

STS-116 SPACE SHUTTLE MISSION REPORT

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National Aeronautics and
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Lyndon B. Johnson Space Center
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NOTE

The STS-116 Space Shuttle Program Mission Report was prepared from inputs received from the responsible Space Shuttle Program Offices and Subsystem Engineers from other organizations. The following personnel can be contacted should any questions arise concerning the technical content of this document.

Phyllis F. Grounds
Flight Manager
281-483-7479

Payloads and Experiments

Timothy Reith
281-853-1616

Orbiter and Subsystems

Cynthia Snoddy
256-544-3017

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

Kenneth L. Brown
281-483-3891

FCE and GFE

Aaron Mears
281-483-9163
Kenneth L. Brown
281-483-3891

EVA Operations and
Equipment
FCE and GFE

Aaron Mears
281-483-9163

EVA Operations and
Equipment

STS-116

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Prepared by

R. W. Fricke, Jr.
ESCG/Mission Evaluation Room Support Section

Approved by

/s/ Benjamin Pawlik

Benjamin Pawlik
STS-116 Lead Mission Evaluation Room Manager
Orbiter Project Office

/s/ James J. Hill

James J. Hill
STS-116 Lead MER Integration Manager
Systems Engineering & Integration Office

/s/ N. Wayne Hale, Jr.

N. Wayne Hale, Jr.
Manager, Space Shuttle Program

Prepared by

Jacobs Sverdrup Engineering and Sciences Contract Group
for the
Space Shuttle Program Mission Evaluation Room

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058
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STS-116 SPACE SHUTTLE MISSION REPORT

INTRODUCTION

The Space Transportation System (STS) -116 Space Shuttle Mission Report presents a discussion of the Orbiter activities on the mission, as well as a summary of the External Tank (ET), the Solid Rocket Booster (SRB), the Reusable Solid Rocket Motor (RSRM) and the Space Shuttle Main Engine (SSME) performance during the 117th mission of the Space Shuttle Program. The purpose of this mission, designated as Flight 12A.1, was to deliver and install International Space Station (ISS) assembly hardware, and deliver critical supplies and cargo to the ISS.

STS-116 was the 4th mission since the return to flight following the STS-107 mission, and the 20th to the ISS. STS-116 was also the 33rd flight of the *Discovery* vehicle.

The flight vehicle consisted of the OV-103 Orbiter; the ET, a super lightweight tank (SLWT) designated ET-123; three Block II SSMEs that were designated as serial numbers (S/Ns) 2050, 2054, and 2058 in positions 1,2, and 3, respectively; and two SRBs that were designated BI-128. The two RSRMs were designated flight set RSRM-95. The individual RSRMs were S/N 360W095A (left) and S/N 360W095B (right). Launch pad 39B and Mobile Launch Platform (MLP) -1 were used as the platform for launch of the STS-116 mission.

The primary objectives of the STS-116 mission were as follows:

1. Deliver and install the Integrated Truss Segment (ITS) -P5 Short Spacer Truss Segment (SSTS) to the ISS, connect power and utilities to the ITS, reconfigure ISS power systems, activate Ammonia loops, and relocate the Photovoltaic Radiator Grapple Fixture (PVRGF) and Crew Equipment Translation Aid (CETA) carts;
2. Perform a crew rotation, replacing Thomas Reiter for Sunita Williams;
3. Perform three extravehicular activities (EVAs) to attach the P5 truss segment and reconfigure power and cooling;
4. Power down and stow the port P6 solar array prior to the activation of the P4 array, and
5. Transfer logistical assets and supplies to the ISS

During the mission, difficulties in retracting and stowing the P6 solar array resulted in the addition of a fourth EVA, which was successfully completed.

The STS-116 flight was planned to be a 12-day plus 2-contingency-day flight. An additional docked day was approved during the flight by the Mission Management Team (MMT) to allow for the additional EVA, but one of the two contingency days, the weather waveoff day, was deleted to allow the late Micrometeoroid Orbital Debris (MMOD) to remain on the timeline.

All times during the flight are given in Greenwich Mean Time (GMT) and mission elapsed time (MET). Appendix A contains the sequence of events. Appendix B provides a table containing all Orbiter, SRB, ET, and Integration in-flight anomalies (IFAs) and their status at the time of the publication of this report. Appendix C provides a list of sources of data, both formal and informal, that were used in the preparation of this report. Appendix D provides a list of acronyms, abbreviations and definitions as used throughout this report.

The eight crewmembers (seven up, seven down) that were on the STS-116 flight were Mark Polansky, Civilian, Commander; William Oefelein, CDR, U. S. Navy, Pilot; Nicholas Patrick, Ph.D., Civilian, Mission Specialist 1; Robert Curbeam, Jr. Captain, U.S. Navy, Mission Specialist 2; Christer Fuglesang, Civilian, European Space Agency, Mission Specialist 3; Joan Higginbotham, Civilian, Mission Specialist 4; Sunita Williams, CDR, U. S. Navy, ISS Flight Engineer (up to ISS); and Thomas Reiter, Civilian, European Space Agency, ISS Flight Engineer (down from ISS).

STS-116 was the third Shuttle flight for Mission Specialist 2, second flight for the Commander, and the first flight for the Pilot, Mission Specialist 1, Mission Specialist 3, Mission Specialist 4, and ISS Flight Engineer Williams. Flight Engineer Reiter has previously flown on the Soyuz to Mir, and also flown to the ISS on STS-121.

MISSION SUMMARY

Pre-Launch

During S0007 checkout activities at 339/03:26:25 GMT, the Orbiter main bus A experienced a voltage transient that exceeded the specification for both the 32-V/200-msec allowable and the 37-V absolute allowable levels. An in-depth evaluation of all main bus A hardware was performed, and all systems were determined to be unaffected. An Operations Maintenance Requirements and Specification Document (OMRSD) waiver was processed, and the countdown was continued.

The first countdown for the December 7, 2006, launch of the STS-116 mission was scrubbed because of a Range Safety weather violation (cloud cover) throughout the 10-minute launch window. The launch was rescheduled for 48 hr later on December 9, 2006.

Ascent and Flight Day 1

Launch of the STS-116 mission occurred at ignition of the SRB RSRMs at 344/01:47:35.009 GMT (20:47:35.009 Eastern Standard Time) on December 9, 2006. STS-116 was the first night launch since the return-to-flight following STS-107.

All Orbiter subsystems performed nominally during ascent and post-insertion.

Solid Rocket Booster (SRB) separation and External Tank (ET) separation were clearly visible from the ET camera. A nominal Orbital Maneuvering System (OMS) assist maneuver was performed following SRB separation. Ignition occurred at 344/01:49:49.992 GMT [00/00:02:14.983 Mission Elapsed Time (MET)], and the maneuver was 97.3 sec in duration.

Main Engine Cutoff (MECO) occurred at 344/01:55:57.150 GMT.(00/00:08:22.859 MET). The Orbiter separated from the ET at 344/01:56:19 GMT (00/00:08:44 MET).

A nominal OMS-2 maneuver was performed at 344/02:24:42.592 GMT (00/00:37:07.583 MET). The maneuver was 121.6 sec in duration with a differential velocity (ΔV) of 187.6 ft/sec. The achieved orbit was 122.8 by 135.2 nmi.

Vent doors, ET doors, Payload Bay Doors (PLBDs) and star tracker doors all operated nominally within dual motor times.

During post-insertion, a single Input/Output (I/O) error was annunciated when the crew assigned integrated display processor (IDP) 4 from the Backup Flight System (BFS) to General Purpose Computer (GPC) 4. This was recognized as an explained condition resulting from the crew not reassigning the BFS GPC from BFS prior to assigning to the Primary Avionics Software System (PASS) GPC.

The Ku-Band antenna was deployed, using the dual-motor mode, at 344/03:29 GMT (00/01:41 MET). The system was powered on four min later and the radar completed self-test at 12 min after the deployment.

A nominal OMS 3 (NC-1) maneuver was a dual OMS engine firing with an ignition time of 344/04:36:42 GMT (00/02:49:07 MET), and the firing time was of 65 sec with a ΔV of 101.4 ft/sec.

The port-side manipulator positioning mechanisms (MPMs) were deployed at 344/04:50 GMT (00/03:02 MET) and the starboard MPMs followed 2 min later. During the Shuttle Remote Manipulator System (SRMS) checkout, it was determined that the AUTO release capability on the end effector was failed (IFA STS-116-V-01). The manual-release capability was still functional, as well as a backup-release mode. This condition did not impact the RMS operations during the mission.

During the post-launch pad walkdown, the KSC Debris Team found one Flexible Reusable Surface Insulation (FRSI) plug near the ramp for the freight elevator on the west side of the launch pad apron. The post-flight turnaround operations identified two locations with missing FRSI plugs on the Space Shuttle Main Engine (SSME) 3 dome heat shield (IFA STS-116-V-06).

Flight Day 2

During the crew's first sleep period, the Flash Evaporator System (FES) Primary B did not come out of standby (IFA STS-116-V-03). The crew power-cycled the FES controller after crew awakening, and after the FES operated for about 1 min, the FES shut down again. FES Primary A was working nominally, and this condition was verified with a water dump. This was only a loss of redundancy, and as a result, no additional mission impact occurred.

At 344/14:12:37 GMT (00/12:25:02 MET), the fuel cell 3 Oxygen (O₂) flow-meter went to an off-scale low (OSL) reading (IFA STS-116-V-02). The OSL indication correlated to a 2-sec 1.6 A increase on Mid Power Control Assembly (MPCA) 3. The fuel cell 3 O₂ flow-meter circuit is protected by a 1 Ampere (A) fuse installed in MPCA 3. Based on the signatures and the specified fuse maximum -current of a 1.5-A load, the fuse blew. The loss of the fuel cell 3 O₂ flow-meter did not impact fuel cell 3 operation during the mission.

The OMS 4 (NC-2) maneuver was a dual OMS engine firing with an ignition time of 344/18:45:13.992 GMT (00/16:57:38.983 MET), and the firing time was 36 sec with a ΔV of 56.4 ft/sec. The resulting orbit was 159.9 by 187.6 nmi. Engine performance was nominal.

The Orbiter Boom Sensor System (OBSS) Manipulator Release Latches (MRLs) were released at approximately 344/19:13 GMT (00/17:25 MET). The OBSS surveys went very smoothly, however, video coverage of the upper-port-carrier panels (6-11) was not

obtained. The OBSS was berthed and the associated MRLs were latched at approximately 345/01:25 GMT (00/23:37 MET). The RMS was parked in the pre-cradle position with the brakes on.

The Orbiter Docking System (ODS) was activated at 344/23:53:33 GMT (00/22:05:58 MET), and the ODS was deactivated after an avionics power-on time of 7 min, 51 sec. Ring extension to the initial position was nominal, beginning at 344/23:56:00 GMT (00/22:08:25 MET) and ended after 3 min, 42 sec (dual motor time). The ODS ring extension activity was nominal.

The NC-3 maneuver was a +X Reaction Control System (RCS) firing with an ignition time of 345/04:44:18.426 GMT (01/02:56:33.427 MET) with a firing time of 9 sec and a ΔV of 3.8 ft/sec. The resulting orbit was 160.3 by 188.7 nmi. Thruster performance was nominal.

Flight Day 3

The Wing Leading Edge Impact Detection System (WLEIDS) identified a response that was consistent with an impact in the region of the port wing between WLE panels 19 and 22 at 345/09:45:11 GMT (01/07:57:36 MET). The impact registered 0.7g and satisfied the four criteria for an impact. Following detailed imagery evaluation, discussions were held in the Orbiter Project Office (OPO) in which the RPM imagery, SRMS imagery, Micrometeoroid Orbital Debris (MMOD) impact test data, Wing Leading Edge Subsystem (WLESS) data, and damage-hole growth were reviewed.

At 345/17:30 GMT (01/15:42 MET), the payload bay floodlights were turned on. The crew reported that the mid-port payload bay floodlight was not illuminated (IFA STS-116-V-04). A switch retention device was installed over this switch so that it could not be used for the remainder of the flight.

The OMS-5 (NC-4) maneuver was a dual OMS engine firing which had an ignition time of 345/17:56:31.800 GMT (01/16:07:56.791 MET) with a firing time of 15.8 sec and a ΔV of 24.9 ft/sec. The resulting orbit was 159.9 by 190.7 nmi. Engine performance was nominal.

The NCC maneuver was a multi-axis RCS firing with an ignition time of 345/18:30:43.789 GMT (01/16:43:08.780 MET). The firing duration was 4.48 sec with a ΔV of 0.9 ft/sec. The resulting orbit was 173.1 by 191.1 nmi.

The OMS-6 transfer Initiation (TI) maneuver was performed using the left Orbiter Maneuvering Engine (OME) only and had an ignition time of 345/19:28:22.2 GMT (01/19:40:47.2 MET) with a firing time of 15.5 sec with a ΔV of 8.1 ft/sec. The resulting orbit was 176.7 by 192.4 nmi. Engine performance was nominal.

The R-Bar Pitch Maneuver (RPM) started at 345/21:04:46 GMT (01/19:17:11 MET) and ended 7 min 33 sec later. During the maneuver, the peak pitch rate was approximately

0.70 deg/sec. The maximum roll error reached approximately 6.5 deg. Performance was nominal. The findings from the digital pictures taken by the ISS crew resulted in no requests for a focused inspection.

The ODS was activated at 345/21:36:20 GMT (01/19:48:45 MET) and was deactivated after the avionics had operated for 56 min 40 sec. Shuttle's capture of the Space Station occurred at 345/22:11:55 GMT (01/20:24:20 MET). The ring drive-in command was given at 345/22:16:11 GMT (01/20:28:36 MET), and operated for approximately 7 sec, after which the system was stopped and allowed to dampen out for approximately 79 sec. In accordance with the normal procedure, a ring drive out command was given beginning at 345/22:17:37 GMT (01/20:24:20 MET), and the ODS operated for 7 sec during which time any stuck dampers were cleared. No stuck dampers were observed prior to ring retraction. The final ring drive in command was issued at 345/22:19:00 GMT (01/20:31:25 MET). Ring retraction, using dual motors, proceeded nominally for approximately 3 min, 25 sec with good ring alignment. The hooks were driven closed nominally and final ring extension was performed, releasing the capture latches with ring final position being acquired at approximately 345/22:26:33 GMT (01/20:38:58 MET), at which time docking operations were complete.

As on previous ISS missions, docked air-to-ground audio issues were reported by the crew. Good 2-way Intercommunications (ICOM) were confirmed, as well as docked air-to-ground from the ISS to the Orbiter. Air-to-ground from the Orbiter to the ISS, however, was not functioning. The Battery Powered Speaker Microphone Unit (BPSMU) was used by the crew as a workaround.

Flight Day 4

The Shuttle Remote Manipulator System (SRMS) unberthed the P5 Truss Segment and handed it off to the Space Station Remote Manipulator System (SSRMS). The P5 Truss was grappled at 346/01:17:30 GMT (01/23:29:55 MET). After the truss was slowly unberthed, the SSRMS then moved in to grapple the truss, allowing the SRMS to ungrapple the P5 at 346/03:22:11 GMT (02/01:34:36 MET). During the ungrappling operations, which were performed in the manual mode, the expected "Uncommanded Release Warning" annunciation did not occur, which may indicate that the previous auto-mode release failure had cleared.

The first of three scheduled EVAs was performed and the duration was 6 hr 36 min. The crew egressed from the ISS airlock. The primary purpose of EVA 1 was to perform the P5 launch-lock removal, P5 installation, removal and repositioning of the Photovoltaic Radiator Grapple Fixture (PVRGF) on the Integrated Truss Segment (ITS) P5 to a noninterference location on the ISS, and removal and replacement of an External Television Camera Group (ETVCG) camera on the S1 truss.

The SRMS was parked overnight in a position to view the region of the port wing between Wing Leading Edge (WLE) panels 19 and 22 where the WLEIDS had previously identified a response that was consistent with an impact.

The crew reported that the "Tens of Seconds" thumbwheel (third from the left) was not consistently updating the Aft Event Timer with the proper value when the timer was set (IFA STS-116-V-05). The crew also reported that a camcorder bracket, on the middeck by panel ML94B near the forward bulkhead, broke off (IFA STS-116-V-07).

Flight Day 5

Solar flares resulted in raised radiation levels. The crew slept in areas that had better shielding properties. Radiations levels remained elevated throughout the day.

The Thermal Protection System (TPS) Tile and Reinforced Carbon-Carbon (RCC) Teams completed their review of all imagery data (IFA STS-116-V-06). A SSME dome heat shield blanket patch was found to be debonded, but the vehicle was cleared for entry. A large number of tile damages were noted around the ET door and aft fuselage. The damages were assessed and determined to be not critical, and the TPS was cleared for entry.

During the ISS P6 4B Solar-Array Wing (SAW) retraction, the array could not be fully retracted and stowed after multiple attempts. However, it was retracted enough to allow the Solar Alpha Rotary Joint (SARJ) to rotate. A special Team 4 was created by Mission Operations Directorate (MOD) to investigate possible ways to resolve the solar array retraction problem.

The star tracker doors were closed during the solar array retraction. Operation of the doors was nominal and within dual-motor time. The doors were reopened at the conclusion of the SAW retraction operations. At the completion of the SAW retraction activities, the -Z Star Tracker was powered on for about 45 sec to open the Star Tracker doors. The -Z Star Tracker annunciated a "pressure-fail" Built-In Test Equipment (BITE) indication when it was powered on (IFA STS-116-V-10). The "pressure-fail" indication remained on until the star tracker was powered off. There was no impact to the performance of the star tracker from a "pressure-fail" indication. The star trackers are pressurized to prevent moisture or contamination from being ingested during entry. The OMRSD requires a purge and re-pressurization during turnaround for a Star Tracker with an in-flight pressure-fail indication.

The O₂ transfer from the Orbiter to the ISS was completed and 69 lb was transferred.

Flight Day 6

The crew's main task for the day was the second EVA which was completed successfully in 5 hr. The primary purpose of EVA 2 was to perform ISS power channel reconfiguration to reroute power from the P6 solar array to the P4 solar array brought up on the STS-115 mission, to relocate the Crew and Equipment Translation Aid (CETA) cart, and perform EVA 3 preparations. Several additional attempts to retract the 4B SAW were added to the timeline, but all were unsuccessful.

The SRMS was used to complete the CETA cart-relocation viewing operation. The SRMS was maneuvered to the pre-cradle position at 348/23:58:26 GMT (04/22:10:51 MET). SRMS performance during this operation was nominal.

After completion of the EVA, the ISS attempted to start up Momentum Manager (MM) attitude control mode in the nominal attitude. The Control Moment Gyroscopes (CMGs) began to approach saturation limits within about 36 min, and attitude control was handed over to U.S. Thrusters-Only (USTO) control prior to saturation. Flight Control attempted to adjust the pitch Torque Equilibrium Attitude (TEA) target and restart the MM, but again saturation limits were approached. Control of the stack was again handed over to USTO. Prior to the crew-sleep period, attitude control was handed over to the Vernier Reaction Control System (VRCS) on the Orbiter, and the Orbiter remained in control for 15 1/2 hr. The problem with ISS taking control previously was determined to be the atmospheric model not accounting for changes in the atmospheric density due to the increase in solar activity. Control was handed back to ISS after an Orbiter maneuver to the nominal attitude from the simultaneous water dump (SIMO) attitude

The simultaneous waste and supply water dump was accomplished satisfactorily.

Flight Day 7

Flight day 7 was an off-duty day for the crew.

A Nitrogen (N₂) Orbiter-to-ISS tank-to-tank transfer was initiated. An Orbiter waste and supply water dump was also accomplished satisfactorily.

Flight Day 8

The crew's main task for the day was the third EVA, which was completed successfully in 6 hr 38 min. The primary objective of EVA 3 was to reconfigure the Main Bus Switching Unit (MBSU) channel 1/4, and transfer the Service Module Debris Panel from the Integrated Cargo Carrier (ICC) to the ISS. The crew had additional time after the nominal EVA 3 tasks to troubleshoot and attempt to retract the P6 Solar Array. As a result of the crew's efforts, six additional bays of the solar array wing were retracted leaving 11 bays extended. During the course of the EVA, a digital camera was lost overboard (IFA STS-116-V-08). The camera was attached to the front of the Extravehicular Mobility Unit (EMU).

The N₂ transfer from the Orbiter to the ISS was completed and approximately 47.2 lb were transferred.

The MMT decided to add a fourth EVA to troubleshoot and retract the 4B SAW, and the mission was extended one day. A weather extension day has been given up to preserve a day for the late inspection of the RCC for MMOD damage. Landing was

planned to occur on Flight Day 14. The Mission Evaluation Room (MER) and Flight Control assessed the elimination of FCS Checkout and RCS Hotfire requirements to protect for an additional waveoff day, but concluded that the full checkout and hotfire are required.

Flight Day 9

A supply water dump on Flash Evaporator System (FES) Primary A began at 351/18:50 GMT (07/17:02 MET) and was completed approximately 8 hr later. A total of 333.6 lb of supply water was dumped.

Supply Water Tank A quantities experienced two dropouts. This behavior has been seen on previous flights, and was not an impact to the mission.

Flight Day 10

The crew's main task for the day was the fourth EVA, which was completed successfully in 6 hr 38 min. The P6 solar array was successfully retracted and latched.

A second Primary A FES water dump was started at approximately 353/01:30 GMT (08/23:42 MET) and was terminated at approximately 3 hr later.

At 353/01:42 GMT (08/23:54 MET), the SRMS was maneuvered from its viewing position to the pre-cradle position, where it remained through undocking.

