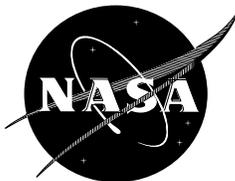


STS-133 SPACE SHUTTLE MISSION REPORT

July 2011



**National Aeronautics and
Space Administration**

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

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STS-133
SPACE SHUTTLE MISSION REPORT

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STS-133 SPACE SHUTTLE MISSION REPORT

INTRODUCTION

The Space Transportation System (STS) -133 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 Reusable Solid Rocket Booster (RSRB), the Reusable Solid Rocket Motor (RSRM) and the Space Shuttle Main Engine (SSME) performance during the 133rd mission of the Space Shuttle Program. STS-133 was the 20th mission since the return-to-flight following the STS-107 mission, and the 35th mission to the International Space Station (ISS). STS-133 was also the 39th, and last, flight of Orbiter Vehicle (OV) -103, *Discovery*.

The purpose of the STS-133 mission was to deliver and install the Express Logistics Carrier (ELC) -3 and the Permanent Multipurpose Module (PMM), which included the delivery of the first humanoid robot in space, Robonaut 2. Also, two Extravehicular Activities (EVAs) were performed.

The primary objectives of the STS-133 mission are as follows:

1. Rendezvous and dock with the ISS.
2. Install and activate the ELC-3.
3. Install, activate and checkout the PMM.
4. Transfer and stow critical items per the Transfer Priorities List (TPL).
5. Perform two EVAs.
6. Transfer a minimum of 25 lb of oxygen and nitrogen, and
7. Transfer water per the TPL.

The flight vehicle consisted of the OV-103 Orbiter; the ET, a Super Lightweight Tank (SLWT), designated ET-137; three Block II SSMEs that were designated as Serial Numbers (S/Ns) 2044, 2048, and 2058 in positions 1, 2 and 3, respectively; and two RSRBs that were designated BI-144. The two RSRMs were designated flight set RSRM-112. The individual RSRMs were S/N 360W112A (left) and S/N 360W12B (right). Launch pad 39A and Mobile Launch Platform (MLP) -3 were used as the platform for launch of the STS-133 mission.

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 six crewmembers that were on the STS-133 flight were Steven W. Lindsey, Colonel, USAF (Retired), Commander; Eric A. Boe, Colonel, USAF, Pilot; B. Alvin Drew, Colonel, USAF (Retired), Mission Specialist 1; Stephen G. Bowen, Captain, U. S. Navy, Mission Specialist 2; Michael Barratt, M.D., NASA, Mission Specialist 3; and Nicole Stott, Civilian, NASA, Mission Specialist 4.

STS-133 was the fifth flight for the Commander, third flight for Mission Specialist 2 and Mission Specialist 4, the second flight for the Pilot, Mission Specialist 1, and the first Shuttle flight for Mission Specialist 3.

Mission Specialists 3 and 4 have performed a long-duration mission as a Flight Engineer on the ISS. Mission Specialist 4 was a crewmember on a Shuttle flight up and down from the ISS, whereas Mission Specialist 3 was transported to and from the ISS in the Soyuz spacecraft.

Timothy L. Kopra was initially assigned as a member of the STS-133 crew as Mission Specialist 2; however, he was involved in a serious accident. As a result of an injury sustained during the accident, it was necessary to replace him with Stephen Bowen as Mission Specialist 2.

MISSION SUMMARY

The objectives of the STS-133 mission include the installation and activation of the Express Logistics Carrier (ELC); installation, activation and checkout of the Permanent Multipurpose Module (PMM); performance of two Extravehicular Activities (EVAs); transfer and stowage of critical items in accordance with the Transfer Priority List (TPL); and delivery of Robonaut 2 (first humanoid robot in space).

Pre-Launch

The planned launch for November 1, 2010, was delayed to November 3 to complete repairs on the right Orbital Maneuvering System (OMS) pod. When the system was being pressurized, helium and nitrogen leaks were detected. The quick-disconnect fittings used to pressurize the system were replaced.

The November 3 launch was then scrubbed to evaluate the condition of the backup controller for Space Shuttle Main Engine (SSME) 3. During the checkouts, the backup controller for SSME 3 showed an irregular power drop. There appeared to be an issue with one of the three power phases, which narrowed down the issue to either a circuit breaker or a switch that provides power to the controller. Both the circuit breaker and the switch were cycled and power was restored without issue. However, to provide engineering personnel time to analyze the data, the launch was rescheduled for November 4. The hardware was replaced during a subsequent launch delay.

The November 4 planned launch was scrubbed prior to the start of tanking operations because of unacceptable weather conditions (rain, low clouds, high crosswinds), and the launch was delayed 24 hours to November 5.

The November 5 launch was scrubbed because of a hydrogen leak in the Ground Umbilical Carrier Plate (GUCP) [In-Flight Anomaly (IFA) STS-133-I-001]. In addition, the External Tank (ET) post-drain inspection identified a large crack in the foam on the Liquid Oxygen (LO₂)-Intertank (I/T) flange closeout in the Panel 1 area between stringers 6 and 7. Investigation teams were assembled to address both of these anomalies.

The decision of the Mission Management Team (MMT) was to postpone the launch to the next window, which would open on November 30, to repair the GUCP and to continue evaluating the ET foam issue.

In the process of removing the cracked foam from the ET Intertank area as part of the anomaly investigation, two 9-in cracks on either side of one of the stringers were found. A repair plan was developed and the process of the preparing the area for the repair, two additional cracks were found on an adjacent stringer. The

November 30 planned launch was delayed to December 3 so that analysis and repair of the cracked ET stringers could be completed. However, it was later determined that more extensive analysis would be required to build flight rationale and therefore, the December-3-to-December-7 launch window was not attainable.

The Shuttle Program Requirement Control Board (PRCB) met on December 2, 2010, and the decision was made to delay the launch to no earlier than February 3, 2011. A ET Tanking Test was planned for December 15, however, because of instrumentation problems; the test was delayed to December 17. The ET tanking test was performed with satisfactory results. The vehicle was rolled back to the Vertical Assembly Building (VAB) on December 22, 2010. Technicians completed the ET X-ray scans beneath the foam insulation of all 108 stringers and found additional cracked stringers. It was not known whether those cracks occurred during the initial tanking or during the tanking test. The remaining sensors that were installed on the ET for the tanking test were removed after completion of the X-ray scans.

As a result of the findings and subsequent analysis, radius blocks were installed over the feet of the all accessible stringers to increase the strength of the stringers and reduce the risk of cracking. The installation of the radius-blocks, and the reapplication of foam and trimming operations were completed on January 27, 2011. The vehicle was moved to Launch Pad 39A on January 31, 2011, in preparation for the planned launch on February 24, 2011.

The root cause of the stringer cracks anomaly (IFA STS-133-I-002) is currently unknown. Three potential contributors have been identified through a fish-bone investigation. The potential contributors are:

1. Two suspect material lots of Aluminum AL 2090;
2. Stringer residual assembly stresses; and,
3. Stringer thickness.

Stephen Bowen replaced Timothy Kopra as Mission Specialist 2 following an injury while riding a bicycle injury on January 15, 2011, that prohibited Kopra from supporting the launch window. Bowen last flew in May 2010 on the STS-132 mission. Flying on the STS-133 mission made Mark Bowen the first astronaut to fly on consecutive missions.

Later in the final launch countdown, the Range Safety Central Command Computer became no-go after indications its Central Command Computer was having an issue. The countdown was held at T-5 minutes. The Central Command Computer was regained and the countdown was resumed and the launch was completed.

Ascent and Flight Day 1

The STS-133 mission was launched at 055/21:53:24.016 Greenwich Mean Time (GMT) on February 24, 2011. This mission was the thirty-fifth Space Shuttle Program (SSP) vehicle to the ISS, and the thirty-ninth and final flight of the Discovery (OV-103) Orbiter vehicle.

The launch occurred approximately three minutes after the planned in-plane launch time due to an unplanned hold to resolve an Eastern Test Range (ETR) constraint.

The Reusable Solid Rocket Booster (RSRB) performed as expected with no anomalies noted, and separation was visible through cutoff at 055/21:55:29 GMT [00/00/02:05 Mission Elapsed Time (MET)].

A nominal OMS assist maneuver was performed following RSRB separation. Ignition occurred at 055/21:55:41.4 GMT (00/00/02:17 MET), and the maneuver was 152.50 sec in duration.

During ascent, three separate ET debris releases were noted.

Main Engine Cutoff (MECO) occurred at 055/22:01:48 GMT (00/00/08:24 MET). The ET was separated from the Orbiter at 055/22:02:09 GMT (00/00/08:45 MET).

The open indication for both of the fill and drain valves for the Main Propulsion System (MPS) were received; however, the inboard valve open indication was lost for 10 sec after which it returned. Review of the Operations Recorder data showed the loss of the MPS inboard fill and drain valve open-indication was a real-time data dropout issue.

A nominal OMS-2 maneuver was performed at 055/22:31:54.2 GMT (00/00/38:30 MET). The maneuver was 63.4 sec in duration with a Differential Velocity (ΔV) of 96.5 ft/sec. The achieved orbit was 85.0 by 125.0 Nautical Miles (nmi).

The payload bay doors were opened at 055/23:29:30 GMT (00/01:36:06 MET).

The Ku-Band Antenna was deployed at 055/23:49:03 GMT (00/01:55:39 MET). The system was powered ON at 055/23:53:08 GMT (00/01:59:44 MET), and the RADAR self-test was started at 055/23:58:17 GMT (00/02:04:53 MET). The Ku-Band system failed the self-test due to a failed task 8.3 (beta-angle rate), which was not an issue. The crew placed the system in the Communications (COMM) mode at 056/00:03:08 GMT (00/02:09:44 MET).

After the Ku-Band was taken to COMM mode, the Ku-Band locked up with detect and track indications in the General Purpose Computer (GPC) Designate (DESIG) mode and did not radiate, The KU-Band did not have OPERATE or 216 Synchronized (SYNC) indications, and the return channels 2 and 3 showed OFF.

The Main Bus C (MNC) Ku-Band Signal Processor circuit breaker was not pushed-in during activation. The crew pushed the circuit breaker in upon request from Mission Control Center (MCC) and once the circuit breaker was closed, all Ku-Band COMM operations were nominal.

The Shuttle Remote Manipulator System (SRMS) On-Orbit Initialization was completed at 056/00:49 GMT (00/02:56 MET) and power-up was completed at 056/01:50 GMT (00/03:57 MET). The SRMS checkout was completed at 056/02:44 GMT (00/04:51 MET), and the maneuver to Pre-Cradle position was completed at 056/02:50 GMT (00/04:57 MET) with no anomalies reported

Flight Day 2

The main activities on Flight Day (FD) 2 were the survey of the Reinforced Carbon-Carbon (RCC), the Orbital Maneuvering System (OMS) pods survey, checkout of the Extravehicular Activity (EVA) suits and Orbiter Docking System (ODS) ring extension.

The crew reported a small amount of water carry-over on Humidity Separator B than had to be wiped up (IFA STS-133-V-01). No additional water was detected during a follow-up inspection. Periodic visual checks were performed throughout the mission to monitor for additional water carry-over.

Ignition for the OMS-3 [Nominal Correction (NC) 1] maneuver, which was a dual OMS engine firing, occurred at 056/01:28:55.7 GMT (00/03:35:31.7 MET). The maneuver was completed at 056/01:29:24.5 (00/03:36:00.5 MET). The firing time was 28.8 sec, and the ΔV was 43.8 ft/sec.

As a result of frequency conflicts between the Shuttle S-Band Low Frequency (LF) operation and the H-II Transfer Vehicle (HTV) Proximity (PROX) communications system, the Shuttle S-Band system was switched to High Frequency (HF) at 056/03:14:38 GMT (00/05:21:14 MET). After the switch to HF, the S-Band began experiencing noisy uplink events that were lasting up to 20 min over both Tracking and Data Relay Satellites (TDRS) located at the Zone of Exclusion (ZOE) and West positions (IFA STS-133-V-05). Because of these events, contingency plans were considered that would result in extended mission-operations periods in Low Frequency (LF). The system was commanded back to LF and the NASA Frequency Manager worked with the Goddard Space Flight Center (GSFC) Network to determine if it is possible to identify and/or remove the source of conflicting Radio Frequency (RF).

The right Reaction Control System (RCS) fuel primary regulator was creeping at approximately the pre-launch rate of about 2500 scch (IFA STS-133-V-04). The secondary regulator demonstrated an in-specification creep-rate pre-launch. This regulator leakage continued to be monitored.

The crew began the Reinforced Carbon-Carbon (RCC) survey with the unberthing of the Orbiter Boom Sensor System (OBSS) at 056/14:56 GMT (00/17:02:35 MET) followed by Starboard (STBD) Wing survey at 056/16:11 GMT (00/18:17:36 MET). The Nose Cap survey was completed at 056/18:31 GMT (00/20:37:36 MET) followed by the completion of the Port Wing survey at 056/19:28 GMT (00/21:34:36 MET).

Ignition for the OMS-4 NC2 maneuver, which was a single left OMS engine firing, occurred at 056/14:43:53.0 GMT (00/16:50:29 MET). The maneuver was completed at 056/14:44:06 GMT (00/16:50:42.2 MET). The firing time was 13.2 sec, and the ΔV was 10.0 ft/sec.

The first on-orbit fuel cell purge was a manual purge beginning at 056/15:18 GMT (00/17:24:36 MET), and the purge was completed satisfactorily.

All rendezvous tools were successfully checked out in preparation for the rendezvous operations and docking.

The Orbiter Docking System (ODS) ring extension procedure was initiated at 056/23:22:09 GMT (01/01:28:45 MET) and was successfully completed at 056/23:32:53 (01/01:39:29 MET) for a total on-time of 10 min 43 sec. The avionics power-on time was 7 min 27 sec, and the ring extension time was 3 min 43 sec. The guide ring extended from 4.4 percent to the nominal 77.2 percent. The ODS performed satisfactorily and was ready for docking operations.

Flight Day 3

The main activities on FD 3 were rendezvous and docking with the ISS, hatch opening, and grapple and installation of the ELC 4 on the Starboard 3 (S3) lower-inboard attachment system.

The Fuel Cell Monitoring System (FCMS) data recording was performed, beginning at 056/23:39 GMT (01/01:46 MET). All individual cell voltages were nominal. No pin-sharing was identified on fuel cell 3 cells 41/42 or 95/96 as observed during pre-launch.

The Primary Reaction Control System (PRCS) maneuver (NC3) was a +X firing using thrusters L1A and R1A. Ignition for the PRCS maneuver was 057/01:06:18.2 (01/03:11:54 MET). The firing time was 24.0 sec with a ΔV was 5.9 ft/sec. The resulting orbit was 117.5 by 124.9 nmi.

A nominal OMS-5 [Nominal Height (NH)] maneuver was performed at 057/14:15:59 GMT (01/16:22:35 MET). The maneuver was 83.4 sec in duration with a ΔV of 129.2 ft/sec. The achieved orbit was 121.9 by 191 nmi.

The OMS-6 Nominal NC4 maneuver was a dual-engine firing and ignition occurred at 057/15:01:23.6 GMT (01/17:08 MET). The firing duration was 65.6 sec with a ΔV of 103.0 ft/sec. The Terminal Initiation (TI) (OMS-7) maneuver was a straight-feed left-engine OMS firing. Ignition was at 057/16:33:24.3 GMT (01/18:40 MET). The firing duration was 10.6 sec with a ΔV of 8.2 ft/sec that placed the Orbiter into a 183.8 by 192.9 nmi orbit.

The crew switched the Ku-Band system to COMM mode at 057/13:47:54 GMT (01/15:54:30 MET) and the system operated nominally. The crew switched the system to RADAR mode for rendezvous at 057/15:49:14 GMT (01/17:55:50 MET) and detected the ISS at a range of 143,000 ft. The Ku-Band RADAR mode operated as expected. The crew returned the Ku-Band to COMM mode at 057/18:43:52 GMT (01/20:50:28 MET) at a range of 320 ft.

The Midcourse Correction (MC) 1 maneuver was initiated at 057/16:53:26 GMT (01/19:00:02 MET). The ΔV delivered was 0.37 ft/sec. The out-of-plane maneuver was initiated at 057/17:08:31 (01/19:15:07 MET). The MC2 maneuver was initiated at 057/17:27:17 GMT (01/19:33:53 MET). The ΔV delivered was 1.5 ft/sec. The MC3 maneuver was performed at 057/17:44:13 GMT (01/19:50:49 MET). The ΔV delivered was 1.8 ft/sec. The MC4 maneuver was initiated at 057/17:54:11 GMT (01/20:00:47 MET). The ΔV delivered was 2.3 ft/sec. The orbit at the completion of the MC maneuvers was 185.0 by 192.9 nmi.

The Rbar Pitch Maneuver (RPM) began at 057/18:15:48 GMT (01/20:22:24 MET) and was complete at 057/18:23:48 GMT (01/20:30:24 MET).

The Orbiter Discovery made initial contact with the ISS at 057/19:14:22 GMT (01/21:20:58 MET) and hard-mate was completed with the hooks-drive command terminated at 057/20:04:09 GMT (01/22:10:45 MET). During the Stuck-Damper procedure, oscillation of petals 1 and 3 (around petal 2) was observed. A guide ring misalignment indication occurred at 057/19:26:02 GMT (01/21:32:38 MET) at a guide-ring position of 38 percent. Another guide ring misalignment occurred at 057/19:28:07 GMT (01/21:34:43 MET) at a guide-ring position 34 percent. The ISS/Shuttle system entered gravity-gradient conditions causing the guide-ring positions to diverge for approximately 23 min 56 sec before final guide-ring retraction could be initiated. This scenario was previously observed during STS-130 docking.

The SRMS successfully handed off the ELC 4 at 058/00:35 GMT (02/02:42 MET) and the SRMS was maneuvered to the OBSS Handoff Pre-Grapple position.

The RCC and Thermal Protection System (TPS) Damage Assessment Teams (DATs) completed review of all imagery and determined that a focused inspection was not required.

A Main Bus B overvoltage alarm was received at 058/04:39:48 GMT (02/06:46:24 MET). The crew reacted to the alarm, and recognized it as the same issue as observed

on STS-128 and STS-131. The alarm was the result of a known transducer bias, which caused the voltage to read higher than it actually was, and the increased bus voltage required for Station-to-Shuttle Power Transfer System (SSPTS) operations. This is a known condition and the Main Bus is protected by the SSPTS overvoltage protection circuitry should an actual overvoltage condition occur.

The S-band system was commanded to High Frequency (HF) at 058/21:36 GMT (02/23:43 MET) to avoid ISS frequency conflicts during docked operations. Forward link dropouts continued to be observed.

A review of Modular Auxiliary Data System (MADS) Pulse Code Modulated (PCM) data showed erratic indications throughout ascent for the left wing spar differential pressure (IFA STS-133-V-02). This was an instrumentation issue and it did not impact the mission.

Flight Day 4

The main activities on FD 4 were cargo transfer, OBSS handoff to the SRMS, and EVA preparation and procedure review, and EVA crew campout.

The OBSS was grappled and unberthed by the Space Station Remote Manipulator System (SSRMS) following release of the starboard Manipulator Release Latches (MRLs) at 058/15:23 GMT (02/17:29:36 MET). The OBSS was maneuvered to the OBSS Handoff position where it was grappled by the SRMS at 058/15:48 (02/17:54 MET). The SRMS/OBSS maneuvered to the PMM Install Viewing position.

A total of 50 lb of Oxygen (O₂) was transferred to the ISS.

Further troubleshooting and data analysis of the S-Band HF operation indicated the Forward link dropouts could have been attributed, in part, to a problem in the Radio Frequency (RF) path between the Lower Left antenna and the Transponder in HF.

During the S-band system HF troubleshooting, the Power Amplifier 1 (PA1) RF power-out was 148 Watts (W) and was unstable. This was an increase of 15 W from the power-out seen during the Communication Activation approximately 24 hr before launch. This was initially thought to have been a signature of an internal Traveling Wave Tube (TWT) degrading to failure. A TWT typically will fail soon after this signature is observed. This TWT had flown on the 26 previous flights with no anomalies.

Results from the RCC and TPS DATs were presented to the MMT. The MMT accepted both DATs' recommendation that a Focused Inspection (FI) was not required. The RCC DAT assessment was completed, and the TPS assessment to clear the vehicle for entry continued.

Flight Day 5

The main activities on FD 5 were the first EVA and transfer activities.

Crew egress for the first EVA was approximately 30 min ahead of schedule at 059/15:46 GMT (03/17:53 MET). The Wireless Video System (WVS) for Extravehicular Crewmember (EV) 1 was not functional for the first half of the EVA despite on-orbit and ground troubleshooting (IFA STS-133-V-06). However, the WVS was recovered midway through the EVA. The crew completed all nominal tasks including the transfer of the failed Pump Module (PM) for return to the Earth as well as several get-ahead tasks. The hatch was closed at 059/22:15 GMT (04/00:22 MET) for a total duration of 6 hr 34 min 20 sec.

During the EVA vent-tool setup for venting the PM, which was planned for the second EVA, ground video showed a kink in the vent-tool extender. This condition was further discussed and planned for inspection during the second EVA.

The transfer of Gaseous Nitrogen (GN₂) was initiated at 060/12:34 GMT (04/14:40 MET).

The crew filled and transferred three Contingency Water Container-Iodine's (CWC-I) and two Portable Water Reservoirs (PWRs). The first CWC-I was filled at 059/14:37 GMT (03/16:44 MET) with 37.3 lb_m of water. The second CWC-I was filled at 059/15:00 GMT (03/17:07 MET) with 35.4 lb_m. The third CWC-I was filled at 059/22:20 GMT (04/00:27 MET) with 37.2 lb_m. The first PWR was filled at 059/23:06 GMT (04/01:13 MET) with 18.9 lb_m. The second PWR was filled at 059/23:47 GMT (04/01:54 MET) with 17.2 lb_m.

Dropouts in the S-Band system HF mode continued with most dropouts occurring on the lower left antenna. Review of the Terminal Countdown Test (TCDT) data from Power Amplifier (PA) -1 when operating in HF mode showed an uneventful and nominal warm-up similar to that of STS-131. The evaluation of this condition continued.

The MMT approved the addition of a docked day to the mission, increasing the mission duration to 12+1+2.

Flight Day 6

The main activities on FD 6 were the installation of the PMM to the nadir port on the ISS Unity module, EVA preparation and crew campout.

The crew filled and transferred two CWC-I. The first CWC-I was filled at 060/11:37:41 GMT (04/13:44:17 MET) with 35.9 lb_m of water. The second CWC-I was filled at 060/14:01:09 GMT (04/16:08:45 MET) with 39.8 lb_m of water.

The transfer of GN₂, which was initiated on FD 4, was completed at 060/15:29:10 GMT (04/17:35:46 MET). A total of 37 lb_m of GN₂ was transferred.

The Shuttle and ISS Mission Evaluation Room (MER) teams reviewed the EVA 2 plan for the PM ammonia venting with the potentially bent vent-hose discovered during the first EVA. All affected systems concurred with the proposed venting plan.

The DAT completed their imagery analysis based on FD 2 inspection and RPM data. The MMT accepted the DAT's recommendation to clear the TPS for entry.

Flight Day 7

The main activities on FD 7 were the second EVA and the internal outfitting of the PMM.

The SRMS/OBSS was maneuvered to the second EVA Viewing position at 061/16:29 GMT (05/17:46 MET). Later, the SRMS/OBSS was maneuvered to the Undock position at 061/22:12 GMT (06/00:18 MET).

The crew successfully completed all EVA 2 tasks, which included get-ahead tasks. The EVA start was delayed approximately 15 min because the EV1's suit failed a leak check. A damaged Lithium Hydroxide (LiOH) cartridge O-ring was noted and replaced. The EVA was cleared to proceed with the successful leak check. During the EVA, the condition of the PM venting-tool hose was verified, and the venting was performed as planned. The EVA began at 061/15:42 GMT (05/17:48:35 MET) and was completed 6 hr 14 min later.

At the start of the second EVA, the helmet camera for the EV1 could not be activated. This condition also occurred during the first EVA. The camera spontaneously recovered just over 2 hr into the EVA.

