 to vacuum before undocking.

Undocking from the ISS was initiated at 262:03:43:44.13 G.m.t. (09:14:57:57 MET). The undocking was completed 2 minutes 14 seconds later at 262:03:45:58.17 G.m.t. (09:15:00:11 MET).

During the undocking, docking hook groups 1 and 2 opened in 2 minutes 16 seconds and 2 minutes 8 seconds, respectively, starting at 262:03:43:44 G.m.t. (09:14:57:57 MET). However, during hook opening, data showed that hook 8 in group 2 temporarily lost its closed indication 6 seconds prior to the other hooks in the group. The closed indication was lost for 2 seconds, regained for 4 seconds, and then permanently lost at the same time that the other hooks in group 2 lost their closed indication.

#### **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 outputs throughout the duration of the flight.

The Orbiter cabin and external airlock were depressurized to 10.2 psia after pressurizing the PMA 2 and vestibule and isolating the ISS. The Orbiter cabin was repressurized to 13.5 psia during the EVA and equalized with the Spacehab and ISS pressures. After the EVA, the Orbiter, Spacehab and ISS were equalized at 14.9 psia and a partial pressure of oxygen (PPO<sub>2</sub>) of 3.62 psia. The 14.7-psia regulator inlet valves remained closed for most of the docked period, and the ISS stack was allowed to bleed down through nominal structural leakage.

Before undocking, the ISS stack and Orbiter were pressurized to 14.9 psia using oxygen, and the station back-out procedure was performed to leak check the ISS hatches and thus leave the ISS modules at the pre-determined pressures. The Functional Cargo Block (FGB) was isolated at 14.9 psia; the ball and PMA 1 were left at 12.7 psia, Node 1 at 14.2 psia and PMA 2 at vacuum. The Orbiter was repressurized to 14.7 psia before undocking.

The complete pressure control subsystem (PCS) 1 switchover from nitrogen to oxygen flows and from oxygen to nitrogen flow did not occur during the docked operations because the Orbiter cabin pressure was higher than 14.7 psia during most of the docked operations. However, a complete switchover was observed when the PCS was configured to system 2.

## Atmospheric Revitalization Subsystem

The atmospheric revitalization subsystem (ARS) performed nominally during the STS-106 mission with the following exceptions.

During preflight preparations, the ARS cabin fan A had an anomalous condition that was identified as dings on the impeller blades. Ground testing and review of previous flight data indicated that no fan performance degradation was detectable because of the dings on the blades. The condition was accepted for flight. A comparison of the cabin fan differential pressure data for the STS-106 and the STS-101 flights showed no differences.

The avionics bay 3A fan differential pressure was slightly higher for STS-106, averaging 4.5 inches of water as compared to 4.3 inches of water on STS-101. This condition resulted from the installation of the Space-to-Space Orbiter radio (SSOR) avionics. The bay 3A fan differential pressure peaked to 4.69 inches of water; however, this occurred during the generic repressurization of the Orbiter and ISS when the cabin pressure was at 14.9 psia. In addition, the avionics bay 2 fan differential pressure averaged 4.0 inches of water for the STS-106 mission compared to 3.85 inches of water for the STS-101 mission. The addition of the advanced air data transducer (AADT) contributed to the higher differential pressure.

During the 10.2-psia cabin pressure operations, the cabin temperature climbed to 79.52 °F, which is well below the 85 °F temperature limit. Prior to the flight, the Mission Operations Directorate (MOD) and ECLSS engineering personnel agreed to allow the cabin temperature environment to operate within an 85 °F temperature limit during the 10.2-psia cabin operations. The 85 °F temperature limit may become the standard or generic operating temperature environment while the cabin pressure is at 10.2-psia, depending on the analysis of the STS-106 data from the Microwave Wireless Instrumentation System (Micro-WIS) instrumentation. The Micro-Wis data, transmitted from the air inlet of the cabin temperature sensor location during 10.2 psia operation indicated a temperature reading of 80.79 °F. Editorial Note: Additional Micro-Wis discussions are found in the Development Test Objectives section of this report. Additional Micro-Wis instrumentation supported the flight of STS-106 with recorders and transmitters at selected locations. Twelve (12) temperature recorders recorded both the inlet air and outlet air temperature of selected avionics. Twelve transmitters at various middeck cabin locations also supported the mission.

The second booster fan, fan B was powered on at the beginning of the ISS O<sub>2</sub> repressurization and remained operational for the duration of the mission.

A total of six lithium hydroxide (LiOH) cartridges were transferred to ISS. Preflight, the ISS program purchased two LiOH and one ATCO or Hydrazine absorber element from the Space Shuttle program. This was to complete the CO<sub>2</sub> Removal Kit (CRK). The additional four LiOH canisters were part of the preflight canisters manifest for ISS use in a contingency case.

At 257:10:40 G.m.t. (04:21:54 MET), the cabin temperature controller was configured to the secondary controller. The bypass valve operated normally on controller 2 for the remainder of the flight.

During the launch-ascent phase of the flight, the heat exchanger outlet temperature peaked to 63.41° F at 4 minutes and 16 seconds into the flight, with the cabin air temperature peaking to 75.9°F at 54 minutes and 10 seconds after launch. The cabin humidity peaked near 46-percent approximately 6 minutes after launch.

### **Active Thermal Control Subsystem**

The active thermal control subsystem (ATCS) performed nominally throughout the flight. About 2 minutes into the flight during ascent, the flash evaporator subsystem (FES) Freon outlet temperature experienced a pre-evaporative cooling transient with the temperature dropping about 14 °F. The amount of cooling seen is not unusual and is within the historical range of all pre-evaporative cooling. The primary A general purpose computer (GPC) controller was used during ascent to control FES outlet temperatures. FES outlet temperature instabilities were observed shortly before main engine cutoff (MECO). The outlet temperature wavered within the FES control band. It is highly likely that the midpoint sensor used by the primary A controller was experiencing thermal lag, attributable to the sensor not being properly packed in its sensor well. This behavior did not impact the mission. No other FES outlet temperature instabilities were observed after MECO. This type of behavior has been documented in other vehicles in the past and repacking of the sensor usually resolves the problem.

Radiator flow was initiated about 215:14:08 G.m.t. (00:01:23 MET) and the FES controller was switched from primary A command to primary B command shortly thereafter. The primary B command was used because supply water tanks A and B were ganged together to accommodate the accumulation of water for contingency water container (CWC) water transfers to the ISS. The FES was inhibited for a majority of the mission from 254:14:26 G.m.t. (02:01:41 MET) through 259:02:58 G.m.t. (06:14:13 MET) and from 259:03:52 G.m.t. (06:15:07 MET) through 261:04:48 G.m.t. (08:16:03 MET) to conserve cryogenics (for electrical power) and to accumulate water for the CWCs. A total of three water dumps through the FES were performed. Two of the FES water dumps were performed after 261:01:20 G.m.t. (08:12:35 MET), and were under primary A controller. These followed after water tanks B, C, and D were ganged together for post-CWC fill operations. The first half of the first FES water dump performed at 259:02:57 G.m.t. (06:14:12 MET) was under primary A controller and the last half was under primary B controller.

Both flow proportioning valves (FPV) remained in interchanger position from launch through landing. During postlanding operations, the Freon coolant loop (FCL) 2 FPV was placed in the payload position. The forward radiator panels were not deployed in this mission.