Flight Day 11

All planned transfers were completed and the Orbiter was undocked from the ISS at 353/22:09:32 GMT (09/29:21:57 MET). The ODS performed satisfactorily.

A fly-around (1/2-lap), required approximately 24 min, and was initiated with +X pulse at 353/22:35:13 GMT (09/20:47:38 MET). The separation 1 maneuver was an RCS maneuver that was a 6-sec +X pulse at 353/22:58:15 GMT (09/21:10:40 MET). The separation 2 maneuver was performed at 353/23:26:26 GMT (09/21:38:51 MET). This firing was a 40-sec +X maneuver with a ΔV of 9.4 ft/sec. The resulting orbit was 171.1 by 192.5 nmi.

The OMS 7 final separation maneuver was a two-engine OMS engine maneuver starting at 354/00:11:46.392 GMT (09/22:24:11.383 MET) with a firing time of 11.4 sec and a ΔV of 18.3 ft/sec. The resulting orbit was 169.2 by 183.2 nmi. Engine performance was nominal.

Flight Day 12

The MMOD late inspection of the port, starboard, and nose-cap RCC was successfully completed. The OBSS was berthed and latched at 354/21:47 GMT (10/19:59 MET)

with no issues. The SRMS was cradled and latched at 354/22:20 GMT (10/20:32 MET) with no issues. All of the inspection data were downlinked for review by the Damage Assessment Team (DAT). No issues were identified.

A FES Primary A water dump was started at approximately 354/17:55 GMT (10/16:07 MET) and was terminated 4 hr 47 min later.

Two payloads, the Micro-Electromechanical System Based Pico Satellite Inspector (MEPSI) and Radar Fence Transponder (RAFT), were successfully deployed at 355/00:19:35 GMT (10/22:32:00 MET) and 355/01:56:46 GMT (11/00:09:11 MET), respectively.

Equipment and personnel were transferred from the Kennedy Space Center (KSC) to White Sands Space Harbor (WSSH) to support a possible landing at that facility. MER and KSC assessed the capability to allow the Orbiter to remain powered post-landing at WSSH to protect Orbiter systems from the effects of freezing weather, but concluded that a postlanding powerdown is required due to inadequate ground purge cooling, and lack of ground power available to prevent overheating of the fuel cells.

The Wing Leading Edge Impact Detection System (WLEIDS) experienced an inadvertent shutdown as a result of a suspected sensor unit firmware error (IFA STS-116-V-13). The system was recovered after a laptop was rebooted, and no sensor data were lost.

Flight Day 13

Review of the imagery from the Flight Day 12 OBSS late inspection was completed, and no issues were identified. The vehicle was cleared for entry, and the WLEIDS was powered down.

The Flight Control System (FCS) checkout was performed with no anomalies. The RCS hot-fire was initiated at 355/16:12 GMT (11/14:24 MET) and completed 14 min later. All 38 RCS thrusters were fired at least once for at least 0.320 sec on each pulse.

During the simultaneous waste and supply water dump, an unusual signature was observed in the rate of reduction of the waste-tank quantity (IFA STS-116-V-09). The waste quantity was asymptomatic rather than straight line as expected. The dump was stopped at 20-percent versus the planned 5-percent capacity. There was no indication of ice in the nozzle bake-out signature. No troubleshooting was performed on orbit, as no further dumps were required.

The Atmospheric Neutral Density Experiment (ANDE) was deployed at 355/18:23 GMT (11/16:35 MET), with a multi-axis RCS separation maneuver performed at 355/18:53 (11/17:05 MET). The F2F and F3F RCS thrusters were used for the maneuver. The

second sphere from the ANDE did not deploy from the canister as expected, and the ANDE was tracked as a single object until canister deploy occurred.

Flight Day 14

While still in OPS 2 mode operation, the Miniaturized Airborne GPS Receiver (MAGR) peripheral channel maintained lock on satellite PRN17 for over 21 min (normal lock by the peripheral channel on a satellite should be less than one min) before correcting itself (IFA STS-116-V-11). As a result of this condition, the MAGR was unable to switch in new navigating satellites to maintain an optimized satellite geometry.

All three U.S. landing sites were activated on planned landing day, as no plus 2-day deorbit capability existed and the first available landing site would be selected. The PLBDs were closed nominally at 356/17:30:29 GMT (12/15:42:54 991 MET) in preparation for landing at one of the three landing sites. The first Kennedy Space Center (KSC) and Edwards Air Force Base (EAFB) opportunities were waved off due to unacceptable weather conditions, but a successful landing was performed on the second KSC opportunity.

The deorbit maneuver was performed on orbit 203 for the second landing opportunity at KSC, a dual-engine straight-feed firing that was initiated at 356/21:27:05.00 GMT (12/19:39:30.991 MET). The duration of the deorbit maneuver was 226.5 sec and the ΔV was 385.4 ft/sec. The orbit following the deorbit firing was 185.2 by 17.8 nmi.

Entry interface occurred at 356/21:59:55 GMT (12/20:12:20 MET), and entry was completed satisfactorily. The main landing gear touchdown occurred on KSC concrete runway 15 at 356/22:31:58 GMT (12/20:44:23 MET) on December 22, 2006. The drag chute was deployed at 356/22:32:03.7 GMT (12/20:41:28.69 MET). Nose-gear touchdown occurred at 356/22:32:11 GMT (12/20:44:36 MET). Wheels stop occurred at 356/22:32:57 GMT (12/20:45:22 MET). The rollout was normal in all respects. The flight duration was 12 days 20 hr 45 min 22 sec. The last Auxiliary Power Unit (APU) was shutdown at 356/22:50:44 GMT (17 min 47 sec after landing).

The STS-116 flight duration was 12 days, 20 hr, and 44-min.

Postlanding, an over-temperature condition was identified on the L/H elevon cove, resulting in discoloration/deposit and tile damage downstream of the trailing edge gap filler and Columbian seal gap filler (IFA STS-116-V-14). All other damages found during postlanding TPS inspection are covered under IFA STS-116-V-06.

PAYLOADS AND EXPERIMENTS

SUMMARY AND ACCOMPLISHMENTS

All ISS and payload mission objectives were accomplished during the STS-116 mission.

The ISS 12A.1 launch package consisted of the P5 truss segment, the Spacehab (SH) Single Logistics Module (SLM), and the Integrated Cargo Carrier (ICC). Integrated onto the ICC were the Russian Service Module Debris Panels (SMDP) and the Space Test Program-Houston (STP-H2) payload.

The STP-H2 consisted of three payloads and their respective launch mechanisms:

- 1) The first payload was the Atmospheric Neutral Density Experiment (ANDE) and it launched from the Canister for All Payload Ejections (CAPE) launch system. The ANDE payload was sponsored by the Naval Research Laboratory and consisted of two perfect spheres, one 19-in. in diameter, the Moc ANDE Active (MAA), and one 17.5-in in diameter, the Fence Calibration (FCal). The purpose of the investigation was to measure the neutral density in low Earth-orbit and provide supporting information on the coefficient-of-drag calculations. It also provided additional calibration objects for the radar fence.
- 2) The second payload was the Micro-Electromechanical System Pico-Satellite Inspector (MEPSI) and it was launched from a MEPSI PICOSAT Launcher Assembly (PLA) mounted on the side of CAPE. The MEPSI payload was sponsored by Department of Defense (DOD) and The Aerospace Corporation and was a demonstration of the nanotechnology required for inspector satellite capability. It consisted of two 4-in by 4-in by 5-in satellites tethered together.
- 3) The third payload was the Radar Fence Transponder (RAFT) and it was launched from a Space Shuttle PICOSAT Launcher (SSPL) mounted to the opposite side of the CAPE from MEPSI. The CAPE was mounted to a wedge which was mounted on the ICC. The RAFT payload was sponsored by the U.S. Naval Academy (USNA) and consisted of two 5-in by 5-in by 5-in satellites. These satellites provided calibration objects (one active and one passive) for the radar fence to track small satellites.

The ISSP Utilization payloads that were flown in the Middeck or in the Spacehab were Passive Observatories for Experimental Microbial System (POEMS), Perceptual Motor Deficits in Space (PMDIS), Anomalous Long Term Effects on Astronauts (ALTEA), Double Coldbag (sample return for Tropi/CARD/Immuno) and Commercial Generic Bioprocessing Apparatus (CGBA) – 4. Short Duration Bioastronautics Investigations (SDBIs) were performed during the mission included Midodrine (SDBI-1503-S), Sleep Short (SDBI 1634) and Latent Virus (SDBI 1493). Additional Utilization payload hardware was manifested onboard the vehicle to support ISS research during the 12A.1 stage.

The Ram Burn Observations (RAMBO) and Maui Analysis of Upper-Atmospheric Injections (MAUI) were flown as payloads of opportunity. And Development Test Objective (DTO) 805 (Crosswind Landing Performance) was manifested for this flight.

CREW ACTIVITIES

After docking, the Shuttle Remote Manipulator System (SRMS) unberthed the P5 Truss Segment and handed it off to the Space Station Remote Manipulator System (SSRMS). The P5 truss was placed in an overnight parked position in preparation for EVA 1 that was planned for the following day, FD 4.

During the docked timeframe, the crew performed three scheduled EVAs and 1 unscheduled EVA as well as middeck and transfer operations between the Shuttle and ISS and the ISS and the Shuttle. The ISS reboost maneuver was not performed.

At the request of the ISS Program, a decision was made by the Mission Management Team (MMT) to add a fourth EVA to complete the full retraction of the P6 4B Solar Array Wing (SAW). This retraction task was initiated, but not successfully completed on FD 5. To accommodate the fourth EVA, the docked mission duration was extended one day.

MEPSI was deployed on December 20, 2006, at 6:19:49 p.m. CST [355/00:19:49 GMT and 10/22:32:14 Mission Elapsed Time (MET)] and ejected successfully. The satellites deployed un-powered, then booted up and took its first picture in less than 2 sec. The images were downloaded to the MEPSI ground station approximately 25 min after deployment. All of the minimum mission objectives were met.

RAFT deployed on December 20, 2006, at 7:56:43 p.m. CST (355/01:56:43 GMT and 11/00:09:08 MET). The satellites ejected successfully and contact was made with RAFT 1 by the USNA less than one-hr after deployment, and all telemetry was nominal. The second RAFT satellite, MARSCOM was not contacted, and was assumed to be in too close proximity to the RAFT 1.

ANDE was ejected successfully from the CAPE on December 21, 2006, at 12:22:57 p.m. CST (355/18:22:57 GMT and 11/16:35:22 MET). The spheres were enclosed in the Internal Cargo Unit (ICU), which separated 43 sec after the deployment. It was expected to separate at 40-sec, and the slight delay was assumed to be caused by cold temperatures. The spheres were also expected to separate simultaneously; however, the FCal cylinder separated about 2-sec before the MAA cylinder. The MAA did not release from the ICU at the expected time. The crewmembers continued to observe and photograph the components, and it was confirmed via photography that the MAA sphere did eject from the canister approximately 30-min after the deployment. Contact was made by ground stations with the FCal less than one hr after deployment and contact was also made with the MAA almost 4-hr after the deployment and telemetry for both spheres was nominal. The North American Defense (NORAD) confirmed 24-hr later via radar that the MAA did release from the canister.

The MAUI was flown as a payload of opportunity and it was not performed during the mission. The Ram Burn Observations (RAMBO) was also flown as a payload of opportunity and it was not performed during the missions.

TRANSFER WEIGHT SUMMARY

A total of 100 percent of the transfers was accomplished. The total cargo weight transferred from the Shuttle to the ISS was 4877 lb. The total cargo weight transferred from the ISS to the Shuttle was 4911 lb.

In addition, Orbiter consumables transferred to the ISS were:

1. **Water** – A total of 2 CWCs were transferred (190 lb)
2. **Oxygen** – A total of 69 lbm were transferred to ISS airlock high pressure gas tanks.
3. **Nitrogen** – A total of 49 lbm were transferred to ISS airlock high pressure gas tanks.

SIGNIFICANT FIRSTS

The significant firsts that occurred during the STS-116 mission are as follows.

1. The first flight where docking and handing over the payload to the ISS was performed on the docking day.
2. The first unscheduled Extravehicular Activity (EVA) and the first person to perform four EVAs in one mission.
3. First mating of an ISS element outboard of the Solar Array Rotating Joint (SARJ).
4. The first on-orbit retraction of an ISS SAW
5. The first SARJ operation with the SAWs fully deployed.
6. Placing the SAWs on line required two separate major shutdowns of the ISS power systems for reconfiguration.
7. First activation of the ISS permanent External Thermal Control System (Two loops (A and B)).
8. First use of ISS airlock for four EVAs and campout.
9. The first uses of the Spacehab Single Logistics Module for ISS re-supply.

SIGNIFICANT ISS ANOMALIES

The retraction of the Port 6 4B SAW required a series of partial deploy/retract sessions by the IVA crew and ground controllers to bring the 4B SAW within the 19 bays-out requirement for the P4 SARJ to fully rotate and automatically track the Sun. There was no immediate impact for the incomplete retraction, and the configuration would not have impacted the undocking of Discovery or the next planned vehicle docking of the Progress 24. However, the planned

Soyuz 14 relocation scheduled in April 2007 would have exceeded the allowable loads on the SAW. A team evaluated the condition and its final recommendation to the MMT was to add a fourth EVA to the mission to assist the retraction of the SAW.

MISSION PAYLOAD AND EXPERIMENT PRIORITIES COMPLETED

The following table provides a listing of the payload and experiment priorities as well as the completion status of each of the items.

MAJOR ISS MISSION PRIORITIES COMPLETED

Mission priority	Mission Task	Method(s)	Complete
1	Perform Orbiter Reinforced Carbon-Carbon (RCC) inspection and downlink sensor data to the ground for evaluation.	IVA/SRMS/O BSS	FD 2
2	Rendezvous, perform Orbiter tile inspection using ISS imagery during the R-bar Pitch Maneuver (RPM) and dock with the ISS.	IVA	FD 3
3	Rotate Expedition 13 Flight Engineer-2 (FE-2) crewmember with Expedition 14 FE-2 crewmember, transfer mandatory crew rotation cargo per flight 12A.1 Transfer Priority List (TPL) (in the Flight Rules annex), and perform mandatory tasks consisting of Individual Equipment Liner Kit (IELK) install, Sokol suit checkout and the safety briefing, and the crew safety handover.	IVA	FD 3
4	Transfer maximum amount of Shuttle O ₂ , as available, to ISS to replenish ISS airlock tanks.	IVA	FD 5
5	Transfer and return Elektron liquid unit No. 9	IVA	Complete
6	Transfer mandatory quantities of water from Shuttle to ISS per flight 12A.1 TPL (in the flight rules annex).	IVA	Complete
7	Perform robotic installation of P5 on ISS with EVA crew assist.	IVA,EVA, SRMS SSRMS	FD 4
8	PVRGF relocation to P5 keel.	EVA	FD 4
9	Perform EVA/IVA tasks for ISS power reconfiguration and activation.	IVA, EVA	FD 6 and FD 8
10	Retract P6 port (Channel 4B) SAW to one bay and initiate P3/P4 SARJ Sun tracking.	IVA and EVA4	FD 5 and FD 10
11	Remove DC-to-DC Converter Unit (DDCU)-E thermal covers from P1-3A, S1-4B, and S04B.	EVA 2 and 3	FD 6 and FD 8
12	Uplink the D1 patch to Portable Computer System (PCS) R9	Prelaunch, IVA	FD 4
13	Perform up to 48 hours of mated attitude control using Orbiter propellant during ISS power reconfigurations, in the event ISS cannot provide attitude control.	IVA	Complete
14	Transfer "Critical Cargo Items" per flight 12A.1 TPL (in the Flight Rules annex).	IVA	Complete

MAJOR ISS MISSION PRIORITIES COMPLETED (Continued)

Mission priority	Mission Task	Method(s)	Complete
15	Perform late Orbiter RCC inspection of the wing leading edge (both wings) and nose cap prior to deorbit and landing to detect Micrometeoroid/Orbital Debris (MMOD) damage and downlink the sensor data to the ground for evaluation	IVA/SRMS /OBSS	FD 12
16	Perform EVA tasks to remove SMDPs from the ICC and transfer to the ISS PMA-3 Aft GF.	EVA,SRMS	FD 8
17	Perform two CETA cart relocations from starboard side to port side to support S3/S4 berthing (allows Mobil Transporter (MT) to be in correct location) on 13A.	EVA,SRMS	FD 8
18	Perform minimum crew handover of 12 hours per rotating crewmember.	IVA	Complete
19	Perform the following activities and return hardware: a. Remove and Replace (R&R) the Oxygen Recharge Compressor Assembly (ORCA) b. R&R the Carbon Dioxide Removal Assembly (CDRA) front bed with (modified, if available) CDRA.	IVA	FD 7 FD 8
20	Perform ISS Sortie and Short Duration Bioastronautics Investigations (SDBI) payloads. Relative priorities between the Utilization Payloads are: a. Test of Midodrine as a Countermeasure Against Postflight Orthostatic Hypotension (reference NSTS 16725, Flight Test and Supplementary Objectives Document (FTSOD) SDBI 1503-S). b. Passive Observatories for Experimental Microbial Systems (POEMS). c. Sleep-Wake Actigraphy and Light Exposure During Spaceflight (Sleep Short) (reference FTSOD SDBI 1634.) d. Monitoring Latent Virus Reactivation and Shedding in Astronauts (reference FTSOD SDBI 1493). e. Perceptual Motor Deficits in Space (PMDIS) [operated on ISS]. f. Anomalous Long Term Effects on Astronauts (ALTEA). g. Double Coldbag (Tropi Samples). h. Double Coldbag (CARD/IMMUNO/Nutrition samples). i. Commercial Generic Bioprocessing Apparatus (CGBA)-4	IVA	Complete Complete Complete Complete Complete FD 4 FD 9 Complete Complete
21	Transfer remaining cargo items per flight 12A.1 TPL (in the Flight Rules annex).	IVA	Complete
22	Perform EWIS P5 to P4 power connection.	EVA	FD 4
23	Transfer the Adjustable Grapple Bar (AGB) from the ISS interior to the FHRC on ESP-2.	IVA/EVA	FD 8
24	Perform P64B final retraction and Solar Array Blanket Box (SABB) latching.	IVA/EVA IVA	FD 10
25	Install SO Channel 1/4 Power Cable and SO Channel 2/3 Power Cable.	EVA IVA	FD 6 and FD 8

MAJOR ISS MISSION PRIORITIES COMPLETED (Concluded)

Mission priority	Mission Task	Method(s)	Complete
26	Perform STP-H2 deploy operations. Relative priorities between the STP-H2 payloads are: a. ANDE b. MEPSI c. RAFT	IVA	FD 13 FD 12 FD 12
27	Perform the following: a. R&R the Treadmill Vibration Isolation System (TVIS) Gyro b. R&R the Charcoal Bed Assembly c. Respiratory Support Pack Checkout	IVA	FD 6 FD 7 Complete
28	Transfer Nitrogen from the Orbiter to the ISS	IVA	FD 9
29	Perform an additional 4 hours per rotating crewmember of ISS handover (16 hours total per crewmember total).	IVA	Complete
30	Perform imagery survey of the ISS exterior during Orbiter flyaround after undock.	IVA	FD 11
31	Perform payload operations to support MAUI and RAMBO.	IVA	Tests cancelled
32	Transfer O ₂ from Orbiter to the ISS High Pressure Gas Tank (HPGT) if Orbiter margins allow.	IVA	Completed
33	The following tasks fit within the existing EVA timelines; however, they may be deferred if the EVA is behind schedule. The EVA will not be extended to complete these tasks. a. Install SSRMS Force Moment Sensor (FMS) Multilayer Insulation (MLI). b. Install the starboard and port Fluid Quick Disconnect (QD) bags on the Joint Airlock. c. Install S0/N1 primary power cable (S0 side only) and reconfigure the Z1 patch panels and Russian power to operate from primary power (i.e., Main Bus Switching Unit (MBSU)). d. Install the PM Jumper Bag onto the Joint Airlock. e. Install the Vent Tool Extension (VTE) Bag onto the Joint Airlock.	EVA	FD 6 FD 6 FD 8 FD 6 FD 6
34	Perform program-approved EVA get-ahead tasks. a. Connect P5 to P4 umbilicals (six). b. Open the P5 capture latch assembly and partially close (~1 turn). c. Remove P5 to P6 Rocketdyne Truss Attachment System (RTAS) launch locks.	EVA	FD 4
35	Perform Station Development Test Objective (SDTO) 13005-U, ISS Structural Life Validation and Extension, for the 12A.1 Orbiter undocking.	Ground	FD 11

VEHICLE PERFORMANCE

LAUNCH DELAY

The first launch attempt of STS-116 (ISS 12A.1, P5/Spacehab Single Logistics Module (SM)/ Integrated Cargo Carrier (ICC)) mission on OV-103, Discovery, on December 7, 2006 was scrubbed due to a Range Safety weather violation that was present throughout the 10-min launch window. As a result of the unfavorable weather forecast for December 8, a 48-hr launch scrub was declared. The second launch attempt on December 9th was successful with the launch occurring at 7:47:35 P.M., CST (344/01:47:35.009 GMT).

SOLID ROCKET BOOSTERS

All Solid Rocket Booster (SRB) systems performed as expected during the launch countdown and ascent. The SRB pre-launch countdown was nominal and three SRB in-flight anomalies (IFAs) were identified from the review and analysis of data, and these are discussed in later paragraphs of this section. No SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) waivers or exceptions were written during the countdown. No SRB LCC or OMRSD violations occurred. The flight loads data, obtained from the Aft Strut load instrumentation, provided data to validate the analytical prediction methods for SRB Aft Strut and ETA ring loads. There was no indication of stud hang-ups from the Orbiter accelerometers.