At 5 hr 21 min into the EVA, EV 2's EVA Helmet Interchangeable Portable (EHIP) Light/EMU RF Camera Assembly (ERCA) detached from the helmet. Attempts by EV1 to reinstall the unit were not successful and the Rechargeable EVA Battery Assembly (REBA) was powered off. The unit was tethered and EV2 returned to the Airlock earlier than planned. EV1 completed the remaining tasks.

The second on-orbit fuel cell purge was performed, beginning at 061/16:05 GMT (05/18:12 MET). During the 121-hr purge interval, the approximate voltage decay was 0.19 Vdc in fuel cell 1, 0.12 Vdc in fuel cell 2, and 0.13 Vdc in fuel cell 3.

The crew filled and transferred one CWC-I and two PWRs. The first PWR (no. 7) was filled at 061/18:54 GMT (05/21:00 MET) with 19.6 lb_m of water. The second PWR (no. 8) was filled at 061/19:26 GMT (05/21:33 MET) with 19.7 lb_m of water.

The one CWC-I (no.6) was filled at 061/19:43 GMT (05/21:49 MET) with 38.8 lb_m of water.

The 1553 cable to support direct HTV communication to the ISS was successfully installed and activated. With the installation of this cable, the Orbiter was no longer constrained to operate strictly in the S-Band HF mode, so the S-Band system was commanded to the LF mode at 062/00:56:05 GMT (06/03:02:41 MET).

The Shuttle Orbiter Communications Adapter (OCA) router could not be contacted from the ground using Shuttle assets (IFA STS-133-S-001). After some crew troubleshooting, the hard drive was identified as the most likely cause. The crew changed out the hard drive and the OCA router was recovered.

Flight Day 8

The main activities on FD 8 were the cargo transfer to the ISS and crew off-duty time.

The Orbiter executed the Configuration-3 Vernier Reaction Control System (VRCS) reboost maneuver of the Orbiter-ISS mated stack. The hand-over to Orbiter control occurred at 062/13:39:22 GMT (06/15:45:58 MET). Ignition for the maneuver occurred at 062/14:03:37 GMT (06/16:10 MET), and the reboost cutoff was at 062/14:32:26 GMT (06/16:39 MET), resulting in a firing duration of approximately 28 min. The reboost was performed in straight-feed and resulted in a ΔV of 3.3 ft/sec and an altitude increase of 0.92 nmi. The orbit at the completion of the maneuver was 185.9 by 195.0 nmi.

The GN₂ repressurization of the ISS was terminated at 062/16:53 GMT (06/19:00 MET) with an estimated 36 lb_m of GN₂ transferred.

Two CWC-I bags were filled and transferred to the ISS. The first CWC-I (no. 9) was filled with approximately 41.4 lb_m of water at 062/15:53 GMT (06/17:59 MET). The second CWC-I (no. 10) was filled with approximately 42.7 lb_m of water at 062/16:16 GMT (06/18:22 MET).

The ground reported intermittent dropouts in the data from the OCA router. The dropouts could not immediately be attributed to the TDRS or ground-related issues since the problem was not seen when the communication was switched to ISS assets. This was the same laptop that previously had the hard-drive replaced. It was later reported that the root cause was a ground configuration problem.

The MMT approved the addition of another docked day to the mission, increasing the mission duration to 13+0+2 days.

Flight Day 9

The main activities on FD 9 were a joint crew news conference, PMM outfitting, and transfer operations.

Three CWC-I bags were filled and transferred to the ISS. The first CWC-I (no. 9) was filled with approximately 23.3 lbm of water at GMT 063/14:37 (MET 07/16:44). The second CWC-I (no.10) was filled with approximately 37.3 lbm of water at GMT 063/15:07 (MET 07/17:14). The third CWC-I (no. 11) was filled with approximately 39.1 lbm of water at 063/21:40 GMT (007/23:47 MET).

The right RCS fuel primary regulator continued to leak. After the re-boost on FD 8, the observed leak was approximately 1700 scch.

Flight Day 10

The main activities on FD 10 were PMM outfitting, In-Flight Maintenance (IFM) for the Carbon Dioxide Recycling Assembly (CDRA) and Oxygen Generation Assembly (OGA) remediation kit installation.

The Flash Evaporator System (FES) controller mid-flight operation switch was completed with controller B being turned off and controller A now operating.

Two O₂ repressurizations were performed with a total estimated 35 lbm of O₂ released into the stack. Tank-to-tank transfer of O₂ to the ISS was progressing nominally.

Three CWC-I bags were filled. The first CWC-I (no. 12) was filled with approximately 34.5 lbm of water at 064/17:05 GMT (08/19:12 MET). The second CWC-I (no. 13) was filled with approximately 34.0 lbm of water at 064/17:17 GMT (08/19:24 MET). The third CWC-I (no. 14) was filled with approximately 39.5 lbm of water at 064/19:37 GMT (08/21:44 MET).

The right RCS fuel primary regulator creep continued to be monitored. At the time, the observed leakage rate was approximately 1250 scch. Fuel pressure was 258 psia.

Flight Day 11

The main activities on FD 11 were transfer operations, off-duty time and hatch closure.

All planned transfer activities were successfully completed. The hatches between the ISS and the Orbiter were closed at 065/21:35 GMT (09/23:41 MET), and the vestibule was leak-checked successfully.

The O₂ tank-to-tank transfer and teardown was completed at 065/19:30 GMT (09/21:37 MET). The preliminary estimated total O₂ transferred to ISS was 110 lb_m.

The sixteenth and last Contingency Water Container (CWC) was filled at 065/12:28 GMT (09/14:35 MET) with 34.3 lb_m. The total supply water transferred to the ISS was 756.0 lb_m.

Rendezvous tool checkout for Rendezvous Proximity Operators Program (RPOP), Trajectory Control Sensor (TCS), and Hand-held Light Intensification Detection and Ranging (LIDAR) was completed with no anomalies observed.

Flight Day 12

The main activities on FD 12 were undocking and fly-around, the separation 1 and 2 maneuvers, and RCC surveys.

The Orbiter resumed attitude control with the Digital Autopilot (DAP) in the automatic-mode at 066/10:40:47 GMT (10/12:47:23 MET).

The undocking from the ISS was initiated with the hook-drive command at 066/11:58 GMT (10/14:04 MET). The total drive time was approximately 2 min and 15 sec and Hook Groups 1 and 2 operated nominally. The Orbiter ODS performed nominally for undocking.

The fly-around maneuver was initiated with RCS +X-axis pulses of the L3A and R3A thrusters at 066/12:23:15 GMT (10/14:29:51 MET).

Prior to the separation 1 maneuver, the Ku-Band was taken to the RADAR mode at 066/13:02:29 GMT (10/15:09:05 MET) and locked on to the ISS at an approximate range of 651 ft. The Ku-Band was configured back to the COMM mode at 066/13:40:05 GMT (10/15:46:41 MET) at a range of approximately 8960 ft.

The separation 1 RCS maneuver was initiated with a 6-sec +X-axis pulse from L3A and R3A thrusters at 066/13:09:13 GMT (10/15:15:49 MET). The separation 2 RCS maneuver was performed at 066/13:37:21 GMT (10/15:43:57 MET), and was a 11.9-sec +X-axis firing using L3A and R3A thrusters.

During an attempt to playback High-Definition (HD) video taken during the fly-around, the crew was unable to downlink video via the high-definition path. The crew noticed that the fiber optic (F/O) Light Emitting Diode (LED) was not illuminated on the Digital Television (DTV) Multiplexer (MUX). After troubleshooting, the crew determined that optical cable was not working. Once the cable was replaced, the F/O LED was illuminated on the DTV MUX and telemetry on the DTV ground software indicated the fiber optic signal was successfully being seen at the MUX. HD downlink was restored and verified after Late Inspection.

The Starboard RCC survey began at 066/16:53 GMT (10/18:59 MET) and was completed at 066/17:52 GMT (10/19:58 MET). The Nose RCC was surveyed from 066/18:20 GMT (10/20:26 MET) to 066/18:52 GMT (10/20:58 MET). The Port RCC was surveyed from 066/19:15 GMT (10/21:21 MET) to 066/20:19 GMT (10/20:19 MET).

The OBSS was berthed by the SRMS at 066/21:11:22 GMT (10/23:17.58 MET). The SRMS was cradled at 066/21:37:13 GMT (10/23:43:49 MET) and powered down at 066/21:50 GMT (11/23:56 MET).

Flight Day 13

The main activities of FD 13 were the Flight Control System (FCS) Check-out (C/O), RCS hot-fire and a PAO event.

Prior to FCS checkout, the Water Spray Boiler (WSB) 1, 2 and 3 vent heaters were activated on Controller B. The WSB steam vent temperatures rose above 122°F (off-scale low limit). Nominal heater cycling (144 °F to 186 °F) was observed on all three WSB System "B" vent heaters throughout FCS C/O.

The FCS C/O was performed satisfactorily. An additional FCS channel 1 override-to-auto switch toggle was required by the crew to clear an Ascent Thrust Vector Control (ATVC) channel 1 failure of all six TVC actuators (IFA STS-133-V-07). The data review showed that the power supply did not restart following the momentary loss of power, which occurs concurrently with the toggling of FCS channel overrides.

The Auxiliary Power Unit (APU) 1 start occurred at 067/10:37:55 GMT (11/12:44:31 MET). The APU 1 FCS C/O run duration was 5 min 9 sec, with shutdown at 067/10:43:04 GMT (11/12:49:40 MET). Because of the short APU run-time, the APU lubrication-oil spray cooling was not required. The maximum APU lubrication-oil return temperature after APU shutdown was 213 °F. All of the Elevon Actuator switching valves as well as the Rudder Speed Break (RSB) Power Drive Unit (PDU) switching valve were verified that the configuration was correct.

The RCS hot-fire procedure was initiated at 067/11:23:37 GMT (11/13:30:13 MET) and terminated at 067/11:29:37 GMT (11/13:36:13 MET). All 38 RCS thrusters were fired at least twice. No anomalies were observed during the hot-fire checkout. Additionally, a successful payload of opportunity, Ram Burn Observation (RAMBO), was performed at 067/12:23:46 GMT (11/14:30:22 MET). This was a set of three 10-sec +X firings using the L3A and R3A thrusters.

An Orbit Adjust maneuver (OMS-8), which was a dual-engine straight-feed firing, was performed at 067/20:00:00 GMT (11/22:06:36 MET). The burn was 14.0 sec in duration with a ΔV of 25.5 ft/sec. The orbit after the deorbit maneuver was 171.6 by 192.2 nmi.

The stowing of the Ku-Band using dual-motors was performed nominally at 067/21:05:20 GMT (011/23:11:56 MET).

The DAT reported that the imagery analysis from the STS-133 late inspection was completed with no issues noted. The MMT accepted the recommendation to clear the RCC for entry.

Flight Day 14 and Landing

The STS-133 mission was successfully completed with a landing at Kennedy Space Center (KSC), Florida on runway 15.

Both Payload Bay Doors (PLBDs) were closed and latched nominally by 068/13:53:24 GMT (12/15:26:07 MET) in preparation for landing.

The deorbit maneuver for the first landing opportunity at KSC was performed on orbit 202. Ignition for the deorbit maneuver was 068/15:52:04.180 GMT (12/17:58:40 MET) and cutoff was at 068/15:54:32.9 GMT (12/18:01:08 MET). The maneuver duration was 148.8 sec and the ΔV was 276.4 ft/sec. The orbit at the completion of the maneuver was 23.6 by 193.1 nmi.

Entry interface occurred at 068/16:25:43 GMT (12/18:32:19 MET).

The Ammonia Spray Boiler, when activated on the Primary B General Purpose Computer (GPC), experienced an outlet temperature oscillation when it approached the control band (IFA STS-133-V-08). The boiler warmed up to about 47 °F, then returned to the control band and performed nominally for the rest of the mission.

The main landing gear touchdown occurred KSC runway 15 at 068/16:57:15 GMT (12/19:03:41 MET) on March 9, 2011. The drag chute was deployed at 068/16:57:18 GMT. The nose gear touchdown occurred at 068/16:57:26 GMT. Drag chute jettison occurred at 068/16:57:46.9 GMT. Wheels stop occurred at 068/16:58:11 GMT. The rollout was normal in all respects.

The flight duration was 12 days 19 hr 03 min 41 sec. The last APU was shutdown 18 min 48 sec after landing.

HISTORY OF SPACE SHUTTLE DISCOVERY

The Space Shuttle Orbiter Vehicle (OV) 103, *Discovery*, has ended its career with more missions (39) than any other vehicle in the Shuttle fleet. *Discovery* accumulated 365 days in space, and travelled 148,221,675 miles during which 5,830 orbits of the Earth were completed. A total of 252 crewmembers have flown on *Discovery*.

The choice of the name *Discovery* carries on a tradition drawn from many historic Earth-bound exploring ships of the past. One of these sailing forerunners was a vessel used in the early 1600s by Henry Hudson to explore Hudson Bay and search for a northwest passage from the Atlantic to the Pacific. Another was a ship used by James Cook in the 1770s during voyages in the South Pacific. In addition, two British Royal Geographical Society ships carried the name *Discovery* on expeditions to the North Pole and the Antarctic.

The Space Shuttle *Discovery* served as a symbol of American pride and leadership in human space flight. The construction of *Discovery* began in August 1979 and the vehicle was delivered to NASA Kennedy Space Center in November 1983. The first space flight of *Discovery* was STS-41D on August 30, 1984. Since that time, *Discovery* has flown 38 additional space flights.

Destined for exploring the heavens instead of the seas, *Discovery* carried the Hubble Space Telescope (STS-31) into space as well as performing two Hubble servicing missions (STS-82 and STS-103). *Discovery* was twice chosen as the "Return to Flight" vehicle following the losses of *Challenger* and *Columbia*. In addition, *Discovery* docked once with the Russian space station *Mir* and docked 13 times with the International Space Station.

On April 12, 2011, it was announced that *Discovery* would be put on display at the Smithsonian's National Air and Space Museum Steven F. Udvar-Hazy Center in Chantilly, Virginia.

PAYLOADS AND EXPERIMENTS

The STS-133/ Utilization Logistics Flight 5 (ULF5) mission was successfully launched on February 24, 2011. This mission was the thirty-fifth Space Shuttle Program (SSP) vehicle to the International Space Station (ISS) and the thirty-ninth and final flight of the Discovery Orbiter vehicle.

The primary purpose of the mission was to deliver and robotically install the Express Logistics Carrier 4 (ELC4) on the Payload Attach System (PAS) on Truss Segment 3 (S3) and install the Permanent Multipurpose Module (PMM) on the Node 1 Nadir common berthing mechanism (CBM).

LAUNCH PACKAGE OVERVIEW

The ULF5 Launch Package (LP) consisted of two major cargo elements in the payload bay, which were the ELC4 and the PMM that were carried in the payload bay as well as utilization payloads and crew resupply items stowed in the middeck. The PMM carried US logistics cargo within the pressurized module. The ELC4 was unpowered while it was in the payload bay.

Two extravehicular activities (EVA's) were successfully performed during the mission, totaling 12 hr, 48 min of EVA time. All scheduled EVA tasks, including several EVA get-ahead tasks, were completed. The airlock campout protocol was used in support of both EVA's.

The ULF5 LP consisted of utilization payloads and crew resupply items stowed in the PMM as well as the middeck. The powered middeck- payloads consisted of two animal enclosure modules (AEMs), two general laboratory active ISS experiment refrigerator's and a Commercial Genetic Bio-processing Apparatus (CGBA).

Utilization Payloads: Short duration research completed during STS-133/ULF5 included

1. Mouse immunology – Animal Enclosure Modules (AEMs) 1 and 2;
2. National Laboratory Pathfinder (NLP) - Vaccine-11 in CBGA;
3. Growth and survival of Colored Fungi in Space –A (CFS-A);
4. Sleep-wake actigraphy and light exposure during spaceflight – short;
5. Spinal elongation; and,
6. Mycological (Myco) evaluation of crew exposure to space station ambient air.

The Orbiter delivered a large number of research experiments to the ISS for use during the following stage operations. A listing of these experiments can be found in the Customer Support Room (CSR) Report.

CREW ACTIVITY SUMMARY

The STS-133/ULF5 mission was successfully launched at 3:53 pm CDT, February 24, 2011. Discovery's performance during the ascent was nominal. After Reusable Solid Rocket Booster (RSRB) separation, the Main Engine Cutoff (MECO) occurred at 00/00:08:24 Mission Elapsed Time (MET) with the External Tank (ET) separation 21 sec later. The payload bay doors were opened at 00/01:36:06 MET. The Ku-Band antenna was deployed and the self-test was completed with satisfactory results.

Other activities that were completed on Flight Day (FD) 1 included the installation of the AEM muffler and the daily status check, Microbe sample collection and integrated immune liquid saliva sample collection.

On FD 2, the Shuttle Remote Manipulator System (SRMS) checkout and the maneuver to the pre-cradle position were completed satisfactorily.

Photographic imagery of the Orbiter Thermal Protection System (TPS) tile was performed as Discovery approached the ISS for docking. A complete analysis of the data from the Wing Leading Edge Impact Detection System (WLE IDS), the in-flight imagery, the inspection of the Reinforced Carbon-Carbon (RCC) and Orbital Maneuvering System (OMS) pods was reviewed by the Debris Assessment Team (DAT). The results of the analysis were presented to the Mission Management Team (MMT).

The rendezvous and docking were in process with the ISS on FD 2.

Prior to docking with the ISS on FD 3, Discovery completed the Radius-vector (R-bar) Pitch Maneuver (RPM) while the ISS crew obtained imagery of the Orbiter's TPS during rendezvous. The photographic images were downlinked for ground analysis by the Imagery and Debris Assessment Teams. Discovery successfully docked at the ISS Pressurized Mating Adapter (PMA) - 2 at approximately 1:30 pm CST. The hatches were opened at 3:36 pm CST and both crews completed a safety briefing and handover.

The Space Shuttle crew grappled and un-berthed the ELC4 with the Space Station Remote Manipulator System (SSRMS) from the Space Shuttle payload bay. Then the SSRMS was repositioned and the ELC4 was handed off to the SRMS. The SSRMS was maneuvered and re-grappled the ELC4, which was successfully installed on the PAS on Truss segment S3.

Transfer of logistics resupply and crew supplies began in earnest on FD 4 and the crew quickly got ahead on the scheduled transfer activities.

The Mission Management Team (MMT) determined that no focused inspection was required.

The ISS and Shuttle crewmembers prepared the equipment lock and EMU's, completed the tool configuration, reconfigured the oxygen system in preparation for performing EVA pre-breathe using Space Shuttle oxygen, and conducted an EVA procedure review in preparation for first EVA to be performed on FD 5.

The first EVA for this mission was successfully performed on FD 5 in 6 hr, 34 min with all scheduled tasks and get-ahead tasks completed.

The MMT concurred with recommendations to extend the mission duration to 12+1+2, to facilitate PMM outfitting.

On FD 6, the PMM was grappled and un-berthed from the Space Shuttle payload bay by the SSRMS, The PMM was installed on the Node 1 Nadir CBM. The PMM was pressurized and a leak check was performed on the vestibule between the Node 1 Nadir hatch and the PMM hatch. PMM vestibule operations continued with the removal of the thermal cover and mating the power and data jumpers. PMM vestibule control panel assemblies (CPA's) were removed and the Inter-module Ventilation (IMV) duct installed prior to opening the hatch and ingressing the PMM. The crew ingressed the PMM and began the reconfiguring of the PMM for on-orbit operations on FD 7.

The Shuttle crewmembers reviewed the EVA procedures and configured tools in preparation for second EVA. The two EV crewmembers began the campout pre-breathe protocol including mask pre-breathe and 10.2-psia Airlock depressurization.

On FD 7, the second EVA for this mission was successfully performed in 6 hrs, 14 min. All of the scheduled and several get-ahead EVA tasks were completed.

Robonaut hardware was relocated from the PMM to the Laboratory. In addition, the Resupply Stowage Platform (RSP) fences and the launch hardware were dismantled. Some of the hardware was bagged for disposal. Stowage items and hardware inside the PMM were reconfigured and temporarily stowed in the PMM end-cone.

On FD 8, Discovery's mission was extended another day by the MMT. The additional docked day allowed more time for the Space Shuttle crew to assist with PMM unpacking, outfitting and stowage in the Japanese HTV.

The Orbiter/ISS mated stack completed a re-boost using Vernier Reaction Control System (VRCS) thrusters. The re-boost supports phasing for 24 Soyuz (S) landing, 26S launch and the launch of STS-134/ULF6. The burn lasted for 26 min at a Differential-Velocity (ΔV) of 1 msec.

FD 8 activity included a Public Affairs event and a crew off-duty day.

On FD 9, activities to reconfigure the PMM were completed, which included the transfer of items between the PMM and the US Lab, installation of pivot fittings and brackets, and relocation of ZSR's. The ER8 was also moved from its launch location in the PMM to the Lab for installation. Reconfiguration of the PMM will continue on FD10

On FD-10, The Space Shuttle crew continued reconfiguring the PMM and reorganizing stowage on the ISS. Launch support equipment was removed from the six Resupply Stowage Platform's (RSP's) located in the PMM and the Launch Support Equipment was transferred to the H2 Transfer Vehicle (HTV) 2 for disposal. Other stowage items were consolidated and placed behind the six RSP's. Resupply items were transferred from the Orbiter middeck and the HTV to ISS. Two EMU's which had been temporarily stowed in the JEM pressurized module were moved to the airlock, and a Zero-g Stowage Rack (ZSR) was installed in the Columbus module.

On FD 11, the final transfer operations were completed. The Oxygen (O₂) and Nitrogen (N₂) transfers were completed. The crew farewells were made and the hatch was closed. The crew performed the rendezvous tools checkout in preparation for undocking.

On FD 12, Discovery successfully undocked from the ISS and the Orbiter completed a flyaround of the ISS, taking photographs of the ISS. Inspections of the starboard and port wings, nose-cap TPS and RCC were performed and the files were downlinked for analysis by the DAT. The OBSS was berthed and the SRMS was powered off.

On FD 13, Flight Control System (FCS) checkout and Reaction Control System (RCS) hot-fire were performed successfully. Cabin stow operations were completed in preparation for the anticipated de-orbit and landing.

The Ram Burn Observation (RAMBO) RCS firing was completed, and a Public Affairs event was completed.

On Flight Day 14, the deorbit preparations were completed, the radiator was stowed and the payload bay doors were closed. The deorbit maneuver was completed and Discovery landed on the first landing opportunity at Kennedy Space Center (KSC

TRANSFER WEIGHT SUMMARY

All of the transfers were successfully accomplished during the mission. The following table and discussion provides an overview of the total transfers

TOTAL WEIGHT TRANSFERRED DURING THE MISSION

Parameter	To ISS, lb _m	From ISS, lb _m
Cargo Bay	36,146	808
Middeck	2599	2031
Totals	38,745	2839

1. **Water** – Total amount of water transferred was 932 lbm. A total of 16 Contingency Water Container-Iodine (CWC-I) transferred 608.1 lbm, one Contingency Water Container (CWC) - technical transferred 96.5 lbm, and 8 Payload Water Reservoirs (PWRs) transferred 148 lbm. Two CWCs were filled with 81.7 lbm of condensate, which transferred for processing.
2. **Oxygen** – A total of 110 lbm of transferred to airlock High Pressure Gas Tank (HPGT) on ISS. A total of 72 lb was transferred via ISS cabin repressurization.
3. **Nitrogen** – A total of 26 lbm was transferred to ISS airlock tanks. A total of 50.0 lbm transferred to the ISS stack.
4. **Lithium Hydroxide** – The Shuttle transferred 11 unused canisters to ISS. ISS transferred six unused canisters to the Shuttle.
5. **Food** – As a result of the ascent performance margin and launch date change, the ISS crew shared their food with the Space Shuttle crew while docked.

SIGNIFICANT FIRSTS

No significant firsts were noted during the STS-133 mission.

SIGNIFICANT ISS ANOMALIES

On FD3, the Vozdukh experienced an un-commanded power down. That was the 4th such occurrence in the previous 5 days on the ISS. Early indications showed a potential vacuum pump failure. A Vozdukh removal and replacement (R&R) is scheduled during ULF5. The R&R of the Vozdukh is a 4-day procedure.

During EVA 1, the SSRMS was used to ferry EV1 Bowen between worksites as he carried the failed PM to the storage position. The SSRMS was operating from inside the ISS, using the Cupola RWS. During the release of the PM, the software in the Cupola RWS detected an unexpected internal software state and shut down unexpectedly. The crew switched to the Lab RWS, which was in hot backup. The ground was later able to bring the Cupola RWS back up as the hot back up workstation.