The radiator coldsoak for entry was initiated at 264:02:00 G.m.t. (11:14:15 MET). The radiator bypass/FES checkout, performed one hour after the radiator coldsoak started, was successful. Both secondary high load and secondary topping modes checked out successfully. At 11 minutes before main landing gear (MLG) touchdown, the radiators were placed in radiator flow mode thus utilizing the coldsoak. About 3 minutes after touchdown, the radiators were placed in the high setpoint mode to prepare for the use of the ammonia boiler subsystem (ABS). At 9 minutes after MLG touchdown, the ABS A secondary control was activated. About 27 minutes after MLG touchdown, the FPV in FCL 2 was configured from interchanger flow to payload flow to provide cooling to the

Spacehab payload. About 47 minutes after MLG touchdown, the ABS system A tank began to blow down, indicating the depletion of ammonia. Two minutes later, the ABS controller was switched from A secondary to B primary. Ground cooling was initiated about 54 minutes after MLG touchdown and the B primary controller was powered down. The ABS performed nominally.

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

The Supply Water and Waste Management Systems performed normally throughout the mission. By the completion of the mission all of the scheduled in-flight checkout requirements were satisfied.

Tanks "A" and "B" were ganged together and were dedicated for storing water for filling CWCs to be transferred to ISS. Tanks "B", "C" and "D" were ganged together for post-CWC fill operations. Eight CWCs were filled with a total of 779 lb of water and transferred to the ISS.

Supply water was managed through the use of the FES and the overboard dump system. Seven supply water dumps at an average rate of 1.6-percent per minute (2.64 lb/min) and three FES dumps were performed. The supply water dump line temperature was maintained between 60 °F and 95.8 °F throughout the mission with the operation of the line heater.

Waste-water was generated at about the predicted rate. Seven waste-water dumps were performed at an average rate of 1.8-percent per minute (3.0 lb/min). The waste-water dump line temperature was maintained between 61 °F and 75.8 °F throughout the mission. Vacuum vent line temperature was maintained between 58.5 °F and 77.3 °F.

### **Waste Collection Subsystem**

The waste collection subsystem performed satisfactorily throughout the flight. No anomalies or problems were reported by the crew.

### **Airlock Support System**

The airlock support system performed satisfactorily in the support of the EVA. The active system monitor parameters indicated normal outputs throughout the remainder of the flight.

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

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

### **Flight Data Subsystem**

The flight data subsystem performed nominally during the mission. STS-106 was the second flight of the multifunction electronic display system (MEDS).

## Flight Software

The flight software performed satisfactorily throughout the mission. No problems or in-flight anomalies were noted. The navigation and control software performed as planned during the rendezvous and docking portion of the mission. The undocking and separation software also performed satisfactorily. The software performed satisfactorily during entry.

## Flight Control Subsystem

The FCS performed satisfactorily throughout the mission. One in-flight anomaly was noted and it is discussed in the following paragraphs.

During the post-insertion star tracker activation at 252:14:42:00 G.m.t. (00:01:56:13 MET), the -Z star tracker annunciated three failure discretes (Flight Problem STS-106-V-02). These were the Tracker Good discrete, the Power Supply Good discrete and the Self-Test Magnitude Fail discrete. The Self-Test Magnitude Fail discrete is set when the star tracker fails self-test because of a magnitude error. Since a self-test had not been initiated, it was completely anomalous to have this discrete. The star tracker was not bypassed but did show signs of off-nominal operation (no target suppression or bright object indications). The -Z star tracker was an older image dissector tube (IDT) type star tracker.

At 252:15:22 G.m.t. (00:02:36 MET), all three of the discretes cleared simultaneously without any action from the crew. A self-test was then performed and it failed with indications that the bright object sensor/shutter close functions were not operating. It was then observed that the shutter was not closing during daylight. With the -Z Orbiter axis pointing to the Earth, it was expected that either the bright object sensor (BOS) or the target suppression logic would close the shutter. The star tracker was powered off to prevent possible sunlight damage.

On flight day (FD) 2, the -Z star tracker was activated during a scheduled inertial measurement unit (IMU) alignment and similar built in test equipment (BITE) indications were again observed, and the star tracker failed to scan when attempting to acquire a star. The star tracker was powered down for the remainder of the mission. The Commander's heads up display (HUD) was calibrated and verified to ensure a backup was available for IMU alignments. The -Y star tracker performed nominally throughout the mission and the mission impact from the loss of the -Z star tracker was minimal. The star tracker was removed and replaced with a solid-state star tracker during the postflight processing.

On STS-101, during the secondary actuator check portion of FCS checkout, the speedbrake channel 3 secondary  $\Delta P$  exhibited an approximate 1.7-second delay when the positive stimulus was applied. The channel bypassed nominally during the negative stimulus portion of the test. As a result, during the STS-106 FCS checkout the negative stimulus was run first and the test was repeated in each direction. Performing the negative stimulus first was intended to determine whether the performance was dependent on the direction of the initial stimulus. The stimulus was repeated to confirm that the servo-valve responded properly in both directions after the first stimulus. The speedbrake channel 3 bypassed nominally during each portion of the test.

Entry FCS operation was nominal. No anomalies or problems were noted in any sensor, controller or hydraulic actuator during the deorbit, entry and landing operations.

Descent navigation performed nominally. The external sensors [drag, tactical air navigation (TACAN), air data transducer assembly (ADTA), and microwave scanning beam landing system (MSBLS)] data were incorporated into the onboard navigation state vector at their expected region of operations. The residuals and residual ratio values from the external sensors were nominal and no navigation editing was required.

One item of note during the entry was the loss of MSBLS line replaceable unit 2, which was unable to maintain lock-up for the range measurement from approximately 16,000 ft altitude to landing (Flight Problem STS-106-V-03). This condition, however, did not affect the onboard navigation solution, as the selected MSBLS measurements were the average of the measurements from the two remaining units.

The miniature air-to-ground receiver (MAGR-S) performed well throughout the mission. The entry portion of this Development Test Objective (DTO) 700-14 for this flight included the MAGR-S operation without a valid key (C/A code). During entry, outside of the expected high figure-of-merit (FOM) period during the plasma region, the receiver encountered one FOM chimney of 66 seconds duration as the vehicle flew around the heading alignment circle (HAC). The analysis of the chimney indicated that it was triggered by a loss-of-lock on the navigation satellite, which resulted in a poor intermediate geometry as the receiver picked up an alternate satellite. Note that the loss-of-lock events were more frequent and at a higher tracking signal when operating without a valid key. Still, the observed FOM chimney passed the system requirements for all FOM chimneys to be less than 138 seconds in duration from 140,000 ft altitude to landing.

The guidance, navigation and control (GN&C) subsystems performed nominally during the rendezvous and proximity operations through docking. No anomalies were noted while operating during the rendezvous period. Likewise, the undocking and fly-around were nominal. Separation occurred after two complete revolutions were made of the ISS, and it was followed by the OMS separation maneuver. The two fly-around maneuvers at a distance of 450 ft provided the U. S. and Russian officials time to view and photograph the newly attached modules of the ISS.

### **Displays and Control Subsystem**

The displays and control subsystem performed nominally throughout the STS-106 mission. No in-flight anomalies or problems were identified from the review and analysis of the data.

### **Communications and Tracking Subsystem**

The communications and tracking subsystem performed nominally in meeting all requirements of the mission. One in-flight anomaly was identified and it is discussed in a following paragraph.