Power up and operation of all igniter and field joint heaters was accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. The heated, ground supplied, aft skirt purges maintained the case/nozzle joint and flex bearing temperatures within the required LCC ranges.

Video imagery from the aft-pointing Forward Skirt Camera shows a debris piece of unknown origin hitting the Orbiter during separation at 125.209 MET (STS-116-B-001). The Booster Trowelable Ablative (BTA) is missing from Left Hand Booster Separation Motor Nozzles. Two tests indicated liberation of BTA, which led the Postflight Assessment Team (PFAT) to suspect the debris noted by the NASA Imagery. Investigation could be BTA from the BSM Nozzles.

A frangible threaded bolt half (1 of 4) was noted to be missing from the left-hand SRB T-0 Umbilical Plate during the post-flight inspection (STS-116-B-002). During the Main Launch Platform (MLP) walkdown, the head of the bolt was found to have been retained by the ground carrier assembly. Therefore, the fastener was installed prior to launch. The umbilical plate received (and passed) a go/no-go gage check and has been removed as a contributor. A data review of procurement on the bolts was performed and all bolts were inspected to be within tolerances. A review indicates that there is no positive retention mechanism inherent in the design, thus, the design functioned within nominal parameters.

The post-flight inspection of the SRBs showed missing BTA material from both the left-hand and right-hand BSMs (STS-116-B-003). Material was missing from thin overlaps of BTA wrapped around the sides of the BSM support structures as part of the application to prevent the material from pulling away due to gravity prior to cure. This causes the wrap-around area to cure under a shear load. The left-hand SRB BSM had a wedge-shaped piece missing that had a dimension 2.5-in by 1.0-in by 0.06-in. The fracture surface had a slightly sooty appearance. The right-hand SRB BSM had a wedge-shaped piece missing that had a dimension 1.5-in by 1.0-in by 0.09-in. The anomaly was under investigation when this report was written.

REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motors (RSRM's) performed nominally with no violations of the RSRM LCC or OMRSD. Data indicate that the flight performance of both RSRMs was well within the allowable performance envelopes and typical of the performance observed on previous flights. Two in-flight anomalies were identified in the review and analysis of the data, and these are discussed later in this section.

All Ground Environmental Instrumentation (GEI) and Operational Flight Instrumentation (OFI) performed within established requirements. All available data were recorded, transmitted, and analyzed without incident. It was determined that all sensors operated as expected. No significant hardware problems or weather concerns occurred during the successful countdown.

The delivered burn rates at 80 °F Propellant Mean Bulk Temperature (PMBT) and 625 psia were 0.3694 and 0.3695 in/sec for the left and right motors, respectively, and these rates were nominal. Adaptive guidance throttling (AGT) did not make any corrections that were due to off-nominal thrust.

The motor performance parameters were within Contract End Item (CEI) specification limits. Reconstructed performance parameters adjusted to a 60°F PMBT standard are listed in the following table. The calculated PMBT was 68°F at time of launch. The maximum trace shape variation of pressure vs. time during the 62 to 80-sec time frame was calculated to be 0.51-percent at 70.5 sec (left motor) and 0.65-percent at 68.5-sec (right motor). These values were within the 3.2-percent allowable limits.

RSRM PERFORMANCE PARAMETERS AT 60° F PMBT

Parameter	CEI specification limit, 60 °F	Left motor delivered	Right motor delivered
Web time, sec	105.4 – 116.7	110.6	110.4
Action time, sec	115.2 – 131.2	122.6	122.8
Head end pressure, psia	847.9 – 965.7	915.1	916.2
Maximum sea level thrust, Mlbf	2.88 – 3.26	3.06	3.06
Web time average pressure, psia	629.9 – 700.5	667.2	668.0

RSRM PERFORMANCE PARAMETERS AT 60° F PMBT (Concluded)

Parameter	CEI specification limit, 60 °F	Left motor delivered	Right motor delivered
Web time average vacuum thrust, Mlbf	2.46 – 2.74	2.61	2.62
Web time total impulse, Mlbf sec	285.8 – 291.6	288.8	288.7
Action time impulse, Mlbf sec	293.7 – 299.7	296.7	296.6
ISP average delivered, lbf sec/lbm	266.5 – 270.3	268.6	268.5
Loaded propellant weight, lbm	>1103840	1105331	1105186

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

The RSRM propulsion performance is shown in the following table.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 72 °F		Right motor, 72 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	66.17	66.06	66.24	65.92
I-60, 10 ⁶ lbf-sec	176.82	176.34	176.98	176.49
I-AT, 10 ⁶ lbf-sec	296.92	297.11	296.88	297.00
Vacuum Isp, lbf-sec/lbm	268.6	268.8	268.6	268.7
Burn rate, in./sec @ 60 °F at 625 psia	0.3694	0.3689	0.3697	0.3695
Event times, seca	0.232	N/A	0.232	N/A
Ignition interval	107.9	108.3	107.8	108.1
Web timeb	117.9	117.9	117.7	117.6
50 psia cue time	120.1	120.0	119.9	120.3
Action timeb	122.3		122.3	
Separation command				
PMBT, °F	80	80	80	80
Maximum ignition rise rate, psia/10 ms	90.8	N/A	90.8	N/A
Decay time, sec (59.4 psia to 85 K)	3.1	2.9	3.1	3.7
Tailoff impulse imbalance differential ^c	Predicted N/A		Actual 342.5	

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

^bReferenced to liftoff time (ignition interval).

^cImpulse imbalance = integral of the absolute value of the left motor thrust minus right motor thrust from web time to action time.

The RSRM-95B trace shape was out of historical experience from 8.5 to 21.5-sec. The minimum trace shape variation during this time was -1.524 percent at 12.5-sec, which is 0.475 percent lower than the historical minimum of -1.049 percent.

Within the duration of this historical excursion, the RSRM-95B motor was out of K-sigma expectation at three instances:

1. From 12.5 - 13.5 sec, the minimum trace shape variation was -1.524 percent at 12.5 sec, which was 0.019-percent lower than the K-sigma value of -1.50 percent;
2. From 16.0 to 18.5 sec, the minimum trace shape variation during this time was -1.350 percent that is -0.048-percent lower than the K-sigma value of -1.302 percent; and,
3. From 21.0 to 21.5 sec, the minimum trace shape variation during this time was -1.250 percent, which is -0.027 percent lower than the K-sigma value of -1.223 percent.

The RSRM-95A motor (left) was out of historical experience at two time instances. The first, which occurred from 11.0 to 12.0-sec, showed a minimum trace shape variation of -1.128 percent, which is 0.018 percent lower than the historical minimum of -1.110 percent. The second occurred at 16.0-sec, where the trace-shape variation of -0.954 percent was 0.011 percent lower than the historical minimum of -0.943 percent. An investigation to evaluate these excursions was continuing as this report was written.

The ambient temperatures recorded during the 131-hr prior to launch of STS-116 varied from 52 to 74 °F. The data recorded during this time frame was at the $\pm 1.0\sigma$ range from historical December average hourly temperatures. At the time of launch, the ambient temperature was 65 °F. The average historical ambient temperature for the time of launch for the month of December is 63 °F.

Igniter joint heaters operated for 14-hr 4-min during the launch countdown. Power was applied to the heating elements 73 percent (average) of the time during the LCC time frame of the countdown to keep the igniter joints in their normal operating range. The total activation time for both countdowns was 29-hr 42-min.

Field joint heaters operated for 14-hr 12-min during the launch countdown. Power was applied to the heating elements 49 percent (average) of the time during the LCC time frame of the countdown. The total activation time for both countdowns was 30 hr 28-min.

The aft skirt purge was activated three times during the final countdown for 11-hr 38-min. The total activation time during the recorded 131-hr timeframe prior to launch was 33-hr 19-min. A total of eight activations occurred during this time. It was necessary to thermally condition the aft skirt region prior to launch to achieve the nozzle/case joint seals minimum LCC temperature of 75 °F. However, it was not

necessary to thermally condition the flex bearings to meet the 60 °F mean bulk temperature requirement.

During the LCC time frame, the left- and right-hand motor nozzle/case joint sensor temperatures ranged from 75 to 83 °F and 76 to 84 °F, respectively. The final Flex Bearing Mean Bulk Temperature (FBMBT) was calculated to be 79 °F.

Effective with the previous launch (STS-115), the outboard case acreage sensors, located at 45 and 135 degrees, became LCC sensors. This launch was the second use of the instrumentation change to the igniter joints, field joints, nozzle-to-case joints and case acreage; changing from a variety of temperature ranges to one standard temperature range (10.2 °F to 135.2 °F). With these and other changes to the temperature measurement system, these last two launches have been the cleanest as far as measurement tightness (minimal gauge-to-gauge variation/error) in the RSRM program.

The two RSRM in-flight anomalies are discussed in the following paragraphs.

An area of missing stiffener ring foam (approximately 6-in by 4-in by $\frac{3}{4}$ -in) with heat effects was observed on the Left-Hand (LH) motor center stiffener ring foam ramp at the 5-degree location (IFA STS-116-M-001). Although the initial data assessment suggests a entry event, insufficient data are available to preclude the possibility of an ascent occurrence. Assuming material loss was a single event during ascent, the analysis provided the following conditions.

1. The estimated lost material mass (approximately 0.03 lb) exceeds NSTS 60559, Table C-1 risk assessment mass (0.0002 lb); and
2. The estimated lost material mass (approximately 0.03 lb) was less than NSTS 60559 SRB allowable mass for ETA ring foam (0.218 lb).

The ETA ring foam is more forward on the RSRM (nearer the Orbiter) than the stiffener ring foam. During ascent, it is assumed the ETA foam loss would pose a greater debris risk than stiffener ring foam loss. The ETA ring foam-loss allowable-limits are greater than the stiffener foam-loss allowable-limits. An assessment is underway to determine the ETA ring foam-loss allowable-limit applicability to the stiffener foam-loss allowable-limit.

Two shallow parallel grooves (each 0.40-in wide by 0.06-in deep, and approximately 0.40-in apart) were found in the Right Hand (RH) Nose Cap Outer Diameter (OD) Carbon Carbon material. The Phenolic material is located approximately 1.5-in from the nose tip (IFA STS-116-M-002). There was no associated downstream wash erosion. The Nose Cap was robust, with an average Performance Factor of 2.6; the requirement is 1.4. The groove depths are much less than typical intermittent wash erosion on flight Nose Caps (0.01 to 0.22-in deep).

EXTERNAL TANK

The External tank (ET) identification was Super Lightweight Tank ET-123. All objectives and requirements associated with propellant loading and flight operations were met. No significant oxygen or hydrogen concentrations were detected in the intertank. All ET electrical equipment and instrumentation operated satisfactorily. Purge and heater operations were monitored and performed properly. The Liquid Oxygen (LO₂) and Liquid Hydrogen (LH₂) tank ullage-pressures were at predicted levels during the flight. All 49 ET measurements performed satisfactorily. No ET LCC or OMRSD violations occurred, nor were any in-flight anomalies identified during the review and analysis of the data.

ET-123 enhancements are as follows:

1. Redesigned intertank thrust panels (replaced external ribs with internal stiffeners);
2. Replaced aluminum 2195 with aluminum 2219 in LO₂ forward ogive, and LO₂ and LH₂ dome gore frame);
3. Changed Gaseous Oxygen (GO₂) vent duct internal close-out foam;
4. GO₂/Gaseous Hydrogen (GH₂) vent valves supplier changed;
5. GO₂/ GH₂ pressurization-line supplier change and re-qualification;
6. Internal LH₂ feedline bellows supplier change and re-qualification;
7. Redesigned ET flight side of Ground Umbilical Carrier (GUCA) Assembly; and
8. Changed BX 250 to BX 265 on the LO₂ tank to Intertank Flange closeout.

The Final Inspection Team (FIT) pre-flight showed that, generally, the ET was dry. ET surface temperatures ranged from 55 to 76 °F. No ET acreage frost or ice was noted. Several ET protuberance bondline frost formations were noted. All ice/frost formations were within NSTS 08303, "Ice/Debris Inspection Criteria". No LCC, OMRSD violations or IPR conditions were reported.

Main Engine Cutoff (MECO) occurred at approximately 504 sec MET with ET separation occurring at 524 sec MET. The ET altitude at separation was 344.723 ft, and the ET impacted within the predicted footprint 58 nmi uprange from the preflight predicted impact point. The coordinates of the impact point were 36.833 deg S latitude and 159.107 deg W longitude.

SPACE SHUTTLE MAIN ENGINES

All SSME parameters were nominal throughout the pre-launch countdown and were typical of previous flights. There were no LCC or OMRSD violations. Engine "Ready" was achieved at the proper time, all LCC's were met, and thrust build up was nominal.

This was the first flight of the following design changes:

1. Advanced Health Monitoring System (AHMS) Controller, monitor mode only;
2. Non-Integral Spark Igniter System (NISIS); and

3. Low Pressure Fuel Duct (LPFD) Kevlar Insulation System.

Flight data indicate that SSME performance during mainstage, throttling, and shutdown, was nominal. The initial review of AHMS vibration measurements on SSME 2058 indicates nominal performance. The High Pressure Oxidizer Turbopump (HPOTP) and High Pressure Fuel Turbopump (HPFTP) temperatures were within specification limits throughout engine operation. Commanded Max Q throttle down was a one-step throttle to 74 percent.

There were no in-flight anomalies, nor any significant SSME problems identified during the review and analysis of the flight data.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. There were no OMRSD or LCC violations.

All SRSS Safe and Arm (S&A) devices were armed and system inhibits turned off at the appropriate times. As planned, the SRB safe and arm devices were safed and SRB system power was turned off prior to SRB separation.

ORBITER SYSTEMS

During S0007 checkout activities at 339/03:26:25 GMT, the Orbiter main bus A experienced a voltage transient that exceeded the specification for both the 32-V/200-msec allowable and the 37-V absolute allowable levels. An in-depth evaluation of all main bus A hardware was performed, and all systems were determined to be unaffected. An OMRSD waiver was processed, and the countdown was continued.

Main Propulsion System

The Main Propulsion System (MPS) performed satisfactorily throughout the STS-116 mission. The LO₂ and LH₂ Engine Cutoff (ECO) sensors passed all pre-flight checkouts. There were no LCC or OMRSD violations. No in-flight anomalies were identified in the review and analysis of the data.

The maximum hydrogen concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fastfill, was 104 ppm (uncorrected). System A of Hazardous Gas Detection System (HGDS) 2000 was used to determine the maximum concentration. This concentration level compares favorably with previous data for this vehicle.

Data indicate that the LO₂ system performed as planned. The LH₂ pre-pressurization cycle count was 10 cycles with 14 cycles being the LCC limit. Engine inlet net positive suction pressure requirements were met throughout the flight.

The overall GH₂ system in-flight performance was nominal. All three flow control valves performed nominally. The cycle count was SSME 1 was 6 cycles; SSME 2 was 1 cycle; and SSME 3 was 3 cycles.

The GO₂ fixed-orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely matched the actual ET ullage pressure measurements.

Helium system performance for the SSME pneumatic Helium systems was nominal. Entry helium usage was 59.2-lb, which is within the requirements. All other parameters were nominal.

Two issues were noted during the prelaunch operations and these are discussed in the following paragraphs.

Hydrogen leak detectors 56 and 57 at the LH₂ T-0 8-In Fill/Drain Purge Shroud indicated levels that exceeded 5000 ppm. This trend was documented; however, the LCC limit is 40,000 ppm. As a result, no troubleshooting was required. The leak detectors dropped below 5000 ppm as soon as the ET LH₂ tank vent valve was opened for transition to LH₂ topping.

Elevated hydrogen concentration levels of approximately 17,000 ppm were detected in the Ground Umbilical Carrier Plate (GUCP) interface about 2½ min after transitioning to topping. This also occurred on the first launch attempt. This phenomenon has occasionally occurred on previous flights.

Hazardous Gas Concentrations

The aft hazardous gas concentrations during the loadings for the two loadings are shown in the following tables.

HAZARD GAS CONCENTRATIONS

First Launch (Attempt)		
Parameter	Peak, ppm	Steady State, ppm
Helium	8760	6460
Hydrogen	96	6
Oxygen	56	7
LD54/55	600/-600	-1200

Second Launch Attempt (Launch)		
Parameter	Peak, ppm	Steady State, ppm
Helium	7852	5400
Hydrogen	100	9
Oxygen	20	8
LD54/55	n/a	n/a

Gas Sample Analysis

All six redesigned gas sampler system bottles functioned as expected. All measured pressures were within the range of acceptable pressures established by the Propulsion Systems Integration Group (PSIG) Subcommittee in March 1995. A summary of the Right Hand (RH) and Left Hand (LH) bottle pressure and gas concentration for STS-116 is given in following table. .

SUMMARY OF BOTTLE PRESSURES AND GAS CONCENTRATION

Bottle no.	Position	Pressure, psia	Helium, %	Measured Oxygen, %	Hydrogen, %
1	RH1	3.77	0.62	1.99	0.04
2	LH1	1.51	0.46	1.69	0.05
3	RH2	1.36	0.79	1.34	0.07
4	LH2	0.82	1.04	2.15	-0.05
5	LH3	0.18	1.48	1.34	0.11
6	RH3	0.06	3.37	1.12	0.34

The Ascent Hazard Analysis indicates the maximum hydrogen firing leak rate for STS-116 was 2100 scim. The estimated firing leak rates for all sample bottle data from this flight are summarized in the following table.

HYDROGEN FIRING LEAK RATES

Bottle no.	Position	Hydrogen Firing Leak Rate, scim
1	RH1	2100
2	LH1	1280
3	RH2	1670
4	LH2	850
5	LH3	510
6	RH3	580

The maximum-allowable firing-leak-rate on ascent is 57,000 scim. A firing leak rate less than 57,000 scim ensures the Orbiter aft compartment environment does not exceed the lower flammability limit (LFL) for hydrogen during ascent. The actual LFL is a function of the trajectory and will vary slightly from flight to flight. The upper limit of 57,000 SCIM was chosen based on a standardized trajectory and conservatively envelopes the majority of trajectories flown.

The complete results of the gas chemical analysis, provided by Kennedy Space Center, Materials and Chemical Analysis Branch laboratory are shown in the following table.

AFT FUSELAGE SAMPLE BOTTLE GAS ANALYSIS

	Position	Sec	Actual pressure torr	Ar %	Air from Ar %	He %	CO %	CH ₄ %	CO ₂ %	O ₂ from air %	O ₂ found %	H ₂ %	H ₂ pyro-corrected, %
1124 FLT-3	RH1	60	194.9	0.07	7.82	0.62	<0.01	<0.01	0.02	1.64	1.99	0.04	0.04
1107 FLT-3	LH1	74	77.9	0.06	6.42	0.46	<0.01	<0.01	0.01	1.35	1.69	0.05	0.05
1125 FLT-3	RH2	74	70.3	0.05	5.35	0.79	<0.01	<0.01	0.01	1.12	1.34	0.07	0.07
1120 FLT-3	LH2	82	42.4	0.09	9.53	1.04	0.27	<0.01	0.02	2.00	2.15	0.10	-0.05
1122 FLT-3	LH3	101	9.17	0.07	7.07	1.48	0.12	<0.01	0.01	1.48	1.34	0.18	0.118
1127 FLT-3	RH3	116	3.15	0.04	4.39	3.37	0.04	<0.01	0.03	0.92	1.12	0.37	0.34

Purge, Vent and Drain System

The Purge, Vent and Drain (PV&D) system performed nominally during the first and second launch attempts and during entry and landing.

During tanking for the first launch attempt, the oxygen concentration level exceeded 4 percent in the LH₂ T-0 carrier cavity. Prior to the second loading for the launch, the area was inspected. A wrinkle in the seal and a loose fitting were repaired and the oxygen levels during the second loading were almost zero.

The GUCP leak detectors LD23 and LD25 registered a spike of hydrogen ranging from 11,700 ppm to 17,400 ppm when transitioning to the top-off mode. This occurrence was not unexpected, but has been seen before. There was a seal modification made (first flight of the modification) to prevent leaks during loading, and this leak occurred during the transition. The system returned to nominal readings and no further leaks were noted.

The LD56 and LD57 detected concentrations of hydrogen in excess of 5,000 ppm, which went back to almost zero as soon as LH₂ tanking went to the topping phase. This was also seen during the first loading, but it did not exceed 5,000 ppm. The documentation limit is a maximum hydrogen concentration of 40,000 ppm.

Reaction Control System

The Reaction Control System (RCS) performed nominally. The data review and analysis identified one in-flight anomaly that occurred during entry and is discussed later in this section.

This was the first flight of the redesigned Forward Reaction Control system (FRCS) Tyvek weather covers. The covers released as predicted with nominal performance. Cover release times and speeds are given in the following table.

TYVEK COVER RELEASE TIMES AND VEHICLE VELOCITIES

Cover	MET, sec	Velocity, miles/hr
F1D	4.2	50
F3D	4.7	56
F2F	5.1	62
F3F	5.2	63
F2D	5.5	67
F1F	5.7	70
F4D	5.9	73
F1U	7.0	88
F1L	7.1	89
F3U	7.3	92
F3L	7.7	98
F2U	7.8	99
F2R	8.2	105
F4R	9.0	117

The RCS firings, times initiated, Differential Velocities (ΔV s), and firing times are listed in the table in the following table.