The Lab CO₂ Removal Assembly Bed 2 experienced an un-commanded heater operation along with an unexpected increase in power usage. After ground teams deactivated the CDRA, the bed temperature continued to rise, which was indicative of an electrical short. The RPC to the Primary Heater was opened, which halted the

temperature rise. The CDRA was reactivated successfully in dual bed ops with single string heaters. Ground teams assessed forward actions, including the possibility of installing a new CDRA bed delivered on ULF5 in the Node 3 ARS rack.

On the night of FD7, the Elektron experienced an un-commanded shut down just after crew sleep. Russian specialists looked at the data to develop a forward plan. This Elektron unit was already operating on the back-up pump. The primary pump had failed many months ago. There was one remaining spare unit onboard, but its functionality was questionable since the parts were scavenged from previously failed Elektron Liquid Units. After the SPDM was parked, ground controllers powered down the MSS to the Keep Alive state. To prepare the system to for next ground operations, the Lab RWS was then commanded to Active. But the command failed with a fatal error from the software, and at the same time power was removed from the SPDM. Ground controllers were able to put the Cupola RWS in Backup and then Active, and then were able to bring the Lab RWS system back in Keep Alive state. The SPDM and CTC were without power for about 2 hours and 30 minutes. The shortest thermal clock was 30 hours. Ground controllers were able to configure the system for increment operations with the Lab RWS as Active and the Cupola RWS as Backup.

DC1 and SD's 2 and 3 falsely annunciated a fire event. The ISS crew took CSA-CP samples and verified that there was no smoke in those areas. Specialists determined that the cause of the alarm was due to a configuration of the DC1 SD's after the LQBM restart. Ground controllers reconfigured and recovered to a nominal configuration.

MAJOR ISS MISSION PRIORITIES AND END-OF-MISSION STATUS

The following table provides the status of the mission priorities at the end of the mission.

ISS MISSION PRIORITIES COMPLETION STATUS

Item	Task	Flight Day Task Completed
Category 1 Tasks		
1	Install ELC4 on S3 Nadir Inboard Common Attach System (CAS)	FD3
2	Install PMM to ISS Node 1 Nadir port.	FD6
Category 2 Tasks		
3	PMM activities	
	a. Perform minimal PMM activation and checkout to preserve the module and cargo	FD6
	b. Perform PMM passive CBM sealing surface inspection	FD3
4	Activate ELC 4	FD3
5	Transfer critical middeck items	FD3

ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
Category 3 Tasks		
6	Complete the following EVA tasks to support ISS operations:	
	a. Install J612 Cable and relocate Node 3 P612.	FD5
	b. Relocate PM from MBS POA to ESP2 and vent ammonia [Robotics]	FD7
	c. Retrieve LWAPA from Columbus Nadir external payload facility and install in Payload Bay (PLB). [Robotics]	FD7
	d. Install camera wedge at CP3	FD5
	e. Perform port stowage beam assembly troubleshooting	FD7
	f. Install CLA cover on CLPA (IVA) and install CLPA assembly on SPDM	FD7
	g. Remove SPDM EP1 thermal cover	FD7
	h. Perform JAXA Message in a Bottle	FD5
7	Activate and check out PMM	
	a. Activate PMM systems	FD6
	b. Ingress PMM	FD6
	c. Install one Portable Fire Extinguisher (PFE) and one Portable Breathing Apparatus (PBA) in PMM.	FD6
8	Support communication requirements (voice and video) for Russian Space Agency (RSA) EVA prep. (Reference Flight Rule ULF5 C13 Air-to-Ground and Space-to-Ground Availability during Joint Operations).	Deleted
9.	Perform daily ISS payload status checks as required	Daily
10	Transfer O ₂ from the Orbiter to the ISS airlock high pressure gas tanks (HPGT's) (75 lb minimum).	110 lb transferred
11	Transfer N ₂ from the Orbiter to the ISS airlock HPGT's (25 lb minimum).	26 lb transferred
12	Transfer remaining middeck cargo items per Flight ULF5 Transfer Priority List (TPL).	
	a. Activate and check out CSA's-CP's	FD9
	b. Install and return radiation area monitors (RAM's) Install and return Radiation Area Monitors (RAM's)	FD4
13	Perform daily middeck activities to support payloads (includes cases where Space Shuttle crew also performs payloads on the ISS).	Daily
14	Perform ISS payload research operations tasks	FD4-FD11

ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
15	The following EVA tasks are deemed to 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. Remove Multilayer Insulation (MLI) from ELC4 ExPRESS Pallet Controller Assembly (ExPCA)	FD7
	b. Close P1 radiator beam valve module (RBVM) thermal bootie	FD7
	c. Retrieve Articulating Portable Foot Restraint (APFR) 4, relocate tool a. stanchion and remove heat shield IVA	FD5, FD6
	d. Reinstall APFR No. 4 on ISS external	FD7
	e. Install SSRMS Latching End Effector (LEE) A Elbow CLPA lens cover	
	f. Stow Vent Tool Extension Bags 1 and 2 on airlock	FD7
	g. Retrieve jettison stowage bags	FD7
	h. Install P3 CETA light	FD7
	i. Remove MLI tent from Node 3 Nadir/PMA3 interface	FD7
	j. Install lens cover on POA CLA	FD7
	k. Install SPDM CLPA 2 lens cover	FD7
	l. Open Z1 Remote Power Controller Module (RPCM) MLI flaps	FD5
16	Complete CP3 camera calibration, checkout and survey after the CP3 wedge is installed and downlink data for analysis	FD5
17	Perform IVA tasks:	
	a. Recycle Filter Tank Assembly (RFTA) installation	FD3
	b. R&R Node 3 Air Revitalization (AR) rack Carbon Dioxide Removal Assembly (CDRA) back bed	FD4
	c. R&R condensate pump	FD7
18	Transfer water from Orbiter to ISS per Flight ULF5, TPL.	FD4-FD10
19	Reboost the ISS with the Orbiter if mission resources allow and are consistent with ISS trajectory analysis and planning.	FD9
20	Perform imagery survey of the ISS exterior during Orbiter flyaround after Undocking from ISS	FD12
21	Perform checkout of ELC4.	FD3
22	Perform Development Test Objective (DTO) 701B DragonEye.	FD3,FD12
23	Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during ULF5 Orbiter Docking.	FD3
24	Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during ELC4 and PMM installation (ISS Wireless Instrumentation System (IWIS) required Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during ELC4 and PMM installation (ISS Wireless Instrumentation System (IWIS) required	FD3, FD6
25	Perform SDTO 13005-U, ISS Structural Life Validation and Extension, during ULF5 Reboost (IWIS required).	FD9
26	Perform SDTO 13005-U, ISS Structural Life Validation and Extension during ULF5 Orbiter undocking. (IWIS highly desired)	FD12

ISS MISSION PRIORITIES COMPLETION STATUS (Concluded)

Item	Task	Flight Day Task Completed
Category 4 Tasks		
27	Perform MAUI, SEITE, RAMBO-2, and SIMPLEX (Payloads of Opportunity – not required for docked operations) if propellant available.	FD13 (RAMBO Performed)
28	Perform Program-approved EVA get-ahead tasks. The following EVA get-ahead tasks do not fit in the existing EVA timelines; however, the EVA team will be trained and ready to perform should the opportunity arise EVA/MOD has the flexibility to select the tasks to be completed based on efficiencies gained in performing the already scheduled required tasks.	
	a. Reinstall starboard SARJ ETRS, two rail stubs and two launch restraints, reconfigure S3 MT stop and tether Space Shuttle stops for Worksite 1.	FD5
	b. Reconfigure port CETA cart.	FD7
	c. Relocate Strela adapter	FD7
	d. CP13 light R&R	Deferred
	e. Remove S1 FHRC P-clamps	Deferred
	f. Install bootie/grounding connector. (ESP2 J57A) inside S0 truss Bay 3.	Deferred
	g. Perform tool reconfiguration	FD7
29	Perform program-approved IVA get-ahead tasks. The following IVA get-ahead tasks do not fit in the existing IVA timelines; however, the IVA team will be trained and ready to perform should the opportunity arise.	
	a. Perform PMM outfitting tasks.	FD?
	b. R&R N1-4B-C RPCM.	FD5
	c. Node 2 SD2 General Lighting Assembly (GLA) trouble shooting.	Deleted preflight
	d. Install hatch handle guide ring assemblies to Node 3 starboard and Nadir hatches.	Deleted preflight
	e. Intermodular Ventilation (IMV) valve set screw troubleshooting.	Deleted preflight
	f. PMA1 to Node 1 IMV screen install, fan and muffler cleaning and set screw inspection.	Deleted preflight
	g. Node 1 to airlock IMV flow trouble shooting	Deleted preflight
30	Perform imagery tasks as follows: Perform imagery tasks as follows:	
	a. Perform Russian imagery of RS exterior for historical documentation	Deleted during flight

DEVELOPMENT TEST OBJECTIVES

1.1.1.1 DragonEye Flash Lidar (DTO 701B)

The DragonEye Flash Lidar was mounted to the existing TCS carrier assembly on the ODS, in the starboard location, with the TCS-2 located in the port location. The DragonEye used a single LIDAR of a “flash” type, with a 128-by-128 array of Avalanche Photo-Diodes (APDs) providing a 3D-image based on time of flight of a single laser pulse from the sensor to the target, which will provide range and bearing information.. The targets are on the Nadir sides of JEM, PMA2, and other locations on the ISS that will be used by this sensor on the subsequent ISS visiting vehicles. The sensor unit operates with retro-reflectors in the field-of-view even at close range and is protected against direct sun exposure.

The DragonEye raw data has been retrieved their raw data, and the sponsors are performing analysis at this time this report was written

.Boundary Layer Transition Flight Experiment (DTO 854)

The Boundary Layer Transition (BLT) flight experiment gathers information on the effect of high Mach number boundary layer transition caused by a protuberance on the Space Shuttle during the entry trajectory.

The DTO was successfully flown and entry and temperature data were collected. The protuberance and catalytic coating tiles survived the flight with only minor glazing on the protuberance tile surface. All flight temperatures were below those predicted pre-flight, and analysis of the thermocouple data is was being performed when this report was written.

Shuttle RSRB Chamber Pressure, Strain Gauge and Acceleration Rates Data Collection (DTO 900)

DTO 900 collected higher fidelity data to contribute additional knowledge of Solid Rocket Motor (SRM) flight characteristics for RSRB analysts.

All accelerometers and strain gauges worked properly and data were recorded and retrieved from the RSRB enhanced data acquisition system units. Data from the left-hand and right-hand motors was well matched and all data was nominal when compared to the flight family. There were no anomalies observed.

Crosswind Landing Performance (DTO 805)

This DTO of opportunity was not performed during landing due to crosswind conditions.

DEVELOPMENT SUPPLEMENTARY OBJECTIVE

1.1.1.2 Physiological Factors Contributing to Postflight Changes in Functional Performance (Functional Task Test) (DSO 640)

The objective of this study is to identify the key underlying physiological factors that contribute to changes in performance of a set of functional tasks that are representative of critical mission tasks for lunar and Mars operations. The crewmembers will be tested on an integrated suite of functional and interdisciplinary physiological tests before and after short and long-duration spaceflight. Post-flight testing for DSO 640 on STS-133 was successfully completed for the R+0 day, R+1 day and R+6 day sessions. The R+30 day test remains to be performed.

PAYLOADS OF OPPORTUNITY

Maui Analysis of Upper Atmospheric Injection (MAUI)

The MAUI payload experiment matrix involved dedicated Orbital Maneuvering System (OMS), Shuttle Primary Reaction Control System (PRCS) and Vernier RCS thruster firings. Observations of firings in the vicinity of the ISS (particularly ISS reboost firings), are performed passively. The Space Shuttle engine exhaust plumes are observed utilizing optical telescope sensors and all-sky imagers at the Air Force Maui Optical and Supercomputing Site (AMOS) at Maui, Hawaii. The Space Shuttle thruster firings and attitude maneuvers were to be conducted during night passes over AMOS. However, no MAUI observation opportunities occurred during the mission.

Shuttle Exhaust Ion Turbulence Experiment (SEITE)

The SEITE utilizes the Space Shuttle to investigate plasma turbulence caused by the OMS engine exhaust in the ionosphere using space-based sensors. Data are collected by flying satellites through the plasma turbulence during a conjunction with the Space Shuttle. Observations of density and electric field disturbances are utilized to develop quantitative models of plasma turbulence that affects tracking and imaging radars. No SEITE observation opportunities occurred during this mission.

Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX)

The objective of the SIMPLEX activity is to determine the source of very high frequency radar echoes caused by the Orbiter and its OMS engine firings when in the field-of-view of a SIMPLEX radar or radio telescope ground-site. The collected data is used to examine the effects of orbital kinetic energy on ionospheric irregularities and to understand the processes that take place with the venting of exhaust materials.

A dedicated 10-second dual OMS firing for the SIMPLEX payload was performed at 145/15:23:20 GMT (10/21:03:11 MET), which occurred over the Blackstone, VA radar site. The principal investigator indicated that the radar site functioned nominally throughout the pass.

Ram Burn Observations (RAMBO) -2

The objective of the RAMBO-2 activity is to use the Space Shuttle to acquire data for developing a method to decipher satellite maneuvers from plume observations and to characterize monopropellant plume radiance. RAMBO-2 uses two Space Tracking Surveillance System satellites to make observations of Space Shuttle PRCS plumes.

The Department of Defense (DoD) Space Test Program representatives from JSC attended a classified presentation of data collected during the RAMBO-2 experiment on STS-133. The OMS-2 firing collected and provided unique and spectacular data. Data was collected from multiple sensor look-angles that will allow the plume to be modeled in three dimensions and compared to calculated predictions. This is new and uniquely different from previous observational payloads. The volume of data collected is so great that it is taking additional time to analyze the data.

VEHICLE PERFORMANCE

LAUNCH DELAYS

The planned launch for November 1, 2010, was delayed to November 3 to complete repairs on the right Orbital Maneuvering System (OMS) pod. When the system was being pressurized, helium and nitrogen leaks were detected. The quick-disconnect fittings used to pressurize the system were replaced.

The November 3 launch was then scrubbed to evaluate the condition of the backup controller for Space Shuttle Main Engine (SSME) 3. During the checkouts, the backup controller for SSME 3 showed an irregular power drop. There appeared to be an issue with one of the three power phases, which narrowed down the issue to either a circuit breaker or a switch that provides power to the controller. Both the circuit breaker and the switch were cycled and power was restored without issue. However, to provide engineering personnel time to analyze the data, the launch was rescheduled for November 4. The hardware was replaced on a subsequent launch delay.

The November 4 planned launch was scrubbed prior to the start of tanking operations because of unacceptable weather conditions (rain, low clouds, high crosswinds), and the launch was delayed 24 hours to November 5.

The November 5 launch was scrubbed because of a hydrogen leak in the Ground Umbilical Carrier Plate (GUCP) [In-Flight Anomaly (IFA) STS-133-I-001]. In addition, the External Tank (ET) post-drain inspection identified a large crack in the foam on the Liquid Oxygen (LO₂)-Intertank (I/T) flange closeout in the Panel 1 area between stringers 6 and 7. Investigation teams were formed to address both of these anomalies.

The decision of the Mission Management Team (MMT) was to postpone the launch to the next window, which would open on November 30, to repair the GUCP and to continue evaluating the ET foam issue.

The team addressing the GUCP leak determined that the interface concentricity alignment was sensitive to a number of factors including vent-arm loading. Additional steps were added to the assembly process to ensure that the alignment issues were minimized.

The LO₂ flange TPS crack investigation led to major modifications of the ET. Subsequent to drain-back operations, detailed inspections discovered cracks on the ET Intertank stringers as the cause for the LO₂ flange TPS foam cracking.

During the delay, the circuit breaker associated with the SSME 3 backup controller was removed and replaced. Failure analysis on the circuit breaker indicated that

contamination in the breaker likely resulted in an intermittent contact that caused the irregular power drop.

In the process of removing the cracked foam from the ET Intertank area as part of the anomaly investigation, two 9-in cracks on either side of one of the stringers were found. A repair plan was developed and the process of the preparing the area for the repair, two additional cracks were found on an adjacent stringer. The November 30 planned launch was delayed to December 3 so that analysis and repair of the cracked ET stringers could be completed. However, it was later determined that more extensive analysis would be required to build flight rationale and therefore, the December-3-to-December-7 launch window was not attainable.

The Shuttle Program Requirement Control Board (PRCB) met on December 2, 2010, and the decision was made to delay the launch to no earlier than February 3, 2011.

A ET Tanking Test was planned for December 15, however, because of instrumentation problems; the test was delayed to December 17. The ET tanking test was performed with satisfactory results. Additional cracks were found on the ET intertank stringers were found near the LO₂ flange during Nondestructive Evaluation (NDE).

The vehicle was rolled back to the Vertical Assembly Building (VAB) on December 22, 2010. Technicians completed the ET X-ray scans beneath the foam insulation of all 108 stringers and found additional cracked stringers. It was not known whether those cracks occurred during the initial tanking or during the tanking test. The remaining sensors that were installed on the ET for the tanking test were removed after completion of the X-ray scans.

As a result of the findings and subsequent analysis, radius blocks were installed over the feet of the all accessible stringers to increase the strength of the stringers and reduce the risk of cracking. The installation of the radius blocks and the reapplication of foam and trimming operations were completed on January 27, 2011. The vehicle was moved to Launch Pad 39A on January 31, 2011, in preparation for the planned launch on February 24, 2011.

The root cause of the stringer cracks anomaly (IFA STS-133-I-002) is currently unknown. Three potential contributors have been identified through a fish-bone investigation. The potential contributors are:

4. Two suspect material lots of Aluminum AL 2090;
5. Stringer residual assembly stresses; and,
6. Stringer thickness.

NATURAL ENVIRONMENTS

The T-0 (instantaneous) surface conditions (based on measurements at the 60-ft level of Camera Site 3) were as follows; wind speed was 4.5 knots, wind direction was 69 degrees, temperature was 68 °F, humidity was 82-percent and ambient pressure was 30.07 inch Hg.

The I-loads were designed with the L-4:50-hr due to lost radar tracks on the L-4:50 hr Jimsphere. No exceedances of the February 90th percentile database limits for the in-plane or out-of-plane components were present based on the Launch (L) - 2:20 hr Day of Launch I-Load Update (DOLILU) assessment profile. The maximum measured wind velocity was 133 ft/sec at 37,000-ft and at 309 deg. There were no wind shear exceedances.

There were no violations of the in-plane or out-of-plane wind change redlines from the L-4:50-hr DOLILU I-Load design wind profile to the final assessments based on the L-2:20-hr Jimsphere balloon and the 2130 Universal Time Coordinated (UTC) 50 MHz Doppler Radar Wind Profiler (DRWP).

The L-1:08 Jimsphere balloon was used to clear the roll maneuver region and was validated with the 2031 UTC False Cape 915 MHz profiler. The maximum measured wind velocity in the roll maneuver region was 28.5 ft/sec at 6500 ft and 189 deg.

REUSABLE SOLID ROCKET BOOSTERS

The STS-133 Reusable Solid Rocket Boosters (RSRBs), identified as BI-144, performed satisfactorily during the launch countdown and ascent with no In-Flight Anomalies (IFAs) identified. Separation was visible through cutoff at 055/21:55:29 Greenwich Mean Time (GMT) [00/00:02:05 Mission Elapsed Time (MET)].

Two RSRB flight design changes were made on this mission. The RSRB Froth-Pak foam trimming operations were revised to no longer require the top-seal-coat application. The second flight design change was using Phase II Fuel Pump, which was flown for the first time on one of the four Auxiliary Power Units (APUs).

No RSRM Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred. Likewise, no Interim Problem Reports (IPRs) occurred during the launch countdown.

Both RSRBs were successfully separated from the External Tank (ET) and were recovered and returned to Kennedy Space Center (KSC) for inspections and disassembly. The post-flight inspection of the RSRB revealed no IFAs or FIDs.

REUSABLE SOLID ROCKET MOTORS

The STS-133 Reusable Solid Rocket Motors (RSRMs) set, identified as RSRM-12, performed within established and predicted limits (nominal). One flight-design change was made to the RSRM for this mission. The change was the installation of low temperature O-ring material in the nozzle-joint 2, which has been used in the field joints on all flights beginning with STS-125 and all nozzle joints since STS-126.

No RSRM Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred. Likewise, no Interim Problem Reports (IPRs) occurred during the launch countdown. The RSRM Predicted Mean Bulk Temperature (PMBT) was 62 °F.

Power-up 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 nozzle/case joint and flex bearing temperature within the required LCC ranges.

EXTERNAL TANK

The STS-133 External Tank (ET), which was designated as a Super Lightweight Tank (SLWT) -137 performed satisfactorily throughout the final launch countdown and ascent. All ET objectives and requirements associated with propellant loading and flight operations were met. No significant Gaseous Oxygen (GO₂) and Gaseous Hydrogen (GH₂) concentrations were detected in the Intertank or the Ground Umbilical Carrier Plate (GUCP). All electrical equipment and instrumentation operated satisfactorily. Purge and heater operations were monitored and performed properly. Liquid level and Engine Cut-off (ECO) sensors performed as designed. The Propellant Mean Bulk Temperature (PMBT) was 62 °F at launch.

The Final Inspection Team (FIT) reported all observations were acceptable per NSTS 08303, Ice Debris Inspection Criteria. Tank observations were consistent with environmental conditions. Light to moderate condensate was noted on the LH₂ tank, with dry surfaces on the LO₂ tank and Intertank. Multiple intertank stringer valley cracks were observed, all typical and acceptable. Six small frost spots were observed on the LH₂ flange closeout, but four of them dissipated during the inspection. A typical crack with no offset was noted on the -Y vertical strut cable tray, and another crack was observed on the underside of the +Y vertical strut.

No ET Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred. Likewise, no Interim Problem Reports (IPRs) occurred during the launch countdown.

The ET separation was normal. The post-flight predicted ET intact impact point is approximately 32 nmi up-range from the preflight prediction. The coordinates for the impact point were a latitude of 35.535 Deg South and a longitude of 158 deg West.

The launch delays resulting from the ET foam and Intertank (IT) issues are discussed in the Launch Delay section of this report.

SPACE SHUTTLE MAIN ENGINES

The Space Shuttle Main Engine (SSME) pre-launch countdown was nominal and Engine Ready was achieved at the proper time. The SSMEs flown were Block II engines and were identified as 2044, 2048 and 2058 in positions 1, 2, and 3, respectively. All LCCs were met and thrust build-up was nominal. Flight data indicates nominal SSME performance during startup, mainstage, throttling and shutdown.

No SSME Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred. Likewise, no Interim Problem Reports (IPRs) occurred during the launch countdown.

Data indicated the High Pressure Oxidizer Turbo Pump (HPOTP) and the High Pressure Fuel Turbo Pump (HPFTP) temperatures were well within specifications throughout engine operation.

The commanded Maximum Dynamic Pressure (Max Q) throttle-down was a single-step throttle bucket to 72 percent (%) Rated Power Level (RPL), and the Adaptive Guidance Throttle (AGT) was not activated.

The predicted average SSME specific impulse (ISP) tag value (using the ground-based tag value method) was 451.91 seconds at 104.5% Rated Power Level (RPL). Indications are that the delivered ISP are within the expected range.

Review of Advanced Health Monitoring System (AHMS) vibration data indicates nominal performance. No FIDs were reported to the Vehicle Data Table (VDT) from start preparation through propellant dump on all engines. All accelerometer measurements appeared healthy. Detailed vibration data review will occur after recovery of the on-board Modular Auxiliary Data System (MADS) recorder post-landing.

During the GUCP delay, the circuit breaker associated with the SSME 3 backup controller was removed and replaced. Failure analysis on the circuit breaker indicated that contamination in the breaker likely resulted in an intermittent contact that caused the irregular power drop.

The SSME Dome Mounted Heat Shield (DMHS) blanket on SSME 1 appeared to have fraying at the 6 o'clock position. The SSME 2 and 3 blankets appeared to be in excellent condition with a very low amount of fraying. Base heat shield tiles appeared to have less than typical damage.

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 RSRB S&A devices were safed and RSRB system power was turned off prior to RSRB separation.

ORBITER SYSTEMS

Main Propulsion System

The Main Propulsion System (MPS) performed satisfactorily with no LCC or OMRSD violations occurring. One item was noted and it is discussed in a later paragraph in this section.