The Ku-Band radar acquired the ISS at 254:02:13 G.m.t (01:13:27 MET) at a range of 145,000 feet (approximately 24 nmi.) and tracked the ISS to a range of 320 feet when the Ku-Band was placed in the Communications mode to provide downlink television of



the docking. The performance of the Orbiter trajectory control sensor (TCS) in support of the docking with the ISS was nominal.

The MSBLS 2 initially locked on in range for a few seconds, and then lost lock for the remainder of the landing (Flight Problem STS-106-V-03). The unit provided nominal azimuth and elevation data during landing operations. The other MSBLS units operated satisfactorily in providing nominal range, azimuth and elevation data. This problem did not impact the landing operations. The MSBLS consists of two line replaceable units (LRUs), the radio frequency (RF) assembly and the decoder assembly. The failure signature indicates that the problem is most likely in the RF assembly for which three spares exist.

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

The operational instrumentation (OI) subsystem and Modular Auxiliary Data Subsystem (MADS) performance was nominal in meeting all mission requirements. No in-flight anomalies were identified; however, the operations recorder (OPS) 1 did have a problem that is discussed in the following paragraph.

At approximately 258:22:27 G.m.t. (06:09:41 MET), a defective tape segment on operations recorder 1 track 2 at a tape location of 65-percent to 67-percent was detected. The data recording consistently dropped out for about 2 seconds at the affected segment. Recorded and played-back data in the forward and reverse direction of the tape demonstrated the problem. Further testing revealed that most tracks on the recorder tape had the same problem in the 61- to 68-percent region of the tape. Data were played back from tracks 3, 4, 5, 6, 7, 8, 9, 10, and 14, and in the 61- to 68-percent region of the tape, short data dropouts occurred (typically 1 to 2 seconds). For the remainder of the mission, whenever possible, operations recorder 2 was used as the loss-of-signal (LOS) recorder. However, when the operations recorder 1 had to be used, the affected region of the tape was not used.

The problem indicates a tape-induced problem. The recorder had a 9-year-old Memorex 897 tape installed. The use of this tape system was discontinued in June 1999 because of excess shedding, bit error rate (BER) dropouts and sticky tape. The tape is being replaced on an attrition basis. This recorder was last tested using the acceptance test procedure (ATP) in August 1997.

### **Structures and Mechanical Subsystems**

The structures and mechanical subsystems performed acceptably with one anomaly noted.

The ET/Orbiter separation devices (EO-1, EO-2 and EO-3) functioned normally. No ordnance fragments were found although pieces of room temperature vulcanizing (RTV) material from the umbilical plate pyrotechnic interfaces were found on the runway beneath both umbilical wells. All of the EO-2 and EO-3 fitting retainer springs (three per side) were pushed out of position. No umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH<sub>2</sub> recirculation line disconnect. The payload bay doors were opened at 252:14:23:30 G.m.t. (00:01:37:43 MET). All voltages were nominal and the motors opened the doors within the nominal time.

The payload bay doors were closed and latched for landing at 264:04:14:41 G.m.t. (11:15:28:54 MET).

During the OPS 301 major mode vent door close operations, the left vent doors 8 and 9 close microswitch 2 failed to annunciate (Flight Problem STS-106-V-04). As a result, drive motor 2 came on and remained on until the software terminated operation after approximately 10 seconds (single motor time). The left vent doors 8 and 9 were subsequently opened prior to the deorbit maneuver. When the doors were once again closed during the major mode 304 transition prior to entry interface (EI), the close microswitch 2 performed nominally. However, during postlanding vent door purge positioning, the left vent doors 8 and 9 purge microswitch 1 did not indicate the purge position. As a result, drive motor 1 continued to drive the doors until the closed position was reached. This problem did not impact the entry or post-landing operations, since the doors were in the correct position during entry and the right-hand doors were placed in the purge position post-landing.

The landing gear tires were in good condition for a landing at KSC. No ply undercutting was noted on the main landing gears tires. The landing and braking data are shown in the following table.

#### LANDING AND BRAKING PARAMETERS

Parameter	From Threshold, Ft	Speed, Keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	3066.2	186.3	-2.68	N/A
Nose gear touchdown	5506.2	153.2	N/A	-5.3
Brake initiation speed		78.3 knots		
Brake-on time		46.05 seconds		
Rollout distance		9114.5 feet		
Rollout time		77.08 seconds		
Runway		15 (Concrete) KSC		
Orbiter weight at landing		222,800 lb		
Brake sensor Location	Peak Pressure, Psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	745.7	Left-hand inboard	13.89	
Left-hand inboard 3	745.7			
Left-hand outboard 2	586.2	Left-hand outboard	8.69	
Left-hand outboard 4	586.2			
Right-hand inboard 1	706.9	Right-hand inboard	6.52	
Right-hand inboard 3	706.9			
Right-hand outboard 2	646.6	Right-hand outboard	5.71	
Right-hand outboard 4	646.6			

The drag chute was deployed at 264:07:56:46.0 G.m.t. The nose gear touchdown occurred at 264:07:56:51.8 G.m.t. The drag chute was jettisoned at 264:07:57:23.3 G.m.t.

## **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.

### **Thermal Control Subsystem**

There were no passive thermal control subsystem (TCS) issues during the mission. All heater systems operated nominally, and all subsystem temperatures were maintained within acceptable limits.

The X-axis perpendicular to the orbital plane (XPOP) attitude pitch bias of +25 degrees provided very cold environments for the main landing gear (MLG) tires. During the preflight planning, pitch biases of +15 and +30 degrees were recommended so that the anytime return limit temperature of  $-42^{\circ}\text{F}$  would not be violated. The minimum pressure-inferred tire temperature was  $-34^{\circ}\text{F}$  on the starboard side tires.

Lowering the set points for circulation pump activation significantly reduced the hydraulic circulation pumps run-times. This procedure had been adopted on previous flights. The RSB PDU heater and elevon actuator heaters were configured to the higher set-point heaters during the docked phase to further reduce the run-times of the circulation pumps. The nose-to-the-sun type attitudes were cold for the RSB PDU and the elevons. The drag-chute compartment temperatures indicate the RSB environment and the compartment temperature reached  $-58^{\circ}\text{F}$ .

The external airlock water line heaters performed nominally throughout the flight and during the EVA. STS-106 was the first flight of the oxygen sensor that was relocated from the quick-disconnect panel.

The OMS crossfeed system B heaters were not enabled after ascent because of the current spike, discussed in Electrical Power Subsystem section, on the bus that supplies power to the heaters. Although one B heater was verified to have cycled normally during ascent, it was not possible to exonerate the heaters as being the source of the electrical short.

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

The thermal protection subsystem (TPS) performed satisfactorily. Boundary layer transition from laminar flow to turbulent flow cannot be determined as the MADS data from entry, which could be used to confirm the transition, has at this writing not been released for evaluation. The bondline temperature data indicate a higher-than-usual temperature rise, which may indicate the occurrence of early transition.

Following the rendezvous and docking, the crew reported that a damaged advanced flexible reusable surface insulation (AFRSI) thermal blanket was observed on the top of the left OMS pod. The RMS was used to provide video, which was recorded for analysis. From the video, it was determined that the trailing edge of an AFRSI blanket had a tear approximately 4 inches long and 1 inch wide. The AFRSI blanket was

identified and repair history indicated that this blanket had a fabric patch repair installed at that location. Thermal analysis of the damage site determined that the maximum temperature on a nominal entry would not exceed 500 °F. It was determined that no structural damage would occur given that with a maximum outer mold line temperature of 500 °F, the presence of the inner mold line fabric and the bondline RTV adhesive alone is sufficient to prevent structural over-temperature. Also, aerodynamic loading that could lead to further blanket damage does not occur until after the peak heating period.