RCS MANEUVERS AND FIRING DATA

Firing	Time of Ignition, GMT	ΔV , ft/sec	Firing Time, sec
RCS Window Protect	344/01:49:38	N/A	2.03
ET Sep	344/01 56:19	N/A	6.0
NC3	345/04:44:18.4	3.8	15.5
NCC	345/18:30:43.8	0.9	4.48
MC1	345/19:48:27.3	0.85	6.1
Out of Plane Null	345/20:07:46	N/A	0.40
MC2	Not Required		
MC3	345/20:37:58	1.95	5.4
MC4	345/20:47:58.3	1.9	4.6
ISS Undock	353/22:09:39		
ISS Fly Around - Full	353/22:35:13		
Sep 1	353/22:58:15		6.0
Sep 2	353/23:26:26	9.4	40.0
RCS Hotfire	355/16:12:00	N/A	36 thrusters at least two 0.320 sec pulses and 2 thrusters at least 0.240 sec pulses
ANDE Sep Maneuver	355/18:52:38.8	1.8	7.38
FRCS Dump	356/21:41:55.9	N/A	60.5

The RCS window-protect maneuver was initiated at 344/01:49:38 GMT [(00/00:02:03 Mission Elapsed time (MET))] and had a duration of 2.03 sec. During the maneuver, thrusters F1U, F2U, and F3U were fired. The intent of the window-protect maneuver was to deflect the exhaust from the SRB separation motors away from the windows during SRB separation.

The ET separation was performed at 344/01:56:19 GMT (00/00:08:44 MET) and was a 6.84-sec, 10-thruster translation maneuver. The ET photo maneuver was not performed because of the night launch.

The RCS preflight propellant load was 4351 lb of oxidizer and 2735 lb of fuel, for a total of 7086 lb of propellant loaded for the mission. The residual propellants, as calculated by the Primary Avionics Software System (PASS), were 2089 lb. The propellant used was 4529.6, which included 417.8 lb used from the OMS during RCS interconnect operations.

As part of the undocking preparations, thrusters F1U, F2U, and F3U were reselected at 353/21:27:01 GMT (09/19:39:26 MET). Undocking was initiated with a +Z pulse at

353/22:35:13 GMT (09/20:47:38 MET). ISS undocking was nominal. The flyaround and separation from the ISS were accomplished nominally. Data for the two separation maneuvers is shown in the previous table.

The RCS hotfire was completed satisfactorily, and 36 thrusters were fired at least twice for at least 0.320 sec on each pulse and two thrusters were fired at least two 0.240 sec pulses. No problems were detected during hotfire.

Attitude control responsibilities between the ISS and Shuttle are summarized in the following table.

CONTROL RESPONSIBILITIES BETWEEN ISS AND SHUTTLE

Control Responsibility	Control Start, GMT	Control End, GMT	Elapsed Time, hr:min:sec	Comments
Docked	345/22:11:35	345/22:36:35	00/01:20:24	
Orbiter	345/22:36:35	345/22:36:48	00/01:20:37	DAP AUTO - TEA Maneuver
Station	345/22:36:48	345/22:37:04	00/01:20:53	DAP Free Drift
Orbiter	345/22:37:04	345/22:47:09	00/01:40:58	DAP AUTO
Station	345/22:47:09	345/22:47:17	00/01:41:06	DAP Free Drift
Orbiter	345/22:47:17	345/22:57:29	00/01:51:18	DAP AUTO
Station	345/22:57:29	345/22:57:35	00/01:51:24	DAP Free Drift
Orbiter	345/22:57:35	345/23:09:17	01/21:21:42	DAP AUTO
Station	345/23:09:17	349/05:58:10	05/04:10:35	DAP Free Drift
Orbiter	349/05:58:10	349/06:09:02	05/04:21:27	DAP AUTO – ISS CMG de-saturation
Station	349/06:09:02	349/06:09:55	05/04:22:20	DAP Free Drift to Load DAP A15
Orbiter	349/06:09:55	349/17:02:35	05/15:15:00	DAP AUTO - ISS CMG de-saturation and water dump
Station	349/17:02:35	349/17:03:19	05/15:15:44	DAP Free Drift – Load DAP A12
Orbiter	349/17:03:19	349/21:27:10	05/19:39:35	DAP AUTO - Water Dump and maneuver to TEA
Station	349/21:27:10	350/22:12:02	06/20:34:27	DAP Free Drift - EVA 3
Orbiter	350/22:12:02	351/01:43:12	06/23:55:37	DAP AUTO
Station	351/01:43:12	351/01:43:55	06/23:56:20	DAP Free Drift – Start P6 SAW Retract
Orbiter	351/01:43:55	351/01:48:46	07/00:01:11	DAP AUTO - Solar Array Retract Attempt
Station	351/01:48:46	351/01:49:12	07/00:01:36	DAP FREE DRIFT
Orbiter	351/01:49:12	351/01:50:22	07/00:02:47	Solar Array Retract Attempt
Station	351/01:50:22	351/01:50:47	07/00:03:12	Solar Array Retract Attempt
Orbiter	351/01:50:47	351/01:56:33	07/00:08:58	Solar Array Retract Attempt
Station	351/01:56:33	351/01:57:06	07/00:09:31	Solar Array Retract Attempt
Orbiter	351/01:57:06	351/01:59:33	07/00/11:58	Solar Array Retract Attempt
Station	351/01:59:33	351/02:00:01	07/00:12:26	Solar Array Retract Attempt
Orbiter	351/02:00:01	351/02:01:18	07/00:13:43	Solar Array Retract Attempt
Station	351/02:01:18	351/02:01:44	07/00:14:09	Solar Array Retract Attempt
Orbiter	351/02:01:44	351/02:09:59	07/00:22:24	Solar Array Retract Attempt
Station	351/02:09:59	351/02:10:35	07/00:23:00	Solar Array Retract Attempt

CONTROL RESPONSIBILITIES BETWEEN ISS AND SHUTTLE (Concluded)

Control Responsibility	Control Start, GMT	Control End, GMT	Elapsed Time, hr:min:sec	Comments
Orbiter	351/02:10:35	351/02:14:46	07/00:27:11	Solar Array Retract Attempt
Station	351/02:14:46	351/02:14:53	07/00:27:18	Solar Array Retract Attempt
Orbiter	351/02:14:53	351/02:15:21	07/00:27:46	Solar Array Retract Attempt
Station	351/02:15:21	351/02:16:08	07/00:28:33	Solar Array Retract Attempt
Orbiter	351/02:16:08	351/02:25:50	07/00:38:15	Solar Array Retract Attempt
Station	351/02:25:50	351/02:26:15	07/00:38:40	Solar Array Retract Attempt
Orbiter	351/02:26:15	351/02:39:43	07/00:52:08	Solar Array Retract Attempt
Station	351/02:39:43	353/19:26:45	09/17:39:10	DAP Free Drift
Orbiter	353/19:26:45	353/22:09:35	09/20:22:00	DAP AUTO – Undocking
Orbiter	353/22:09:35	EOM		ISS Sep at 353/22:09:39

The RCS pressurization and propellant isolation valves were configured for entry. After the planned landing waveoff, the RCS pressurization and propellant isolation valves were reconfigured for on-orbit operation. The RCS pressurization and propellant isolation valves were again configured for entry. The FRCS dump (four thrusters) was satisfactory and lasted 88.44 sec. The dump consumed 1040.3 lb of forward RCS propellant.

The primary thrusters were fired 3275 times, for a total firing time of 1032.76 sec. The vernier thrusters were fired 10522 times, with a firing time of 14099.56 sec.

Orbital Maneuvering System

The OMS functioned satisfactorily throughout the mission, with no in-flight anomalies identified during the review and evaluation of the data. No LCC or OMRSD violations were documented during either the launch attempt or the subsequent launch. The standard OMS configuration and OMS maneuvers are provided in the following tables.

OMS CONFIGURATION

Vehicle/equipment	Flight	Orbital Maneuvering Engine (OME)	Ancillary data
Left Pod (LP) 01	36 th	L-OME S/N 115	3 rd rebuilt flight - 18 th flight
Right Pod (RP) 03	34 th	R-OME S/N 106	7 th rebuilt flight, 31 st flight

The OMS firings and interconnect options are given in the tables on the following page.

OMS MANEUVERS

Maneuver designation	Configuration	Time of ignition, GMT	Firing time, sec	ΔV , ft/sec/ interconnect usage, percent
Assist	Dual OME	344/01:49:50	97.3	N/A
OMS-2	Dual OME	344/02:24:42	121.6	187.6
OMS-3 (NC1)	Dual OME	344/04:36:42	65.0	101.4
OMS-4 (NC2)	Dual OME	344/18:45:14	36.0	56.4
OMS-5 (NC4)	Dual OME	345/17:56:32	15.8	24.9
OMS-6 (TI)	Left OME	345/19:28:22	11.0	8.1
OMS-7 Sep	Dual OME	354/00:11:46	11.4	18.3
DOB (D/O)	Dual OME	356/21:27:05	227.5	385.3

INTERCONNECT USAGE, PERCENT/POUNDS

Parameter	Interconnect usage, percent	Interconnect usage, lb
Left interconnect	1.993	258.113
Right interconnect	1.289	159.685

The engine inlet pressure, chamber pressure, and regeneration jacket temperatures for both engines were as expected. OMS firing times and propellant consumption were consistent with predictions and verified proper performance.

Helium usage during OMS firings and repressurizations was as predicted, verifying no detectable external leakage. Lockup pressures were within the specification performance band for these regulators. Tank ullage pressures during the firings were as expected (within accepted tolerance of previous flight data).

All of OMS firings this mission except OMS-6 and OMS-7 were of sufficient duration to achieve steady-state regulator performance. At the end of the mission, the propellant quantities were within expected limits and the engine inlet pressures were within expectation during all of the engine firings.

Pressure/temperature data during coast periods indicated no detectable leakage. Gage data from the on-orbit engine firings indicated no loss of propellant from the aft compartment, confirming the bulkhead screen integrity.

Aft gage residuals all agree closely with the firing time integration calculations and are within acceptable limits. Official propellant residuals should be taken from the following table using the gage residuals for both the fuel and oxidizer. The residuals as determined by the Shuttle Operational Data Book (SODB) flowrates and firing-time

integration are presented for comparison purposes.

PROPELLANT DATA

Parameters	Left OMS pod		Right OMS pod	
	Oxidizer	Fuel	Oxidizer	Fuel
Loaded, lbm	7722	4688	7711	4686
Residual, lbm (aft gage)	541	326	624	441
Residual, lbm (burn time integration)	419	259	703	441
Residual, lbm (SODB flow rate)	555	322	692	457

Auxiliary Power Unit System

The Auxiliary Power Unit (APU) System performance was nominal throughout the STS-116 mission. No in-flight anomalies were recorded on the APU System.

The run times and fuel consumption for the APUs, including the S/N of each, during STS-116 are summarized in the following tables.

APU RUN TIMES

APU (S/N)	Ascent, hr:min:sec	FCS Checkout, hr:min:sec	Entry, hr:min:sec	Total time, hr:min:sec
1 (310)	00:19:14	00:00:00	01:03:17	01:22:31
2 (403)	00:19:28	00:00:00	01:28:19	01:47:47
3 (204)	00:19:38	00:05:56	01:03:32	01:29:06

APU FUEL CONSUMPTION

APU (S/N)	Ascent, lb	FCS Checkout, Lb	Entry, Lb	Total, lb
1 (310)	46	0	114	160
2 (403)	52	0	171	223
3 (207)	52	17	137	206

The following APU in-flight anomalies occurred during STS-116

During on-orbit operations, it was noted that APU 3 had peak gas generator (GG) injector temperatures on the 'A' Heater lower than typically seen on other APUs. The APU 1 and 2 peak temperatures were approximately 461 °F while APU 3 was at 431 °F. STS-116 was this first flight of APU 3 with a GG that has the double-wall spring clip in the GG injector well. The spring clip holds the GG bed temperature and injector temperature sensors in place. This design change was implemented to lower GG

temperature sensor movement caused by spring-clip relaxation over time. The noted lower peak injector temperature readings were attributed to the new GG spring clip design installation. This lower peak injector temperature reading resulted in selection of APU 3 for Flight Control System (FCS) checkout.

The heater reconfiguration was completed after undocking for all APU heaters except those operating through the "Gas Gen/Fuel Pump" heater switches. The heater reconfiguration procedure was changed to maintain these switches in the Auto position for the entire flight. This crew procedure change was presented as risk mitigation for the in-flight anomaly that occurred during the STS-121 and was implemented to protect against a possible in-flight failure since the failure investigation prior to the flight had found that the Gas Generator Valve Module (GGVM) 'B' heater was more susceptible to the failure that was experienced during STS-121. Additionally, at approximately TIG-10, min before the deorbit maneuver, which is 5 min before start of APU 2 for entry, all APU heaters operated via the "Gas Gen/Fuel Pump" heater switches were deactivated by the crew based on the updated Flight Data File. This change also allowed the GG injector temperatures to drop within restart limits prior to APU start which also factored into the time selected for heater deactivation. This crew procedure change was presented as risk mitigation for the STS-121-V-09 anomaly and was implemented to protect against the possible ignition hazard of an electrical arc in the post-landing environment should a shorting condition develop during entry.

Hydraulics/Water Spray Boiler System

Overall, the performance of the Hydraulics (HYD) and Water Spray Boiler (WSB) System during STS-116 was nominal. STS-116 was the first flight of the Space Shuttle Program as well as the first flight for OV-103 to use Propylene Glycol Monomethyl Ether (PGME) water additive in all WSB system water tanks to preclude post-ascent freezing during all mission phases. No in-flight anomalies were identified during the review and analysis of the mission data, and all File IX requirements were satisfied. .

WSB heater activation was confirmed with vent nozzle temperatures maintained above the 130 °F minimum and exhibited nominal cycling. The WSB 1, 2 and 3 vent heater temperatures reached the 122 °F minimum temperature indication in a nominal time period. The WSB "READY" Indication was confirmed shortly after the WSB GN₂ isolation valves were opened prior to launch.

HYD circulation pump 1 was operated to perform the elevon park while on-orbit. Nine additional circulation pump runs were performed for thermal conditioning to protect against the lower start-up temperature limit of 20 °F at the circulation pump inlet. All thermal runs were commanded from the ground and nominally the pump runs were approximately 5 min in duration. No accumulator recharges were required during this mission.

Following the FCS checkout with APU3/HYD System 1, the Rudder Speedbrake (RSB) Power Drive Unit (PDU) body temperature appeared to be non-responsive and tended

to flat-line in a -ZLV -XVV, Beta minus 43-degree Orbiter attitude. This condition was observed in almost the identical attitude on the previous flight of this vehicle when performing FCS checkout with APU3/HYD System 1. There was no impact to the vehicle or mission. The RSB PDU body temperature functioned perfectly during the entire on-orbit period and perfectly tracked the heater ON/OFF set-point ranges during the five RSB PDU heater cycles which occurred while docked to the ISS. Also, the FCS checkout with APU3/HYD System 1 was nominal in all respects.

Water Spray Boiler usage during Ascent for spray cooling was as follows (specification is no-greater-than 8 lb/sys):

1. System 1 = 1.1 lb
2. System 2 = 2.6 lb
3. System 3 = 2.9 lb

Water Spray Boiler usage during entry for spray cooling was as follows (specification is no-greater-than 45 lb/sys):

1. System 1 = 15.4 lb
2. System 2 = 25.3 lb
3. System 3 = 11.9 lb

Power Reactant Storage and Distribution System

The Power Reactant Storage and Distribution System (PRSD) performance was nominal during STS-116. The PRSD system supplied the fuel cells with 3001 lb of oxygen and 378 lb of hydrogen for the production of 4384 kWh of electrical energy. The PRSD system also supplied the Shuttle Environmental Control and Life Support System (ECLSS) with 195 lb and 69 lb were transferred to ISS for a total of 264 lb. The O₂/H₂ manifold isolation valves were cycled for the crew-sleep periods, which satisfied the OMRSD File IX In-flight Checkout requirement. There were no in-flight anomalies identified in the PRSD system as a result of data analysis and evaluation.

The initial loading of the five PRSD tank sets was performed on December 5, 2006. With the fuel cells operating, hydrogen tanks 2, 3, 4, and 5 were topped-off on December 9, 2006, following the launch scrub on December 7, 2006. The prelaunch reactant boiloff rate averaged 0.049 lb/hr/tank for hydrogen and 0.21 lb/hr/tank for oxygen.

PRSD OXYGEN AND HYDROGEN TANK QUANTITIES

Oxygen	Tank 1, percent	Tank 2, percent	Tank 3, percent	Tank 4, percent	Tank 5, percent	Total Mass, lb
Loaded	101.8	101.8	100.9	101.4	101.8	3965
Launch	99.6	99.2	98.3	98.7	99.6	3869
Landing	22.6	23.9	16.9	8.5	5.5	604

PRSD OXYGEN AND HYDROGEN TANK QUANTITIES (Concluded)

Hydrogen	Tank 1, Percent	Tank 2, percent	Tank 3, percent	Tank 4, percent	Tank 5, percent	Total Mass, Lb
Loaded	101.9	101.9	102.3	102.3	103.2	470.7
Launch	95.7	101.0	101.5	101.5	101.9	461.5
Landing	24.5	32.9	30.7	0.7	2.0	83.5

The Orbiter landed with 604 lb of oxygen and 83.5 lb of hydrogen remaining in the PRSD system. A 33-hour mission extension capability existed at landing, based upon the PRSD O₂ (the limiting reactant) tank quantities and an average flight power level of 14.2 kW. At an extension day power level of 13.491 kW, a 35-hour mission extension was available.

At 344/16:02:44 GMT (00/14:15:09 MET), the O₂ tank 3 heaters were powered off, and 33 sec later O₂ tank 4 heaters were powered on. During the next 8 heater cycles of O₂ tank 4, the pressure in O₂ tank 3 increased during the heater cycles of O₂ tank 4. This indicated leakage past the check-valve in O₂ tank 3. The magnitude of the pressure increases decreased with each cycle until the O₂ tank-3 check-valve was fully seated. Following this occurrence, the check valve functioned nominally for the remainder of the mission.

Several notable instances of O₂ tank de-stratification and pressure collapses were observed during STS-116. The heaters on oxygen tanks 3, 4, and 5 had been active prior to the associated pressure decays after the fluid de-stratified. Most notable was O₂ tank 4, which was used to transfer 69 lb oxygen to ISS immediately prior to the event. Initially, the quantity decreased to approximately 18 percent as the pressure decreased and in addition, a quantity increase is usually observed. Oxygen tank 4 was used again after about 7 days of heat leak into the tank increased the pressure near to the single-phase fluid state. Two-tank operation to supply high O₂ demand would reduce the fluid stratification effects, but the cryogenic configuration does not always allow this condition to be used.

All PRSD OMRSD File 9 in-flight checkout requirements were completed on STS-116 except the O₂ tank 3 check valve for O₂ tank 3 check valve did not reseal for several heater cycles of O₂ tank 4, and this condition is discussed earlier in this section.

Fuel Cell System

The overall performance of the fuel cell system was nominal for STS-116 except for fuel cell 3 oxygen flowmeter failed to an off-scale low indication (IFA STS-116-V-02). Following the launch scrub on December 7, 2006, hydrogen Tanks 2, 3, 4, 5 topped-off on December 9, 2006, with the fuel cells operating. The fuel cells remained operating following the launch scrub.

The fuel cells installed in OV-103 for STS-116 were serial numbers 114, 120, and 115 in positions 1 through 3, respectively. Fuel-cell startup was initiated December 7, 2006, at 05:45:05 a.m. and was completed approximately 2 hr 25 min later. Startup and prelaunch operations were nominal. Fuel cell operating times, which are the times accumulated on the fuel cells during the prelaunch, on-orbit, and postlanding operations were 381:44:00 (hr:min:sec) for fuel cell 1, 381:20:23 for fuel cell 2, and 380:14:07 for fuel cell 3. The end-of-mission accumulated operating times for these fuel cells 1, 2 and 3 are 794, 2167, and 1755 hr, respectively.

The Orbiter electrical power level averaged 14.2 kW and the total Orbiter load averaged 461 amperes. For the 308.76-hr mission, the fuel cells produced 4384 kWh of electrical energy and 3379 lb_m of potable water. The fuel cells consumed 3001 lb of oxygen and 378 lb of hydrogen. Six fuel cell reactant purges were performed, and these occurred at approximately 24, 86, 145, 207, 264 and 299 hours MET. The actual fuel-cell voltages at the end of the mission were 0.15 Vdc above predicted for fuel cell 1, 0.00 Vdc above predicted for fuel cell 2, and 0.20 Vdc above predicted for fuel cell 3. The voltage margins above the minimum performance curves at 200 amperes at the end of the mission were 1.20 Vdc above minimum for fuel cell 1, 0.90 Vdc above minimum for fuel cell 2, and 0.90 Vdc above minimum for fuel cell 3.

The overall thermal performance of the fuel cell water relief, water line, and reactant purge heater systems was nominal. Water relief and water line system A was used during prelaunch, ascent, and up to 354/01:04 GMT (09/23:17 MET) when system B was selected for the remainder of the flight. All of the water system heaters cycled to satisfy the In-flight Checkout Requirements, except for the fuel cell 1, 2, and 3 water relief valve B heaters, which are discussed later in this section.