The maximum hydrogen concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fastfill, was 83.1 ppm (System B was used to determine the maximum concentration). This compares favorably with previous data for this vehicle.

All Liquid Hydrogen (LH₂) and Liquid Oxygen (LO₂) loading parameters were nominal. All LO₂ and LH₂ fill-and-drain valves performed nominally during the flight, however, the inboard valve open indication was lost for 10 seconds after which it returned. The LO₂ and LH₂ Engine Cut off (ECO) sensors passed all pre-flight checkouts and operated nominally through ascent.

The LH₂ pre-pressurization cycle count was 9 cycles; 14 cycles or more violates the LCC criteria. The engine inlet Net Positive Suction Pressure (NPSP) requirements were met throughout the flight. Pressurization performance was nominal indicating proper operation of the Flow Control Valve (FCV) hardware.

Hazardous Gas Concentrations

The aft hazardous gas concentrations during loading were nominal. The following table summarizes the results.

HAZARD GAS CONCENTRATIONS AT LAUNCH

Parameter	Peak, ppm	Steady State, ppm
Helium	8449	6580
Hydrogen	83	8.5
Oxygen	18.7	11.2
LD54/55	0/0	0/0

Gas Sample Analysis

The flight history of the Orbiter Aft Fuselage Gas Sampler System (OAFGSS) sample bottles on STS-133 shows that one of the six bottles failed to obtain data. Five of the six measured sample bottle pressures were within the allowable range. The fourth bottle in the sequence, left hand no. 2, had a reported pressure that was less than 0.5 TORR (IFA STS-133-V-09). Post-flight inspection indicates the opening valve did not move.

STS-133 was the 20th flight using the new gas chromatograph /mass spectrometer at the Kennedy Space Center Materials Science Laboratory.

Hydrogen concentrations were well below the flammability limit in each bottle. The highest estimated leak rate was 590 SCIM from bottle left hand no. 3. No sample was obtained from left hand no. 2 due to the opening valve failure.

The oxygen concentrations were below the flammability limit. The highest concentration was 2.16-percent in the left hand no. 3 bottle. Argon indicates air as the major source of the oxygen in all six bottles and not Orbiter system leakage.

The highest helium concentration was 8.78-percent in the right hand no. 3 bottle. Through STS-133, the highest helium concentration on OV-103 is 12.91-percent. The average for all bottles is 1.53-percent, but the average for right hand no. 3 is 5.56-percent. Due to the low pressure at the time the last bottle acquired its sample and the lack of a diluting atmosphere, the last bottle typically has the most variation in helium concentration. The following three tables provide the results from the analysis of the data.

SUMMARY OF BOTTLE PRESSURES AND GAS CONCENTRATION

Bottle No.	Position	Pressure, psia	Helium, %	Measured Oxygen, %	Hydrogen, %
1	RH 1	3.98	0.47	1.40	<0.01
2	LH 1	1.61	0.43	1.26	0.02
3	RH 2	1.60	1.07	1.12	0.02
4	LH 2	N/A	N/A	N/A	N/A
5	LH 3	0.19	1.64	2.16	0.12
6	RH 3	0.08	8.78	1.30	0.21

The Ascent Hazard Analysis indicates the maximum hydrogen firing leak rate

HYDROGEN FIRING LEAK RATES

Bottle no.	Position	Hydrogen Firing Leak Rate, scim
1	RH 1	545
2	LH 1	537
3	RH 2	535
4	LH 2	N/A
5	LH 3	590
6	RH 3	463

The complete results of the gas chemical analysis, provided by Kennedy Space Center, are shown in the following table.

AFT FUSELAGE SAMPLE BOTTLE GAS ANALYSIS

S/N	Position	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-2	RH1	206.0	0.05	5.25	0.47	<0.01	<0.01	<0.01	1.10	1.40	<0.01	<0.01
1105 FLT-3	LH1	83.2	0.05	5.57	0.43	0.00	0.01	0.00	1.17	1.26	0.02	0.02
1131 FLT-2	RH2	82.8	0.05	5.46	1.07	0.00	0.01	0.00	1.15	1.12	0.02	0.02
1120 FLT-2	LH2	<0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1122 FLT-2	LH3	9.85	0.10	10.71	1.64	0.00	<0.01	0.01	2.25	2.16	0.13	0.12
1133 FLT-2	RH3	3.94	0.09	9.10	8.78	0.04	<0.01	0.02	1.91	1.30	0.24	0.21

Purge, Vent, and Drain System

The Purge, Vent and Drain (PV&D) system performed nominally. Purge flow rates and temperatures were nominal.

Reaction Control System

The Reaction Control System (RCS) performed all functions required for successful completion of the mission. One IFA was identified from the data and the IFA is discussed in a later paragraph of the section.

The propellant loading for the mission is shown in the following table.

RCS PROPELLANT LOADING

Parameter	Forward RCS		Left RCS		Right RCS	
	Oxidizer	Fuel	Oxidizer	Fuel	Oxidizer	Fuel
Target, %	67.70	67.41	100.48	100.76	100.48	100.76
Target, lb	1141.0	721.0	1523.0	962.0	1523.0	962.0
Calculated, %	72.22	68.98	100.72	100.53	100.56	100.61
Advertised, %	1202.0	725.3	1526.2	960.0	1523.1	960.7
PASS WHI ^a	4.4009	4.2776	4.3848	4.2543	4.3971	4.2140
BFS WHI ^b	4.4057	4.2807	4.3999	4.2659	4.4124	4.2486

Notes:

^a PASS WHI – Primary Avionics Software System Initial Weight of Helium Load

^b BFS WHI – Backup Flight System Initial Weight of Helium Load

After RCS Helium regulator activation, the Right RCS Fuel Primary Regulators exhibited internal leakage of 3300 scch (IFA STS-133-V-04). The Shuttle Operational Data Book (SODB) has an acceptable limit of no more than 600 scch. Both the A-Leg and B-Leg parallel regulators were online for launch, since it was not initially clear which regulator was leaking. The leakage caused the right RCS fuel- tank-ullage pressure to increase until the secondary regulator stage lock-up occurred. From that point on, the secondary regulator stage leaked at an in-specification value of approximately 500 scch. The right RCS Helium A-leg isolation valve was closed at 053/02:44 GMT (prior to launch) to further limit the ullage-pressure rise. A waiver was approved to continue with launch countdown. The right RCS He A isolation valve was re-opened at 055/11:52:24 GMT returning the RCS to the nominal launch configuration.

All Tyvek covers released at nominal speeds. Tyvek cover release speeds and vehicle alpha/beta angles at cover release are given in the following table.

TYVEK COVER RELEASE TIMES, VELOCITIES AND ALPHA/BETA ANGLES

Cover	MET (sec)	Velocity (mph)	Alpha (deg)	Beta (deg)
F1D	5.0	57	-4	8
F3D	5.8	68	-5	7
F2D	6.0	70	-5	6
F4D	6.6	78	-5	6
F1L	7.8	94	-5	6
F3U	8.1	99	-5	5
F2R	8.8	109	-3	4
F3F	9.1	112	-3	4
F4R	9.1	112	-3	4
F2U	9.2	115	-3	4
F3L	9.2	115	-3	4
F2F	9.5	118	-3	3
F1U	9.8	123	-3	3
F1F	10.4	133	-2	2

The RCS window-protect firing, using thrusters F1U, F2U and F3U, was initiated at 055/21:55:30 Greenwich Mean Time (GMT) [00/00:02:06 Mission Elapsed Time (MET)] for total duration of 2.08 sec. The Forward RCS (FRCS) performance was nominal. The window-protect firing deflects exhaust from the RSRB separation motors away from the windows during RSRB separation.

The ET Separation maneuver was performed at 055/22:02:08 GMT (00/00:08:44 MET) and was a 7-sec, 10-thruster translation. The ET Photographic requirement was performed at 055/22:02:17 GMT and was a 10.4-second, 4-thruster translation. The ET Photo Pitch maneuver was performed at 055/22:03:00 GMT (00/00:08:53 MET).

The Left and Right RCS helium valves were configured for orbit at 055/22:34:43 GMT (A-GPC, B-CLOSED). Forward RCS helium valves were configured for orbit at 055/22:35:29 GMT (A-GPC, B-CLOSED). The heaters (including FRCS, Left and Right pods and crossfeed) were configured to the A-strings at 055/22:45:50 GMT.

The RCS firings, times initiated, ΔV , and firing times are listed in the following table.

RCS MANEUVERS AND FIRING DATA

Maneuver/Firing	Engine/System	Time of Ignition, GMT	ΔV , ft/sec	Duration, sec
RCS Window Protect	RCS	055/21:55:30.1	N/A	2.08
ET Separation	RCS	055/21:55:41.4	N/A	152.2
ET Photo +X	RCS	055/22:02:17.9	N/A	10.4
ET Photo Pitch	RCS	055/22:03:00		
NC3	RCS	057/01:06:18.2	1.7	24.0
NCC	RCS	057/15:35:42	0.75	
MC1	RCS	057/16:53:26	0.37	Not Reported
Out of Plane Null	RCS	057/17:08:31		
MC2	RCS	057/17:27:17	1.5	Not Reported
MC3	RCS	057/17:44:13	0.1	Not Reported
MC4	RCS	057/17:54:11	2.3	Not Reported
R-bar Pitch Maneuver	RCS	057/18:15:50		
TORVA	RCS	057/18:26:55		
Docking	RCS	057/19:14:19		
Reboost Maneuver	RCS	062/14:03:37	3.3	28 min
Orbiter Undocking	RCS	066/12:00:22		
ISS Fly Around	RCS	066/12:23:15		
Separation 1	RCS	066/13:09:13.4		6.00
Separation 2	RCS	066/13:37:21.1		11.9
RCS Hotfire	RCS	067/11:23:37		
RAMBO	RCS	067/12:23:46		10.0
Forward Reaction Control System Dump	RCS	068/16:07:44.9		18.7

A configuration 3 Vernier (RCS) reboost was performed. Ignition for the reboost maneuver was 062/14:03:37 GMT, and burn cutoff was at 062/14:32:26 GMT (06/16:10:13 MET), resulting in firing duration of approximately 28 min. The reboost was performed in straight feed. The reboost delivered a total ΔV , including the pre- and post-reboost attitude maneuvers, of 3.3 ft/sec (2.1 for the reboost only), resulting in 0.92 nmi increase in altitude. Vernier pulse totals are given in the following table.

REBOOST FIRING DATA

Thruster Position	Number of Pulses	Seconds Firing Time
F5L	46	2001.76
F5R	47	2128.20
L5D	263	1194.88
L5L	118	104.40
R5D	118	1231.88
RSR	124	160.12

In-flight, the first half of the mission was performed on the A-Leg regulators. The right RCS fuel-tank pressure was managed through normal RCS usage during the pre-docking period. The propellant usage dropped the ullage pressure to the primary regulator flow pressure. The primary regulator locked up at approximately 250 psia, at which point the creep began again. After docking with the ISS, the A-Leg regulator exhibited an internal leak rate of approximately 1200 scch over a period of more than 4 days, eventually reaching secondary lockup. Within a day of achieving secondary lockup, an ISS reboost was performed using the RCS tanks. This returned the tank pressures to primary regulator lockup pressure and the primary regulator began leaking again at approximately 1300 scch. The RCS usage related to ISS undocking and flyaround occurred prior to reaching secondary regulator lockup. Post-flyaround, the RCS was configured on the B-Leg regulators (per nominal procedures) and the leakage was back within specification.

The failure was manageable both pre-launch and in-flight, the failure signature was consistent with historical failures, and STS-133 is the last flight of OV-103. Thus, no post-flight testing of the regulator is planned. This regulator package had a history of internal leakage following Helium servicing and regulator activation for flight (most recently on STS-116, -120, -124, and -119). This leakage typically corrected itself post-launch following ET Separation usage and did not repeat during post-flight regulator checkouts. Thus, the leakage for these cases was attributed to soft-seating during regulator activation. However, for this failure, the leakage did not correct itself in-flight so the soft-seat is not a likely cause. However, during the preparation for STS-133, the upstream A-leg helium isolation valve was replaced due to its intermittent failure-to-close during the previous flow and flight. Thus, the most likely cause of this failure is contamination introduced during the helium isolation valve replacement that caught up on or damaged the primary stage sealing surface.

The attitude control responsibilities between the ISS and the Orbiter are shown in the following table.

CONTROL RESPONSIBILITIES BETWEEN ISS AND SHUTTLE

Control Responsibility	Control Start, GMT	Orbiter DAP Mode	Comments
	057/19:14:19	FREE DRIFT	Docking / ISS Capture
Orbiter	057/20:09:54	VERNIER	
ISS	057/20:12:15	FREE DRIFT	
Orbiter	057/20:12:15	AUTO	
ISS	057/20:22:06	FREE DRIFT	
Orbiter	057/20:26:35	AUTO	TEA Maneuver
Orbiter	057/20:57:56	B	Collapse Dead Band
ISS	057/21:08:55	FREE	
Orbiter	062/13:40:43	AUTO	Handover For Reboost
ISS	062/15:10:34		Post-Reboost-TEA Attitude
Orbiter	066/10:40:47	LVLH	Maneuver to Undocking Attitude
ISS	066/11:42:01	FREE DRIFT	Logic Configuration
Orbiter	066/11:43:26	AUTO	
ISS	066/11:57:25	FREE	Driver configuration
Orbiter	066/11:57:51	B/ALT	No Low Z
ISS	066/12:00:22		Undock

The RCS hot-fire was initiated at 067/11:23:37 GMT (11/13:30:13 MET) and terminated at 067/11:29:37 GMT (11/13:36:13 MET). All 38 RCS thrusters were fired at least twice. Two pulses of at least 0.240 sec per pulse were verified for all 38 thrusters. No fail-off or fail-leak problems were detected during the satisfactory hot-fire. Manifold 5 circuit breaker test was also performed satisfactorily at 067/11:32:16 GMT (11/13:38:52 MET).

The RCS pressurization and propellant isolation valves were configured for entry at 068/15:28:12 GMT (12/17:34:48 MET). Heaters were configured for entry at 068/15:31:42 GMT (12/17:38:18 MET). The forward RCS Dump, using four thrusters, was initiated at 068/16:07:45 GMT (12/18:14:21 MET) and lasted 18.72 sec. The dump consumed 10.4-percent (228.3 lb) of the Forward RCS propellant.

The post-flight Redundant Circuit Verification test was initiated at 068/17:24:25 GMT and finished at 068/17:29:38 GMT. Performance for all of the valves was nominal.

The Vernier RCS thrusters were fired 2402 times for a total of 17876.2 sec. The Primary RCS thrusters were fired 2996 times for a total of 956.02 sec.

The residual propellants at the end of the mission are shown in the following table.

RCS RESIDUAL PROPELLANTS

Parameter	Mission Operations Calculation		PASS Model Calculation ^a	
	%	lb	%	lb
Forward Oxidizer	5.0	67.5	4.4	59.4
Forward Fuel	0.0	0	0.4	3.4
Left Oxidizer	50.4	680.4	49.4	666.9
Left Fuel	48.2	409.7	47.8	406.3
Right Oxidizer	49.0	661.5	48.4	653.4
Right Fuel	47.2	401.2	47.0	399.5

Note:

^a The official JSC Engineering RCS propellant residuals are those listed under the PASS model

The RCS propellant consumption was calculated by subtracting the Primary Avionics Software System (PASS) Model residuals from the advertised propellant loads with the unusable quantities omitted.

RCS PROPELLANT CONSUMPTION

Parameter	Oxidizer, lb	Fuel, lb	Mixture ratio, Oxidizer/Fuel
Forward RCS	915.6	582.9	1.57
Left RCS	692.8	448.2	1.55
Right RCS	704.2	455.7	1.55

Orbital Maneuvering System

The Orbital Maneuvering System (OMS) performed satisfactorily throughout the STS-133 mission. No IFAs were identified during the review and analysis of the flight data.

The standard OMS hardware configuration is shown in the following table.

OMS CONFIGURATION

Vehicle/equipment	Flight	Orbital Maneuvering Engine (OME)	Ancillary data
Left Pod (LP) 01	42 nd	L-OME S/N 115	9 th rebuilt flight - 24 th flight
Right Pod (RP) 03	40 th	R-OME S/N 106	13 th rebuilt flight 37 th flight

The following table provides a listing of the OMS-maneuver data.

OMS MANEUVERS

Maneuver designation	Configuration	Time of ignition, GMT	Firing time, sec	ΔV , ft/sec/ interconnect usage, %
Assist	Dual Engine	055/21:55:41.4	152.2	N/A
OMS-2	Dual Engine	055/22:31:54.2	63.4	96.5
OMS-3 (NC1)	Dual Engine	056/01:28:55.7	28.8	43.8
OMS-4 (NC2)	Right Engine	056/14:43:53.0	13.2	10.0
OMS-5 (NH)	Dual Engine	057/14:15:59.4	83.4	129.2
OMS-6 (NC4)	Dual Engine	057/15:01:23.6	65.6	103.0
OMS-7 (TI)	Left Engine	057/16:33:24.3	10.6	8.2
OMS-8 (Orbit Adjust)	Dual Engine	067/20:00:00.4	14.0	25.5
(Deorbit)	Dual Engine	068/15:52:04.2	148.4	276.3

The interconnect usage from the OMS to the RCS is shown in the following table.

INTERCONNECT USAGE, %/POUNDS

Parameter	Total, %	Total, pounds
Left OMS	3.450	446.81
Right OMS	2.682	347.34

PROPELLANT USAGE DATA

Parameters	Left OMS pod		Right OMS pod	
	Oxidizer	Fuel	Oxidizer	Fuel
Loaded, lbm	7704	4650	7704	4650
Residual, lbm (aft gage)	629	329	644	1467 ^a
Residual, lbm (burn time integration)	550	306	725	350
Residual, lbm (SODB flow rate)	653	353	637	390

^a Right OMS Fuel Gage performance not correct.

The ROMS Fuel Totalizer was noted to be biased prelaunch, reading off-scale-high when it should have read approximately 95-percent quantity remaining. The totalizer reading came back on scale during the OMS Assist firing, maintaining a constant bias of approximately 11.4-percent above the expected value (Fuel Quantity minus Oxidizer Quantity). This fuel minus oxidizer quantity discrepancy increased slightly during subsequent maneuvers (up to approximately 12.6-percent

quantity during beginning of the deorbit firing and approximately 13-percent above the indicated aft probe reading following update using the aft- probe reading). While this performed nominally last flight, an existing deferred Problem Report documents this failure during servicing for a prior flight.

During the Deorbit firing, the right OMS fuel aft compartment gauging probe indicated 30-percent remaining (maximum aft gage quantity) during the entire firing, rather than decrementing with the fuel usage. While this is the first time this particular probe has shown this issue, this is not the first occurrence of this failure mode. Moreover, the OMS gaging system is Criticality 3/3 hardware used for propellant servicing preflight, and the system has a long history of failures/bad behavior. Indeed, this right OMS fuel gaging system has a deferred PR although it is not specifically for this problem. We have no spares, no working Ground Support Equipment (GSE), no vendor, and the Program has decided on several occasions that the hardware would be "abandoned in place" if/when it failed to the point of being unusable since loading can be (and often is) performed using GSE flowmeters. Thus, both this failure and the preceding totalizer issue are documented in this report, but no failure analyses will be performed on the gaging system hardware

Auxiliary Power Unit System

The Auxiliary Power Unit (APU) system performance was nominal throughout the STS-133 mission. There was one post-landing issue, and no In-flight Anomalies (IFAs) were recorded against the APU system the ST-133 mission. The post-landing issue is discussed in a later paragraph in this section.

During heat soak-back after the APU 2 entry, the Gas Generator Valve Module (GGVM) heat-sink temperature reading exceeded the Shuttle Operational Data Book (SODB) non-operating limit of 200 °F. The maximum temperature reached during soakback was approximately 206 ° F. This temperature limit has been exceeded on the previous four flights of this APU (STS-117, STS-122, STS-125, and STS-129). The SODB limit sets the maximum acceptable GGVM temperature for restarting an APU.

The two tables provide data on the run times and the fuel consumption.

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)	00:19:54	00:05:09	01:02:38	01:27:41
2 (403)	00:20:18	00:00:00	01:28:33	01:48:51
3 (408)	00:20:39	00:00:00	01:03:02	01:23:41

APU FUEL CONSUMPTION

APU (S/N)	Ascent, lb	FCS Checkout, lb	Entry, lb	Total, lb
1 (310)	48	16	117	181
2 (403)	52	0	158	210
3 (408)	53	0	130	183

Hydraulics/Water Spray Boiler System

The Hydraulic/Water Spray Boiler (HYD/WSB) system performance was nominal during all phases of the mission. No IFAs were identified from the flight data and the post-mission analysis.

All three WSB system cores were loaded with approximately 5.0 lb of the additive mixture (53-percent water; 47-percent Propylene Glycol Monomethyl Ether (PGME). The initial PGME/Water Tank loading for all WSBs was approximately 133.8 lb. Nominal WSB performance was observed on all three systems during ascent. WSB data for the ascent phase is shown in the following table.

WSB PERFORMANCE DATA DURING ASCENT

WSB	Spray Start Temp (°F)	Spray Start Time	Steady State Temp (°F)	PGME/H2O Usage (lb)
System 1	243	055/22:02:12	249	2.2
System 2	259	055/22:02:34	257	2.8
System 3	257	055/22:02:35	253	3.4

2.0 THE WSB STEAM VENT HEATERS WERE POWERED ON IN PREPARATION FOR LANDING AND THE VENT TEMPERATURES INCREASED ABOVE THE OFF-SCALE LOW LIMIT OF 122 °F BEGINNING AT 068/12:20:10 GMT (12/14:26:46 MET) ON SYSTEM 2. THE PORT AND STARBOARD MLG BRAKE-LINE HEATERS WERE ACTIVATED ON ALL THREE SYSTEMS IN PREPARATION FOR ENTRY AT 068/13:46:40 GMT (12/15:53:16 MET). ALL HEATERS FUNCTIONED NOMINALLY. THE FOLLOWING TABLE SHOWS WSB DATA DURING THE ENTRY PHASE.

WSB PERFORMANCE DATA DURING ENTRY

WSB	Spray Start Temp, °F	Time, GMT	Steady State Temp, °F	PGME/H ₂ O Usage, lb
System 1	241	068/16:20:01	247	22.2
System 2	259	068/15:54:11	255	35.6
System 3	257	068/16:20:46	255	22.2

Power Reactant Storage and Distribution System

The OV-103 Power Reactant Storage and Distribution (PRSD) system performance was nominal during STS-133 and no IFAs were identified from the mission data. Only four tank-sets were installed for this mission; the fifth tank-set was removed during the turnaround to provide increased launch performance.

The loading of the four PRSD tank sets was performed on February 22, 2011. The stabilization times were 053:22:11 GMT for the Hydrogen (H₂) tanks and 054:04:04 GMT for the Oxygen (O₂) tanks. The O₂ tank heaters were used in each tank to boil off 125 lb_m of oxygen to reduce the quantity to the target offload quantity. Eight pounds of O₂ had boiled off from the tanks from the end of the loading to the beginning of the offload. The heater on-times ranged from 90 min for tank 3 to 124 min for tank 2. The prelaunch reactant boiloff rate averaged 0.068 lb_m/hr/tank for H₂ and 0.23 lb_m/hr/tank for O₂. Eight days of pad-hold time was available.

The PRSD system supplied the fuel cells with 1886 lb_m of oxygen and 238 lb_m of hydrogen for the production of electrical energy. A 59-hour mission extension was possible at the 12.72 kW mission extension average power level with the reactants remaining at landing (wheel stop). The total oxygen supplied to Shuttle/ISS ECLSS was 326 lb_m from PRSD. A total of 110 lb of the oxygen supplied was for an oxygen tank-to-tank transfer to ISS. The H₂ tank 4 and O₂ tank 4 were depleted to residual quantities.

The following tables show the O₂ and H₂ tank quantities at loading, lift-off and landing.