The postlanding inspection of the Orbiter TPS identified a total of 105 impacts of which 17 had a major dimension of 1-inch or larger. The distribution of these impacts on the vehicle is shown in the following table. 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. Of special note was the absence of tile damage from debris hits on the leading edge of the vertical stabilizer. Although, hits were recorded on the window perimeter tiles and OMS pod leading edges, no damage sites larger than 1-inch in length were present.

#### TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	17	73
Upper Surface	0	0
Window Area	0	16
Right Side	0	4
Left Side	0	1
Right OMS Pod	0	5
Left OMS Pod	0	6
Total	17	105

A comparison of the number of damage sites with statistics from previous missions indicates that both the total number as well as the number of damage sites that were 1-inch or larger almost matched the fleet averages. The fleet averages were 102.6 damage sites on the vehicle with 16.1 damage sites larger than 1-inch.

The Orbiter lower surface sustained 73 hits (damage sites), of which 17 had a major dimension of 1-inch or larger. Approximately 20 damage sites (with five larger than 1-inch) were located in the area from the nose landing gear to the main landing gear wheel wells on both the left and right chines. These findings are consistent with the loss of foam from the ET thrust panels. The quantity and average size of the damage sites when compared with previous flights shows the numbers were considerably reduced as a result of the prelaunch TPS venting modification. Some of the hits may be attributed to impacts from ice on the LO<sub>2</sub> feedline bellows. In general, the lower surface tile damage on this flight was much improved from previous flights. The table on the following page presents a comparison of lower surface damage for the last 10 flights.

Numerous tile damage sites around the ET/Orbiter umbilicals were most likely caused by umbilical ice or pieces of the umbilical purge barrier material flailing in the airstream and contacting tiles before pulling loose and falling aft.

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

Parameter	STS -89	STS -90	STS -91	STS -95	STS -88	STS -96	STS -93	STS -103	STS -101	STS -106
Lower surface total hits	95	76	145	139	80	160	161	84	70	73
Lower surface hits > 1 in.	38	11	45	42	21	66	42	13	19	17
Longest damage site, in.	2.8	3.0	3.0	4.0	4.5	4.0	6.0	1.5	8	6
Deepest damage site, in.	0.2	0.25	0.5	0.4	0.5	0.5	0.5	0.25	0.75	0.50

Less than the usual amounts of tile damage occurred on the base heat shield. All SSME dome heat shield closeout blankets were in excellent condition, though there was some slight fraying of the material on SSME 1 at the 6:00 o'clock position and SSME 3 at the 9:00 o'clock position.

No unusual tile damage was noted on the leading edges of the OMS pods and the vertical stabilizer. Damage sites on the window perimeter tiles were less than usual in quantity and size. Hazing and streaking of forward-facing windows was moderate.

The postlanding walkdown of runway 15 was performed immediately after landing. No unexpected flight hardware was found. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing line cutter pyrotechnic devices were expended.

The potential identification of debris damage sources for this mission will be based on laboratory analysis of Orbiter postlanding microchemical samples, inspection of the recovered SRB components, film analysis and aerodynamic debris particle trajectory analysis. The results will be documented in a KSC publication.

### Gas Sample Analysis

STS-106 was a successful flight for the redesigned gas-sample bottles. The hardware provided the program with six excellent gas samples on this thirty-first flight of the redesigned hardware. The data obtained during ascent in the gas sample bottle system were nominal. All six bottle-pressures were in the expected range. The hydrogen concentration was within the database for all Space Shuttle vehicles. The oxygen data were within the bands of error as is determined by the argon measurement, and the amount detected can be attributed to air.

This was the third successful flight for these reprocessed bottles. New pyrotechnic valves were installed on all bottles after they had been cleaned. The bottles were committed to the same cleaning and vacuum processing cycle as when they were new.

## EXTRAVEHICULAR ACTIVITY

The planned extravehicular activity (EVA) was completed in 6 hours and 14 minutes. The EVA was successful in that all planned tasks were completed satisfactorily, and the EVA was completed 16 minutes ahead of the planned schedule. All EMU systems and EVA tools performed nominally during the EVA.

The extravehicular mobility unit (EMU) checkout was performed and three good EMU's were verified ready for the scheduled extravehicular activity (EVA). The checkout involved communications testing between the three EMUs (EV3, EV2 and EV1), the Space-to-Space Orbiter Radio (SSOR) and the Mission Control Center (MCC). Audio between EV3 and MCC was broken during the first set of checkouts. The cause of the broken communications was believed to be the result of poor microphone placement causing intermittent voice-operated transmission (VOX) and was corrected during subsequent voice checks. The SSCS checks were successfully completed and verified ready to support the EVA.

During the previous flight of the space-to-space communications system (SSCS), some problems were noted in the SSCS operation. During this mission, the overall performance of the SSCS was nominal with good audio quality, and no network upsets or frame synchronization dropouts were noted.

## **REMOTE MANIPULATOR SYSTEM**

All remote manipulator system (RMS) operations were nominal during the fifty-sixth flight of the arm. The primary task of the RMS was to support extravehicular activity (EVA) operations while the Orbiter was docked to the International Space Station (ISS).

The RMS was powered up at 253:06:15:00 G.m.t (00:17:29:50 MET) for the start of RMS checkout. The checkout, which included testing of the end effector, was completed successfully at 253:07:00 G.m.t. (00:18:14:13 MET). The RMS was then used to perform a payload bay survey. The RMS was powered down at 253:08:28:00 G.m.t. (00:19:42:13 MET).

After powering the RMS for EVA operations, the arm was used to perform two inspections. The first was of a flexible reusable surface insulation (FRSI) tile on the port orbital maneuvering subsystem (OMS) pod. The second inspection that was performed was of a solar array on the service module. After these inspections, the arm was maneuvered to support the EVA. The EVA tasks included attaching a 6-foot long magnetometer and boom to a port on the Service Module (SM); and the connection of electrical, data, and television cables between the SM and the Zarya Control Module.

Data showed that the end effector backup release time during the RMS checkout was 34 seconds. Although this time was higher than normal, it was still considered acceptable. The backup release of the end effector snares is driven by a mechanical spring within the end effector. Backup release performance is affected by temperature and is subject to some variability between tests (even at the same temperature). An eddy current energy-damping device within the end effector is particularly susceptible to low temperatures and increases the backup release times as the temperatures decrease. On this mission, the temperatures were the coldest at which the end effector backup release had been tested on-orbit.

The RMS was powered down after undocking from the ISS on September 16, 2000, and was not used for the remainder of the mission.



## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The overall performance of the government furnished equipment (GFE) and flight crew equipment (FCE) was nominal. One in-flight anomaly was identified and it is discussed in the following paragraph.

The crew reported that upon initially applying power to the ODS centerline camera in preparation for docking, the camera failed to power up (Flight Problem STS-106-V-05). The crew switched from the primary to the backup harness assembly, and the camera was successfully powered up. No other problems with powering the camera were reported. The cameras are GFE, and the harness assemblies are Contractor furnished equipment (CFE). The harnesses will be checked during the postflight period. The preflight checkout process of the cameras and harness will also be reviewed to determine if changes are required.