At 344/14:12:37 GMT (00/12:25:02 MET), the fuel cell 3 O₂ flowmeter failed off-scale-low (IFA STS-116-V-02). This coincided with 1.6 A increase on Mid-Power Control Assembly (MPCA) 3. The fuel cell 3 O₂ flowmeter circuit is protected by a 1 A fuse, in MPCA 3. It is specified to “blow” at 150-percent load of its 1 A rating. The flowmeter circuits are known to have overstressed EEE components. Most likely, the flowmeter components were overloaded and the fuse opened. Post-flight troubleshooting will verify the condition of the 1 A fuse and the circuitry downstream of MPCA 3 that powers the flowmeter.

The Fuel Cell Monitoring System (FCMS) was used to monitor individual cell voltages prelaunch, on-orbit, and postlanding. Full-rate on-orbit data was recorded for almost 15 min beginning at 345/05:23:46 GMT (00/12:25:02 MET). All of the cell voltages were nominal. The prelaunch baseline Cell Performance Monitor (CPM) values for fuel cell 1 were 2, 8, and 26 mV, for fuel cell 2 were 24, 16, and 50 mV, and for fuel cell 3 were 16, 4, and 30 mV.

The fuel cell 3 alternate water line temperatures indicated leakage through the alternate water check valve. Intermittent leakage was observed when potable water tank A was at 100-percent quantity. When tank A is at 100 percent, the upstream pressure on the

check valve increases enough to crack-open the check valve and allow leakage of the 140 °F product water past the check valve. This influences the alternate water temperature transducer and line heater cycles. Leakage this flight was less than observed on the two most recent flights of this vehicle.

A waiver/deviation documented the OMRSD exception and LCC violation because of the dynamic CPM readings observed on fuel cell 2, substack 3 during the Acceptance Test Procedures (ATP). This was most likely caused by Catalyst-Migration, resulting from the stack being exposed to oxygen during the replacement of a leaking Noryl Insulator Plate. As a precaution, the waiver/deviations were processed in the event that fuel cell 2, substack 3, violated the 28 mV sensitivity CPM limit during load changes due to the effects of Catalyst-Migration. The limit was increased to 50 mV. Although fuel cell 2, substack 3, CPM readings were noisier and more dynamic than the other CPM indications, the initial 28 mV limit was not violated.

Electrical Power Distribution and Control System

The Electrical Power Distribution and Control (EPDC) system performed nominally during all STS-116 mission phases. The data review and analysis of all available EPDC parameters have been completed and there were no EPDC failures or anomalies on this flight of the vehicle. All File IX requirements were met.

As a minimum, the following EPDC parameters were analyzed

1. Fuel cell voltages and currents;
2. Essential bus voltages;
3. Control bus voltages;
4. Forward Power Control Assemblies voltages and currents;
5. Mid Power Control Assemblies voltages and currents;
6. Aft Power Control Assemblies voltages and currents;
7. AC bus voltages and currents;
8. AC bus Monitor/auto switch status and overload/over-voltage alarm;
9. Main bus to Control bus RPC status;
10. Forward, Mid and Aft Motor Control Assemblies ops status;
11. Fuel cell to Essential bus switches status;
12. Main bus to Essential Bus RPC and switch status: and
13. Drag chute Pyro Controller Functions.

During prelaunch operations at 340/04:26:25 GMT while performing S0007.200, and transferring the Orbiter main-bus power supplies to the local-sense operations, the Ground Support Equipment (GSE) power supply over-responded to a voltage-increase command. The result was that when it exceeded the 40-V trip setting, it tripped off. As a result, Orbiter Main Bus A and bus AC1 were lost. Prior to being lost, Main Bus A exceeded the allowable voltage of 32.0 Vdc for 0.48 sec. Additionally, a voltage transient of 37.92 Vdc occurred for 50 msec. The Mid Main A voltage exceeded 32.0 Vdc for 0.48 sec with a maximum value of 37.84 Vdc. The Forward (FWD) Main A

voltage exceeded 32.0 Vdc for 0.401 sec with a maximum value of 37.76 Vdc. No Orbiter avionics cooling requirements were violated. All the systems that were powered during the over-voltage condition were reviewed for their performance, and no evidence of component or equipment damage was seen as a result of the over-voltage condition.

Orbiter Docking System

The Orbiter Docking System (ODS) performed satisfactorily with no in-flight anomalies identified in the data.

The ODS Docking Control Panel (DCP) circuit breakers were activated on FD 3 at 345/21:36:19 GMT (01/19:483:44 MET) for a total time of 56 min and 47 sec. (including power to avionic instrumentation, which was 49 min 33 sec).

The Shuttle captured the ISS at 345/22:11:55 GMT (01/20:24:20: MET). Ring Drive (Ring In) began 4 min 16 sec later after initial damping and ran approximately 7 sec. The system was stopped to allow dampening of any movement, and alignment was regained after approximately 1 min 19 sec. A Ring Drive (Ring Out) command was given for 1 min 7 sec to allow any possible stuck damper to clear, using established procedures. Final Ring Drive (Ring In) command was issued 7 min 7 sec after capture and ring retraction proceeded nominally with good ring alignment for 3 min, 25 sec using with dual motors. During ring retraction prior to hard mating, which occurs at 5 percent ball-screw linear advancement, ring alignment was momentarily lost for approximately 5 sec, and then regained. This behavior has been seen on the previous 2 flights and is not a problem. The hooks were driven closed nominally in 2 min 14 sec, and the final ring extension was performed, and docking was completed satisfactorily.

On FD 9, the Orbiter undocking from the ISS began with powerup at 353/22:07:16 GMT (09/19:55:45 MET) and hook release at 353/22:09:21 GMT (09/20:21:46 MET). The Orbiter completed the undocking sequence from the ISS 2 min 14 sec later, and ODS powerdown was at 353/22:14:47 GMT (09/20:27:12 MET).

Atmospheric Revitalization Pressure Control and Airlock Systems

The Pressure Control System (PCS) and Airlock systems performed nominally throughout the mission. No in-flight anomalies were identified during the review and analysis of the mission data. One File IX requirement was not completely satisfied.

The PCS 1 and 2 systems were configured for manual operation during docking with the ISS. After docking, the PCS 2 system was placed in Auto. Since all Extravehicular Activities (EVAs) were performed from the ISS, the PCS was not required to support these EVAs. An Orbiter-to-ISS tank-to-tank Oxygen (O₂) transfer was performed and a total of 69 lb of O₂ were transferred. In addition, Nitrogen (N₂) was transferred to the ISS tank with 47.2 lb of N₂ being transferred.

The Airlock Vestibule passed all leak-check verifications for docked and undocking operations. Four ISS-based EVAs were supported by Orbiter, which provided O₂ via transfer. The O₂ was transferred for EVA use via the Airlock Transfer panel and the ISS Recharge Oxygen Orifice Bypass Assembly (ROOBA). An ISS repressurization was performed prior to undocking using the Orbiter PCS. The repressurization was performed to approximately 14.68 psi using both N₂ and O₂ to support the ISS atmosphere pressure mixture.

Supply and Waste Water System

The Supply Water and Waste Management Systems performed nominally throughout the mission and only one of the scheduled in-flight checkout requirements was not satisfied.

Four waste-water (from waste tank) nozzle dumps at an average rate of 1.87 percent/min (3.08 lb/min) were performed. During the simultaneous waste water dump (waste and supply water tanks), a nominal waste dump rate of 1.7percent/min was observed until the nozzle temperature reached 50 °F, where the dump is procedurally required to be terminated to reheat the nozzle to 250 °F. The waste dump was terminated and the nozzle was reheated to 250 °F. The dump valve was reopened for dumping the remaining waste water; however, the dump was decreasing to an off-nominal dump rate (approximately 0.74 percent/min). As a result, the waste dump was terminated after 11 min because of time constraints (IFA STS-116-V-09). There was no indication of ice on the nozzle bake-out signature.

Both the Supply and Waste water dump line isolation valves were configured to the closed position for entry and the lines were purged after the final nozzle dump. This was necessary because of the low predicted-temperatures at the backup landing site (White Sands Test Facility). The purge was planned prior to the off-nominal dump. A nominal nozzle bake-out was observed at the end of the purge. The degraded flow rate event resulted in violating a File IX requirement. KSC will perform tests prior to the next flight for system integrity. During this mission, one Contingency Water Container (CWC) containing Orbiter condensate was dumped through the waste water dump nozzle. The waste water dump line temperature was maintained between 59.9 °F and 86.2 °F throughout the mission.

Supply water was managed through the use of the Flash Evaporator System (FES), water transfer to the International Space Station (ISS) and the overboard nozzle dump system. Four supply water nozzle dumps at a nominal dump rate of 1.6 percent/min (2.6 lb/per min) were performed. In addition, one Payload Water Reservoir (PWR) was dumped through the supply line. The line heaters maintained the supply water dump line temperature between 75 °F and 94 °F throughout the mission.

Two Contingency CWC's were filled with supply water and transferred to the ISS, for a total of 201.9 lbm. In addition, 3 PWR of iodinated water for a total 59.7 lbm were filled and transferred to ISS.

Vacuum vent line temperature was maintained between 61.6 °F and 79.6 °F.

Smoke Detection and Fire Suppression System

The Smoke Detection and Fire Suppression (SDFS) operated nominally. The SDFS in-flight checkout was performed during Flight Day 2. All Smoke detection A and B sensors circuits passed after the retest on Smoke Detection Circuit Test B Part 1. Use of the Fire Suppression system was not required.

Atmospheric Revitalization and Active Thermal Control System

The Atmospheric Revitalization System (ARS) and Active Thermal Control System (ATCS) supported the Orbiter and Spacehab satisfactorily. One in-flight anomaly occurred during the mission and is discussed in a later paragraph.

The cabin air temperature peaked to 81.6 °F at 5 hr 26 min MET and then decreased to 71 °F. The air temperature averaged 73 °F for the duration of the flight.

The Partial Pressure Carbon Dioxide (PPCO₂) was maintained below 4.2 mmHg with single Lithium Hydroxide (LiOH) canister changes occurring during the pre-sleep period and dual canister changes occurring during the post-sleep activity periods.

Cabin humidity averaged 32.5 percent during the mission.

The Ammonia Boiler System (ABS) continued satisfactory operation on System A for 40-min (tank blow down) after which System B was activated for 6 min when system B was terminated for ground cooling activation. The cabin air temperature was maintained below 75 °F, which is the Flight Rule limit through crew egress.

At 344/11:28 GMT (00/09:40:25 MET), the FES Primary B Controller was in the topping mode and it failed to come out of stand-by during the crew-sleep period. When in the topping mode, the FES supplements cooling primarily provided by the radiators, so this failure presented no immediate impact to the crew or the mission. Prior to this event, the FES had been working with no anomalous signatures. Two restart attempts, one at 344/15:59 GMT (00/14:11:25 MET) and the other at 345/00:03 GMT (00/22:15:25 MET), were unsuccessful (IFA STS-116-V-03). Troubleshooting will be performed during the turnaround activities at KSC.

Flight Software

Performance of all flight software (Primary Avionics Software System (PASS) and Backup Flight System (BFS) was nominal throughout the STS-116 mission.

During the first launch attempt, the BFS annunciated two Class 2 Caution and Warning (C&W) alarms. The analysis determined that both alarms were expected. The first

alarm was an expected result of the cabin depressurization due to the hardware dp/dt limit being exceeded. The second C&W alarm occurred when BFS was moded to RUN as part of the OPS 101 transition. The alarm was an expected annunciation as a result of Spacehab being powered off (ARS Fan Differential Pressures were below their lower limit). These expected alarms were also annunciated during the final launch countdown.

Data Processing System Hardware

Data Processing System (DPS) hardware performed nominally throughout the STS-116 mission. This hardware includes the General Purpose Computers (GPC), Multiplexer Interface Adapters (MIA), Data Bus Couplers (DBC), Data Bus Isolation Amplifiers (DBIA), Keyboard units (KBU), Multiplexer/Demultiplexers (MDM and EMDM), Engine Interface Units (EIU), and Master Events Controllers (MEC) / Backup Flight Controllers (BFC). The data review and analysis of DPS hardware parameters have been completed and no in-flight anomalies or issues were identified.

Multifunction Electronics Display System

During the post-insertion reconfiguration activity for on-orbit operations, a single "Multiplex Interface Adapter (MIA) busy Input/Output (I/O) error" was reported by general Purpose Computer (GPC) 4. This error was annunciated because temporary dual GPC commanders were assigned to Integrated Display Processor (IDP) 4. This single error cleared on the next IDP-GPC poll cycle and no additional I/O errors were logged. The crew reported that they did not unassign BFS GPC 5 from IDP4 prior to assigning it to the PASS GPC4 per procedure. IDP4 performance was nominal for the duration of the mission

Displays and Controls System

The Displays and Control (D&C) system performance was satisfactory. Two in-flight anomalies were identified, but neither of them impacted the flight.

At 2006/345/17:30 GMT (01/15:42 MET), the payload bay floodlights were turned on. The crew reported that the mid-port payload bay floodlight was not illuminated (IFA STS-116-V-04). A switch retention device was installed over this switch so that it could not be used for the remainder of the flight. There were no impacts to mission success or safety. Operation of the mid-port floodlight will be checked during turnaround operations to determine if the light bulb has failed.

The crew reported that the "ten of seconds" thumbwheel was not consistently updating the aft event timer with the proper value when the timer was set (IFA STS-116-V-05). The crew used the other event timer or either of the mission timers on the vehicle. There were no impacts to mission success or safety. Operation of the thumbwheel will be verified during the turnaround activity.

Flight Control System

Flight control hardware/ effector systems performed nominally throughout the mission.

During ascent, the SRB Thrust Vector Controller (TVC), MPS TVC, and Aerosurface Actuators (AAs) were positioned exactly where the GPCs commanded them with normal driver currents, secondary differential pressures, and elevon primary differential pressures. The rate outputs of the four Orbiter Rate Gyro Assemblies (ORGAs) and four Station Rate Gyro Assemblies (SRGAs) tracked each another normally, and there were no Spin Motor Rotation Detector (SMRD) dropouts. The outputs of the four AAs also tracked each other normally. The Reaction Jet Driver (RJD) operation was also normal with no thruster failures or other anomalies noted. The Data Display Unit (DDU) and controller operation was nominal and the Rotational Hand Controller (RHC) and Translational Hand Controller (THC) were both used and exhibited normal channel tracking.

The OMS-TVC File IX no-back requirements were met and OMS-TVC actuator rates were normal. Flight control actuator temperatures were also normal. Rudder Speedbrake Power Driver Unit (RSB PDU) motor backdrive did not occur during hydraulic systems shutdown.

Flight control hardware operation was nominal during the FCS checkout. No anomalies were found in aerosurface drive data, individual channel test data, ORGA and AA test data, nosewheel steering test data, and DDU/controllers data.

The pre-Time of Ignition (TIG) OMS gimbal profile was as expected with the OMS actuator active and standby channels reaching nominal drive rates. All aerosurface actuators performed normally. Secondary differential pressures for all actuators were well within the equalization threshold and all actuator positions closely tracked GPC commands. Entry hydraulic system temperatures were comparable to previous flights with aerosurface actuator temperatures being within the normal limits. MPS TVC Actuator performance was normal with secondary differential pressures within the threshold and the TVC actuator positions and GPC commands following each other closely.

Air Data Transducer Assembly

All four Air Data Transducer Assemblies (ADTAs) functioned nominally during the pre-launch tests, FCS checkout and entry operations. ADTA transducer entry performance was nominal from deorbit through wheel-stop. No LCC or OMRSD violations occurred during the prelaunch operations, and no in-flight anomalies were identified during the data analysis and evaluation.

The right and left air data probe (ADP) deployments were initiated at approximately Mach 4.98 using the deploy switch positions. Both ADP deployments were nominal, and deploy timing was within specification at less than 15 sec. The crew accepted air

data and placed it in the Navigation System at Mach 2.92 and the Guidance and Control system (G&C) at Mach 2.90. All 16 transducers tracked during the pre-probe deployment phase of entry. No ADTA dilemmas or redundancy management failures occurred during deployment through wheel-stop. The ADP heaters were not used though there was some discussion about heater activation because of the potential for flight through rain and clouds.

The ADTA 2 total temperature measurement was first observed to perform erratically during the STS-121 terminal countdown demonstration test (TCDT) on June 14, 2006. The measurement was nominal during the approximately first 5 hours of ADTA operation on STS-121, but began to drift lower than the ADTA 1, 3, and 4 total temperature measurements. The measurement also appeared to be noisier. For STS-116, the ADTA 2 temperature measurement was not nearly as erratic, but did show a slight bias as compared to the ADTA 4 measurement. Post-mission STS-121 troubleshooting determined that the source of the problem is external to the ADTA and is in the wiring or probe temperature sensor. After removal of the Forward Reaction Control System (FRCS), which was completed following STS-116, continued troubleshooting and repair was completed.

Inertial Measurement Unit and Star Tracker System

The Inertial Measurement Unit (IMU) and Star Tracker Systems performed satisfactorily throughout the STS-116 mission. No in-flight anomalies or problems were identified during the analysis of the IMU data, however, on Star Tracker in-flight anomaly was identified during the mission. This anomaly did not impact to the performance of the star tracker during the mission.

At the completion of the SAW retract activities, the -Z Star Tracker was powered on for about 45 sec to open the star tracker doors. The -Z Star Tracker annunciated a Pressure Fail BITE indication when it was powered on (IFA STS-116-V-10). The pressure fail indication remained on until the star tracker was powered off. The -Z star tracker was again powered on at 353/20:51:28 GMT (09/19:03:53 MET). The BITE indication was still present; however, it cleared approximately 13 min after powerup.

The star trackers are pressurized to prevent moisture or contamination from being ingested during entry. No other anomalies affect this problem. The Star Tracker will be purged and repressurized during the turnaround operations.

Global Positioning System Navigation

The Global Positioning System (GPS) operation during STS-116 was nominal except for one Orbiter in-flight anomaly, which is discussed in a later paragraph in this section. The hardware configuration on this flight consisted of the Miniaturized Airborne GPS Receiver (MAGR) and two preamplifiers, which make up a single-string GPS system. The MAGR was loaded with firmware, which was being flown for the second time.

As planned, the GPS state vector was incorporated into Primary Avionics Software System (PASS) navigation after performance confirmation with high-speed C-band tracking. This occurred at Entry Interface plus 22 min (133,500 ft altitude). The effect was that the PASS navigation state vector residuals were reduced from greater than 5000 ft to less than 100 ft. The PASS navigation state vector residuals remained consistently less than 100 ft from GPS incorporation until data from the Microwave Landing System (MLS) was incorporated.

Power was applied to the GPS approximately 4¼ hr prior to launch and remained on for the entire mission until 16 min after touchdown. The in-flight anomaly occurred in operational sequence MM201 at 356/17:12:47 GMT (12/15:25:12 MET) when the MAGR 5th (peripheral) channel maintained lock on satellite PRN17 for over 21 min (normal lock by the peripheral channel on a satellite should be less than one minute) (IFA STS-116-V-11). During this period, the peripheral channel made no attempts to switch in newly recommended satellites and that resulted in an increase in the Figure of Merit (FOM). One additional item of note during Entry is that the period of high FOM due to Plasma blackout was unusually long for this flight. This event, however, was not anomalous and is explained as an artifact of the GPS satellite constellation geometry at the time. The high FOM period cleared well before GPS incorporation into the PASS navigation system. No "Data Invalid" or FOM Chimneys occurred during the critical phase of Entry (below 140,000 ft altitude).

Communications and Tracking System and Navigation Aids

The Communications and Tracking systems performed nominally during the STS-116 mission. No in-flight anomalies were identified during the analysis and evaluation of the data.

The Closed Circuit Television (CCTV) camera B required four attempts to be operational. This is a known and explained condition where the camera becomes activated, but the A7 lights and telemetry indicator becomes static. The crew is trained to cycle the power on the camera until the indicators are actively operating.

NAVAIDS successfully completed their data analysis with nominal performance and satisfied all File IX requirements. In addition, the S-Band-system 1 was in operation from 349/03:09 GMT to 350/02:49 GMT, and this satisfied the OMRSD File IX requirement, which requires the operation of the S-Band Backup string continuously for 24 hr ± 4 hr.

Operational Instrumentation/Modular Auxiliary Data System

The Operational Instrumentation (OI) performed nominally throughout the STS-116 mission. No anomalies or significant problems were identified after review of the mission data.

The Modular Auxiliary Data System (MADS) provided data from ascent and entry for review. The MADS ascent data were dumped during the mission and reviewed. However, one in-flight anomaly was found in that four measurements of the ascent data exhibited multiple dropouts beginning at 344/01:53:27 GMT (00/03:05:52 MET) (IFA STS-116-V-12). These dropouts in these data did not impact the mission. Testing at KSC revealed that the MADS recorder was not at fault, but rather a vehicle problem.

Mechanical and Hatches System

The mechanical and hatches system performance was nominal and within specification. The system consists of the Payload Bay Doors, ET doors, Star Tracker doors, vent doors, and air data probes. No in-flight anomalies were identified during the review and analysis of the data.

The Payload Bay Doors (PLBDs) were closed nominally at 356/17:30:29 GMT (12/15:42:54 991 MET) in preparation for landing.

Landing and Deceleration System

The main landing gear touchdown occurred on concrete runway 15 at 356/22:31:58 GMT (12/20:44:23 MET) on December 22, 2006. The drag chute was deployed at 356/22:32:03.7 GMT (12/20:41:28.69 MET). Nose-gear touchdown occurred at 356/22:32:11 GMT (12/20:44:36 MET). Wheels stop occurred at 356/22:32.57 GMT (12/20:45:22 MET). The rollout was normal in all respects.

The following table presents the pertinent data on the landing of the STS-115 Orbiter.