PRSD TANK QUANTITIES

Oxygen

Oxygen	Tank 1, %	Tank 2, %	Tank 3, %	Tank 4, %	Total Mass, lb _m
Loaded	101.4	101.4	100.5	100.9	3157
Off-Loaded	97.0	96.6	97.0	96.6	3024
Launch	95.7	95.2	06.1	95.2	2985
Landing	36.1	34.8	22.1	5.9	772

Hydrogen

Hydrogen	Tank 1, %	Tank 2, %	Tank 3, %	Tank 4, %	Total Mass, lb _m
Loaded	102..3	101.9	102.3	101.9	375.7

Launch	98.8	97.9	98.8	98.8	362.8
Landing	43.1	47.5	44.0	1.5	125.2

Fuel Cell System

The overall performance of the OV-103 Fuel Cell system was nominal for STS-133, and no IFAs were identified from the mission data. The average electrical power level and load was 9.1 kW and 292 Amperes (A). The fuel cells produced 2124 lb_m of potable water and 2791 kWh of electrical energy from 1886 lb_m of oxygen and 238 lb_m of hydrogen.

The fuel cell startup was initiated on February 24, 2011, at 055/07:01:02 GMT and the start-up was completed at 055/09:04:30 GMT. Startup and prelaunch operations were nominal. Fuel cell operating times for the, which are the times accumulated on the fuel cells prelaunch, on-orbit, and postlanding, were 335:45:09 (hr:min:sec) for fuel cell 1, 335:29:11 for fuel cell 2, and 334:29:09 for fuel cell 3. The end-of-mission accumulated operating times for these fuel cells are 1936, 2000, and 1232 hours, respectively. Four fuel cell purges were performed and these purges occurred at approximately 17, 138, 251, and 299 hours MET, resulting in purge intervals of 121, 113, and 48 hr.

The actual fuel cell voltages (200 A load) at the end of the mission were 0.10 Volts (V) above the predicted for Fuel Cell 1, 0.12 V above predicted for fuel cell 2, and 0.14 V above predicted for Fuel Cell 3. The voltage margins above the minimum performance curves at 200 A at the end of the mission were 1.06 V above minimum for fuel cell 1, 0.90 V above minimum for fuel cell 2, and 1.06 V above minimum for fuel cell 3.

The prelaunch baseline Cell Performance Monitor (CPM) values for fuel cell 1 were 4, 2, and 4 mV, for fuel cell 2 were 2, 4, and 26 mV, and for fuel cell 3 were 6, 12, and 18 mV. These values were established at 055/13:45 GMT, approximately 3 hr after the completion of the Fuel Cell calibration requirement.

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 12 min beginning at 056/23:39:30 GMT (01/01:45:39 MET); there were no outliers.

Station-to-Shuttle Power Transfer System Operation

The Station-to-Shuttle Power Transfer System (SSPTS) performed satisfactorily and no IFAs were identified from the review and analysis of the data. The SSPTS supplied a total of 1443.9 kWh to the Orbiter during the 202.62 hr of operation. The average power transfer was 7.13 kWh.

STS-133 was the sixth flight of SSTPS on OV-103. The SSPTS transfers and converts power from the 120 Vdc International Space Station (ISS) electrical

system to supplement fuel cell power to the Orbiter's 28 Vdc buses. The system is activated after the Orbiter is docked to ISS and transfers up to about 8 kW of power from the ISS to the Orbiter.

Electrical Power Distribution and Control System

The Electrical Power Distribution and Control (EPDC) system performed nominally during all STS-133 mission phases and no IFAs were identified from the review and analysis of the data.

Orbiter Docking System

The Orbiter Docking System (ODS) performed satisfactorily, and no IFAs were identified from the review and analysis of the data.

The initial application of power to the ODS and ring extension were performed nominally during Flight Day (FD) 2 and the ODS was activated for 10 min 43 sec, and the avionics hardware was powered for 7 min 17 sec. The docking ring was extended to the normal 77.2 percent position at 056/23:31:03 GMT (01/01:57:39 GMT (01/01:57:39 MET). The system was ready for rendezvous and docking with the ISS.

The application of power for the docking activities was initiated at 057/18:47:17 GMT (01/21:54:04 MET), and the ODS was powered for 1 hr 24 min 17 sec with power to the avionics hardware for 1 hr 16 min 22 sec. The initial contact and capture of the ISS occurred at 057/19:14:20 GMT (01/21:40:56 MET). The total damping was 33 min 55 sec and performance of the "Disable and Release Dampers" procedure was necessary to ensure that any stuck dampers were disengaged. The start of drive-in function began at 057/19:17:16 GMT (01/21:43:52 MET), and was completed in 4 min 56 sec. The drive- start time for the Hooks-Close function was 057/20:01:56 GMT (01/22:28:32 MET). The capture latches were released in 2 sec. The final position for completion of docking was 056/20:05:40 GMT (01/22:32:16 MET), and the docking was complete.

In preparation for undocking, the ODS was activated at 066/11:36:15 GMT (10/14:02:51 MET). The undocking and separation from the ISS was completed satisfactorily at 066/12:00:12:10 GMT (10/14:06:46 MET). The ODS was powered for 42 min 32 sec with power to the avionics hardware for 28 min 04 sec for the undocking operations.

Life Support Systems

Atmospheric Revitalization Pressure Control System

The Atmospheric Revitalization Pressure Control System (ARPCS) performed nominally throughout the mission. After ascent, the Pressure Control System (PCS)

was configured to system 1. Although system 1 performed nominally, a complete checkout was not observed prior to 14.7-psi regulator configuration for docking. After undocking, the system 1 was configured and used for the remainder of the mission.

During STS-128 and STS-119, the PCS System 1 checkout was confirmed. During STS-133, at undocking, the cabin pressure was higher than the 14.7-psi regulator control pressure (approximately 14.92 psi) due to three late oxygen repressurizations. The cabin environment enabled a switch-over from Nitrogen (N₂) to Oxygen (O₂) late in the mission (approximately 12:14 MET), but did not allow for activation of a switch-over from O₂ to N₂.

There was no indication of a controller failure, only that the Partial Pressure Oxygen (PPO₂) sensor reading did not get high enough to activate a switch-over from O₂ to N₂. On a previous mission of this vehicle, the PPO₂ control was nominal.

There was one Orbiter-to-International Space Station (ISS) tank-to-tank transfer of N₂ on this mission that transferred 23 lb_m of N₂. Also, an Orbiter-to-ISS tank-to-tank transfer of O₂ on this mission that transferred 110 lb_m. There were four Orbiter/ISS stack N₂ repressurizations performed using the Orbiter PCS. Four O₂ repressurizations of the ISS were performed using Orbiter direct O₂ during docked operations.

Airlock System

The Airlock Systems performed nominally throughout the mission. and all of the no Orbiter-based EVAs during this mission. All water line and vestibule heaters were cycled on all systems. It was verified that all airlock structural heater measurements cycled with the exception of the internal temperature on lower bulkhead heater, which didn't cycle using main A power, but did cycle on Main B power.

There was no indication that the heater is failed, only that the thermostat did not get cold enough to activate the heater while on Main A. During recent missions when the environment was cold enough, the heater associated exhibited nominal activation on Main A.

Supply and Waste Water System

The Supply Water system performed nominally throughout the mission. The Supply water was managed with the use of the Flash Evaporator, water transfer to the ISS and the dump nozzle. The supply water dump-line temperature was maintained between 64 °F and 95 °F throughout the mission.

The Waste Water Management performed nominally throughout the mission and three Waste Management System dumps were performed successfully. The first

two dumps were performed as Simultaneous Supply and Waste water dumps. The third dump was followed by a Contingency Water Container (CWC) dump. The dump rate for the three dumps was a nominal average dump rate of 2.0 %/min (3.3 lb/min). The wastewater dump line temperature was maintained between 56 °F and 91 °F throughout the mission.

A total of 16 Contingency Water Container-Iodine (CWC-I), 1 CWC and 8 Portable Water Reservoirs (PWRs) were filled with supply water and transferred to the ISS, for a total of 1266.6 lb_m (608.1 lb_m from CWC-I's and 96.5 lb from CWC and 147.9 lb_m from PWRs).

Two CWCs were used to collect condensate. The Orbiter condensate CWC was used to collect 31.7 lb_m of condensate. It was transferred to the ISS to be processed by ECLSS Regenerator and returned to Shuttle empty. The ISS second CWC was used to collect approximately 50 lb_m of condensate. The estimate of the total condensate transferred was approximately 81.7 lb_m.

The quantity sensors in the supply water tanks A, B and D exhibited quantity dropouts throughout the mission. Such dropouts have been experienced in previous flights and the problem was caused by either contamination on the collector bar and/or surface defect on the collector bar, of the potentiometer which cause an intermittent break in continuity.

The Vacuum vent line temperature was maintained between 83°F and 59 °F.

Smoke Detection and Fire Suppression System

The Smoke Detection and Fire Suppression (SDFS) operated nominally with no issues. The Smoke detector self-test checks were performed. All Smoke detection A & B sensor circuits passed. Use of the Fire Suppression system was not required.

Active Thermal Control System

The Active Thermal Control System (ATCS) met all requirements for the mission. The radiators were not deployed this flight. Two IFAs were identified, and these IFAs are discussed in the following paragraphs.

The Carbon Dioxide (CO₂) level during the on-orbit mission phase was controlled below the flight-rule maximum limit of 5 mmHg. The highest level recorded was 4.39 mmHg at 059/00:59:59 GMT (003\03:06:35 MET). There were no limits exceeded during this flight.

The Ammonia Boiler System (ABS) tank A & B in-flight leak rate was calculated at approximately 0.02 lb_m/day for tank A and 0.02 lb_m/day for tank B with the required leak rate being not more than 0.05 lb_m/day.

During the Flight Day (FD) 2 post sleep period, the crew discovered water carryover (unprocessed condensate) at the air outlet of humidity separator B in the lower equipment bay (IFA STS-133-V-01). The crew estimated that ½ cup of water was cleaned up with a tool constructed of a similar design used in STS-125. A second inspection, conducted in the middle of the mission showed about ¼ cup of water at the air outlet and the water was subsequently cleaned up. The crew set up the condensate collection configuration ahead of schedule to help provide pressure relief in the lines downstream of the humidity separators. Subsequent inspections for the remainder of the flight showed no carryover.

The Ammonia Boiler System (ABS) B experienced an unexpected switchover from primary to secondary control (34 ± 3 °F nominal band) about 51 sec after activation, during post-landing operations (IFA STS-133-V-08). As a result, the Freon temperature at the FES outlet dropped from 60 °F to 38.3 °F while under Primary B control, then warmed up to 47 °F after switchover was initiated to Secondary B, and then finally stabilized down to 37.5 °F. The Freon ramp-down temperature performance was smooth on both controllers' operations, and the temperatures stabilized within the control band when the B Secondary was active. This suggests that both primary and secondary controller performances were good.

Data Processing System Hardware

The Data Processing System (DPS) performed satisfactorily throughout the mission. No IFAs were identified during the mission and the postflight evaluation.

Flight Software

The Primary Avionics Software System (PASS) and Backup Flight System (BFS) Flight Software (FSW) performed nominally.

The PASS flight software moded successfully from Major Mode (MM) 101 through MM106, and the BFS maintained tracking during the ascent profile. There were no unexpected DPS LRU internal errors or Fault Summary Messages logged or annunciated during ascent.

Multifunction Electronic Display System

The Multifunction Electronic Display System (MEDS) performed satisfactorily.

Displays and Controls System

The Display and Controls (D&C) system, including lighting, performed nominally throughout the STS-133 mission. No IFAs were identified from the flight data during the review and analysis.

Flight Control System

The Flight Controls System (FCS) performed nominally during the preflight, countdown, ascent, on-orbit, FCS checkout. Deorbit preparations, entry, landing and post-landing operations. One IFA was identified and the IFA is discussed in a later paragraph of this section of the report.

The FCS hardware/effector systems performed nominally during ascent through APU shutdown. At all times, the Solid Rocket Booster (SRB) Thrust Vector Controller (TVC), Main Propulsion System (MPS) TVC, and aerosurface actuators were positioned as commanded 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 SRB RGAs tracked one another normally, and there were no Spin Motor Rotation Detector (SMRD) dropouts. The outputs of the four Accelerometer Assemblies (AAs) also tracked one another normally. Reaction Jet Driver (RJD) operation was also normal with no thruster failures or other anomalies noted. Device Driver Unit (DDU) and controller operations were also nominal. Both the Rotational Hand Controller (RHC) and the Transitional Hand Controller (THC) were used and exhibited normal channel tracking.

The OMS TVC actuator rates were normal. Flight control actuator temperatures were also normal. Rudder/Speed Brake Power Drive Unit (RSB PDU) motor backdrive did not occur during hydraulic system shutdown.

The FCS hardware checkout in the OPS-8 mode performance was nominal. No anomalies were found in aerosurface drive data, individual channel test data, ORGA and AA test data, nose-wheel steering test data, and DDU/controller data. However, during the individual channel test, the Ascent Thrust Vector Control (ATVC) 1 failed to restart after the Flight Control Channel 1 switch was toggled from Auto to Override and back to Auto as part of the normal switch-throw sequence (IFA STS-133-V-07). The ATVC was later restored to normal function with one additional toggle of the switch.

The pre-OMS deorbit maneuver ignition 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 General Purpose Computer (GPC) commands. The entry hydraulic system temperatures were comparable to previous flights with aerosurface actuator temperatures being within the normal limits. The MPS TVC actuator performance was normal, with secondary differential pressures within threshold and TVC actuator positions and GPC commands following each other closely.

Air Data Transducer Assembly

The Air Data Transducer Assemblies (ADTAs) performed nominally during preflight, countdown, orbit, FCS checkout, deorbit preparation, entry, landing and post landing operations. No IFAs were identified from the review and analysis of the flight data.

All four ADTAs functioned nominally from power-on until nominal data loss at the T-minus-20-min transition on launch day. The ADTA self-test performed shortly after power-on was nominal. There is no insight into ADTA performance during the ascent phase until after the elevons are parked during the post-insertion period. All ADTA mode/status words were nominal during the elevon park activities. All 16 transducer outputs showed nominal responses.

Entry performance was nominal from de-orbit through wheels-stop. All 16 transducers tracked during the pre-probe deployment phase of entry. Air data probes were deployed at approximately Mach 4.7, and deployment timing was within specification at less than 15 sec. ADTA data were incorporated into Guidance, Navigation, and Control (GN&C) at about Mach 3.0. No ADTA dilemmas or Redundancy Management (RM) failures occurred during deployment through wheels-stop.

Inertial Measurement Unit and Star Tracker System

The Inertial Measurement Unit (IMU) system performed satisfactorily. During the On-Orbit operations, one adjustment of the on-board IMU accelerometer compensation values was performed on all three IMUs. Two adjustments of the IMU drift compensation values were also performed.

The Star Tracker (ST) system performed satisfactorily. The -Y ST star acquired a navigation star 271 times during the mission, and missed navigation stars 207 times during the mission. The missed stars are caused by bright objects, Orbiter attitudes, Extravehicular Activities (EVAs), docking orientation and Orbiter maneuvers.

The -Z ST performed satisfactorily and showed an even distribution of star acquisitions for both dim and bright stars. The -Z ST acquired a navigation star 76 times and missed the navigation star 60 times. The missed stars occurred during the rendezvous and docking activities with the International Space Station.

Global Positioning System Navigation

Overall, Global Positioning System (GPS) performance during STS-133 was nominal. The GPS was powered 5 hr and 3 min prior to launch. The GPS remained ON for the mission duration. During entry, after the Plasma period, a

Figure of Merit (FOM) value of 1 was achieved at about 169,000 ft altitude and the FOM remained at 1 through wheel-stop.

The GPS was incorporated into the Primary Avionics Navigation System navigation at approximately 146,000 ft altitude, immediately after the call to incorporate Tactical Air Navigation (TACAN) data. The effect of GPS incorporation was that the PASS and Backup Flight System (BFS) navigation state-vector residuals were reduced significantly, as expected, and the PASS navigation state-vector residuals remained consistently low from GPS incorporation down to the Microwave Landing System (MLS) incorporation at approximately 1,000 ft where the PASS automatically stops taking GPS updates per design. Likewise, the BFS navigation state-vector residuals remained consistently low from GPS incorporation all the way through rollout as designed since BFS does not process MLS.

Communications and Tracking System and Navigation Aids

The Communications and Tracking systems provided the necessary communications for the mission. One IFA was identified and that IFA is discussed in a later paragraph.

An issue arose during the attempts to improve the High Frequency (HF) performance and Power Amplifier (PA) -1 was used for a short period of time. After the event, initial data plots suggested a negative trend had started in the Travelling Wave Tube (TWT). However, later analysis indicated that this condition was caused by Radio Frequency (RF) leakage or reflections, both of which were causing an instrumentation-sensitivity issue. No apparent impact to operations or the Line Replaceable Unit (LRU) life-function-expectancy was identified. The primary suspects causing this condition were the PA circulator or a mismatch in the connection to the load. Both of these issues are PA internal components. This characteristic is believed to be a telemetry problem only, and no functional failure or IFA has occurred.

The S-band uplink was unstable and difficult to maintain during HF operations for all configurations (IFA STS-133-V-05). When this condition was most obvious it occurred with no significant reflected-power indications of instability. The primary suspect of this condition was the Diplexer Switch Assembly of the Preamplifier, which is a single point that is common to all configurations. Mission Operations plans required operations to remain in HF because of mutual interference that would arise if the Shuttle were to switch frequencies. The H-II Transfer Vehicle (HTV) was docked in a operation- configuration that required the use of their Proximity transceivers as long as Shuttle operations could function with the periods of interruption of uplink voice and commands. As soon as the International Space Station (ISS) configuration allowed, the switch was made to Low Frequency (LF), which was used for the remainder of the mission. The Ku-Band provided redundancy while on orbit and S-Band utilizing Ground Stations can be used during entry. All possible configuration changes were attempted without improvement.

This problem remained open until post-mission evaluation/resolution could be considered. Later Orbiter Project Office (OPO) discussions and both Problem Resolution Teams (PRTs) concluded that no post-mission testing would be required because STS-133 was the last flight of the OV-103 vehicle.

The Navigation Aids (NAV AIDS) successfully completed the post-mission data analysis, which showed nominal performance. In addition, S-Band system 1 was in operation for 30 hr 00min, which satisfied the intent of the requirement to operate the S-Band backup string/frequency continuously for 24 hr \pm 4 hr. Although the S-band normally expects to see one orbit of HF operation during the string-1 timeframe, that was not the case because those functions were proven earlier in the mission and the performance was known to be inadequate. On this basis, the HF portion was considered to have failed the requirement .

Operational Instrumentation/Modular Auxiliary Data System

The Operational Instrumentation (OI) and Modular Auxiliary Data System (MADS) performed satisfactorily. One IFA was identified during the mission and is discussed in later paragraph.

The OI system postlanding data showed the Auxiliary Power Unit (APU) 3 Gas Generator (GG) injector temperature reading took a step-drop of 151 °F for approximately one minute and returned to normal. Flight rationale exists for the failure modes that can cause this signature. No postflight testing will be performed since this is the last flight of this vehicle.

The MADS Pulse Code Modulation (PCM) data on the Solid State Recorder (SSR) was dumped during the mission. Data reviews during the mission and post-mission period identified no problems

The MADS data showed erratic data during ascent (IFA STS-133-V-02) and caused no impact to the mission. No post-flight testing is required as this vehicle will not be flown again.

Mechanical and Hatches System

All mechanical and hatch systems performed satisfactorily during the prelaunch, on-orbit, preparations for entry, entry and post-landing. No IFAs were identified during the review and analysis of the flight data.

Landing and Deceleration System

The Landing System performance at Kennedy Space Center (KSC) was nominal through roll out. This assessment includes all events from landing gear deployment, main gear touchdown, nose gear touchdown, drag chute deployment and brake/deceleration. It was the first flight of the nose landing gear tires. They

were in good condition and performed nominally. The main landing gear tires appeared nominal. Normal appearance of tread-cord materials on areas of the tire's surface, which is a known expected condition, is a characteristic of the new tire design. Parachute deployment and jettison occurred nominally. No unexpected affects of performance of the drag chute occurred.

The landing parameters for the mission are shown in the following table.

LANDING PARAMETERS

Parameter	From threshold, ft	Time from MLG touchdown, sec	Speed, keas ^a	Speed, kgs	Sink rate, ft/sec	Pitch rate, deg/sec
Main Landing gear touchdown	2504.4	0.0	196.3	179.7	-1.1	
Drag Chute Deployment	3442	3.15	183.1	168.0		
Drag Chute Disreef	4880	8.48	161.2	145.3		
Nose Landing Gear Touchdown	5420.6	10.97	140.9	128.9		-5.28
Drag Chute Jettison	8507	32.03	75.8	58.1		
Brakes On	8641	33.35	74.4	56.6		
Wheels Stop	9713.8	55.46	0	0		
Parameter			Data			
Brake Initiation Speed, keas			74.4			
Brake On Time, sec			22.1			
Rollout Distance, ft			7209.1			
Rollout Time, sec			55.46			
Runway Location, Surface and Degrees			KSC/15 (concrete)			
Orbiter Weight at Landing, lb			205,021.5			
Parameter		Maximum Brake Pressure, psia		Total Brake Energy, Mft/lb		
Left inboard		870.9		6.21		
Left outboard		833.3		5.66		
Right inboard		849.0		7.84		
Right outboard		714.3		5.06		

^aKnots equivalent air speed

Aerothermodynamics, Integrated Heating and Interfaces

The overall Orbiter Thermal Protection System (TPS) performed satisfactorily. The lower structural temperature data indicated normal entry heating. The recorded structure temperatures were within the flight experience of the OV-103 vehicle. From the MADS surface thermocouples, Boundary Layer Transition (BLT) was symmetric and occurred at Body Point (BP) 1602 around Mach 7.8 or 1222 sec after Entry Interface (EI) based on the pre-flight End of Mission (EOM) trajectory. For the area inside the turbulent wedge of the BLT FE, the inception transition

occurred around Mach 18.5 or 882 sec after EI. The peak temperature on the protuberance was around 2290 °F.

The post-landing runway report and post-flight inspection pictures indicated that overall the vehicle had only minor TPS damages. Most of the damages noted during the on-orbit inspection appeared to be in the same condition as the on-orbit images, except the Right-Hand (RH) Forward Reaction Control System (FRCS) F4R thruster thermal barrier patch was found torn open and the inner material was exposed and had charring. A protruding gap filler was found during the on-orbit inspection at the RH Main Landing Gear Door (MLGD) was still present on the runway. The protrusion was measured 0.1-in. at the highest point. The BLT flight experiment was still in good condition with some glazing on the tip of the protuberance, but no visual tile slumping appeared. The catalytic coating flight experiment looked good except missing some coating from the forward outboard edge.

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)	137.7	126.7
Lower fuselage forward left-hand (B2)	174.5	168.6
Lower fuselage forward mid left-hand (B3)	153.5	167.8
Lower fuselage mid center (B4)	150.8	155
Lower fuselage mid aft center (B5)	171.9	168.5
Lower fuselage aft center (B6)	171.9	148.1
Left-wing center (LW)	122	131.3
Right wing center (RW)	119.4	131.2
Port side FRCS forward (P1)	174.9	132.8
Port side fuselage forward center (P2)	119.4	95.8
Port side fuselage forward mid center (P3)	103.8	90.2
Port side fuselage mid aft center (P4)	83	66.9
Port side fuselage aft center (P5)	09.6	61.9
Starboard side FRCS Forward (S1)	174.5	135.3
Starboard side fuselage forward center (S2)	143	131.9
Starboard side fuselage forward mid center (S3)	111.6	82.6
Starboard side fuselage mid-aft center (S4)	83	94.7
Starboard side fuselage aft center (S5)	88.2	74.6
Left-hand OMS pod side forward (LP)	83	56.6
Right-hand OMS pod side forward (RP)	67.5 ^a	41.1 ^a
Lower body flap center	98.6	77.3
Right-hand PLBD forward	75.3 ^a	117.4

ENTRY MAXIMUM TEMPERATURE AND MAXIMUM TEMPERATURE RISE DATA (Concluded)

Thermal Sensor Location	Maximum Temperature, °F	Maximum Temperature Rise, °F
Left-hand PLBD forward	75.3 ^a	102.3 ^a
Right-hand PLBD aft	83.0 ^a	112.6 ^a
Left-hand PLBD aft	83	97.4
Right wing upper center	98.6	115.5
Left wing upper center	103.8 ^a	113.1 ^a
Forward RCS center	103.8 ^a	82.5
Forward Fuselage Upper Center	77.9	84.6

Notes

^a Maximum temperature occurred 30 min after wheel stop.