Following power up of the ODS centerline camera, the crew reported that the centerline camera crosshair was slightly misaligned in the X-axis. This condition was evaluated and it was determined that docking could be accomplished using the nominal procedures without any corrective action. Camera alignment is checked prior to each flight. Photographs from the STS-101 and STS-106 preflight alignment checks were reviewed and the alignment appeared to be satisfactory. No camera adjustments were made during the two missions. Postflight, the crew was asked to describe their alignment process and what was observed. The crew stated that the misalignment resulted in the horizontal bar of the green cross (on the monitor) being displaced upward from the center of the crosshair ring. The magnitude of the misalignment remained constant with zoom setting and there was no angular misalignment. The crew also stated that the misalignment did not repeat itself upon reinstallation of the camera prior to undocking. Investigation into the cause of this condition is continuing.

At 256:00:35 G.m.t (03:11:49 MET) during Orbiter space vision system (OSVS) operations, the camera C iris was commanded closed but failed to close completely. The camera was powered off and the iris did not fully close. The ground controllers then powered the camera up and commanded the camera through a complete range of lens functions, after which the camera iris was successfully closed. However, the camera was not responding to automatic light control (ALC) requirements. After another power cycle, the ALC functions were regained, but the camera iris would not close completely when later deactivated. After an additional power cycle, the ground successfully commanded the camera through all functions. The preliminary analysis of a videotape from this camera indicated that a problem might exist in the lens iris mechanism. The camera continued to operate for the remainder of the mission.

A blurred or fuzzy image was noted in the video downlinked from camera B. The blurred image was noted in the center of the lens. No additional degradation in the image was noted and there was no mission impact.

The camera contains lenses that are not free of chrysene, which is expected to be the problem because of the chrysene outgassing in the lens assembly. The camera will be returned to the manufacturer for repair so that it may be used as planned on the STS-97 mission.

## **CARGO INTEGRATION**

Integration hardware performance was nominal throughout the mission.

## POSTLAUNCH PAD INSPECTION

The inspection of the launch pad and surrounding area did not reveal any flight hardware, and damage to the pad and surrounding area was minimal. Minimal debris was noted on the pad apron and surrounding acreage. A 12-inch by 6-inch piece of aluminum flashing was found in the south flame trench.

There was no evidence of stud hang-ups. Erosion was typical for the South posts. The North hold-down post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt gaseous nitrogen purge lines were broken. The right-hand side purge line was broken, but it remained attached by the flexible line braided shield. The left-hand side was severed and was found near the no. 6 holddown post. There was no evidence of protective tape on either of the flexible lines.

Both tail service masts (TSMs) appeared undamaged and the bonnets were closed properly. The main launch platform (MLP) deck was in generally good shape. A stainless steel bolt and a pip pin were found on side 2 (west) of MLP surface. The room temperature vulcanizing (RTV) rubberized paint applied to the camera and other exposed surfaces was relatively intact with minimal erosion.

The gaseous hydrogen ( $\text{GH}_2$ ) vent line latched in the sixth of eight teeth of the latching mechanism when it was retracted. The ground umbilical carrier plate (GUCP) 7-inch quick disconnect sealing surface exhibited no damage. The vent line sustained more than the usual plume impingement as indicated by the severe scorching of the 4-foot vacuum-jacketed flexible hose, the GUCP housing and the electrical wiring. The  $\text{GH}_2$  vent-line latching mechanism release lever had a missing pip pin. Several grating clamps were found loose adjacent to the vent line deceleration mechanism.

The Orbiter Access Arm (OAA) appeared to be intact with no evidence of plume impingement. Emergency egress basket 7 was found deployed and was at the landing site near the bunker. The gaseous oxygen ( $\text{GO}_2$ ) vent arm, hood, ducts and structure appeared to be in good condition with no indications of plume damage.

The inspection of the flight service structure (FSS) showed no significant damage in the flame trenches, and no flight debris was found on the Launch Pad acreage. At the 95-foot level, a handrail on the east side was broken. At the 155-foot level, an electrical box on the north side of the FSS had broken latches. Also, several pip pins were found damaged, and there were broken tethers throughout the FSS.

**DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY  
OBJECTIVES/HUMAN EXPLORATION AND DEVELOPMENT OF SPACE  
TECHNOLOGY DEMONSTRATION**

**DEVELOPMENT TEST OBJECTIVES**

**DTO 257 – Structural Dynamics Model Verification**

Development Test Objective (DTO) 257 – Structural Dynamics Model Verification was scheduled to be performed on flight day 9, but was not accomplished because of delays in the International Space Station (ISS) ingress activities. The objective of this DTO was to collect mated Shuttle/ISS structural dynamics data to allow better tuning of the Shuttle control system on STS-97. These data would have allowed the effect of the addition of the Service Module (SM) and Progress to the ISS to be updated from the data collected on STS-88. The desired dynamics data involved a pitch bending mode, a lateral bending mode and a torsional bending mode of the ISS relative to the Shuttle. The most critical part of these data is the pitch bending mode, and it was recovered during the Shuttle reboost of the ISS on this mission. The loss of the data from the other two objectives will be recovered during the performance of this DTO on STS-97.

On STS-97, the Shuttle will dock to the new pressurized mating adapter 3 (PMA 3), which was installed during STS-92, and the missed objectives from that flight will now recover the PMA 3 induced changes to the dynamics along with the SM and the Progress effects on the two bending modes. The interpretation of the STS-97 dynamic data will be more complex because of the STS-92 data loss; however, it is expected to fall within the four-hour commitment to process the data and clear the Shuttle primary control system for use, if required.

**DTO 675 – Incapacitated EVA Crewmember Transition**

Time constraints during extravehicular activity (EVA) 4 precluded this DTO of Opportunity from being performed.

**DTO 689 – USA SAFER Flight Demonstration**

The Simplified Aid for EVA Rescue (SAFER) DTO 689 was performed on EVA 4. Both crewmembers successfully completed all DTO objectives. Both SAFER units performed nominally.

**DTO 700-14 – Single String Global Positioning System**

The Miniature Air-to-Ground Receiver (MAGR) payload and general support computer (PGSC) was configured for launch and a review of the downlisted data showed that the MAGR performance during the first six minutes of ascent was poor, but this condition was not unexpected because of the External Tank (ET) blockage. Following the roll-to-heads-up procedure and ET separation, performance improved to nominal

The MAGR on-orbit setup was completed on flight day 2. The crew reported that 122 data files had been recorded during ascent, and this was approximately the number

expected. MAGR performance was nominal. Almost daily checks of the MAGR PGSC recording status were performed, and all reports

### **DTO-700-21 - SIGI Operational Attitude Readiness**

The ISS DTO 700-21 [Space Integrated Global Positioning System/Inertial Navigation System (SIGI) Operational Attitude Readiness (SOAR) was conducted, completing 100-percent of its pre-docked and docked activities on this the second flight of SOAR. The SOAR successfully collected data during the entire mission in numerous local-vertical local-horizontal (LVLH) and inertial attitudes. Postflight analysis is continuing on the SOAR data.

During the ISS X-axis perpendicular to the orbital plane (XPOP) attitude data collection period, the SIGI performance was better than expected. During the ISS torque equilibrium attitude (TEA) data collection period, coverage was excellent and the SIGI computed good attitude solutions.

During the CRV data collection periods, valuable data were gathered on SIGI blended attitude performance (used for CRV only, not ISS). As expected, the blended attitude diverged to a biased attitude. Data obtained in the CRV attitudes will be used to improve the blended attitude filter.