LANDING PARAMETERS

Parameter	From threshold, ft	Speed, keas ^a	Sink rate, ft/sec	Pitch rate, deg/sec
Main landing gear touchdown	1935.5	207.4	2.79	N/A
Nose landing gear touchdown	5607.4	151.9	N/A	6.03
Parameter		Data		
Brake Initiation speed	94.0 keas			
Brake-on time	27.57 sec			
Rollout distance from touchdown to stop	8136.4 ft (touchdown to wheel stop)			
Rollout time	52.48 sec			
Runway	15 (Concrete) KSC			
Orbiter weight at landing	224041.0 lb			

LANDING PARAMETERS (Concluded)

Parameter	Maximum Brake Pressure, psia	Total Brake Energy, M ft/sec
Left inboard	820.43	11.21
Left outboard	781.73	8.34
Right inboard	863.0	14.27
Right outboard	781.73	9.34

^aKnots equivalent air speed

Aerothermodynamics, Integrated Heating and Interfaces

The post-flight inspections indicate that the overall Orbiter TPS looked normal with no signs of excessive local heating. The Orbiter Boundary Layer Transition (BLT) onset time was 1086 sec after entry interface or Mach 12.75 based on the location of X/L = 0.6 based on MADS data and the Best Estimated Trajectory (BET). The lower surface structural temperatures indicated that the entry heating was higher than normal and the BLT was symmetrical. In theory, the early BLT on this flight would cause higher heat loads, which would lead to higher maximum structure temperatures and the flight data proved that theory. In comparison with the flight history data, these maximum temperatures and maximum temperature rises vs. BLT Mach number were in line with the flight experiences.

The following table shows the maximum temperatures and maximum temperature rise during entry.

ENTRY MAXIMUM TEMPERATURE AND MAXIMUM TEMPERATURE RISE DATA

Thermal Sensor Location	Maximum Temperature, °F	Maximum Temperature Rise, °F
Lower fuselage forward center (B1)	150.8 ^a	139.8 ^b
Lower fuselage forward left-hand (B2)	198.3	184.7
Lower fuselage forward mid left-hand (B3)	177.2	181.4
Lower fuselage mid center (B4)	174.5	181.3 ^b
Lower fuselage mid aft center (B5)	201	197.6 ^b
Lower fuselage aft center (B6)	198.3	171.9
Left-wing center (LW)	135.1	152.4
Right wing center (RW)	135.1	154.5 ^b
Port side FRCS forward (P1)	179.8	150.9 ^b
Port side fuselage forward center (P2)	109	108.1
Port side fuselage forward mid center (P3)	103.8	100.4
Port side fuselage mid aft center (P4)	75.3	71.8

**ENTRY MAXIMUM TEMPERATURE AND MAXIMUM TEMPERATURE RISE DATA
(Concluded)**

Thermal Sensor Location	Maximum Temperature, °F	Maximum Temperature Rise, °F
Port side fuselage aft center (P5)	90.8	67
Starboard side FRCS Forward (S1)	174.5	150.7 ^b
Starboard side fuselage forward center (S2)	127.3	98.3
Starboard side fuselage forward mid center (S3)	109	92.8
Starboard side fuselage mid-aft center (S4)	85.6	77.1
Starboard side fuselage aft center (S5)	96	74.7
Left-hand OMS pod side forward (LP)	80.5	66.8 ^a
Right-hand OMS pod side forward (RP)	72.7 ^a	46.3 ^a
Lower body flap center	106.4 ^a	74.9 ^a
Right-hand OMS-pod side forward	72.7 ^a	46.3 ^a
Left-hand OMS-pod side forward	80.5	66.8
Right-hand PLBD forward	70.1 ^a	87.0 ^a
Left-hand PLBD forward	70.1 ^a	81.9 ^a
Right-hand PLBD aft	93.4	110.3
Left-hand PLBD aft	90.8	107.7
Right wing upper center	96	102.7
Left wing upper center	93.4 ^a	84.9 ^a
Forward RCS center	103.8	69.7
Forward fuselage upper center	72.7	84.5

Thermal Control System

The Thermal Control System (TCS) performed satisfactorily and all temperatures were maintained within nominal limits. No In-flight anomalies were identified in the review and analysis of the data.

Thermal Protection System

Tile and Blanket Flight Assessment

The Thermal Protection System (TPS) tiles and blankets performed satisfactorily, and a consolidated in-flight anomaly (STS-116-V-06) was assigned for all identified on-orbit issues. A Flexible Reusable Surface Insulation (FRSI) plug was found on the pad after launch, and was later identified as coming from the base heat shield. No protruding gap fillers were identified during RPM inspections. No entry thermal concerns were identified, and no focused inspection was required. One area of damage on the forward edge of the RH OMS pod was cleared on FD6 after additional analysis.

RCC Flight Assessment

All available ascent data was reviewed by the Leading Edge Subsystem (LESS) Damage Assessment Team (DAT). Ascent Imagery identified no impact events on the LESS. Radar tracking identified no impact events on the Orbiter as evidenced by no range/Doppler shifts that would indicate a debris-trajectory change. The Wing Leading Edge Impact Detection System (WLEIDS) identified a total of four events that exceeded the 1.0 Grms threshold for ascent impacts. All indications were used to direct the on-orbit inspections to ensure that all threats were addressed by inspecting to the on-orbit critical flaw-size criteria.

All FD2 Laser Dynamic Range Imager (LDRI) imagery was evaluated and a total of 360 Regions of Interest (ROIs) were identified during the evaluation (504 ROIs during STS-115). None of the ROIs exhibited damage characteristics. From the FD2 LDRI imagery and the correlations to ascent data (WLEIDS, radar, imagery), no focused inspections were requested by LESS Problem Resolution Team (PRT).

The WLEIDS identified an impact in the region of the port wing between WLE panels 19 and 20 at 345/09:45:11 GMT that registered 0.7g and satisfied the four criteria for an impact. This trigger occurred after the performance of the FD2 OBSS LDRI survey. The LESS PRT was presented this finding and identified it as a credible threat that warranted consideration as a focused-inspection candidate. However, the PRT pursued other assets to acquire the necessary imagery to attempt to clear these RCC panels. Imagery was obtained from the available non-OBSS assets to attempt to clear the potential damage from the on-orbit WLEIDS indication. Imagery resolution was determined to be 0.33 in, which exceeded the critical flaw size of 0.160 in. Review of MMOD impact test data suggests that the silicon carbide coating damage would be twice the diameter of the exposed carbon substrate. Therefore, a critical hypervelocity defect with 0.160 in exposed carbon would be over 0.300 in, which is near the detectability threshold for the SSRMS television imagery. The late mission LDRI inspection of the WLE performed a direct comparison to the FD2 on-orbit baseline, which was acquired prior to the WLEIDS indication. This LDRI inspection has a detectability threshold of 0.125 in, that is below the 0.160 in critical flaw-size in this area, and as a result, the suspected area was cleared for entry.

Post-landing Assessment

The Orbiter TPS performed satisfactorily throughout the mission. Overall, the Orbiter post-landing inspection showed the vehicle to be in very good condition with some minor items that are discussed in later paragraphs of this section.

Based on the postlanding runway inspection, the Orbiter lower surface sustained a total of 120 hits, of which 22 had a major dimension of 1 in or larger. The upper surface/windows sustained 25 hits, of which only one had a major dimension greater than 1 in. The overall condition of the lower surface was within the previous flight experience.

SUMMARY OF IMPACT SITES FOR EACH ORBITER SURFACE

Orbiter Surface	Impacts > 1in.	Total impacts
Lower surface	22	120
Upper Surface/Window	1	25
Right side	2	11
Left side	0	8
Right OMS pod	0	6
Left OMS pod	1	6
Totals	26	176

The drag chute door, sabot can, drogue parachute, and main parachute were in good condition. The landing gear door corner tiles did not have any chipping or tile material loss. The nose cap appeared nominal. Some of the RCC panels had the typical streaks on the surface. These were panels 7 and 11 on the left-hand side, and panel 16 on the right-hand side. Base heat shield tile damage was nominal; there was a ½" tile damage area near SSME 3 that was seen on film after SSME startup.

There were four typical areas of drag-parachute-induced tile damage on the stinger on the lower side of the vertical stabilizer.

Some fraying of the SSME dome-mounted heat shield blankets was noted. SSME 1 had fraying at the 6 o'clock position, and SSME 2 had fraying at the 3 o'clock position.

The ET/Orbiter (EO-1) forward attachment point had an area of protruding thermal blanket around the +y side. The EO-2 and EO-3 aft attachment points were nominal, and had the typical condensation on the surface.

All of the Orbiter tires exhibited acceptable wear, with no tire material loss.

Windows

The six windows on the crew module and have been sent to a vendor for analysis. At the time of this writing, the results of the analysis were not available.

Waste Collection System

The Waste Collection System (WCS) performed nominally throughout the STS-116 mission. A nominal compaction of the WCS unit was performed on FD 09. The Shuttle Urine Pre-Treat Assembly (SUPA) was used for the entire mission. There are no in-flight checkouts or File IX requirements associated with the WCS system.

EXTRAVEHICULAR ACTIVITY

The crew performed three scheduled and EVAs and one unscheduled EVA. At the request of the ISS Program, the Mission Management Team (MMT) decided to add a fourth EVA to complete the full retraction of the P6 4B Solar Array Wing (SAW); a task that was initiated, but not successfully completed on FD5. To accommodate the fourth EVA, the docked mission duration was extended one day. A significant first for the Space Program was a crewmember performing four EVAs in one flight.

The Airlock campout protocol was utilized on this mission in preparation for all of the EVAs.

FIRST EXTRAVEHICULAR ACTIVITY

The primary EVA task performed by MS2 and MS3 was to install the P5 truss segment to the P4 truss. The crew completed the EVA in 6 hr 36 min. The crew mated the P5 to P4 umbilical's, cycled the Capture Latch Assembly (CLA) and removed two of the four P5 outboard launch locks (corners 3 and 4) which were get-ahead tasks. The S1 outboard lower camera, External Television Camera Group (ETVCG) was also replaced at the Camera Port 3 location. The Photovoltaic Radiator Grapple fixture (PVRGF) was successfully relocated to the keel of P5.

A solar flare was detected by the Space Radiation Analysis Group (SRAG) following the EVA crew's ingress into the ISS airlock. Prior to crew sleep, the crew was advised to sleep in areas more highly shielded.

SECOND EXTRAVEHICULAR ACTIVITY

The MS2 and MS3 performed EVA 2 in 5 hr and successfully completed the Channel 2/3 power reconfiguration. The Crew and Equipment Translation Aid (CETA) Carts 1 and 2 were also relocated to the S0 Bay 1 and S0 Bay 3, respectively. The SSRMS Force Moment Sensor (FMS) Multilayer insulation (MLI) blanket was installed. The Z1 patch panel 2 was reconfigured and the Starboard and Port Quick Disconnect Bags, the Vent Tool Extender, and the Pump Module Jumper Bags were installed. During the EVA, the External Thermal Control System (ETCS) Loop B was successfully activated as part of the highly choreographed EVA/Intravehicular Activity (IVA)/ground timeline. Ground controllers observed an unexpected behavior on the Loop B N₂ Gas Pressure Regulating Valve, which resulted in a small loss of nitrogen; however there was no impact to the activation of Loop B.

THIRD EXTRAVEHICULAR ACTIVITY

MS3 and MS4 performed EVA 3 in 7 hr 31 min and successfully completed the Channel 1/4 power reconfiguration. The crew assembled the Service Module Debris Panels (SMDP) bundles onto the adapter and transferred this adapter to the Strela adapter on

the Pressurized Mating Adapter (PMA) 3 using the SRMS. After this task, a digital camera carried by a crewmember came loose from its bracket and floated away. The crew completed the Z1-005 Patch Panel 1 and Russian power reconfigurations. The last nominal task completed was the transfer of the Adjustable Grapple Bar (AGB) to the Flex Hose Rotary Coupler (FHRC). The remainder of the EVA was spent trouble shooting the stuck P6 4B SAW. The crew provided information on grommet orientation and attempted to manually induce oscillation loads in the partially retracted SAW in an effort to free the guide wires and grommets that were preventing the SAW from fully retracting. Several oscillation and retraction attempts were attempted until the EVA had to be terminated due to time constraints. The SAW was retracted an additional 6 bays, leaving 11 bays out. The ETCS Loop A was filled with ammonia and activation was completed after the EVA.

FOURTH EXTRAVEHICULAR ACTIVITY

MS2 and MS3 completed EVA 4 in 6 hr 38 min, and were able to successfully facilitate the retraction of the P6 SAW. The SAW was fully retracted and the 4B blanket boxes were latched. In addition to the SAW retraction, the crew checked the tip Latching End Effector (LEE) FMS MLI which was installed during EVA 2. There was a concern regarding an apparent billowing of the MLI, and it was determined that the billowing was the result of MLI underneath the FMS MLI. Relocation of one Articulating Portable Foot Restraint (APFR) from the External Stowage Platform (ESP) 2 to the CETA cart 2 was also accomplished in preparation for STS-118/13A EVA. The SSRMS supported the EVA 4 operations on P6 with MS2 operating from the end of the arm for more than 5 hr.

REMOTE MANIPULATOR SYSTEM AND ORBITER BOOM SENSOR SYSTEM

The Shuttle Remote Manipulator System (SRMS) and the Orbiter Boom Sensor System (OBSS) performed satisfactorily throughout the STS-116 Mission. One in-flight anomaly was identified and it is discussed in a later paragraph.

STS-116 was the 73rd flight of the SRMS, the 18th flight of SRMS S/N 303, the 4th flight of the Orbiter Boom Sensor System (OBSS), and the second flight of the Inspection Boom Assembly (IBA) S/N 202, which was installed on the SSRMS. The main objective of the mission was to deliver, install, and activate the P5 Truss Segment and reconfigure the International Space Station (ISS) electrical power system, including the retraction of the P6 4B Solar Array Wing (SAW). Also, the Force Moment Sensor (FMS) thermal blanket was installed on the SSRMS.

SRMS initialization and power-up was completed on Flight Day (FD) 1. The port and starboard Manipulator Positioning Mechanisms (MPMs) were deployed and the SRMS shoulder brace was released. The SRMS checkout was also performed.

On FD 2, the SRMS unberthed the OBSS to perform the port and starboard Wing Leading Edge (WLE) Reinforced Carbon Carbon (RCC) and Nose Cap surveys. After berthing the OBSS, the SRMS was used to complete the End Effector Crew Cabin Survey.

On FD 3, Discovery docked with the ISS with the SRMS in the pre-cradle position. The SRMS grappled the P5 Truss Segment and handed it off to the Space Station Remote Manipulator System (SSRMS). It was then moved to the P5 Installation viewing position in preparation for the next day's operations.

On FD 4, the SRMS provided viewing support during the SSRMS installation of the P5 Truss and camera views during the first EVA. It was also used to inspect the Port WLE Panel 19 using the wrist camera to address concerns of a possible micrometeorite or orbital debris impact.

On FD 5, the SRMS was moved from this Panel 19 viewing position to a position from which it could provide camera views of the 4B Solar Array Retraction. On FD 6, the SRMS was maneuvered into position to view the Crew and Equipment Translation Aid (CETA) cart relocation activities of EVA 2. After the EVA, it was relocated to the pre-cradle position, where it remained overnight.

On FD 7, the SRMS was maneuvered back to the 4B Solar Array Retraction viewing position. It provided camera views as the crew "wiggled" the arrays in an attempt to free some of the panel bays that had not properly seated. On FD 8, the SRMS supported the Service Module Debris Panel (SMDP) installation during EVA 3, and the SRMS was fitted with an Articulating Portable Foot Restraint (APFR) to transport an EVA crew

member. After this, the SRMS was moved to a new position for viewing the SAW retraction activities of EVA 4, which were added for FD 10. It remained in this position throughout the EVA. Upon successful completion of the EVA, the SRMS was maneuvered back to pre-cradle position on FD 10 where it remained for undocking on FD 11.

On FD 12, the SRMS grappled the OBSS, and the SRMS/OBSS completed the port, starboard, and nose cap late-inspection LDRI RCC Surveys. The SRMS then reberthed the OBSS and moved back to the pre-cradle position. The SRMS was then cradled and powered down. The port and starboard MPMs were stowed on FD 13.

The one in-flight anomaly was identified during SRMS checkout on FD 1 when one step of the End Effector (EE) Auto Extend Checkout was unsuccessful. The Manipulator Controller Interface Unit (MCIU) did not receive a release command when the Rotational Hand Controller (RHC) trigger was depressed. The 10V auto release switch contact had worked nominally during previous earlier steps of EE checkout.

The crew was instructed to verify the functionality of the manual capture and release contacts of the switch by re-executing portions of EE checkout. The manual release functioned nominally, but telemetry showed that the MCIU was not detecting the 10V release command. However, during later uses of the SRMS and OBSS, the 10V was detected that indicates the failure was intermittent.

After the Orbiter landed at KSC, on-vehicle testing was performed. The RHC and capture/release switch were exercised while the data were monitored. All test results were nominal, with no discrepancies detected. As a result, the RHC was removed and shipped to the contractor.

WING LEADING EDGE IMPACT DETECTION SYSTEM

The Wing Leading Edge Impact Detection System (WLE IDS) ascent-data requests, downloads, downlinks, and analysis began at 6:15 hr MET and continued until 18 hr MET. The ascent in-flight report, released at 14 hr MET contained four impact probable cases above the 1.0 Grms reporting threshold.

ASCENT MONITORING

All units triggered on Space Shuttle Main Engine (SSME) ignition and began recording data at launch within 0.1 sec of each other. A total of four impact probable cases above 1.0 Grms (3 on the port and 1 on the starboard wing) were found and reported during the flight.

Automatic scanning of post-flight data acquired from 10-500 sec MET revealed a total of 84 probable ascent debris impacts on the wing leading edge (38 on the port and 46 on the starboard wing) ranging from 0.1 Grms to 1.3 Grms. However, post-flight analysis did not identify any additional WLE IDS probable impacts above 1.0 Grms. The summary of all probable and questionable impacts above 1.0 Grms for this flight is shown in the following table.

SUSPECTED ASCENT DEBRIS IMPACTS ABOVE 1.0 Grms

Time (s)		Location			Magnitude		Criteria				Impact [†]	
MET	DET	Wing	RCC	Unit-Channel	Maximum Grms	Maximum G	Transient	Local	Spectral	Shock	In-flight	Post-flight
104.0	113.2	Port	7	1085-J3	1.2	4.1	+	+	+	+	P	P
111.0	120.2	Port	11-12	1100-J1	1.3	6.3	+	+	+	+	P	P
121.4	130.6	Starboard	15-16	1071-J3	1.1	4.3	+	+	+	+	P	P
126.3	134.5	Port	10	1070-J3	1.3	5.1	+	+	+	+	P	P

[†] P=probable, Q=questionable, N=no, U=unfound

ORBIT MONITORING

The summary of all WLE IDS MMOD probable impacts for this flight are shown in the following table.

SUSPECTED MMOD IMPACTS

Time	Location			Magnitude		Criteria				Impact [†]	
	GMT	Wing	RCC	Unit-Channel	Maximum Grms	Maximum G	Transient	Local	Spectral	Shock	In-flight
345/09:45:11	Port	19-22	1022-J3	0.1	0.7	+	+	+	+	P	P
345/20:53:58	Port	11-13	1207-J3	0.1	0.4	+	+	+	+	U	P

[†] P=probable, Q=questionable, N=no, U=unfound

A valid 0.7-g MMOD trigger was recorded by WLE IDS on the Port Wing on RCC Interface 19/20 during flight night 2. Analysis determined these data met all of the requirements for a probable impact on panel 19-22. Analysis confirmed that the system was performing nominally and that the data associated with this event were of good quality. No other subsystems were able to identify any events within ± 10 min of the MMOD event.

Following landing, the wing tip Reinforced Carbon Carbon (RCC) panels were inspected and a very small defect (0.029 by 0.026 by 0.0055 in) was visible on the outer surface. This may or may not be related to the WLE IDS event as this is one of the smallest defects on record. To ensure that no other damage exists to the RCC panels in this area, Non-Destructive Evaluation (NDE) and internal inspections were performed to close this issue. The inspection revealed only small cosmetic defects that were attributed to the on-orbit indication and no adverse consequences to the hardware were identified.

The second probable impact was detected by a single accelerometer on the port wing RCC interface 11/12. At that mission time, approximately 11 min until the Rendezvous Pitch Maneuver and 72 min until docking, the Orbiter was closing to within 1000 ft of the International Space Station (ISS). During the approach, the primary and vernier thrusters were being repeatedly fired, however, no definitive correlation of the response with these firings or with the operation of other subsystems was found. Previous flight experience indicates that thruster firings do not typically produce measurable responses on the leading edge spar. Since the transient was not apparent on the other channels of the unit, or any channel of the neighboring unit, the location was isolated to RCC panels 11 thru 13. The magnitude of this response did not meet the defined trigger threshold, but was captured only because of the trigger algorithm anomaly. Until the faulty trigger algorithm is corrected, the data from invalid triggers will be reviewed in-flight for probable impacts. With a corrected algorithm, the trigger threshold may be lowered to improve MMOD detection capability.

ANOMALIES

No ascent data anomalies were found and reported during the mission. Automatic scanning of post-flight ascent data did not reveal any additional anomalies.

While reviewing MMOD monitoring data in-flight, unit 1040 was found to have large, quick, random, bias shifts as well as fluctuating magnitude. These data were reported in-flight to the Wireless Instrumentation System Government Furnished Equipment (WIS-GFE) team for review.