Thermal Control System

The Passive Thermal Control System (TCS) performed satisfactorily in the benign, low-beta angle environment. All PCS temperatures were maintained within acceptable limits. No postflight actions or IFA's were identified from the review of

Thermal Protection System and Post-Landing Assessment

Post-Landing Assessment

The final debris-related tile damage numbers are shown in the following table.

SUMMARY OF IMPACT SITES FOR EACH ORBITER SURFACE

Orbiter Surface	Impacts greater than 1 in.	Total impacts
Lower surface	5	46
Upper Surface/Window	1	7
Right OMS pod	0	2
Left OMS pod	0	1
Totals	6	56

Tile and Blanket Flight Assessment

The overall performance of the TPS was satisfactory and one IFA was identified in the review and analysis of the in-flight imagery.

Following the review of the FD 2 and FD 3 imagery, the DAT determined that there were no requirements for a focused inspection. Eight items were identified in-flight which exceeded pre-defined screening criteria and were entered into the TIIMS Database. All items were cleared using standard procedures/tools.

1. D-133-AFD-540-001 – Pillow gap filler sleeving is protruding and laying over on the adjacent tile.
2. D-133-AFD-540-002 – Tile substrate is exposed.
3. D-133-AFD-550-001 – Blanket patch repair is lifted (IFA STS-133-V-
4. D-133-LDRI-600_4-001 – Tile substrate is exposed. Damage was adjacent to RCC panel #22.
5. D-133-RPM-560-001 – Patch repair appears to be lifted on thruster thermal barrier. The protrusion measurement was 0.49 in +/- 0.2 in.
6. D-133-RPM-560-002 – Donut around blanket insert appeared to be lifted.
7. D-133-RPM-600_1-001 – Ames gap filler protruding on starboard MLGD. Protrusion measurement was 0.29 in +/- 0.1 in utilizing additional imagery. Overall length of gap filler is 2.81 in +/- 0.1 in.
8. D-133-RPM-700_2-001 – Tile substrate was exposed. Damage was on small footprint SIP tile.

There was tile damage on the Right-Hand (RH) nose landing gear door that appears to be in the area of the foam hit seen at 3:51 sec into launch.

There was a broken edge tile on the underside of the rudder speed brake. It is possible that it was drag chute induced.

The External Tank (ET) Liquid Hydrogen (LH₂) umbilical has a wad of dark brown tape on the forward edge of the umbilical periphery. It appears to be darker than the orange tape used on the purge barrier.

There was thermal barrier protruding between the tiles on the leading edge of the RH Orbital Maneuvering System (OMS) pod.

RCC Flight Assessment

The Reinforced Carbon-Carbon (RCC) performed satisfactorily. The Orbiter nose cap appeared to be in nominal condition, as well as Left-Hand (LH) and RH RCC panels.

Windows

The results of the post-flight inspection of the Orbiter Windows are delineated in the following items:

1. Window 1 had 5 defects (hypervelocity-type impacts) and as a result was scrap for orbital flight, but usable for ferry to its final location.
2. Window 2 had one defect and it remains acceptable for flight.
3. Window 3 has been removed, but the detailed inspection has not been completed.
4. Window 4 has been removed, but the detailed inspection has not been completed.

5. Window 5 has been removed, but the detailed inspection has not been completed.
6. Window 6 had 6 defects (hypervelocity-type impacts) and as a result was scrap for orbital flight, but usable for ferry to its final location.
7. Window 7 had 1 defect and it remains acceptable for flight.
8. Window 8 inspection data is not available at the time when this item was written.
9. Window 11 inspection data showed no reportable defects and is acceptable for flight.

Waste Collection System

The Waste Collection System operated satisfactorily.

EXTRAVEHICULAR ACTIVITY

Two Extravehicular Activities (EVAs) were performed nominally by Crew Members Steve Bowen (EV1) and Alvin Drew (EV2) on the International Space Station (ISS) during the STS-133/ULF5 mission. All planned activities plus numerous get-ahead tasks were completed during the two EVAs, which lasted a total of 13 hrs and 0 min.

FIRST EXTRAVEHICULAR ACTIVITY

The first Extravehicular Activity (EVA) was performed on Flight Day (FD) 5, February 28, 2011, and all planned activities were completed during the 6 hr 46 min EVA.

The first task performed was the installation of a extension-cable between a Node 1 connector (J612) and the supplementary Airlock (A/L) power heating cable. This cable was installed to provide future EVA access to the connector before the berthing of the Permanent Multipurpose Module (PMM), which will block access to this connector.

The EVA crewmembers then began relocating the Pump Module that was stowed on the Payload Orbital Replacement Unit (ORU) Accommodation (POA) to prepare it for a return to Earth on the STS-134 mission. The EV1 crewmember performed the relocation of the Pump Module from the POA to the External Stowage Platform 2 (ESP2) while on the Space Station Remote Manipulator System (SSRMS).

The EV2 crewmember retrieved the Ammonia Vent Tool equipment from the Port Crew and Equipment Translation Aid (CETA) Cart and pre-installed the venting tools on External Stowage Platform 2 (ESP2) and the U. S. Laboratory to prepare for a venting operation to be performed during the second EVA. As the EV1 crewmember was finishing at the SSRMS worksite, the EV2 crewmember relocated an Articulating Portable Foot Restraint (APFR) to Z1, relocated a tool stanchion on Z1, opened two Multilayer Insulation (MLI) flaps on two Remote Power Control Modules (RPCMs) and returned the APFR (no. 4) to the Airlock so that a heat-shield removal maintenance task could be performed on the APFR during FD 6.

Both crew members then rendezvoused at S3 to install a wedge on the mounting plate of the Camera Position (CP) 3 camera stanchion so that the camera stanchion would be oriented in a manner that would not interfere with robotics operations to access a Cargo Transport Container on the Express Logistics Carrier (ELC4).

Both crew members then translated to the S3 Solar Alpha Rotary Joint (SARJ) and installed two starboard Rail Stubs for the final task of the EVA. This will enable the Mobile Transporter (MT) to translate to worksite 1 with a starboard CETA cart

installed, since previously the CETA cart would have to be relocated to the port side to allow the MT access to worksite 1.

The EVA glove inspections and post-EVA photographs indicated no glove damage had been incurred during the first EVA.

SECOND EXTRAVEHICULAR ACTIVITY

The second EVA was performed on FD 7, March 2, 2011, and all planned activities were completed during the 6 hr 14 min EVA.

The EV2 crewmember performed the first task, which was to return APFR no. 4 back to service after removing the heat shield during an Intra-Vehicular Activity (IVA). The APFR was installed at the starboard airlock toolbox. The EV2 crewmember then performed the ammonia venting task to vent the ammonia from the Pump Module in preparation for returning the PM to Earth on STS-134. After venting, the EV2 crewmember returned the ammonia venting tools to their permanent stowage location on the US Airlock.

The EV1 crewmember translated to the Columbus Module to retrieve the Light Weight Adapter Plate Assembly (LWAPA). While secured to the SSRMS, EV2 crewmember relocated the LWAPA from the Columbus module and secured the LWAPA in the Shuttle payload bay for the return to the Earth.

The EV1 crewmember installed a Camera Light Assembly (CLA) cover on Camera Light Pan-tilt Assembly (CLPA) prior to the EVA and installed the integrated CLPA no. 1 assembly on the Special Purpose Dexterous Manipulator (SPDM). The EV1 crewmember then installed the protective lens covers on the SSRMS Latching End Effector "A" elbow CLPA, SPDM CLPA no. 2 and the POA CLA. The EV1 crewmember completed the SPDM tasks by removing the Electronics Platform no. 1 MLI.

The EV2 crewmember removed the MLI from the Expedite the Processing of Experiments to Space Station (EXPRESS) Pallet Controller Assembly on EXPRESS Logistics Carrier 4 and the MLI from the Node 3 nadir Pressurized Mating Adapter (PMA) 3 interface. The EV2 crewmember also installed the P3 CETA light, closed the Radiator Beam Valve Module thermal bootie and successfully performed the trouble shooting on the inboard and outboard Radiator Stowage Beams, which left them in a fully secured state on the P1 Truss.

Five get-ahead tasks were performed by the crew after the completion of all the planned tasks. The EV2 crewmember re-aligned the sun-screen shade on the CP3 camera and relocated an APFR from the starboard CETA Cart to the Port CETA Cart Worksite Interface Fixture (WIF) no. 2.

At approximately 5 hr 30 min into the EVA, the helmet light and helmet camera assembly disengaged from the EV2's helmet. The light/camera assembly was still connected to the crewmember by the power/video cable; a tether was added to provide a secondary securing mechanism to ensure that the unit did not become totally detached and lost. Due to the loss of the light/camera assembly, the EV2 crewmember was unable to reconfigure the Port CETA, which would have been his last get-ahead task for the EVA. After securing the light/camera assembly, the EV2 crewmember immediately returned to the airlock while the EV1 crewmember completed his last get-ahead task by relocating the Strela adapter (Russian Crane for ISS).

The EVA glove inspections and post-EVA photographs indicated no glove damage had been incurred during the second EVA.

REMOTE MANIPULATOR SYSTEM AND ORBITER BOOM SENSOR SYSTEM

The Shuttle Remote Manipulator System (SRMS) performed nominally during the mission.

The SRMS on-orbit Initialization began at 056/00:39 GMT [00/02:45 (Mission Elapsed Time (MET))] on Flight Day (FD) 1. The port and starboard Manipulator Positioning Mechanisms (MPMs) were deployed and the SRMS shoulder brace was released. The SRMS power-up began at 056/01:37 GMT (00/03:36 MET) and was completed 13 min later. The SRMS checkout began at 056/01:59 GMT (00/04:05 MET) and was completed 45 min later. Following the SRMS checkout, the crew performed a payload bay survey before maneuvering to the Pre-Cradle Position.

On FD 2, the SRMS grappled the Orbiter Boom Sensor System (OBSS) at 056/15:15 GMT (00/17:21 MET) and maneuvered it to the OBSS Hover Position 20 min later. After unberthing the OBSS, the SRMS maneuvered to the Flat-Field position at 056/16:14 GMT (00/18:20 MET). The Starboard survey began at 056/16:52 GMT (00/18:58 MET) and was completed at 056/18:23 GMT (00/20:29 MET). The Nose Cap Reinforced Carbon-Carbon (RCC) survey began at 056/18:48 GMT (00/20:54 MET) and was completed at 056/19:22 GMT (00/21:28 MET). The Port Survey began at 056/20:10 GMT (00/22:16 MET) and was completed at 056/21:38 GMT (00/23:44 MET). The SRMS maneuvered to the OBSS Hover position at 056/22:06 GMT (01/00:12 MET). The OBSS was berthed in the starboard MPMs 23 min later, and the SRMS was maneuvered to the Pre-Cradle Position.

On Flight Day 3, Discovery docked with the International Space Station (ISS) with the SRMS in the Pre-Cradle position. After docking, the SRMS was maneuvered to the Express Logistics Carrier (ELC) 4 Unberth Viewing position at 057/20:49 GMT (01/22:55 MET). The SRMS then began operations for the ELC4 handoff at 057/23:54 GMT (02/02:00 MET), and successfully grappled the ELC4 at 058/00:08 GMT (02/02:14 MET). Then the SRMS maneuvered to the ELC4 Hand-Back position at 058/01:07 GMT (02/03:13 MET). After grapple by the SSRMS, the ELC4 was released by the SRMS at 058/02:08 GMT (02/14:36 MET). The SRMS arrived at the OBSS Handoff Pre-grapple Position at 058/03:25 GMT (02/05:31 MET) where it remained overnight.

On FD 4, The Space Station Remote Manipulator System (SSRMS) began the OBSS unberthing at 058/15:00 GMT (02/17:06 MET). Shortly after, at 058/15:48 GMT (02/17:54 MET), the SRMS grappled the OBSS while in the handoff position. The SSRMS then released the OBSS at 058/16:04 GMT (02/18:10 MET). The SRMS reached the Permanent Multipurpose Module (PMM) Install-Viewing position at 058/16:18 GMT (02/18:24 MET), where it remained until FD 7.

No SRMS activities were scheduled on FD 5 and 6.

On FD 7, the SRMS maneuvered the OBSS to the PPM Vent Clear Position at 061/12:40 GMT (05/14:46 MET). At 061/16:30 GMT (05/18:36 MET), after the venting was completed, the SRMS/OBSS was maneuvered to the Second Extravehicular Activity (EVA) Viewing position to support the remainder of the EVA. Once the EVA was complete, the SRMS/OBSS was maneuvered to the OBSS Undocking position at 061/22:12 GMT (06/00:16 MET), where it remained until FD 12.

No SRMS operations were scheduled for FD 8 to 1.

On FD 12, the Late Inspection of the Shuttle Starboard Wing RCC began at 066/16:53 GMT (10/18:59 MET) and was completed at 066/17:52 GMT (10/19:58 MET). The Late Inspection of the Nose Cap began at 066/18:21 GMT (10/20:27 MET) and was completed at 066/18:52 GMT (10/20:58 MET). The Port Wing RCC survey began at 066/19:15 GMT (10/21:21 MET) was completed at 066/20:19 GMT (10/22:25 MET). The OBSS was berthed at 066/21:11 GMT (10/23:17 MET) and the SRMS was cradled at 066/21:37 GMT (10/23:43 MET). No more SRMS operations were planned for the remainder of the mission.

WING LEADING EDGE IMPACT DETECTION SYSTEM

ASCENT MONITORING

The Wing Leading Edge Impact Detection System (WLE IDS) ascent summary data downloads began once the crew had the system setup. All requested ascent summary data and 5 half-sec windows of raw data were received. Analysis of the ascent data was completed, and the findings showed two possible impact indications over 1.0 Grms.

All units triggered and began recording data on Space Shuttle Main Engine (SSME) ignition within 0.15 seconds of each other. The Mission Elapsed Time was set to 9.2 sec behind Data Elapsed Time (MET = DET - 9.2 sec) for both the port and starboard wing units.

The two possible impact cases that were above 1.0 Grms (both on the port wing) were found and reported during the flight. The damage likelihood for these indications was less than 1/1000 (Risk Category I). Post-flight analysis of the data found no additional indications above 1.0 Grms. All reportable ascent indications are listed in the following table.

The indication that occurred at 115.1 sec MET (Case A1) was reported as a potential Damage Likelihood Category III indication during the mission at the Flight Day (FD) 2 Orbiter Project Office (OPO). This is because it was not confirmed to be an impact to the lower surface of the Reinforced Carbon-Carbon (RCC), for which the Damage Likelihood would be Category I. The ascent impact location analysis in combination with corroborating imagery from the Reusable Solid Rocket Booster (RSRB) cameras that were made available on FD 6 provided the confidence to associate this indication with the lower surface of Panel 8.

SUSPECTED ASCENT DEBRIS IMPACTS ABOVE 1.0 GRMS

Times		Location			Magnitude		Criteria						Impact		Damage Likelihood
MET	DET	Wing	RCC	Unit-Channel	Max Grms	Max G	Transient	Non-Mission	Shock	Damping	Spectral	Multi Sensor	In-Flight	Post-flight	Category
106.6	115.9	Stbd	10	1057-J2	1.01	4.07	+	+	+	+	+	+	P	P	I
115.1	124.3	Stbd	8	1048-J1	1.84	13.6	+	+	+	+	+	+	P	P	I

Note: 1. Data Analysis Findings: P =Possible
 2. Assessed from Data : I= <1/1000

ORBIT MONITORING

For this mission, the WLE IDS recorded 44 triggers, none of which satisfied all impact criteria. Analysis of the 44 triggers resulted in zero possible or questionable MM/OD impact indications. Review of post-flight data revealed zero additional on-orbit indications.

SUSPECTED MM/OD IMPACTS

GMT ^a	Location			Magnitude	Criteria					Impact ^b	
	Wing	RCC	Unit-Channel	Measured G Peak	Transient	Non-Mission	Spectral	Shock	Multi-Sensor	In-Flt	Post-Flt
056/22:20:30	Port	19/20	1022-J3	0.41	+	o	-	-	-	A	A

^aAdjusted to correct for known differences between the onboard laptop and actual GMT times.

^bA = Anomaly

CONCLUSIONS

The WLE IDS performed satisfactorily for ascent impact monitoring. During the mission, two ascent impact indications above the 1.0 Grms threshold were reported with damage likelihoods of Category I (<1/1000). Post-flight review of the data found no additional ascent indications over 1.0 Grms.

No possible MM/OD impact indications were detected and reported during flight.

Based on the ascent and on-orbit findings from all systems, including WLE IDS, the Orbiter Project Office (OPO) recommended that a focused WLE RCC inspection was not required. Ascent Case A1 was corroborated with RSRB imagery on FD 6. The late mission Orbiter Boom Sensor System (OBSS) survey visually inspected the Wing Leading Edge (WLE) after the Orbiter undocked from the International Space Station (ISS). No critical damage was found.

**GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW
EQUIPMENT**

The overall performance of the Government Furnished Equipment (GFE) and Flight Crew Equipment (FCE) was satisfactory.

POST-LAUNCH PAD INSPECTION

The post launch inspection of the Main Launch Platform (MLP) -3 Pad A Fixed Service Structure (FSS) and Pad A apron/infield/flame trench was conducted on February 24, 2011. The inspection proceeded quickly while Safing Teams secured the Pad. The entire Pad, FSS and MLP were inspected. A piece of Reusable Solid Rocket Booster (RSRB) throat-plug material was the only flight hardware found during the inspection.

The Orbiter lift-off lateral acceleration data indicated a maximum of 0.11g. Hold-down stud hang-ups are typically noted with lateral accelerations above 0.19g.

RSRB HOLD-DOWN POSTS (HDP) INSPECTION

HDP No. 1 – The EA934 poured sidewalls were nominal with moderate pitting, which was acceptable. A Phenolic shim had evidence of heavy blistering and erosion. A total of 18 in. of one firing line was intact. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down.

HDP No. 2 – The EA934 poured sidewalls were nominal with minor pitting, which was acceptable. Delamination was seen on the Southwest poured EA-934 sidewall. The Phenolic shim was nominal. No evidence of either firing line was present. Approximately 3-ft of Range Safety System (RSS) cable remained. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down.

HDP No. 3 – The inspection showed nominal indications of erosion on the Room Temperature Vulcanizing (RTV) -coated blast shield with proper closure.

HDP No. 4 – The inspection showed nominal indications of erosion on the RTV-coated blast shield with proper closure.

HDP No. 5 – The EA934 poured sidewalls were nominal with minor pitting, which was acceptable. The Phenolic shim had a 18-in. by 1 in. blister with missing material. Both firing lines were missing. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down.

HDP No. 6 – The EA934 poured sidewalls were nominal with minor pitting, which was acceptable. The Phenolic shim was nominal. A total of 10 in. of one firing line was intact. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down.

HDP No. 7 – The inspection showed nominal indications of erosion on the RTV-coated blast shield with proper closure.

HDP No. 8 – The inspection showed nominal indications of erosion on the RTV-coated blast shield with proper closure, and the RSS cable was missing.

GN2 PURGE LINES INSPECTION

The Left-Hand (LH) probe was erect and slightly bent Southwest. Protective tape was present with no exposed braiding. No O-ring was present.

The Right Hand (RH) probe was erect and bent South. Protective tape was present with no exposed braiding. The O-ring was present.

SRB T-0 GCAS INSPECTION

1. The LH RSRB T-0 Ground Carrier Assemblies (GCAs) appeared to be in nominal condition with proper demate.
 - a. Several connector housings had broken sidewalls.
 - b. 1J1, 2J1, 3J1, and 4J1 pins and sockets were raised higher than nominal.
 - c. All four frangible bolt halves were present.
2. The RH SRB T-0 GCAs appeared to be in nominal condition with proper demate.
 - a. Several connector housings had broken sidewalls.
 - b. The 1J1, 3J1, and 4J1 pins and sockets were raised higher than nominal.
 - c. All four frangible bolt halves were present.

LO2 AND LH2 TAIL SERVICE MASTS INSPECTION

Both the Liquid Oxygen (LO₂) and Liquid Hydrogen (LH₂) Tail Service Masts (TSMs) appeared to be undamaged and both bonnets appeared to have closed properly.

MLP DECK INSPECTION

The MLP deck was in nominal condition. Typical blast erosion was observed in and around the RSRB flame holes.

ORBITER ACCESS ARM (195-FT LEVEL) INSPECTION

1. The Orbiter Access Arm (OAA) was retracted and secured with no apparent damage.
2. All slide-wire baskets remained secured at 195-ft level with no evidence of damage.
3. The no. 2 slide-wire basket had a pip-pin that was not fully engaged.

GASEOUS HYDROGEN VENT LINE GROUND UMBILICAL CARRIER PLATE (215-FT LEVEL) INSPECTION

1. The Gaseous Hydrogen (GH₂) vent line was latched on the eighth tooth (of eight) on the latching mechanism.
2. The GH₂ vent line was latched nominally and had a nominal arresting cycle. The inspection of the Ground Umbilical Carrier Plate (GUCP) LH and RH pivot assemblies indicated a nominal separation.

3. The External Tank (ET) GUCP 7-in. GH_2 Quick-Disconnect (QD) probe was accessible for inspection and appeared to be undamaged.
4. Both the QD-poppet probe sealing surface and the poppet-valve assembly were in good condition.
5. The ET GUCP exhibited less than typical blast damage and the pyrotechnic bolt fired nominally.
6. The aluminized blanket on the 24-ft. flexible-line suffered blast damage.

GASEOUS OXYGEN VENT ARM (255-FT LEVEL) INSPECTION

The Gaseous Oxygen (GOX) vent arm and hood appeared undamaged. Hood windows and purge ducts appeared to be in nominal condition and the latch mechanism locked properly.

PAD FACILITY INSPECTION

Pad A appeared to be in very good condition and exceptionally clean.

NORTH RSRB FLAME-TRENCH INSPECTION

The NASA as well as the required contractor Flame-Trench Engineering personnel were present for the inspection and noted no Problem Report (PR) conditions existed.

DEBRIS ITEMS FOUND

1. Minor pieces of RSRB throat-plug material were found on the Pad surface.
2. Small pieces of Fondue Fyre were found on both East and West Pad surface area.
3. At the 115-ft level, a 6-in. piece of copper wire sheath was found on the west side as well as minor rust scale.
4. At the 135-ft level, rust-scale was found with paint chips on side 2 from the tool-boxes.
5. At the 75-ft. stairwell, a bracket was found.
6. At the 235-ft. level, a cable tray ribbing was found on the deck near side 4.
7. On the West Pad Surface, Aluminum-box covers were found.
8. At the 195-ft. level, an Oxygen (O_2) analyzer box was not fully secured, and large safety cabinet was not fully secured. Also, a miscellaneous box was found on north side and it was not fully secured. A washer was also found near elevator.
9. Multiple canister lights on FSS were non-functional and the bulbs were intact.
10. At the 175-ft level, a Firex box had opened.
11. On the East Side of the MLP, a LH_2 bellows-cover was separated.

LAUNCH PHOTOGRAPHY AND TELEVISION ANALYSIS

The launch photography provided excellent views of areas requested. One Reusable Solid Rocket Motor (RSRB) camera that was aimed at the External Tank (ET) did not record video of the thrust panel. However, the other five camera provided the expected video. The screening of the video and photography was completed satisfactorily.

VEHICLE OBSERVATIONS

The launch photography provided data for the evaluation by the Debris Assessment Team to determine the condition of the Thermal Protection System (TPS).

1. At 4.905 sec, lift-off debris was observed from the Fixed Service Structure (FSS). This debris was noted in the field-of-view prior to tower clear.
2. At 11.015 sec, a debris release was noted near the right-hand RSRB nozzle exit cone. The debris was observed falling aft.
3. At approximately 58 sec, debris was observed near the front of the Orbiter. The debris entered the field-of-view above and left of the Orbiter and did not impact the Orbiter.
4. At 112 sec, a debris release was observed from the inboard side of the Ice Frost Ramp (IFR) at approximately Xt 676 on the LO₂ tank. The time of release is estimated based on the RSRB separation. The debris appears to travel down the starboard side of the Orbiter nose and out of the field-of-view.
5. At 112.5 sec, multiple pieces of debris was observed outboard of the LO₂ feedline along the cable tray. Source of the debris was forward of the camera. The debris may correlate to the TPS loss at approximately 112 sec.
6. At approximately 115 sec, debris appears to impact the starboard wind Reinforced Carbon-Carbon (RCC) leading edge panel. This event may correlate to the Wing Leading Edge Impact Detection System (WLE IDS) indication at 115.1 sec on the starboard RCC panel 8.
7. At approximately 128 sec, a single piece of debris appeared to impact the starboard wing and fall aft during RSRB separation.
8. At approximately 129 sec, ET TPS loss was noted on the LH₂ tank acreage above EB-8.
9. At 220.9 sec, debris appeared to impact the Orbiter forward of the bipod and then travelled aft of the of the vehicle. The debris originated from forward of the field-of-view of the camera.
10. At 223.2 sec, Multiple debris objects were observed near the Bipod and falling aft. One of the debris objects appeared to impact the vehicle. Another appeared to travel aft through the bipod legs.
11. External Tank (ET) TPS had a loss at the base of the feedline bracket. The loss was noted on the inboard side of the Liquid Oxygen (LO₂) feedline bracket at -1377. The time of occurrence has not been identified.