### **DTO 805 – Crosswind Landing Performance**

Crosswind conditions during landing did not exist; therefore, this DTO of opportunity was not performed.

## **DETAILED SUPPLEMENTARY OBJECTIVES**

### **DSO 493 – Monitoring Latent Virus Reactivation and Shedding in Astronauts**

The premise of this Detailed Science Objective (DSO) is that the incidence and duration of latent virus reactivation in saliva and urine increases during space flight. The objective is to determine the frequency of induced reactivation of latent viruses, latent virus shedding, and clinical disease after exposure to physical, physiological, and psychological stressors associated with space flight.

All of the required samples were acquired during the flight. These will be assessed during the postflight evaluation period. Results will be reported in other documentation.

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

It is well known that space flight alters cardiovascular function significantly. One of the most important changes negatively affecting flight operations and crew safety is the postflight loss of orthostatic tolerance, which causes astronauts to have difficulty walking independently as well as inducing lightheadedness or fainting.

Data were collected during the preflight and postflight periods. The analysis is being performed, and the results will be reported in other documentation

### **DSO 498 – Space Flight and Immune Functions**

Astronauts face an increasing risk of contracting infectious diseases as they work and live for longer periods in the crowded conditions and closed environments of the spacecraft such as the ISS. The affect of space flight on the human immune system, which plays a pivotal role in warding off infections, is not fully understood. Understanding the changes in immune function caused by exposure to microgravity will allow researchers to develop countermeasures to minimize the risk of infection.

Samples were collected from the designated crewmembers during the preflight and postflight periods. The data are being evaluated, and the results will be reported in other documentation.

### **DSO 499 – Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation at Small Angles of Tilt after Space Flight**

Astronauts returning to Earth have experienced perceptual and motor coordination problems caused by sensorimotor adaptation to microgravity. The hypothesis is that the central nervous system changes the way it processes gravitational tilt information that it receives from the vestibular (otolith) system. Eye movements and perceptual responses during constant-velocity off-vertical-axis rotation will reflect changes in the otolith function as astronauts readapt to gravity. The length of recovery is a function of flight duration (i.e., the longer astronauts are exposed to microgravity, the longer they will take to recover).

Data were collected during the preflight and postflight periods. The analysis is being performed, and the results will be reported in other documentation

## **HUMAN EXPLORATION AND DEVELOPMENT OF SPACE TECHNOLOGY DEMONSTRATION**

### **HTD 1403 – Micro-Wireless Instrumentation System**

The Human Exploration and Development of Space Technology Demonstration (HTD 1403) will improve the operational utility and functionality of the Micro-Wireless Instrumentation System (Micro-WIS) on-orbit. The Micro-WIS will be installed initially in the crew cabin of the Shuttle Orbiter and then on the ISS. The Micro-WIS consists of tiny autonomous sensors for data acquisition. Two versions have been developed – a transmitter and a recorder. This HTD is designed to demonstrate these transmitters and recorders.

The Micro-WIS was set up and operational with 12 units reporting data at 253:12:30 G.m.t. (00:23:45 MET). Less than 5 minutes was required to setup the system; 15 minutes were scheduled for the activity. After three hours, no temperature data files had been generated. It was discovered that the Micro-WIS was setup on the Proshare PGSC in the middeck, and the data was expected to be on a different PGSC. The fifth downlink was successfully executed at 255:15:35 G.m.t. (03:02:50 MET).

A Proshare PGSC “lockup” was discovered during the crew sleep period at 255:20:00 G.m.t. (03:08:00 MET). The standard procedure is to reboot all machines daily during the post-sleep activities; however, the Micro-WIS software was not executed

## **PHOTOGRAPHY AND VIDEO TAPE ANALYSIS**

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

A total of eleven 16-mm films, nine 35-mm films and 24 videos of launch operations were screened. No anomalous events or conditions were noted that would affect the Orbiter entry and landing.

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

A total of 57 excellent quality frames imaging the External Tank (ET) were obtained from the film in the 35-mm camera in the liquid oxygen umbilical well. Analysis of these frames has shown that the ET thermal protection subsystem (TPS) was in good condition after ET separation. No anomalous conditions were noted during the review of the photography.

A total of 35 excellent quality hand-held pictures of the ET were acquired using the 35mm Nikon F5 camera with a 400mm lens. The first picture was taken 14 minutes 54 seconds after liftoff, and the ET was 1.6 km distance from the Orbiter. Approximately five and one-half minutes of continuous viewing of the ET was acquired.

Views were obtained of the nose, aft dome, the +Z side of the ET (facing Orbiter during flight), both limbs (+Y and -Y) and the far side of the ET. The ET was fully illuminated with very little shadowing.

In analyzing the photographs, no unusual marks or divots were noted. The tumble rate of the ET was approximately 5 deg/sec, and the rate of separation from the Orbiter was approximately 8 meters/second.

### **LANDING PHOTOGRAPHY AND VIDEO TAPE ANALYSIS**

The landing photography and video data were reviewed and no anomalous conditions were noted.

**TABLE I.- STS-106 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	252:12:40:57.450 252:12:40:58.664 252:12:40:59.899
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	252:12:45:18.948 252:12:45:19.108 252:12:45:19.268 252:12:45:19.388
Main Propulsion System Start <sup>a</sup>	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	252:12:45:40.457 252:12:45:40.573 252:12:45:40.686
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	252:12:45:47.008
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	252:12:45:50.713 252:12:45:50.726 252:12:45:50.737
Throttle down to 98 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	252:12:46:04.497 252:12:46:04.473 252:12:46:04.486
Throttle down to 72 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	252:12:46:20.633 252:12:46:20.646 252:12:46:20.657
Throttle up to 104.5 Percent Thrust <sup>a</sup>	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	252:12:46:38.713 252:12:46:38.726 252:12:46:38.737
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	252:12:46:37
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	252:12:47:44.528 252:12:47:44.568
End RSRM <sup>a</sup> Action <sup>a</sup> Time	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	252:12:47:46.908 252:12:47:47.238
SRB Physical Separation <sup>a</sup>	LH rate APU turbine speed - LOS	252:12:47:49.528
SRB Separation Command	SRB separation command flag	252:12:47:50
OMS Assist Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	252:12:47:59.7 252:12:47:59.8
OMS Assist Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	252:12:48:15.3 252:12:48:15.4
Throttle Down for 3g Acceleration <sup>a</sup>	ME-2 command accepted ME-1 command accepted ME-3 command accepted	252:12:53:10.398 252:12:53:10.407 252:12:53:10.421
3g Acceleration	Total load factor	252:12:53:56.4
Throttle Down to 72 Percent Thrust <sup>a</sup>	ME-2 command accepted ME-1 command accepted ME-3 command accepted	252:12:54:05.758 252:12:54:05.767 252:12:54:05.782