While reviewing MMOD monitoring data post-flight, it was also noted that four units had almost double the background-noise level than in previous flights and all the other units during STS-116. These same units also exhibited sharp bias shifts, seen in approximately 175 windows of data. The following table lists the associated unit number exhibiting the specific anomalous behavior.

ANOMALOUS BEHAVIOR

Anomaly Description	OV-103 Units
High Background Level	1018, 1021, 1024, 1052
Sharp Bias Shifts	1018, 1021, 1024, 1040, 1052

SUPPLEMENTAL DATA COLLECTED

The On-Orbit Group 4 monitoring of the port wing captured Flight Control System (FCS) Checkout. Post-flight analysis confirmed that WLES and FCS checkout event elapsed times are highly correlated.

CONCLUSIONS

The WLE IDS system performed well for ascent impact monitoring, allowing a final ascent report to be published at 14 hr MET. Most of the reported impacts were close to the 1.0 Grms reporting threshold.

The MMOD monitoring capability was limited because of the lack of continuous wing coverage resulting from battery/thermal considerations, gaps in coverage due to lack of Ku-band antenna communications, the time required to request units be brought out of and placed into MMOD monitoring mode, and excessive invalid triggering of the units. However, MMOD monitoring detected two probable impacts, one of which was reported during the mission.

A recommendation to not perform a focused WLE inspection of the RCC was made by the Mission Management Team (MMT) based on the ascent findings from all systems including WLE IDS. A focused inspection for the MMOD impact case was likewise not recommended, but imagery from the R-Bar Pitch Maneuver (RPM) and from the ISS

Remote Manipulator System (SRMS) camera was used to bound a risk assessment. Based on this information, the MMT decided not to perform any Flight Day (FD) 5 focused inspections. Following this decision, the Shuttle RMS wrist camera was parked overnight near the panels associated with the MMOD event, but this yielded no additional insights.

As expected, valid triggers for MMOD monitoring were returned on FD 11 due to excitations from the FCS checkout. No other valid triggers for MMOD monitoring were identified during the mission, but post-flight analysis showed that anomalous background noise on several units satisfied the trigger criteria. That data were not downlinked for evaluation real-time.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The Government Furnished Equipment/Flight Crew Equipment performed nominally during the mission with the exception of one explained condition and one anomaly that are discussed in the following paragraphs.

The Closed Circuit Television (CCTV) camera B required four attempts to be operational. This is a known and explained condition where the camera becomes activated, but the A7 lights and telemetry indicator becomes static. The crew is trained to cycle the power on the camera until the indicators are actively operating.

During the third EVA, a EVA hand-held digital camera separated from its EVA camera mount (STS-116-V-08). The camera was not tethered and floated away from the crewmember. The camera is secured to the camera mount with a slider and rail interface, and one screw secures the camera slider to the bottom of the camera housing. Evaluation of the downlinked photography of the EVA appears that the camera slider screw loosened and allowed the camera separate from the camera slider, which remained in the camera mount. A contributing factor may be that the camera may have been caught in a safety tether. As a result, two tethers will be used for operations (one tether to the camera bracket and one to the D-ring on the Camera until a long-term solution can be found.

DEVELOPMENT TEST OBJECTIVES

DTO 805 Crosswind Landing Performance

The crosswind landing performance DTO was a DTO of opportunity. The DTO was not performed during landing because of a 2-knot crosswind component. The DTO requires at least a 10-knot crosswind at landing to perform the DTO.

POSTLAUNCH PAD INSPECTION

Qualitatively, the items in this report reflect a steady commitment by Pad personnel to continuously improve their systems to reduce debris generation and debris threats to the vehicle. These items show a continuing trend in the reduction of debris as compared to previous efforts following STS 114, 121, and 115. The list below contains items identified in the early post-launch securing window before system turnarounds have begun and only serves as an indicator of Pad quick-look damage status.

At the Fixed Service Structure (FSS) 95-ft level; the elevator doors (East and West) were off of their track. The 95-ft level sign decal was missing from the East wall of elevator shaft, and the ends of two cables on the FSS/Rotating Service Structure (RSS) hinge-line were found loose/unsecured.

At the FSS 115-ft level, the speaker horn on the Southeast corner (overhead) was melted by plume impingement.

At the FSS 175-ft level, the elevator doors on the West side were off track. Also noted at the level was a 5-in long tie-wrap that was found on the west grating. Also, an 8-in-long piece of cardboard tube was found on the west grating.

At the FSS 195-ft level, the East and West elevator doors were off of their track and 7 in long tie wrap was found on west grating.

At the FSS 215-ft-level, the East and West elevator doors were off of their track. Also, one loose clamp was found on Northwest grating below the telephone/communications box that was missing a similar-style clamp.

At the FSS 235-level, the East and West elevator doors were off of their track. Also, the fire-alarm pull-station handle at the Northeast side of the elevator enclosure was loose at one end.

At the FSS 255-ft level, two locations of missing paint were found on the East wall of the elevator enclosure. One spot had approximately a 5-in diameter and the other spot had approximately a 10-in diameter.

On the Pad surface, one unistrut-clamp was found on the deck near the stairwell at the North-side elevator enclosure. In addition, a sheared bolt head was found on the crawler-way near the edge of concrete surface of the Pad.

LAUNCH PHOTOGRAPHY AND TELEVISION ANALYSIS

The launch photography and television analysis showed nominal launch conditions after liftoff. Some minor off-nominal conditions were noted, but none of these items affected the launch or the vehicle in any manner.

APPENDIX A
STS-116 MISSION EVENTS

EVENT	DESCRIPTION	ACTUAL GMT
APU Activation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	344:01:42:47.539 344:01:42:49.473 344:01:42:51.586
SRB HPU Activation	LH HPU System A Start Command LH HPU System B Start Command RH HPU System A Start Command RH HPU System B Start Command	344:01:47:06.969 344:01:47:07.089 344:01:47:07.249 344:01:47:07.409
Main Engine Start	SSME-3 Start Command Accepted SSME-2 Start Command Accepted SSME-1 Start Command Accepted	344:01:47:28.444 344:01:47:28.569 344:01:47:28.686
SRB Ignition	SRB Ignition Command	344:01:47:35.009
Throttle Up 104.5 percent	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	344:01:48:22.421 344:01:48:22.423 344:01:48:22.426
Throttle Down to 74 percent	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	344:01:48:08.021 344:01:48:08.023 344:01:48:08.026
Throttle Up to 104.5 Percent	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	344:01:48:22.421 344:01:48:22.423 344:01:48:22.426
Maximum Dynamic Pressure (Max Q)	Derived Ascent Dynamic Pressure	344:01:48:35
Both SRMs to less than 50 psi	RH SRM Chamber Pressure LH SRM Chamber Pressure	344:01:49:34.889 344:01:49:35.089
End SRM Action	RH SRM Chamber Pressure LH SRM Chamber Pressure	344:01:49:37.009 344:01:49:37.409
SRB Separation Command	SRB Separation Command Flag	344:01:49:40
SRB Physical Separation	LH APU A Turbine Loss of Signal RH APU B Turbine Loss of Signal LH APU B Turbine Loss of Signal RH APU A Turbine Loss of Signal	344:01:49:39.729 344:01:49:39.729 344:01:49:39.769 344:01:49:39.769
OMS Assist Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:01:49:49.9 344:01:49:50.1
OMS Assist Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	344:01:51:27.5 344:01:51:27.6
Throttle Down for 3g	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	344:01:54:56.829 344:01:54:56.832 344:01:54:56.837
3G Acceleration	Total Load Factor (g)	344:01:55:46.7
Throttle down to 67percent for Cutoff	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	344:01:55:50.910 344:01:55:50.913 344:01:55:50.919
SSME Shutdown	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	344:01:55:57.150 344:01:55:57.153 344:01:55:57.159
Main Engine Cutoff (MECO)	MECO Command Flag MECO Confirmed Flag	344:01:55:58 344:01:55:59
ET Separation	ET Separation Command Flag	344:01:56:19

APPENDIX A
STS-116 MISSION EVENTS

EVENT	DESCRIPTION	ACTUAL GMT
APU Deactivation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	344:02:01:58.391 344:02:02:15.144 344:02:02:28.217
OMS 1 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	Not Required
OMS 1 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	Not Required
OMS 2 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:02:24:42.5 344:02:24:42.5
OMS 2 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:02:26:44.6 344:02:26:44.7
Payload Bay Doors Open	Right Payload Bay Door Open 1 Left Payload Bay Door Open 1	344:03:16:09 344:03:17:28
OMS 3 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:04:36:42.5 344:04:36:42.6
OMS 3 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:04:37:47.9 344:04:37:48.0
OMS 4 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:18:45:13.9 344:18:45:14.0
OMS 4 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	344:18:45:50.1 344:18:45:50.2
OMS 5 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	345:17:56:32.1 345:17:56:32.2
OMS 5 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	345:17:56:48.1 345:17:56:48.2
OMS 6 Ignition (Left Engine Only)	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	345:19:28:22.1
OMS 6 Cutoff (Left Engine Only)	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	345:19:28:33.5
Docking	Capture	345:22:11:55
Undocking	Undocking Complete	353:22:09:19
OMS 7 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	354:00:11:46.3 354:00:11:46.4
OMS 7 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	354:00:11:57.8 354:00:11:57.9
Flight Control System Checkout – APU 3 Start	APU-3 Gas Generator Chamber Pressure	355:15:29:30.100
APU 3 Stop	APU-3 Gas Generator Chamber Pressure	355:15:35:24.215
Payload Bay Door Close	Left Payload Bay Door Close Right Payload Bay door Close	356:17:16:20 356:17:19:14
APU 2 Activation	APU-2 Gas Generator Chamber Pressure	356:21:22:14.124
Deorbit Maneuver Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	356:21:27:05.2 356:21:27:05.3
Deorbit Maneuver Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	356:21:30:52.8 356:21:30:52.8
APU 1 and 3 Activation	APU-1 GAS GENERATOR Chamber Pressure APU-3 GAS GENERATOR Chamber Pressure	356:21:47:06.259 356:21:47:11.047
Entry Interface	Orbital Altitude Referenced to Ellipsoid	356:21:59:55

APPENDIX A
STS-116 MISSION EVENTS

EVENT	DESCRIPTION	ACTUAL GMT
Blackout End	Data Locked (High Sample Rate)	No Blackout
Terminal Area Energy Management (TAEM)	Major Mode Code (305)	356:22:25:30
Main Landing Gear Contact	Main Landing Gear Right Hand Tire Pressure Main Landing Gear Left Hand Tire Pressure	356:22:31:58 356:22:31:59
Main Landing Gear Weight on Wheels	Main Landing Gear Right Hand Weight on Wheels Main Landing Gear Left Hand Weight on Wheels	356:22:31:59 356:22:31:59
Drag Chute Deployment	Drag Chute Deploy 1 CP Volts	356:22:32:03.7
Nose Landing Gear Contact	Nose Landing Gear Left Hand Tire Pressure 1	356:22:32:11
Nose Landing Gear Weight on Wheels	Nose Landing Gear Weight on Wheels	356:22:32:12
Drag Chute Jettison	Drag Chute Jettison 2 CP Volts	356:22:32:35.7
Wheels Stop	Velocity with respect to Runway	356:22:32:51
APU Deactivation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	356:22:50:21.220 356:22:50:31.742 356:22:50:42.866

APPENDIX B IN-FLIGHT ANOMALIES

INTRODUCTION

This appendix contains listings and discussions of each of the In-Flight Anomalies (IFAs) that were identified for the STS-116 mission.

1. Orbiter
2. Solid Rocket Booster (SRB)
3. Reusable Solid Rocket Motor (RSRM)
4. External Tank (ET)
5. Space Shuttle Main Engine (SSME)
6. Systems Engineering and Integration (SE&I)
7. Flight Operations & Integration (FO&I)

No External Tank, Space Shuttle Main Engine or Flight Operations and Integration (FO&I) In-Flight Anomalies were identified for the STS-116 Mission.

**APPENDIX B
IN-FLIGHT ANOMALIES**

ORBITER

IFA Number	Title	Comments
STS-116-V-01	Loss of RMS End Effector Auto Release Capability	<p>During the SRMS Checkout, the end effector failed to extend the snare ring carriage (derigidization), indicating a potential problem with the Rotational Hand Controller (RHC) capture/release switch 10V contact. The crew repeated the Auto command a few times with no effect, and it was confirmed by telemetry. The crew was requested to perform a manual close command followed by a manual open command. The crew successfully completed this operation indicating that the manual side of the RHCs capture/release switch was functioning properly. EE Auto Release (10V contact) was working minutes earlier. The crew was advised to use Manual Release and to expect a nuisance "Uncommanded Release" annunciation during ungrappling operations.</p> <p>On FD 3, during ungrappling operations to handoff the P5 to the SSRMS, the manual mode was used, but the expected "Uncommanded Release" annunciation did not occur. The same thing occurred on FD 12 with the ungrappling of the OBSS after the completion of Late Inspection.</p> <p>During post-flight testing, the RHC performed as designed in all configurations and axes. All possible troubleshooting was completed with no repeat of the problem. The RHC will be removed and replaced, and the occurrence will be noted as an Unexplained Anomaly. (Note: Legacy data shows that this RHC has more release commands issued from it than all of the other RHCs in the fleet.)</p>
STS-116-V-02	FC 3 O ₂ Flowmeter Failed	<p>At 344/14:12:37 GMT, Fuel Cell (FC) 3 O₂ flowmeter went to an off-scale-low (OSL) reading. The OSL indication correlated to a 1.6 A increase with a 2-sec duration, while operating on Mid Power Control Assembly 3 (MPCA 3). The FC 3 O₂ flowmeter circuit is protected by a 1 A fuse installed in MPCA 3. Based on the signatures and the specified fuse maximum blow current of a 1.5 A load, the fuse blew. The increased O₂ flowmeter amperage load was most likely caused by overstressed EEE components located in the flowmeter circuitry. It is used primarily to indicate increased O₂ flowrates during FC purges. Other parameters can also aid in verifying purges such as the H₂ flowmeter, Purge Line temperatures, cryogenic-pressure decay and fuel cell performance. The loss of the FC 3 O₂ flowmeter was no impact to fuel cell 3 operation.</p> <p>Post-flight troubleshooting verified a blown fuse in flowmeter circuit. Circuit continuity, resistance and insulation checks were performed with no anomalies noted. Additional troubleshooting planned to verify no issues with MPCA. Fuel cell will be re-flown (with or without operational flowmeter).</p>

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IFA Number	Title	Comments
STS-116-V-03	FES PRI B Failed to Come out of Standby	<p>The FES in the Primary B Controller failed to come out of stand-by during the crew sleep period while operating in the topping mode. During topping mode, the FES supplements cooling primarily provided by the radiators. Prior to this event, the FES had been working with no anomalous signatures. On FD 2, an on-orbit troubleshooting procedure was performed towards the end of the supply water dump operating on FES Primary A. The attempt to continue the supply water dump using the FES Primary B failed. Initial post-flight troubleshooting indicated unstable performance of the Primary B shutdown sensor. Troubleshooting methods were influencing shutdown sensor readings. Additional testing in progress to verify sensor signal drift or exonerate wiring harness and control box.</p>
STS-116-V-04	Port Mid PLB Floodlight Failed	<p>At 2006/345:17:30 GMT, the Payload Bay floodlights were turned on. The crew reported that the Mid-Port PLB Floodlight was not illuminated. The five additional PLB floodlights will be used for the EVA's. A switch lock-out has been installed. The Mid-Port Floodlight was checked out in the Orbiter Processing Facility (OPF) and it was determined that the Ballast Assembly in FEA 1, or associated circuitry has failed. Post-flight inspection found that the Mid-Port floodlight bulb was cracked. Additional inspection found that the forward starboard and aft port floodlights also had cracked bulbs and subsequently failed to illuminate. All cracked bulbs were replaced and failure analysis will be performed to identify the cause. The remaining three bulbs that are not cracked will be functionally tested prior to flight.</p>
STS-116-V-05	A6U Aft Event Thumbwheel Failure	<p>At 2006/346:04:48 GMT, the crew reported that the "tens of seconds" thumbwheel (third from the left) was not consistently updating the Aft Event Timer with the proper value when the timer was set. The lamp test was performed successfully. No mission impact, as the Event Timer is criticality 3, and alternate event and mission timers are available on the vehicle.</p> <p>Post-flight testing found voltage irregularities on the Panel A6 thumbwheel. Currently no spares available.</p>

**APPENDIX B
IN-FLIGHT ANOMALIES**

IFA Number	Title	Comments
STS-116-V-06	TPS Tile and Blanket Anomalies	<p>This anomaly has been established to be the central point for all TPS related damage during STS-116. No focused inspection was required, and the TPS Tile and Blanket were cleared for entry. In-flight assessment included the following areas:</p> <ul style="list-style-type: none"> a) ET Doors b) Vertical Stabilizer Damage c) LH OMS Pod Damage d) Window 4 Damage (TPS Runway Report) e) Port Inboard Elevon Tile Damage f) Port ET Door Perimeter Tile Damages <p>The TPS Post-Flight evaluation and review has shown the following additional items.</p> <ul style="list-style-type: none"> a) Five missing putty repairs identified. b) Sleeving on inboard attachment of Arrowhead Blanket became detached and protruded during flight. c) Two Flight Reusable Surface Insulation (FRSI) plugs were identified as missing from the base heat shield. d) Dome heat shield blanket patch became detached during ascent. e) Advances FRSI blankets were identified as being torn/lifted on the AFRSI/tile interface of the left-hand OMS pod. f) A large number of tile damages were noted around the ET doors and aft fuselage. g) A small tile damage was identified post flight on the forward structure side tile. h) A protruding gap filler was found in the region of gap fillers that were replaced pre-flight. <p>Post-flight Plan: Standard post-flight inspection and repair.</p> <p>Missing putty repairs were within family of previous losses. No putty repairs were lost in the high risk locations forward of windows and RCC. Tactile inspection of putty repairs in critical areas performed on OV-104</p> <p>Inspection of the OV-103 arrowhead blanket indicated that the sleeving material that protruded during flight was "over stretched" during installation. The OV-104 arrowhead plate was removed and the blanket reworked to eliminate the potential for a protrusion. Evaluation of FRSI plug risk is complete.</p> <p>One patch existed on OV-104 and was installed prior to STS-115. Detailed inspections of this patch showed no degradation of the patch, stitches, or parent material.</p> <p>Failures may be due to installation/bonding issue on the dome heat shield tiles related to recent insert installations. OV-104 inserts inspected and pull tested. Four BHS inserts will be replaced at the pad prior to flight.</p>

**APPENDIX B
IN-FLIGHT ANOMALIES**

IFA Number	Title	Comments
STS-116-V-07	ML94B Bogen Bracket Shoe Debonded	A camera Quick Shoe on bulkhead location ML94B became debonded. The most probable cause is Crew applied force during camcorder bracket installation that loaded the fitting and caused it to become debonded, or the bonding agent aged and lost its adhesiveness. The bracket shoe interface will be cleaned and the camera quick shoe will be re-bonded. Potential crew training note to minimize force used when installing bracket and camcorder.
STS-116-V-08	Kodak DCS 760 Digital Camera Lost During EVA	During EVA 3, an EVA hand-held digital camera separated from its EVA camera mount. The camera was not tethered and floated away from the crewmember. The camera is secured to a camera mount with slider and rail interface. There is one screw which secures the camera slider to the bottom of the camera housing. From the downlinked photo of the EVA camera mount, it appears the camera slider screw loosened and allowed the camera to separate from the camera slider which remained in the camera mount. Contributing factor may be that the camera may have been caught in a safety tether. EVA has already initiated the use of two tethers for operations, one to the Camera Bracket and one to the D-Ring on the Camera MLI, as a near-term fix. Engineering is analyzing the problem and will determine a long term fix.
STS-116-V-09	Waste Water Dump Degraded Flow	During simultaneous Dump 4 (Waste and supply water tanks), the nominal waste dump rate (1.7 percent/min) was observed until the nozzle temperature reached 50 °F where the dump was required to be terminated to reheat the nozzle to 250 °F per an established procedure. The waste dump was terminated by closing the dump valve and the nozzle was reheated to 250 °F. The dump valve was then opened to dump the remaining waste water; however, the dump decreased to an off-nominal dump rate and the waste dump was terminated after 11 min. There was no indication of ice on the nozzle-bakeout signature. Reduced dump rate signature is indicative of partial blockage in the waste dump line or in the high-capacity urine solids filter. Post-flight flow check per OMRSD showed no flow degradation with urine filter installed. The filter was replaced and the flown filter was sent to NSLD for inspection and analysis.
STS-116-V-10	-Z Star Tracker Pressure Fail BITE Indication	At the completion of the SAW retract activities the -Z Star Tracker was powered on for about 45 seconds to open the star tracker doors. The -Z Star Tracker annunciated a Pressure Fail BITE indication when it was powered on. The pressure fail indication remained on until the star tracker was powered off. The -Z star tracker was powered on again at 353/20:51:28 GMT (FD 11). The BITE indication was still present; however, it cleared approximately 13 minutes after powerup. There was no impact to the performance of the star tracker for a pressure-fail indication. The star trackers are pressurized to prevent moisture or contamination from being ingested during entry. During post-flight operation, the OMRSD requirements require a purge and re-pressurization during turnaround for a Star Tracker with an in-flight pressure fail indication.