12. The photography showed that a piece of ET TPS was missing on the starboard Bipod closeout.

LAUNCH PAD OBSERVATIONS

1. At minus 2.543 sec, debris was observed exiting from the Firex Nozzle on the LO₂ TSM. Facility debris observed exiting from the Firex nozzle.
2. At minus 3.461 sec, lift-off debris was observed near the LO₂ TSM. Facility rust falls from the LO₂ TSM.
3. At minus 4.307 sec, lift-off debris was observed to fall from the Liquid Hydrogen (LH₂) Tail Service Mast (TSM) during the Space Shuttle Main Engine (SSME) ignition. Facility rust falls from the TSM after SSME ignition.

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APPENDIX A **STS-133 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	055/21:48:34.797 055/21:48:36.331 055/21:48:37.704
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	055/21:52:56.016 055/21:52:56.181 055/21:52:56.341 055/21:52:56.916
Main Engine Start	SSME-3 Start Command Accepted SSME-2 Start Command Accepted SSME-1 Start Command Accepted	055/21:53:17.464 055/21:53:17.571 055/21:53:17.702
SRB Ignition	SRB Ignition Command	055/21:53:24.016
Throttle Up 104.5 Percent	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/21:53:28.378 055/21:53:28.381 055/21:53:28.407
Throttle Down to 72 Percent	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/21:54:04.699 055/21:54:04.701 055/21:54:04.728
Maximum Dynamic Pressure (Max Q)	Derived Ascent Dynamic Pressure	055/21:54:16
Throttle Up to 104.5 Percent	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/21:54:17.819 055/21:54:17.822 055/21:54:17.848
Both SRMs at 50 psi	LH SRM Chamber Pressure RH SRM Chamber Pressure	055/21:55:25.456 055/21:55:26.376
End SRM Action	LH SRM Chamber Pressure RH SRM Chamber Pressure	055/21:55:27.816 055/21:55:28.216
SRB Separation Command	SRB Separation Command Flag	055/21:55:31
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	055/21:55:30.980 055/21:55:30.980 055/21:55:31.020 055/21:55:31.020
OMS Assist Ignition	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	055/21:55:41.3 055/21:55:41.3
OMS Assist Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	055/21:58:13.7 055/21:58:13.7
Throttle Down for 3g	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/22:00:46.145 055/22:00:46.152 055/22:00:46.176
3G Acceleration	Total Load Factor (g)	055/22:01:39.9
Throttle down to 67 percent for Cutoff	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/22:01:40.866 055/22:01:40.874 055/22:01:40.897
SSME Shutdown	SSME-1 Command Accepted SSME-3 Command Accepted SSME-2 Command Accepted	055/22:01:47.386 055/22:01:47.394 055/22:01:47.417
Main Engine Cutoff (MECO)	MECO Command Flag MECO Confirmed Flag	055/22:01:48 055/22:01:48
ET Separation	ET Separation Command Flag	055/22:02:09

APPENDIX A

STS-133 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	055/22:08:25.877 055/22:08:52.071 055/22:09:16.104
OMS 1 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	N/A
OMS 1 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	N/A
OMS 2 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	055/22:31:54.1 055/22:31:54.3
OMS 2 Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	055/22:32:57.9 055/22:32:57.9
Payload Bay Doors Open	Right Payload Bay Door Open 1 Left Payload Bay Door Open 1	055/23:28:12 055/23:29:32
OMS 3 Ignition	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	056/01:28:55.6 056/01:28:55.7
OMS 3 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	056/01:29:24.7 056/01:29:24.8
OMS 4 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	056/14:43:53.0
OMS 4 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	056/14:44:06.4
OMS 5 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/14:15:59.3 057/14:15:59.4
OMS 5 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/14:17:22.8 057/14:17:22.9
OMS 6 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/15:01:23.5 057/15:01:23.6
OMS 6 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/15:02:29.5 057/15:02:29.6
OMS 7 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/16:33:24.3
OMS 7 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	057/16:33:35.1
Docking	Capture	057/19:14:20
Undocking	Undocking Complete	066/12:00:10
Flight Control System Checkout – APU 1 Start	APU-1 Gas Generator Chamber Pressure	067/10:37:54.907
APU 1 Stop	APU-1 Gas Generator Chamber Pressure	067/10:43:03.447
OMS 8 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	067/20:00:00.3 067/20:00:00.4
OMS 8 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	067/20:00:14.7 067/20:00:14.8
Payload Bay Door Close	Left Payload Bay Door Close Right Payload Bay Door Close	068/13:16:10 068/13:18:29
APU Activation	APU-2 Gas Generator Chamber Pressure APU-1 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	068/15:47:13.601 068/16:12:49.907 068/16:12:58.174

APPENDIX A
STS-133 MISSION EVENTS

EVENT	DESCRIPTION	ACTUAL GMT
Deorbit Maneuver Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	068/15:52:04.2 068/15:52:04.3
Deorbit Maneuver Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	068/15:52:32.9 068/15:52:33.0
Entry Interface	Orbital Altitude Referenced to Ellipsoid	068/16:25:43
Blackout End	Data Locked (High Sample Rate)	No Blackout
Terminal Area Energy Management (TAEM)	Major Mode Code (305)	068/16:50:51
Main Landing Gear Contact	Main Landing Gear Right Hand Tire Pressure Main Landing Gear Left Hand Tire Pressure	068/16:57:15 068/16:57:16
Drag Chute Deployment	Drag Chute Deploy 1 CP Volts	068/16:57:18.0
Main Landing Gear Weight on Wheels	Main Landing Gear Left Hand Weight on Wheels Main Landing Gear Right-Hand Weight on Wheels	068/16:57:20 068/16:57:21
Nose Landing Gear Contact	Nose Landing Gear Left Hand Tire Pressure 1	068/16:57:26
Nose Landing Gear Weight on Wheels	Nose Landing Gear Weight on Wheels	068/16:57:26
Drag Chute Jettison	Drag Chute Jettison 2 CP Volts	068/16:57:46.9
Wheels Stop	Velocity with respect to Runway	068/16:58:11
APU Deactivation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	068/17:15:27.757 068/17:15:46:111 068/17:16:03.324

APPENDIX B STS-133 IN-FLIGHT ANOMALIES

INTRODUCTION

This appendix contains listings and discussions of each of the In-Flight Anomalies (IFAs) that were identified for the STS-133 mission.

1. Orbiter
2. Reusable Solid Rocket Booster (RSRB)
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 Software
8. Flight Operations and Integration (FO&I)

APPENDIX B STS-133 IN-FLIGHT ANOMALIES

ORBITER ANOMALIES

IFA Number	Title	Comments
STS-133-V-01	Humidity Separator B Water Carryover	<p>The crew discovered carryover or unprocessed condensate at the air outlet of the humidity separator B in the lower equipment bay. The discovery was noted at approximately 056/13:15 GMT (000/15:20 MET) during the Flight Day (FD) 2 post-sleep period. The crew nominally performs visual checks of the humidity separators at least once a day. The crew estimated about ½ cup of water was cleaned up with a tool constructed of a similar design used in STS-125. A second inspection that was conducted in the middle of the mission day showed about ¼ cup of water, which was subsequently cleaned up.</p> <p>At approximately 056/20:00 GMT (000/22:06 MET), the crew set up the condensate collection configuration ahead of schedule to help provide pressure relief in the lines downstream of the humidity separators; this helped with the condensate issue. Subsequent inspections between the FD 2 pre-sleep through FD 4 post-sleep showed no carryover. The humidity separator B continued to process the condensate as assured by the inspections.</p> <p>Post-flight Plans: Because STS-133 is the last flight of the OV-103 Orbiter, the Operational Maintenance Requirements Specifications Document (OMRSD) flow check on the humidity separator was not required. However, a required citric-acid flush of the waste lines will be needed to be followed up with a freshwater flush of the humidity separator and its downstream lines. Consequently, that freshwater flush will be similar to the flush of the OMRSD flow check on the humidity separator; thus, KSC will check for carryover during this freshwater flush. No additional actions will be required.</p>
STS-133-V-02	MADS Left Wing Spar Differential Pressure Erratic	<p>MADS Left Wing Spar Differential Pressure measurement was erratic during ascent. The measurement is used for housekeeping data and trending purposes.</p> <p>Post-flight Plans: No troubleshooting necessary.</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-03	TPS Anomalies	<p>A total of 8 items were identified in-flight as exceeding pre-defined screening criteria and were entered into the TIIMS Database. All items were cleared using standard procedures/tools:</p> <ol style="list-style-type: none"> 1) D-133-AFD-540-001 – Pillow-gap-filler sleeving is protruding and laying over on the adjacent tile. 2) D-133-AFD-540-00 – Tile substrate is exposed. 3) D-133-AFD-550-001 – Blanket patch repair is lifted. 4) D-133-LDRI-600_4-001 – Tile substrate is exposed. The damage is adjacent to RCC panel no. 22. 5) D-133-RPM-560-001 – The patch repair appears to be lifted on thruster thermal barrier. The protrusion measurement was 0.49-in. ± 0.2-in. 6) D-133-RPM-560-002 – Donut around blanket insert appears to be lifted. 7) D-133-RPM-600_1-001 – Ames gap filler protruding on starboard Main Landing Gear Door (MLGD). The Protrusion measurement is 0.29-in. ± 0.1-in. utilizing additional imagery. The overall length of the gap filler is 2.81-in. ± 0.1-in. 8) D-133-RPM-700_2-001 – Tile substrate is exposed. Damage is on small footprint Strain Isolation Pad (SIP) tile. <p>Post-flight Plans: Repairs to be determined for retirement and ferry flight</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-04	Right RCS Fuel Helium Primary Regulator Creep	<p>During pre-launch operations, the right RCS Fuel Helium Primary Regulators exhibited internal leakage of 3300 scch following Helium system activation. The requirement is no more than 600 scch. The ullage pressure increased to secondary regulator lockup levels. Leakage on the secondary regulator was within the specification limit of approximately 500 scch. A waiver was approved to continue with the launch countdown, and the right Reaction Control System (RCS) Helium A Isolation Valve was closed until approximately 9 hr prior to launch.</p> <p>The in-flight performance of the right RCS Fuel Helium A primary regulator leakage (during periods of low usage prior to rendezvous) was similar to pre-launch. The systems remained on "A" regulators since post-ascent with leakage levels of 2000-to -2500 scch (5-6 psi/day). Similar performance continued post-docking. The right RCS fuel tank pressure was managed through normal usage pre-docking. After docking, the ullage pressure was expected to rise to secondary regulator lockup. The leak rate continued, mostly unchanged, until after undocking. At that point, the normal mid-flight regulator reconfiguration to the B regulators, and the leak went away because the leaky regulator was isolated from that point on until entry.</p> <p>Post-flight Plans: None. Normally a full helium regulator checkout would be performed prior to the next flight. However, since the OV-103 vehicle is to be retired and the leakage signature is well within historical experience on other regulators, no additional testing or subsequent failure analysis work is required.</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-05	S-Band High Frequency Dropouts	<p>Uplink was unstable and difficult to maintain during High Frequency (HF) operations for all configurations. When this condition is most obvious, it occurs with no significant Reflected-Power indications of instability. The primary suspect of this condition is the Diplexer Switch Assembly of the Preamplifier (PA), which is a single point common to all configurations. Mission Operations plans required using HF because of mutual interference that would arise if Shuttle was to use Low Frequency (LF). The HTV was docked in a configuration that their operations required the use of their Proximity transceivers and as long as Shuttle operations can function with the periods of interruption of uplink voice and commands. Data plots show that INCO switched to High Frequency at 056/03:15 GMT (00/05:21:00 MET). Due to the observed dropouts, INCO commanded back to LF at 056/15:12 GMT (00/17:18 MET).</p> <p>Additional dropouts were observed after returning to High Frequency mode. Attempts to preclude the dropouts by powering LRUs from string-1 (PA//XPNDR) were unsuccessful. Observation of the data dropouts indicated a significantly higher portion of the hits were associated with the Lower Left antenna.</p> <p>Post-flight Plans: None</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-06	No Video Received from ERCA 10	<p>During the first Extravehicular Activity, the EVA RF Camera Assembly (ERCA) 19 did not produce a video signal. Nominally, a video signal is seen on both the Shuttle and ISS. In an attempt to recover the video signal, Extravehicular (EV) 1 crewmember power cycled ERCA 19. The video was not recovered. The Commander (CDR) performed the STATIC RF CAMERA troubleshooting steps on the Wireless Video System (WVS) cue card in the Photo/TV Checklist. This troubleshooting was not successful. The next troubleshooting step called up to the Crew was to turn off the Receiver Command Power on the WVS Guidance (GUI). This allowed Ground Engineering to perform some additional troubleshooting via Station assets. This also failed to fix the problem. CATO then relinquished control back to the Orbiter crew. Photo/TV and WVS Engineering personnel developed some additional troubleshooting steps for the crew. However, 2.5 hr into the EVA, the crew reported ERCA 19 was producing video and they had not done anything to recover the video.</p> <p>During the second EVA, ERCA 19 exhibited the same signature (no video) as was seen on EVA 1. The crew attempted the additional recovery steps that were uplinked with no joy. ERCA 19 began working again approximately 2 ur after the start of the EVA and functioned nominally through the end of the EVA.</p> <p>Post-flight Status: The post-flight Crew Debriefing answers were able to exonerate the Orbiter side. It appears to be the problem with the ERCA itself. ERCA 18 will be planned for future EVAs with ERCA 19 available as a back-up. ERCA 19 will likely be changed out for another ERCA on STS-135.</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-07	ATVC Channel 1 Power Supply Failed to Restart	<p>During Flight Control System (FCS) Checkout Secondary Actuator Check, Ascent Thrust Vector Control (ATVC) Channel 1 did not reset when the FCS Channel 1 switch was moved from the OVERRIDE position to the AUTO position. This switch reconfiguration is part of the nominal FCS Checkout procedure. This anomaly resulted in ATVC Channel 1 remaining bypassed with the driver outputs near zero when the switch was in the AUTO position; however, the ASA Channel 1 bypass cleared as expected. The Mission Control Center (MCC) requested the crew to cycle the switch from AUTO, to OVERRIDE, and back to AUTO. This was successful in clearing the anomalous condition on ATVC Channel 1. This signature has occurred before and was documented as IFA STS-56-V-09 on 04/14/1993. A similar signature with an improperly assembled circuit card was documented as IFA STS-9-V-29, on 12/08/1983. The ATVC 1 is s/n 26 which went through tin whisker remediation in 2006. During the Acceptance Test Procedure (ATP), an out-of-tolerance signal necessitated changing the transformer in the AC excitation card. During the repeat of the ATP there was an additional out of tolerance condition that was fixed by replacing the entire AC excitation circuit board assembly. The ATP was completed in November 2006 and the ATVC was installed in OV-103 in February 2007. The anomaly signature indicates that the internal power supply for ATVC 1 did not reset properly, but was recovered upon a subsequent power cycle. No impacts for entry operations. The ATVC functioned properly after the final power reset.</p> <p>Post-flight Status: The switch was thrown an additional 30 times post-landing with no repeats of the original signature.</p>

**APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-133-V-08	Ammonia Spray Boiler System B Unexpected Switchover	<p>The Ammonia Boiler, when activated on the Primary B General Purpose Computer (GPC), experienced an outlet temperature oscillation when it approached the control band. It warmed up to about 47 °F, then returned to the control band and performed normally thereafter. The performance was stable and within requirements after the oscillation.</p> <p>Post-flight Status: Investigation determined that about 50 sec after the Ammonia Boiler System (ABS) B was started in primary control, the boiler experienced a premature activation of the auto switchover which transfers ammonia boiler operations from the primary to the secondary controller. The most probable cause of the premature switchover is a biased switchover temperature sensor. The switchover feature protects the ammonia boiler from under-temperature conditions and is active only during primary controller operations. Because the switchover feature is independent from the primary and secondary controllers, there is no effect on the integrity of both primary and secondary controllers. Due to the redundancies of the ammonia boiler systems, there is no impact to the safety of subsequent missions. No further action is planned</p>
STS-133-V-09	Pressure Low in OAFGSS Two Left (2L) Bottle 1120	<p>The lab report for STS-133 indicated that one bottle, left hand #2, remained near/at vacuum and failed to capture a sample. The pressure was reported to be less than 0.5 TORR. Allowable range for that bottle is approximately 33 to 75 TORR. It is bottle S/N 1120, this was the bottle's third flight.</p> <p>Post-flight Status: After KSC pyro team inspection the initial reports were:</p> <ol style="list-style-type: none"> 1) Both NSIs had fired. 2) The NSIs were removed: <ol style="list-style-type: none"> a) The piston stroke of the closing function of the valve appeared sufficient. b) Both NSI o-rings were in place c) The piston stroke of the opening function did not appear sufficient to open the valve. Stroke was estimated at ~1/32". The valve and NSIs were photographed and shipped to USA Houston for analysis 3) EP is currently: <ol style="list-style-type: none"> a) Locating all hardware that uses lot MTJ NSI's. First check indicated no other uses of MTJ on STS-134. MTJ will not be used on STS-134 OAFGSS. b) Assessing KSC VBA inventory to identify how many lot PGA pyrotechnic valves are on the VBA's. Six VBAs needed per flight. One valve per VBA. Two NSIs per VBA and VBA's are stored without NS.

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES

IFA Number	Title	Comments
STS-133-V-10	WLEIDS Trigger Overlooked by WIS GFE Team	<p>Post mission, Wireless Instrumentation System Government Furnished Equipment (WIS GFE) was informed by the Wing Leading Edge (WLE) Engineering that a trigger during the last MicroMeteoroid/Orbital Debris (MM/OD) monitoring period of the mission with Group 2 sensors failed to be reported. After this notification, the team reviewed the result-files for the last MM/OD monitoring period for Group 2 Start 2 and confirmed that the very last trigger acquired during the mission was not reported. The missed trigger occurred on Port Sensor unit 1022, Channel 3 (upper 19/20 Reinforced Carbon-Carbon (RCC) panel interface) 7 hr and 7 min (066/19:07:27 GMT) into the 9 hr monitoring period and all units within its sensor group were force triggered. For reference, the Port survey during late inspection was time-lined to start at 066/19:02:16 GMT, indicating that a detrimental impact may have been noticed and reported by the crew. It appears that during a substantial period of spotty KU outages while attempting to download, process, and file the half second windows of previous triggers acquired, the results of the On-Orbit Index ALL commands were misinterpreted by the WIS GFE team, and thus the final trigger, #3, was neither noted internally nor reported externally..</p> <p>The standard WIS GFE process used to determine if a trigger has been acquired consists of requesting an on-orbit summary or index newest file summary by having Orbiter Communications Adapter (OCA) submit the appropriate commands to the units. Once the commands execute on the primary on-board laptop, the result files are downlinked to the ground via OCA for WIS GFE to review, process, and file. Two WIS GFE console support personnel independently review the result files that are downlinked to manually check each file for triggers. Additionally, during the 1st shift, the P5 position also independently reviews the result-files and the triggers are noted in a running trigger tally document as well as on a large overhead whiteboard. The data from the associated sensors was downloaded at Kennedy Space Center (KSC) and sent to the WIS GFE team for processing. The WLE IDS team assessed the data and determined that the trigger did not meet the multi-sensor criteria and therefore was not an MM/OD indication.</p> <p>Future Plans: Process fixes were implemented within the WIS GFE community. This is being documented as a process escape.</p>

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
REUSABLE SOLID ROCKET BOOSTER ANOMALIES

IFA Number	Title	Comments
STS-133-B-001	Video from RH ET Observation Camera Not Recorded as Expected	<p>During the STS-133/BI144 flight, the RH SRB DAS did not record video from the RH ET Observation Camera until approximately 6 seconds prior to the first disreefing of the main parachute. Nominal video was then recorded from that point until 18 seconds after water impact.</p> <p>Failure caused by potting material debris between pin and socket contact surfaces at the interface between the DAS Local Application Control Bus (LANC) Adapter and its mated LANC Shorting Plug. A pair of pins (14 and 15) were jumpered in the LANC Shorting plug, when mated to the LANC Adapter, is designed to power the VCR on at T-0. The marginal nature of the contamination between pin and socket was demonstrated by the VCR being powered off (or on) with a quarter turn of one of two LANC hardware mounting screws.</p> <p>On the bench after flight, the 90-degree mini-stereo plug was disconnected from the flight VCR and reconnected to an unpowered bench VCR. When power was applied to the VCR (as is done at T-0), the VCR briefly powered up, but before recording started, it powered down. When the S/N 2000003 LANC Adapter and its mated Shorting Plug were squeezed slightly together, the bench VCR powered up and began recording. When a slight downward pressure was applied to the pigtail end of the LANC Adapter, tending to flex the mated interface, an apparent power-off command was sent by the LANC Adapter, and the bench VCR powered down.</p> <p>Post-flight Corrective Action: Two new LANC Adapters and Shorting Plugs were fabricated, which will support both left and right DAS units for BI145 and BI146. The hollow pin connectors on the replacement (commercial) LANC Adapters have been removed and replaced with connectors that have solid pins. Two replacement Shorting Plugs were fabricated to ensure absence of debris. The connector contact terminations have been subjected to a pre-pot sealing technique to prevent potting leakage into the connector mating interface, and the DAS pre-flight preparations procedure was revised to confirm the use of solid-pin LANC Adapters and that the LANC connector interfaces are free of debris.</p>

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
REUSABLE SOLID ROCKET MOTOR ANOMALIES

No RSRM IFAs were identified from the postflight data and inspection.

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
EXTERNAL TANK ANOMALIES

IFA Number	Title	Comments
STS-133-T-001	After STS-133 Launch Scrub from GUCP Leak, Cracks were Found in Panel 2 of LO ₂ -Intertank Flange Closeout TPS AND 2 Stringers on ET-137.	<p>A crack was noted in the BX-265 LO₂-Intertank Flange Closeout (80971118414) on Intertank panel 2 assembly (80913000420). The crack in the TPS extended from valley to valley across stringer number 7 on panel 2 (see Figure 1a). Removal of the TPS in the area revealed that two stringers had cracked. Subsequently a crack was noted in the BX-265 LO₂-Intertank Flange Closeout (80971118414) on Intertank panel 2 assembly. The crack in the TPS extended from valley to valley across stringer number 7 on panel 2. Removal of the TPS in the area revealed that two stringers; stringer number 7 and stringer number 6 had cracked.</p> <p>Through the course of the investigation/failure analysis of the removed sections of cracked stringers S7-2 and S6-2, a surface condition described as "mottled" was identified on the S7-2 stringer. This "mottled" surface condition was consistent throughout the entire exposed (not primed) surface of the S7-2 removed section. Closer inspection of the removed stringer S6-2 section determined that one foot of the stringer exhibited this "mottled" appearance Reliability Assurance then performed an inspection of "sister" stringers (stringers received from the same Aerochem manufacturing Lot and same Alcoa Heat Lot) in MAF Inventory Stores exhibited the same surface conditions (i.e. surface fully "mottled" condition for S7-2 sister stringers, and half of stringer mottled for full length on S6-2 sister stringers).</p> <p>A tanking test was successfully performed and the data showed nominal tank performance and that test results were generally bounded by analytical models. No anomalies were detected visually with the structural repairs at panel 2, S6 and S7. The Shuttle stack was then moved back to the Vehicle Assembly Building (VAB) to obtain additional NDE on the Z-side to support the investigation and provide additional flight rationale. The NDE inspections identified additional cracks on panel 6, at stringers S6, S7, and S11 on the LOX end of the Intertank. No evidence of TPS damage was present. The additional cracks were similar to the cracks observed on panel 2, S6 (i.e. cracks in stringer feet ~3 in. long from stringer end).</p> <p>The addition of the TPS repairs and the radius blocks added a total weight of 51 lbs. Based upon this there was no change to the Control Weight and no change to the Center of Gravity.</p>

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
SPACE SHUTTLE MAIN ENGINE ANOMALIES

No SSME IFAs were identified from the postflight data and inspection.