<sup>a</sup>MSFC supplied data



**TABLE I.- STS-106 SEQUENCE OF EVENTS  
(Continued)**

Event	Description	Actual time, G.m.t.
SSME Shutdown <sup>a</sup>	ME-2 command accepted ME-1 command accepted ME-3 command accepted	252:12:54:12.118 252:12:54:12.127 252:12:54:12.142
MECO	MECO command flag MECO confirm flag	252:12:54:13 252:12:54:13
ET Separation	ET separation command flag	252:12:54:32
APU Deactivation	APU-2 GG chamber pressure APU 1 GG chamber pressure APU 3 GG chamber pressure	252:13:00:57.369 252:13:01:08.127 252:13:01:19.946
OMS-1 Ignition and Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
OMS-2 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	252:13:29:47.1 252:13:29:47.2
OMS-2 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	252:13:30:40.7 252:13:30:40.8
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	252:14:22:12 252:14:23:30
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	252:16:30:22.9 252:16:30:22.9
OMS-3 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	252:12:31:41.7 252:12:31:41.7
OMS-4 Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	253:04:45:56.5 253:04:45:56.5
OMS-4 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	253:04:46:21.7 253:04:46:21.7
OMS-5 Ignition	Right engine bi-prop valve position Left engine bi-prop valve position	254:01:26:31.3 254:01:26:31.3
OMS-5 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	254:01:27:02.9 254:01:27:03.1
OMS-6 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	254:02:58:33.3
OMS-6 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	254:02:58:43.9
Docking ring capture	Capture	254:05:10:00
Docking with ISS	Docking ring final position	254:06:04:53
Cabin Depressurization (End)	Cabin pressure	254:10:32:26.7
Airlock Depressurization (End)	Airlock differential pressure 1	255:04:42:45
Begin Extravehicular Activity	Airlock differential pressure 1	
Cabin Repressurization to 13.5 psia	Cabin pressure	255:05:13:40
Airlock Repressurization start	Airlock differential pressure 1	255:11:00:47
End Extravehicular Activity	Airlock differential pressure 1	
Reboost Maneuver 1 Ignition	As reported	255:12:23:49.9
Reboost Maneuver 1 Cutoff	As reported	255:13:29:20.9
Reboost Maneuver 2 Ignition	As reported	258:06:11:56.9
Reboost Maneuver 2 Cutoff	As reported	258:07:14:56.9
Reboost Maneuver 3 Ignition	As reported	259:06:42:32.9
Reboost Maneuver 3 Cutoff	As reported	259:07:45:41.9

**TABLE I.- STS-106 SEQUENCE OF EVENTS  
(Concluded)**

<b>Event</b>	<b>Description</b>	<b>Actual time, G.m.t.</b>
Reboost Maneuver 4 Ignition	As reported	261:03:23:12.9
Reboost Maneuver 4 Cutoff	As reported	261:04:24:11.9
Undocking from ISS	Undock complete	262:03:45:58
Flight Control System Checkout		
APU Start	APU 1 GG chamber pressure	263:01:57:42.529
APU Stop	APU 1 GG chamber pressure	263:02:06:08.857
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	264:04:11:58 264:04:13:42
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	264:06:45:07.695 264:07:11:57.126 264:07:12:01.191
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	264:06:50:07.3 264:06:50:07.4
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	264:06:53:25.3 264:06:53:25.4
Entry Interface (400K feet)	Current orbital altitude above	264:07:25:01
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Management	Major mode change (305)	264:07:50:12
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	264:07:56:44 264:07:56:44
Main Landing Gear Weight on Wheels	LH MLG weight on wheels RH MLG weight on wheels	264:07:56:44 264:07:56:44
Drag Chute Deployment	Drag chute deploy 1 CP volts	264:07:56:46.0
Nose Landing Gear Contact	NLG LH tire pressure 1	264:07:56:52
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	264:07:56:52
Drag Chute Jettison	Drag chute jettison 1 CP Volts	264:07:57:23.3
Wheel Stop	Velocity with respect to runway	264:07:58:02
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	264:08:14:38.062 264:08:14:43.613 264:08:14:48.846

TABLE II- STS-106 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-106-V-01	Aft Main Bus B Current Spike	252:23:54:35 G.m.t. 00:00:08:48 MET IPR 98V-0002 CAR 106RF03	<p>A current spike of approximately 60 amperes and 0.16-second duration was noted on aft main bus B and was also seen on all three of the fuel cell currents at 252:12:54:35.6 G.m.t. (00:00:08:48 MET). There was evident loss of function as a result of the spike.</p> <p>A list of the Orbiter equipment (functions) powered by the bus was developed to aid in determining the cause of the spike. Criteria to exonerate functions were developed and the analysis indicated that all but three functions could be exonerated. Those functions were ET 16-mm camera, the APU 1 and 2GG injector water B heaters, and the OMS crossfeed line B heaters. The ET camera was not powered for the remainder of the mission. There was no restriction on using the APU GG injector water B heaters since power could not be removed from the suspect portion of the circuit. The APU system B heaters were selected at 257:10:50 G.m.t. (04:22:05 MET), and the APU GG injector water B heaters performed nominally. This exonerated the APU system B heaters as a cause of the spike. The OMS crossfeed B heaters were not to be used unless the A heaters failed or insight into heater operation was lost. The OMS crossfeed B heaters were not used during the mission.</p> <p>Postflight troubleshooting of the aft main B bus current spike was performed on 9/22/00. The power control assembly fuse was found blown and camera resistance readings were nominal. The camera was removed and returned to JSC. Troubleshooting at JSC determined that the film had jammed the camera. The jam resulted in the high current draw which was interrupted when the fuse opened.</p>
STS-106-V-02	-Z Star Tracker Failure	252:14:42 G.m.t. 00:01:56 MET CAR 106RF01 IPR 98V-0001	<p>During the post-insertion star tracker activation, the -Z star tracker (IDT S/N 08) announced a Power Supply Fail Bite indication, along with a Tracker Fail BITE and a Magnitude Error BITE. The star tracker was not bypassed but showed signs of off-nominal operation (no target suppression or bright object indications while pointed at the lit earth). The BITE indications cleared simultaneously without any action from the crew. A self-test was performed and it failed with indications that the bright object sensor/shutter-close functions were not operating. The star tracker was powered off to prevent possible sunlight damage during subsequent maneuvers.</p>

TABLE II- STS-106 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-106-V-02 (Continued)	-Z Star Tracker Failure	252:14:42 G.m.t. 00:01:56 MET CAR 106RF01 IPR 98V-0001	<p>On flight day 2, the star tracker was activated during a scheduled IMU alignment and similar BITE indications were once again observed and the star tracker failed to scan when attempting to acquire a star. The star tracker was powered down and the CDR's HUD was calibrated and verified to obtain a backup for IMU alignments. The -Y star tracker, a solid-state unit, performed nominally throughout the mission. The mission impact from the failed -Z start tracker was minimal.</p> <p>KSC: Troubleshooting on 9/27/00 was unable to repeat the flight anomaly. Three self-tests were performed and all were passed. A spare solid-state star tracker is available. Testing and evaluation of the failed star tracker will be performed but the unit will not be repaired.</p>
STS-106-V-03	MSBLS 2 Range Failure	264:07:54:28 011:19:08:41 CAR 106RF06 IPR 98V-0005	<p>The microwave scanning beam landing system (MSBLS) 2 initially locked on in range for a few seconds, and then lost lock for the remainder of the landing. The unit provided nominal azimuth and elevation data during landing operations. The other MSBLS units operated satisfactorily in providing nominal range, azimuth and elevation data. This problem did not impact the landing operations. The MSBLS consists of two LRUs, the RF assembly and the decoder assembly. The failure signature indicates that the problem is most likely in the RF assembly.</p> <p>KSC: Postflight troubleshooting on 9/26/00 duplicated the anomaly after 30 minutes of on-time. The decoder and the RF unit will be removed for further troubleshooting on the bench. There are three spare RF assemblies available on site.</p>
STS-106-V-04	Left-Hand Vent Doors 8 and 9 Microswitch Failure	264:06:25 G.m.t. 022:17:39 MET CAR 106RF05 IPR 98V-0007	<p>During the major mode 301 vent-door close operations during the deorbit preparation operations, the left vent doors 8 and 9 close microswitch 2 failed to indicate closed. As a result, drive motor 2 remained on until the software terminated operation at approximately 10 seconds (single motor time). The left vent doors 8 and 9 were subsequently opened prior to the deorbit maneuver. When the doors were once again closed during the major mode 304 transition prior to entry interface, the microswitch performed nominally. However, during postlanding vent door purge positioning, the left vent doors 8 and 9 purge microswitch 1 did not indicate the purge position. As a result, drive motor 1 continued to drive the doors until the closed position was reached. This problem had no impact on postlanding operations, since the right</p>