**APPENDIX B
IN-FLIGHT ANOMALIES**

IFA Number	Title	Comments
STS-116-V-11	GPS Receiver Failed to Change Satellites	<p>On Entry day while still in OPS 2, the MAGR peripheral channel maintained lock on satellite for over 21 minutes (normal lock by the peripheral channel on a satellite should be less than one minute). As a result of this condition, the MAGR was unable to switch in new navigating satellites to maintain optimized satellite geometry. Consequently, the Figure of Merit (FOM) gradually increased (with a corresponding increase in GPS position/velocity uncertainty). No crew action was required since GPS was not being used during this timeframe. The condition corrected itself after 21 minutes when a loss-of-lock occurred on one of the navigating satellites.</p> <p>Fault log dump retrieval was performed with no receiver hardware issues identified. Most probable cause is due to multipath caused by Earth reflected signal. A User Note will be written to provide Crew workaround of this problem.</p> <p>The GPS Ramp-Up to proceed as planned (GPS incorporation into both PASS and BFS during Entry). Continuous Voice, Telemetry, and 'Go' from MCC are required before GPS usage.</p>
STS-116-V-12	MADS Signal Dropout	<p>Data showed multiple dropouts of measurements E41D3601A, E41D3602A, E41D3605A, and E41D3607A during ascent at 344/01:53:27 GMT. All these measurements go through FDM 1, Mux D. A request has been made to RPS to provide recorded data of the remaining measurements on M1D for evaluation. No other FDM multiplexers reflected similar dropouts. The problem is limited to the loss of data from FDM 1, MUX D. These data are criticality 3/3 and recorded for postflight analysis only. Loss of these data did not impact the mission. The worst case potential would be a requirement for engine inspection. Data from the MADS recorder was dumped again and all MADS data reviewed as part of the MADS data review.</p>
STS-116-V-13	WLE IDS Sensor Unit Inadvertent Shutdown	<p>The Wing Leading Edge Impact Detection System (WLEIDS) was performing on-orbit MMOD monitoring using three sensor units in Port Wing Group 5 (1021, 1025, and 1108). During the execution of a command file, the WLE Graphical User Interface (GUI) was terminated and no longer active. The WLE GUI software was executing on A31P laptop PG5 (STS-7), and was configured as the primary laptop. Sensor unit 1108 had been in on-orbit mode for approximately 14 hr and had successfully processed several commands before this issue. A second attempt to request an index file from sensor unit 1108 was performed towards the later part of the mission after all units were configured for entry and the WLE GUI terminated a second time with a similar signature.</p>

**APPENDIX B
IN-FLIGHT ANOMALIES**

IFA Number	Title	Comments
STS-116-V-14	Elevon Cove Over-Temperature	<p>Postlanding, an over-temperature condition was identified on the left-hand elevon cove, resulting in discoloration/deposit and tile damage downstream of the trailing edge gap filler and Columbium seal gap filler. This over-temperature condition was first identified on STS-114, and post-121 gap filler rework was performed that was aimed at correcting the gap between the Columbium seal and the primary seal panel. Although leak rate testing indicated that the cove seal was improved, the over-temperature condition returned and increased in magnitude.</p> <p>Post flight plan: The following items will be performed or evaluated:</p> <ol style="list-style-type: none"> 1. Scheduled Columbium spring modification to be implemented; 2. Columbium seal gap filler will be replaced and recession eliminated; 3. Gap between trailing edge gap filler and Columbium seal gap filler will be eliminated (may require trailing edge gap filler replacement); 4. Structures assessment of carrier panel integrity required; and 5. Korporon and edge member replacement

**APPENDIX B
IN-FLIGHT ANOMALIES**

SOLID ROCKET BOOSTER

IFA Number	Title	Comments
STS-116-B-001	SRB Separation Debris Impact the Orbiter	<p>Video imagery from the aft-pointing Forward Skirt Camera shows a debris piece of unknown origin hitting the Orbiter at 125.209 MET (during separation). An Anomaly Resolution Team (ART-245) was set up to identify and understand the nature of this debris. The Booster Trowelable Ablative (BTA) is missing from Left Hand Booster Separation Motor Nozzles and is the likely cause. BSM S/Ns 4004201, 4004202, 4004203, and 4004204 were installed on this SRB.</p> <p>Two tests indicated liberation of BTA, which led the Postflight Assessment Team (PFAT) to suspect the debris noted by the NASA Imagery. Investigation continuing. Reportable Database (NIRD) could be BTA from the BSM Nozzles.</p>
STS-116-B-002	Frangible Bolt Missing from T-0 Umbilical on Left SRB	<p>A frangible threaded bolt half (1 of 4) was noted to be missing from the LH SRB T-0 Umbilical Plate during the post-flight inspection. During the MLP walkdown, the head of the bolt was found to have been retained by the ground carrier assembly. Therefore, the fastener was installed prior to launch.</p> <p>ART-246 was formed to determine cause and corrective action. This ART has reviewed all available physical evidence and performed a photographic review. The umbilical plate received (and passed) a go/no-go gage check and has been removed as a contributor. A data review of procurement on the bolts was performed and all bolts were inspected to be within tolerances. Design review indicates that there is no positive retention mechanism inherent in the design, ergo the design functioned within nominal parameters.</p>
STS-116-B-003	Delaminated and Missing BTA on aft Booster Separation Motor Housing	<p>Post-flight inspection of the SRBs from STS-116/BI-128 showed missing BTA material on the Aft BSMs (LH/RH). Material was missing from thin overlaps of BTA wrapped around the sides of the BSM support structures as part of the application to the aft face of the structures to prevent the material from pulling away due to gravity prior to cure. This causes the wrap-around area to cure under a shear load. The left hand SRB BSM had a wedge-shaped piece missing of dimension 2.5-in by 1.0-in by 0.06-in. The fracture surface was slightly sooted. The right hand SRB BSM had a wedge-shaped piece missing of dimension 1.5-in by 1.0-in by 0.09-in. An anomaly resolution team (ART-247) has been formed.</p>

**APPENDIX B
IN-FLIGHT ANOMALIES**

REUSABLE SOLID ROCKET MOTOR

IFA Number	Title	Comments
STS-116-M-001	Missing LH Motor Center Stiffener Ring Foam	<p>An area of missing stiffener ring foam (approximately 6 in by 4 in by ¾ in) with heat effects was observed on the Left-Hand (LH) motor center stiffener ring foam ramp at the 5-degree location. Although the initial data assessment suggests a entry event, insufficient information is available to preclude the possibility of an ascent occurrence. Assuming material loss was a single event during ascent:</p> <ul style="list-style-type: none"> 3. Estimated lost material mass (approximately 0.03 lb) exceeds NSTS 60559, Table C-1 risk assessment mass (0.0002 lb); and 4. Estimated lost material mass (approximately 0.03 lb) was less than NSTS 60559 SRB allowable mass for ETA ring foam (0.218 lbm). <p>The ETA ring foam is more forward on the RSRM (nearer the Orbiter) than the stiffener ring foam. During ascent, it is assumed the ETA foam loss would pose a greater debris risk than stiffener ring foam loss. The ETA ring foam loss allowable limits are greater than the stiffener foam loss allowable limits. An assessment is underway to determine the ETA ring foam loss allowable limit applicability to the stiffener foam loss allowable limits.</p>
STS-116-M-002	Parallel Grooves in RH Nose Cap Outer Diameter	<p>Two shallow parallel grooves (each 0.40-in wide by 0.06 in deep, and approximately 0.40 in apart) in the Right Hand (RH) Nose Cap Outer Diameter (OD) Carbon Carbon Phenolic material were located approximately 1.5 in from the nose tip. There was no associated downstream wash erosion.</p> <ul style="list-style-type: none"> 5. The Nose Cap is robust, with an average Performance Factor of 2.6; the requirement is 1.4. 6. The groove depths are much less than typical intermittent wash erosion on flight Nose Caps (0.01-0.22 inch deep).

**APPENDIX B
IN-FLIGHT ANOMALIES**

EXTERNAL TANK

No External Tank anomalies were identified from the review and analysis of the data and photography.

**APPENDIX B
IN-FLIGHT ANOMALIES**

SPACE SHUTTLE MAIN ENGINE

No Space Shuttle Main Engine in-flight anomalies were identified for this mission.

**APPENDIX B
IN-FLIGHT ANOMALIES**

SYSTEM ENGINEERING AND INTEGRATION

IFA Number	Title	Comments
STS-116-I-001	Ice/Frost Formations noted Hanging from the North GOX Vent Arm Duct Exit	Ice balls were noted hanging from the North Gaseous Oxygen (GO ₂) Vent Arm Duct Exit Flange.
STS-116-I-002	Multiple Pad/MLP HIMS Lost Power'UPS-41/41A Distribution Panel Circuit Breaker 10 Tripped Open	Multiple Pad and MLP HIMS lost power from UPS-41/41A distribution panel circuit breaker 10 when tripped open.
STS-116-I-003	SRB Left-Hand Aft BSM Debris Release Ttraveling Fward and Striking Orbiter	Debris released from and the left-hand aft Booster Separation Motor (BSM) and traveled forward striking the Orbiter. Reference STS-116-B-001.
STS-116-I-004	T-0 Umbilical Frangible Bolt Missing	A ¼ in. frangible bolt was missing from the T-0 umbilical on the left SRB. MSFC has formed an ART (246) to investigate this anomaly. Reference STS-116-B-002.
STS-116-I-005	Delaminated/Missing BTA on Aft BSM Housing with Sooting	Delaminated and missing BTA was noted on the aft Booster Separation Motor (BSM) housing. Reference STS-116-B-003.
STS-116-I-006	Missing Stiffener Ring Foam with Heat Effects	
STS-116-I-007	Felt Reusable Surface Insulation Plugs Missing	
STS-116-I-008	Unexpected Debris/Debris Exceeding Mass Allowables Prior to Pad Clearance (Lift-off Debris)	
STS-116-I-009	Tape on Orbiter Tile May Have Liberated During Ascent	
STS-116-I-010	Intermittent Printer Power	
STS-116-I-011	Orbiter Tile Damage Around ET Door	
STS-116-I-012	Missing Ceramic LIners	
STS-116-I-013	SRB Thermal Curtain Billowing During Ascent	

**APPENDIX B
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SYSTEM ENGINEERING AND INTEGRATION (Concluded)

IFA Number	Title	Comments
STS-116-I-014	PGSC Non-Functioning Desktop LCS Video Downlink During LCS Checkout	
STS-116-I-015	Contamination in Liquid Hydrogen Side of SSME 2058 Found During Post-Flight Inspection	Contamination was found in the Liquid Hydrogen (LH ₂) side of SSME 2058 (position 3) during the post-flight inspection. Reference STS-116-E-001.

APPENDIX C

DOCUMENT SOURCES

MER DAILY REPORTS

The following STS-116 MER Daily Reports by Ben Pawlik, Lead MER Manager:

- First Daily Report (Ascent Plus 2-Hour Report), dated December 9, 2006
- Second Daily Report, dated December 10, 2006
- Third Daily Report, dated December 11, 2006
- Fourth Daily Report, dated December 12, 2006
- Fifth Daily Report, dated December 13, 2006
- Sixth Daily Report, dated December 14, 2006
- Seventh Daily Report, dated December 15, 2006
- Eighth Daily Report, dated December 16, 2006
- Ninth Daily Report, dated December 17, 2006
- Tenth Daily Report, dated December 18, 2006
- Eleventh Daily Report, dated December r 19, 2006
- Twelfth Daily Report, dated December 20, 2006
- Thirteenth Daily Report, dated December 21, 2006
- Landing Plus 2 Hour Report, dated December 22, 2006

ET/SRB/RSRM/SSME REPORTS

- STS-116 SRB, RSRM and ET Console Flash Report, Luke Henke, USA-Huntsville, received December 10, 2006.
- STS-116 Preliminary Event Times, Jonathon D. Mack, MSFC, received December 10, 2006
- RSRM Flash Report, Glen A. Ricks, MSFC-Huntsville, received December 10, 2006.
- STS-116 Final Event Times, Jonathan D. Mack, MSFC, received December 18, 2006
- STS-116 RSRM Executive Summary, Larry Manuel, ATK-Huntsville, received January 12, 2007
- STS-116 ET Impact Data, David W. Morr, USA-Huntsville, April 3, 2007
- STS-116 MSFC Element In-Flight Anomalies, David w. Moor, USA-Huntsville, received April 17, 2007

ORBITER REPORTS

- STS-116 Landing and Deceleration System, Chip C. Heinol, Boeing-Houston, received January 15, 2007.
- STS-116 Final WCS Report, Marco Lorenzana, Hamilton Standard, received January 24, 2007
- STS-116 PV&D Report, J. Goodmark, Boeing-Houston, received January 22, 2007.
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- STS-116 MPS Mission Report, Rusty L. Scheier, Boeing-Houston, received January 19, 2007.
- STS-116 OI/MADS Mission Reports, Dwight A. Favors, Boeing-Houston, received January 18, 2007
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- STS-116 Data Processing System Integrated Report, Lynna Wood. Boeing-Houston, received January 22, 2007
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APPENDIX D ACRONYMS AND ABBREVIATIONS

Acronyms	Explanation
A	Ampere
AA	Aerosurface Actuators
ABS	Ammonia Boiler System
AC	Alternating current
ADTA	Air Data Transducer Assembly
ADP	Air Data Probe
AGB	Adjustable Grapple Bar
AGT	Adaptive Guidance Throttling
AHMS	Advanced Health Monitoring System
ALTEA	Anomalous Long Term Effects on Astronauts
ANDE	Atmospheric Neutral Density Experiment
APFR	Articulating Portable Foot Restraint
APU	Auxiliary Power Unit
ARS	Atmospheric Revitalization System
ATCS	Active Thermal Control System
ATP	Acceptance Test Procedure
BET	Best Estimate Trajectory
BFC	Backup Flight Controllers
BFS	Backup Flight System
BLT	Boundary Layer Transition
BITE	Built In Test Equipment
CAPE	Canister For All Payload Ejections
CCTV	Closed Circuit Television
CDR	Commander
CEI	Contract End Item
CETA	Crew Equipment Transition Aid
CGBA	Commercial Generic Bioprocessing Apparatus
CLA	Capture Latch Assembly
CMG	Control Moment Gyroscope
CPM	Cell Performance Monitor
CTV	Cargo Transport Vehicle
C&W	Caution and Warning
CWC	Contingency Water Container
DAT	Damage Assessment Team
DBC	Data Bus Coupler
DBIA	Data Bus Isolation Amplifier
D&C	Display and Control
DCP	Docking Control Panel
DDU	Data Display Unit
DOD	Department of Defense
DPS	Data Processing System
DTO	Development Test Objective
ΔV	Differential Velocity
EAFB	Edwards Air Force Base
ECLSS	Environmental Control and Life Support System
ECO	Engine Cutoff
EI	Entry Interface
EIU	Engine Interface Unit

APPENDIX D ACRONYMS AND ABBREVIATIONS

Acronyms	Explanation
EMU	Extravehicular Mobility Unit
EO`	ET/Orbiter
EPDC	Electrical Power Distribution and Control
ESP	External Stowage Platform
ET	External Tank
ETA	External Tank Attachment
ETCS	External Thermal Control System
ETVCG	External Television Control Group
FMBBT	Flexible bearing mean bulk temperature
FCal	Fence calibration
FCMS	Fuel Cell Monitoring System
FD	Flight Day
FES	Flash Evaporation System
FIT	Final Inspection Team
FMS	Force Moment Sensor
FOM	Figure of Merit
FRCS	Forward Reaction Control System
FRSI	Flexible Reusable Surface Insulation
FWD	forward
G or g	Gravity
GAP	Group Activation Pack
G & C	Guidance and Control
GEI	Ground environmental instrumentation
GG	Gas Generator
GGVM	Gas Generator Valve Module
GMT	Greenwich mean time
GPC	General Purpose Computer
GPS	Global Positioning System
GSE	Ground Support Equipment
GUCA	Ground umbilical carrier assembly
GUCP	Ground umbilical carrier plate
HGDS	Hazardous Gas Detection System
HPFTP	High-pressure fuel turbopump
HPOTP	High-pressure oxidizer turbopump
HYD	Hydraulic
IBA	Inspection Boom Assembly
ICOM	Intercommunication
IFA	In-flight anomaly
I/O	Input/output
IMU	Inertial Measurement Unit
ISS	International Space Station
ITS	Integrated Truss Segment
IVA	Intravehicular
KBU	Keyboard Unit
KSC	Kennedy Space Center
lbm	pound-mass
LCC	Launch Commit Criteria
LDR1	Laser Dynamic Range Imager

APPENDIX D ACRONYMS AND ABBREVIATIONS

Acronyms	Explanation
LEE	latching edge effector
LFL	Lower Flammability Limit
LH	left-hand
LiOH	Lithium Hydroxide
LPFD	Low Pressure Fuel Duct
MAA	MOC ANDE Active
MADS	Modular Auxiliary Data System
MAUI	Maui Analysis of Upper Atmosphere Injections
MAGR	Miniature Airborne-to-Ground Receiver
MCIU	Manipulator Controller Interface Unit
MEC	Master Events Controller
MER	Mission Evaluation Room
MECO	main engine cutoff
MEDS	Multifunction Electronic Display System
MEPSI	Micro Electrochemical System Based PICO Satellite Inspector
MIA	Multiplexer Interface Unit
Mlbf	Million pounds force
MLI	multilayer insulation
MLP	Main Launch Platform
MLS	Microwave Landing System
MM	Momentum Manager
MMOD	MicroMeteoroid Orbital Debris
MMT	Mission Management Team
MOD	Mission Operations Directorate
MPCA	Mid Power Control Assembly
MPM	manipulator positioning mechanism
MPS	Main Propulsion System
MRL	manipulator release latch
N/A	not applicable
NASA	National Aeronautics and Space Administration
NDE	non-destructive evaluation
NISIS	Non-Integral Spark Igniter System
nmi	nautical mile
NORAD	North American Defense (Center)
OBSS	Orbiter Boom Sensor System
OD	outer diameter
ODS	Orbiter Docking System
OI	Operational Instrumentation
OME	Orbital Maneuvering Engine
OMRSD	Operational Maintenance and Requirements Specification Document
OMS	Orbital Maneuvering System
OPO	Orbiter Project Office
ORGA	Orbiter Rate Gyro Assembly
OV	Orbiter Vehicle
PASS	Primary Avionics Software System
PCS	Pressure Control System

APPENDIX D ACRONYMS AND ABBREVIATIONS

Acronyms	Explanation
PGME	Propylene Glycol Monomethyl Ether
PLA	PICOSAT Launcher System
PLBD	payload bay door
PMBT	propellant mean bulk temperature
PMDIS	Perpetual Motor Deficits in Space
POEMS	Passive Observatories of Experimental Microbial System
PPCO ₂	Partial Pressure Carbon Dioxide
ppm	Parts per million
PRSD	Power Reactant Storage and Distribution System
PRT	Problem Resolution Team
psia	Pound per square inch
PSIG	Propulsion Systems Integration Group
PVD	Purge, Vent and Drain
PVRGF	Photovoltaic Radiator Grapple Fixture
PWR	Payload water reservoir
PVRM	Photovoltaic Module
RAFT	Radar Fence Transponder
RAMBO	Ram Burn Observation
RCC	Reinforced Carbon Carbon
RCS	Reaction Control System
RH	right hand
RHC	rotational hand controller
RJD	reaction jet driver
ROI	Regions of Interest
ROOBA	Recharge Oxygen Orifice Bypass Assembly
RPM	R-Bar Maneuver
RSC PCU	Rudder Speed Brake Power Drive Unit
RSRM	Reusable Solid Rocket Motor
RSS	Rotating Service Structure
S&A	Safe and Arm
SARJ	Solar Alpha Rotary Joint
SAW	Solar Array Wing
SDBI	Short Duration BioAstronautics Investigation
SDFS	Smoke Detection and Fire Suppression
SH	Space Hab
SIMO	simultaneous water dump
SSLM	Single Logistics Module
SLWT	Super Lightweight (ET)
SMDP	Service Module Debris Panels
SMRD	spin motor rotation detector
S/N	serial number
SODB	Shuttle Operational Data Book
SRB	Solid Rocket Booster
SRGA	Station rate gyro assembly
SRMS	Shuttle Remote Manipulator System
SRSS	Shuttle Range Safety System
SSME	Space Shuttle Main Engine

APPENDIX D ACRONYMS AND ABBREVIATIONS

Acronyms	Explanation
SSP	Space Shuttle Program
SSRMS	Space Station Remote Manipulator System
SSTS	Short Space Truss Segment
STP-H2	Space Test Program-Houston
SUPA	Shuttle Urine Pre-treat Assembly
TCDT	Terminal Countdown Test
TCS	Thermal Control System
TEA	Torque Equilibrium Attitude
THC	Translational Hand Controller
TI	Terminal Phase Initiation
TIG	time of ignition
TPS	Thermal Protection System
Tropi	European Modular Cultivation System
TVC	thrust vector controller
USNA	United States Naval Academy
USTO	United States Thrusters Only
V	Volt
VRCS	Vernier Reaction Control System
WCS	Waste Collection System
WLE	Wing Leading Edge
WLEIDS	Wing Leading Edge Impact Detection System
WLESS	Wing Leading Edge Subsystem
WSB	Water Spray Boiler
WSSH	White Sands Space Harbor
deg/sec	degree per second
°F	degrees Fahrenheit
ft	feet
GH ₂	gaseous hydrogen
GN ₂	gaseous nitrogen
GO ₂	gaseous oxygen
kWh	kilowatt hours
LiOH	lithium hydroxide
LH ₂	liquid hydrogen
LO ₂	liquid oxygen
O ₂	Oxygen
lb	Pound
SCIM	standard cubic inches per minute
min	minute
sec	second
hr	hour