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
SYSTEM ENGINEERING AND INTEGRATION ANOMALIES

IFA Number	Title	Comments
STS-133-I-001	Hydrogen Leak at External Tank (ET) Ground Umbilical Carrier Plate (GUCP)	<p>During the launch attempt of STS-133/ET-137 on November 5, 2010, Gaseous Hydrogen (GH₂) leakage exceeding the Launch Commit Criteria (LCC) limit of 40,000 ppm was indicated by leak detectors 23 and 25 located at the ET/GUCP interface. Consequently, the launch was scrubbed. The team consensus was that the concentricity offset, coupled with the shift in the GUCP assembly at the Pad created uneven loading on the two-piece seal creating a leak. Using the improved procedures and based on the corrective actions implemented, including use of:</p> <ol style="list-style-type: none"> 1) two-piece seal configurations, 2) higher-tolerance guide pins, 3) modified/customized pivot feet, and 4) refined concentricity measurements of both the GUCP to ETCA and the ground probe. <p>Based on the ability to monitor and control GH₂ leaks during the launch countdown, STS-133 was successfully launched with no hydrogen leaks being detected at the GUCP interface.</p>
STS-133-I-002	ET Intertank Stringer Cracks	<p>During the tanking for STS-133 on November 1, 2010, a Thermal Protection System (TPS) crack occurred on the LO₂ Intertank (IT) flange closeout at approximately Xt-852 on Panel 2. Non-Destructive Evaluation (NDE) following the tanking test revealed 4 additional cracks near the LO₂ IT flange on stringer feet of Panel 6. The repairs on Panel 2 were visually inspected after the tanking test and no issues were identified. The cracked stringers on Panel 6 were repaired, and radius block modifications were implemented on all accessible stringers.</p> <p>STS-133 was loaded and launched successfully with no visible TPS loss from the Liquid Oxygen (LO₂) IT flange. The root cause for the stringer cracks is currently unknown and remains an unexplained anomaly. Three proximate causes have been identified through a fishbone investigation. They are:</p> <ol style="list-style-type: none"> 1. Two suspect material lots of AL 2090; 2. Stringer residual assembly stresses; and 3. Stringer thickness.

APPENDIX B

STS-133 IN-FLIGHT ANOMALIES

IFA Number	Title	Comments
STS-133-I-003	Unexpected Debris/Expected Debris Exceeding Mass Allowable Prior to Pad Clearance (Liftoff Debris)	<p>Risk Assessment indicated that given the proposed mitigations, the observed debris poses no appreciable increase in risk. Lift-off debris risk is currently characterized as infrequent, catastrophic due to significant uncertainties in controls and analysis. Expected lift-off debris risk is classified as infrequent catastrophic in documentation. Debris release has been mitigated for identified potential sources of critical debris by performing repairs and adding inspections for system-level components (e.g. fasteners for Telephone Mounting Plates and water distribution pipe-mounting fixtures). An additional risk assessment was provided for the Mobile Launch Platform (MLP) Tail Service Mast (TSM) flip-up platforms. The drain holes on the bottom of these structures were observed to have liberated corrosion throughout lift-off. Debris on the MLP deck has been shown to have transport mechanisms toward the vehicle. Investigations identified that MLP-3 has released corrosion exceeding the Risk Assessment Mass (RAM) from these drain holes on every launch since STS-114, while MLP-1 and MLP-2 have not. The underlying cause was identified to be a difference in drain-hole configuration, which on MLP-1 and -2 preclude debris in excess of the RAM from liberating. Closure Rationale for "UNEXPECTED DEBRIS EXCEEDING MASS ALLOWABLES PRIOR TO PAD CLEARANCE (LIFTOFF DEBRIS)" on STS-133 went to the SICB on March 22, 2011.</p>
STS-133-I-004	Debris Released From LH ₂ Flange Area Near the Bipod	<p>During ascent at approximately 231 sec MET, a large piece of TPS foam was released from the ET LH₂ IT flange area between the bipod struts. Several smaller particles were also observed related to the primary release. Debris from this event impacted the Orbiter at least four times. No tile damage was noted in on-orbit imagery that could be correlated to these losses; however, minor damage to a shave repair on the Nose Landing Gear Door (NLGD) documented during the post-landing inspection could be related. The foam loss occurred from the upper part of the LH₂-to-IT Flange closeout and extended into the IT acreage. The integrated concern centers on the potential for similar large debris to release early with the potential to cause catastrophic damage to the Orbiter. The most probable cause for the observed foam loss is cryogen-ingestion. The event timing, site characteristics, and the divot location indicates that a void developed between the chord and foam during tanking and was fed LN₂ through an Intertank skin/chord /fastener interface leak path. Even though the failure mode of cryogen-ingestion is well understood, this specific mechanism was not addressed by Return to Flight (RTF) flange modifications, as potential debris generation was acknowledged to have a late time of release. The mass of 0.154 lb_m for this event exceeds the NSTS 60559 requirement for cryogen-ingestion of 0.041 lb_m. However, this risk assessment mass was based on maximum expected voids within TPS only and does not address structural gap/LN₂ leak paths. ET Project is initiating a CR to add an additional failure mechanism to NSTS 60559 for the LH₂ IT Flange Closeout loss as observed which will include a risk assessment mass for Cryogen- Ingestion due to structural/LN₂ leak paths. Aero and Transport analysis has shown there is a low probability of experiencing significant TPS damage from these late releases.</p>

APPENDIX B

STS-133 IN-FLIGHT ANOMALIES

IFA Number	Title	Comments
STS-133-I-005	Debris Observed Near Right SRB Nozzle	<p>At approximately 11 sec Mission Elapsed Time (MET), a single piece of linear-shaped, flexible debris was observed near the Right-Hand Solid Rocket Booster (RH SRB) thermal curtain. As the vehicle was ascending, the debris can first be seen in the area between the Hold-Down Posts (HDPs) 1 and 3, and it then appears to travel around the thermal curtain/nozzle area towards HDP 4, then fall aft along the SRB plume. The size estimate is 3.4 (\pm 0.3) in. wide and 70 (\pm 15) in. long. The Elements evaluated possible contributing hardware similar in size and properties to what was observed and did not find any debris sources that correlated with the observation. This IIFA was recommended for closure as an unexplained anomaly.</p> <p>The most probable sources are from either SRB or Launch and Landing, simply due to the early timeframe as no imagery indicating debris coming from anywhere on the vehicle to the aft-skirt area and the proximity of hardware of those two elements to the debris in question. VCN and water baggie material are most consistent with the color, shape, location, and behavior of the debris, and organic material deposits from the water in the baggies may also have been the cause. The debris itself posed no threat to the vehicle due to the timeframe and location. If the observed debris is not one of the previously evaluated possible sources, the post-flight assessment of the elements identified no missing critical hardware. As a result, the condition is acceptable from a vehicle performance and debris risk perspective.</p>

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
FLIGHT SOFTWARE ANOMALIES

IFA Number	Title	Comments
STS-133-S-001	OCA Hard Drive Failure	<p>The OCA Officer noticed that even though he was getting Green Lights via STS assets and an apparent good network connection, he could not ping the Shuttle network from the ground via STS assets. However, all the PGSCs through mapped drives on the STS3/KFX PGSC which was connected via ISS assets could still be accessed. Because the computers were still accessible in this manner, it was assumed the Wireless Access Point (WAP) was still working. The crew was asked to reboot the STS OCA Router. The crew was unable to access the reboot capability on the Router (neither via Start Menu nor by using CNTRL+ALT+DEL) so a hard-reboot (powering down, then powering back up the PGSC) was performed. When the computer came back up, the crew received these error comments:</p> <ol style="list-style-type: none"> 1. Client MAC Address - No DHCP or Proxy DHCP offers were Received 2. PXE-M0F - Operating System Not Found <p>It was determined that the Hard Drive most likely had failed (the crew even commented that they had heard a high-pitched whining noise coming from the computer earlier in the day). So the crew was asked to change-out the faulty hard drive (and label it as such for the ground support team) and replace it with the spare OCA Hard Drive that is flown. The Hard Drive change-out was successful and the STS OCA Router began running again with no issues.</p> <p>Post-flight Status: The OCA hard drive that was reported as failed was returned to USA FCE. The hard drive was confirmed damaged after running disk analysis tools:</p> <ol style="list-style-type: none"> 1. Upon return, the hard drive was installed in a GSE unit and it booted-up with no problem. This is not unusual since all modern hard drives have self-correcting capabilities that can mask small surface damage. 2. After the initial boot-up, PGSC engineers decided to perform the standard archival\backup process before performing any trouble-shooting. Obtaining this backup image would provide a snapshot of its last known state before any invasive processes altered the configuration any further. 3. Once the backup was complete, the hard-drive was installed and the hard drive analysis tools were executed (provided by the manufacturer). This analysis software reported there was recent surface damage due to excessive shock.

APPENDIX B
STS-133 IN-FLIGHT ANOMALIES
FLIGHT OPERATIONS AND INTEGRATION ANOMALIES

IFA Number	Title	Comments
STS-133-D-001	17-Second SSP Command Delay	<p>On February 24, 2011, a backup command server out-of-synch condition occurred about 1 hr 10 min after the STS-133 launch. The backup command server was restored and the available log data was investigated to determine the cause of the anomaly. The anomaly was triggered by a 17-sec delay in the prime command server processing a single command. This command was only delayed and was successfully uplinked and executed after the delay. Nominal processing of commands by the command server is expected to occur in .4 sec or less. Consequently, a Tiger team was formed to investigate and understand the root cause of the issue. The team investigation revealed that the command was delayed because the command server was waiting for a connection to the Mission Data Storage Consolidation (MASC.) to perform user and command authentication. The MASC. was unable to service the command server request quickly because it was overloaded by a burst of requests. This connection request burst was found to originate from a script running in the Performance Collector tool, which has every single workstation and server in operations (approximately 550) simultaneously connected to the MASC. to determine the activity for which the machine was configured. Once identified, the team disabled on March 11, 2011, the portion of Performance Collector that created the burst of traffic in MCPC OPS. The data collected is only used by Engineering for some rare troubleshooting activities and alternate ways of collecting the data exist. Subsequent monitoring of the situation has verified that disabling the tool removed the source of MASC traffic connection bursts both in ISS-continuous operations, as well as during a STS-134 ascent simulation. Connections made by the ISS/SSP command servers in MCPC have been delay-free since the tool was disabled.</p> <p>Post-flight Activity: One-flight Interim Disposition was approved for STS-134. The MCPC workstation Performance Collector tool will be disabled for both Shuttle and ISS operations during STS-134. After STS-134, command server performance during the mission will be reviewed and a forward plan and IFA closure rationale for STS-135 will be determined.</p>

APPENDIX C

STS-133 DOCUMENT SOURCES

MER DAILY REPORTS

The following STS-133 MER Daily Reports by Michael D. Wright, Lead MER Manager:

- Launch and First Daily Report, dated February 24, 2011
- Second Daily Report, dated February 25, 2011
- Third Daily Report, dated February 26, 2011
- Fourth Daily Report, dated February 27, 2011
- Fifth Daily Report, dated February 28, 2011
- Sixth Daily Report, dated March 1, 2011
- Seventh Daily Report, dated March 2, 2011
- Eighth Daily Report, dated March 3, 2011
- Ninth Daily Report, dated March 4, 2011
- Tenth Daily Report, dated March 5, 2011
- Eleventh Daily Report, dated March 6, 2011
- Twelfth Daily Report, dated March 7, 2011
- Thirteenth Daily Report, dated March 8, 2011
- Fourteenth Daily Report, dated March 9, 2011
- Landing Plus 2 Hour Report, dated March 9, 2011
- Mission Summary Report, dated March 16, 2011

ET/SRB/RSRM/SSME REPORTS

- STS-133 In-Flight Anomalies, David W. Morr, USA-Huntsville, July 17, 2010
- STS-133 HOSC Console Flash Report, Dino Diluigi, USA-Huntsville, May 14, 2010
- STS-133 RSRM Flash Report, Robert Zahl, ATK, May 14, 2010
- STS-133 SRB Open Assessment, Thomas F. Ford, NASA-KSC, May 19, 2010

ORBITER REPORTS

- STS-133 Landing Parameters, Michael T. Porter, Boeing-Huntington Beach, March 24, 2011
- STS-133 Landing and Deceleration Quick Look Report, Chip. C. Heinol, Boeing-Houston, March 28,, 2011
- STS-133 Communications and Tracking Report, Martha M. May, Boeing-Houston, April 11, 2011
- STS-133 Shuttle Remote Manipulator System, Stephan M. Tabladillo, MDA-Houston, April 5, 2011
- STS-133 HYD/WSB System Report, Charles A. Ritrivi, Boeing-Houston, April 6, 2011
- STS-133 Main Propulsion System Report, Trina A. Martingano, Boeing-Houston, April 13, 2011
- STS-133 Auxiliary Power Unit System, Christopher N. Adi, Boeing-Houston, April 1, 2011
- STS-133 OI/MADS Sensors, Signal Conditioners and Fuel Cell Monitoring System, Dwight A. Favors, Boeing-Houston, March 28, 2011
- STS-133 OI/MADS MUX and Timing Report, Bruce S. Woods, Boeing-Houston, March 31, 20-11
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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

Acronym/ Abbreviation	Explanation
A	Ampere
AA	Accelerometer Assembly
ABS	Ammonia Boiler System
ADTA	Air Data Transducer Assembly
AEM	Animal Enclosure Module
AGT	Adaptive Guidance Throttle
AHMS	Advanced Health Monitoring System
A/L	Airlock
AMOS	Air Force Maui Optical Supercomputing Site
APD	Avalanche Photo-Diode
APFR	Articulating Portable Foot Restraint
APU	Auxiliary Power Unit
ARPCS	Atmospheric Revitalization Pressure Control System
ATCS	Active Thermal Control System
ATVC	Ascent Thrust Vector Control
BFS	Backup Flight System
BFS WHI	Backup Flight System Initial Weight of Helium Load
BLT	Boundary Layer Transition
BP	Body Point
CBM	Common Berthing Mechanism
CDR	Commander
CDRA	Carbon Dioxide Recycling Assembly
CETA	Crew and Equipment Translation Aid
CFS	Colored Fungi in Space
CGBA	Commercial Generic Bioprocessing Apparatus
CLA	Camera Light Assembly
CLPA	Camera Light Pan/Tilt Assembly
C/O	Checkout
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COMM	Communications
CP	Camera Position
CPA	Control Panel Assembly
CPM	Cell Performance Monitor
CSR	Customer Support Room
CST	Central Standard Time
CWC	Contingency Water Container
CWCI	Contingency Water Container Iodine
D & C	Display and Control
DAP	Digital Autopilot

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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

DAT	Debris Assessment Team
Acronym/ Abbreviation	Explanation
DDU	Data Display Unit
DESIG	Designate
DET	Data Elapsed Time
DMHS	Dome Mounted Heat Shield
DOD	Department of Defense
DOLILU	Day of Launch I Load Update
DPS	Data Processing System
DRWP	Doppler Radar Wind Profile
DSO	Development Supplementary Objective
DTO	Development Test Objective
DTV	Digital Television
ΔV	Differential Velocity
ECLSS	Environmental Control and Life Support System
ECO	Engine Cut-off
EHIP	EVA Helmet Interchangeable Portable Light
EI	Entry Interface
ELC	Express Logistics Carrier
EOM	End of Mission
EPDC	Electrical Power Distribution and Control
ERCA	EMU RF Camera Assembly
ESP	External Stowage Platform
EST	Eastern Standard Time
ET	External Tank
ETR	Eastern Test Range
EV	Extravehicular (Crewmember)
EVA	Extravehicular Activity
EXPRESS	Expedite the Processing of Experiments to Space Station
FCE	Flight Crew Equipment
FCMS	Fuel Cell Monitoring System
FCS	Flight Control System
FCV	Flow Control Valve
FD	Flight Day
FES	Flash Evaporator System
FI	Focused Inspection
FID	Failure Identifier
F/O	Fiber Optic
FOM	Figure of Merit
FRCS	Forward Reaction Control System
FSE	Flight Support Equipment

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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

Acronym/ Abbreviation	Explanation
FSS	Fixed Service Structure/Flight Support System
FSW	Flight Software
g/G	Gravity
GCA	Ground Carrier Assembly
GFE	Government Furnished Equipment
GG	Gas Generator
GGVM	Gas Generator Valve Module
GH ₂	Gaseous Hydrogen
GMT	Greenwich Mean Time
GN ₂	Gaseous Nitrogen
GN&C	Guidance Navigation and Control
GO ₂ /GOX	Gaseous Oxygen
GPC	General Purpose Computer
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GUCP	Ground Umbilical Carrier Plate
H ₂	Hydrogen
HD	High Definition
HDP	Holddown Post
HF	High Frequency
HGDS	Hazardous Gas Detection System
HPFTP	High Pressure Fuel Turbopump
HPGT	High Pressure Gas Tank
HPOTP	High Pressure Oxidizer Turbopump
HST	Hubble Space Telescope
HTV	H-II Transfer Vehicle
HYD	Hydraulic
IDS	Impact Detection System
IFA	In-Flight Anomaly
IFM	In-Flight Maintenance
IMV	Intra-Module Ventilation
IMU	Inertial Measurement Unit
IPR	Interim Problem Report
ISP	Integrated Stowage Platform
I _{SP}	Specific Impulse
ISS	International Space Station
I/T	Intertank
IVA	Intravehicular Activity
JSC	Johnson Space Center
KSC	Kennedy Space Center

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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

Acronym/ Abbreviation	Explanation
L	Launch
LCC	Launch Commit Criteria
LED	Light Emitting Diode
LF	Low Frequency
LH	Left Hand
LH ₂	Liquid Hydrogen
LIDAR	Light Intensification Detection and Ranging
LiOH	Lithium Hydroxide
LO ₂	Liquid Oxygen
LP	Launch Package
LWAPA	Light Weight Adapter Plate Assembly
MADS	Modular Auxiliary Data System
MAUI	Maui Analysis of Upper Atmospheric Modification
MAX Q	Maximum Dynamic Pressure
MC	Midcourse Correction
MCC	Mission Control Center
MECO	Main Engine Cutoff
MEDS	Multifunction Electronics Display System
MER	Mission Evaluation Room
MET	Mission Elapsed Time
MLG	Main Landing Gear
MLI	Multi-Layer Insulation
MLP	Main Launch Platform
MLS	Microwave Landing System
MM	Major Mode
MM/OD	MicroMeteoroid/Orbital Debris
MMT	Mission Management Team
MNC	Main Bus C
MPM	Manipulator Positioning Mechanism
MPS	Main Propulsion System
MRL	Manipulator Retention Latch
MT	Mobile Transporter
MUX	Multiplexer
N ₂	Nitrogen
NASA	National Aeronautics and Space Administration
NAVAID	Navigation Aids
NC	Nominal Correction
NCC	Nominal Correction Combination
NDE	Nondestructive Evaluation

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Acronym/ Abbreviation	Explanation
NH	Nominal Height
NLP	National Laboratory Pathfinder
NPSP	Net Positive Suction Pressure
O ₂	Oxygen
OAA	Orbiter Access Arm
OAFGSS	Orbiter Aft Fuselage Gas Sample System
OBSS	Orbiter Boom Sensor System
OCA	Orbiter Communication Adapter
ODS	Orbiter Docking System
OGA	Oxygen Generation Assembly
OI	Operational Instrumentation/Operational Increment (Software)
OME	Orbital Maneuvering Engine
OMRSD	Operational Maintenance and Requirements Specification Document
OMS	Orbital Maneuvering System
OPO	Orbiter Project Office
ORGA	Orbiter Rate Gyro Assembly
ORU	Orbital Replacement Unit
OV	Orbiter Vehicle
PA	Power Amplifier
PAO	Public Affairs Office
PAS	Payload Attach System
PASS	Primary Avionics Software System
PASS WHI	PASS With Initial Helium Load
PCM	Pulse Code Modulation
PCS	Pressure Control System
PDU	Power Drive Unit
PGME	Propylene Glycol Monomethyl Ether
PLBD	Payload Bay Door
PM	Pump Module
PMM	Permanent Multipurpose Module
PMA	Pressurized Mating Adapter
PMBT	Predicted Mean Bulk Temperature
POA	Payload and ORU Accommodation
ppm	parts per million
PRCB	Program Requirement Control Board
PRCS	Primary Reaction Control System
PROX	Proximity
PRSD	Power Reactant Storage and Distribution System
PRT	Problem Resolution Team

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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

Acronym/ Abbreviation	Explanation
PV&D	Purge, Vent and Drain
PWR	Payload Water Reservoir
QD	Quick Disconnect
RAMBO	Ram Burn Observations
RCC	Reinforced Carbon-Carbon
RCS	Reaction Control System
REBA	Rechargeable EVA Battery Assembly
RF	Radio Frequency
RGA	Rate Gyro Assemblies
RH	Right Hand
RHC	Rotational Hand Controller
RJD	Reaction Jet Driver
RM	Redundancy Management
RPCM	Remote Power Control Module
RPL	Rated Power Level
RPM	R-Bar Pitch Maneuver
RPOP	Rendezvous/Proximity Operations Program
R&R	Remove and Replace
RSB	Rudder Speed Brake
RSP	Resupply Stowage Platform
RSRB	Reusable Solid Rocket Booster
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTV	Room Temperature Vulcanizing (material)
RWS	Remote Workstation
S&A	Safe and Arm
SDFS	Smoke Detection and Fire Suppression
SE&I	Systems Engineering and Integration
SEITE	Shuttle Engine Ion Turbulence Experiment
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Firings
SLWT	Super Lightweight Tank
SMRD	Spin Motor Rotation Detector
S/N	Serial Number
SODB	Shuttle Operational Data Book
SPDM	Special Purpose Dexterous Manipulator
SRGA	SRB Rate Gyro Assembly
SRM	Solid Rocket Motor
SRMS	Shuttle Remote Manipulator System
SRSS	Shuttle Range Safety System
SSME	Space Shuttle Main Engine

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Acronym/ Abbreviation	Explanation
SSP	Space Shuttle Program
SSPTS	Station-to-Shuttle Power Transfer System
SSRMS	Space Station Remote Manipulator System
ST	Star Tracker
STBD	Starboard
STS	Space Transportation System
SYNC	Synchronized
TACAN	Tactical Air Navigation
TCDT	Terminal Countdown Demonstration Test
TCS	Thermal Control System/Trajectory Control Sensor
TDRS	Tracking and Data Relay Satellite
THC	Translation Hand Controller
TI	Terminal Phase Initiation/Transfer Initiation
TPL	Transfer Priority List
TPS	Thermal Protection System
TSM	Tail Service Mast
TVC	Thrust Vector Controller
TWT	Travelling Wave Tube
ULF	Utilization Logistics Flight
UTC	Universal Time Code
VAB	Vehicle Assembly Building
VDT	Vehicle Data Table
VRCS	Vernier Reaction Control System
WLE	Wing Leading Edge
WLE IDS	Wing Leading Edge Impact Detection System
WIF	Worksite Interface Fixture
WSB	Water Spray Boiler
WVS	Wireless Video System
ZOE	Zone of Exclusion
ZSR	Zero-G Stowage Rack

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STS-133 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<u>Unit of Measure</u>	<u>Explanation</u>
°F	degree Fahrenheit
deg	degree
deg/sec	degree per second
ft	feet
ft/sec	feet per second
Grms	gravity root mean square
In. Hg	Inches of Mercury
hr	hour
In.	inch
keas	knots estimated air speed
kgs	knots ground speed
kW	Kilowatt
kWh	Kilowatt hour
lb	pound
lb _m /lbm	pound mass
min	minute
mmHg	Millimeters of Mercury
nmi	nautical mile
%	percent
ppCO ₂	partial pressure carbon dioxide
ppm	parts per million
psi	pound per square inch
psia	pound per square inch absolute
scch	Standard Cubic Centimeters-per Hour
sec	second
torr	Unit of pressure (ratio of 760 to one standard atmosphere)
V	Volt
Vdc	Volt direct current
W	Watt