TABLE II- STS-106 SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-106-V-04	Left-Hand Vent Doors 8 and 9 Microswitch Failure	264:06:25 G.m.t. 011:17:39 MET CAR 106RF05 IPR 98V-0007	vent doors 8 and 9 were placed in the purge position. KSC: Postflight troubleshooting was performed on 9/28/00, but the anomaly could not be repeated. There are no spare PDUs available on site.
STS-106-V-05	ODS C/L Camera Harness Assembly Failure	253:14:47 G.m.t. 01:02:01 MET CAR 106RF07	<p>The crew reported that upon initial power-up of the ODS centerline camera, the camera failed to power up. The crew switched from the primary to the backup harness assembly and the camera was successfully powered up. Note that the backup camera was not used.</p> <p>The cameras (prime and backup) are Government Furnished Equipment (GFE) and are stowed in the MAR during launch and landing. The harness assemblies (prime and backup) are Contractor Furnished Equipment (CFE) that is also stowed in the MAR during launch and landing.</p> <p>This problem was elevated to an in-flight anomaly by the PRCB. The prime flight centerline camera cable was continuity tested and hi-pot tested in the Flight Kit Facility, and the cable was found to be bad. An open circuit was evident on pin 11 (plug P9473) which is the camera power line to the standard switch panel. A loose back shell was also discovered. The other cable that was sent with the suspect cable is still in the flight kits. It will also be tested.</p>

## **DOCUMENT SOURCES**

In an attempt to define the official as well as the unofficial sources of data for the STS-106 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-106 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.

AADT	advanced air data transducer
ABS	ammonia boiler system
ADTA	air data transducer assembly
AFRSI	advanced flexible reusable surface insulation
ALC	automatic light control
APCA	aft power control assembly
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
ATP	Acceptance Test Procedure
BER	bit error rate
BITE	built-in test equipment
BOS	bright object sensor
BSM	booster separation motor
CEI	Contractor end item
CFE	Contractor furnished equipment
CGBA	Commercial Generic Bioprocessing Apparatus
CPM	cell performance monitor
CRK	Carbon dioxide (CO <sub>2</sub> ) Removal Kit
CWC	contingency water container
DSO	Detailed Science Objective
DTO	Developmental Test Objective
$\Delta P$	differential pressure
$\Delta V$	differential velocity
ECLSS	Environmental Control and Life Support System
EDAS	enhanced data acquisition system
EGN	Enhanced Gaseous Nitrogen
EI	entry interface
EMU	extravehicular mobility unit
EO	ET/Orbiter
EPDC	electrical power distribution and control
e.d.t.	eastern daylight time
ET	External Tank
EV-1, EV-2, And EV-3	extravehicular crewmember
EVA	extravehicular activity
FCE	flight crew equipment
FCL	Freon coolant loop
FCMS	fuel cell monitoring system
FCP	fuel cell powerplant
FCS	flight control system
FCV	flow control valves
FD	flight day

FES	flash evaporator system
FGB	Functional Cargo Block (Zarya)
FOM	figure of merit
FPV	flow proportioning valve
FRSI	flexible reusable surface insulation
FSS	fixed service structure
ft/sec	feet per second
g	gravity
GAS	Getaway Special
GFE	Government furnished equipment
GG	gas generator
GH <sub>2</sub>	gaseous hydrogen
G.m.t.	Greenwich mean time
GN <sub>2</sub>	gaseous nitrogen
GN&C	guidance, navigation and control
GO <sub>2</sub>	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
GUCP	ground umbilical carrier plate
H <sub>2</sub>	hydrogen
HAC	heading alignment circle
HED	high energy damper
HEDS	Human Exploration and Development of Space
HUD	heads-up display
ICC	Integrated Cargo Carrier
ICD	Interface Control Document
IDT	image dissector tube
IMU	inertial measurement unit
in/sec	inch per second
I <sub>sp</sub>	specific impulse
ISS	International Space Station
IVA	intravehicular activity
JSC	Johnson Space Center
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lb	pound
lbm	pound mass
LCC	Launch Commit Criteria
LDM	Logistics Double Module
LH <sub>2</sub>	liquid hydrogen
LiOH	lithium hydroxide
LMSO	Lockheed Martin Space Operations
LO <sub>2</sub>	liquid oxygen
LOS	loss of signal
LRU	line-replaceable unit
LVLH	local vertical local horizontal (attitude)
MADS	Modular Auxiliary Data System
MAGR	miniature airborne GPS receiver
MCC	Mission Control Center



MECO	main engine cutoff
MEDS	multifunction electronic display system
MET	mission elapsed time
MICRO-Wis	Microwave Wireless Instrumentation System
MLG	main landing gear
MLP	Mobile Launch Platform
mm	millimeter
MOD	Mission Operations Directorate
MPM	manipulator positioning mechanism
MPS	main propulsion system
MSBLS	Microwave Scanning Beam Landing System
NASA	National Aeronautics and Space Administration
NC	rendezvous maneuvers
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O <sub>2</sub>	Oxygen
OAA	Orbiter access arm
ODS	Orbiter docking system
OI	operational instrumentation
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	Operations
OSVS	Orbiter Space Vision System
OV	Orbiter vehicle
PAL	protuberance air load
PCM	pulse code modulation
PCS	pressure control system
PDU	power drive unit
PGME	Propylene Glycol Monomethyl Ether
PGSC	payload and general support computer
PMA	pressurized mating adapter
PMBT	propellant mean bulk temperature
ppm	parts per million
PPO <sub>2</sub>	partial pressure oxygen
PPS	precise positioning service
PRSD	power reactant storage and distribution
psia	pound per square inch absolute
psid	pound per square inch differential
RCS	reaction control subsystem
RF	radio frequency
RM	Risk Mitigation
RMS	Remote Manipulator System
RSB	rudder speedbrake
RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAFER	Simplified Aid for EVA Rescue
SEM	Space Experiment Module
SIGI	Space Integrated Global Positioning System/Inertial Navigation System

SLF	Shuttle Landing Facility
SLWT	super lightweight tank
SM	Service Module (Zvezda)
S/N	serial number
SOAR	SIGI Operational Attitude Readiness
SPS	Standard Positioning Service
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSCS	space-to-space communications system
SSME	Space Shuttle main engine
SSOR	Space-to-Space Orbiter Radio
STS	Space Transportation System
SVS	Space Vision System
SWAR	sea water activated release
TACAN	Tactical Air Navigation
TCS	trajectory control sensor/thermal control system
TDRS	Tracking and Data Relay Satellite
TEA	torque equilibrium attitude
TI	transfer initiation
TPS	thermal protection system/subsystem
TSM	tail service mast
TVC	thrust vector controller
V	Volt
VOX	voice-operated transmitter
WSB	water spray boiler
XPOP	X-axis perpendicular to orbital plane