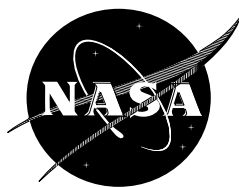


# **STS-134 SPACE SHUTTLE MISSION REPORT**

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September 2011



**National Aeronautics and  
Space Administration**

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

**NOTE**

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**STS-134**  
**SPACE SHUTTLE MISSION REPORT**

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# STS-134 SPACE SHUTTLE MISSION REPORT

## INTRODUCTION

The Space Transportation System (STS) -134 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 134<sup>th</sup> mission of the Space Shuttle Program. STS-134 was the 21<sup>st</sup> mission since the return-to-flight following the STS-107 mission, and the 36<sup>th</sup> mission to the International Space Station (ISS). STS-134 was also the 25<sup>th</sup>, and last, flight of the Orbiter Vehicle (OV) -105, *Endeavour*.

The purpose of the STS-134 mission was to deliver the Utilization and Logistics Flight (ULF) -6 to the ISS. The Launch Package included the delivery of the Alpha Magnetic Spectrometer (AMS) -2 to the ISS. AMS-2 is a particle physics detector designed to search for various types of matter by measuring cosmic rays. Its experiments are designed to help researchers study the formation of the universe and search for evidence of dark matter, strange matter and antimatter. *Endeavour* also carried the Expedite the Processing of Experiment to Space Station (ExPRESS) Logistics Carrier (ELC) 3, a platform loaded with spare parts that will sustain ISS operations after the Space Shuttles are retired from service. Some of the critical spare components included two S-band communications antennas, a high-pressure gas tank, and additional spare parts for Dextre and micrometeoroid debris shields. In addition, four Extravehicular Activities (EVAs) will be performed.

The primary objectives of the STS-134 mission were as follows:

1. Rendezvous and dock with the ISS.
2. Install and activate the AMS-2.
3. Install the ELC 3 to Port 3 (P) 3 Truss Upper Outboard Unpressurized Cargo Carrier Attach System (UCCAS) -1.
4. Transfer and stow critical items per the Transfer Priorities List (TPL).
5. Transfer mandatory items per the TPL.
6. Perform four EVAs.
7. Transfer oxygen and nitrogen.
8. Retrieve Materials International Space Station Experiment (MISSE) from ELC-2 and stow in the Payload Bay for return.
9. Transfer water per the TPL.

The flight vehicle consisted of the OV-105 Orbiter; the ET, which was a Super Lightweight Tank (SLWT), designated ET-122; three Block II SSMEs that were designated as Serial Numbers (S/Ns) 2059, 2061, and 2057 in positions 1, 2 and 3, respectively; and two RSRBs that were designated BI-144. The two RSRMs were

designated flight set RSRM-113. The individual RSRMs were S/N 360W113A (left) and S/N 360W113B (right). Launch pad 39A and Mobile Launch Platform (MLP) -2 were used as the platform for launch of the STS-134 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-134 flight were Mark E. Kelly, Captain, U.S. Navy, Commander; Gregory H. Johnson, Colonel, USAF (Retired), Pilot; Gregory E. Chamitoff, PhD, NASA, Mission Specialist 1; Edward M. Fincke, Colonel, USAF, Mission Specialist 2; Roberto Vittori, Colonel, Italian Air Force, European Space Agency, Mission Specialist 3; and Andrew J. Feustel, PhD, NASA, Mission Specialist 4.

STS-134 was the fourth flight for the Commander, third flight for the Pilot, second for Mission Specialist 4, the second flight for the Mission Specialist 1, and the first for Mission Specialist 2 and Mission Specialist 3.

Mission Specialists 1, 2 and 3 had previously performed a long-duration mission as a Flight Engineer on the ISS, all of which were transported to and from the ISS in the Soyuz spacecraft.



## **MISSION SUMMARY**

The objectives of the STS-134 mission included delivering and installing the Alpha Magnetic Spectrometer (AMS) -2, delivering and installing the Expedite the Processing of Experiments to the Space Station (ExPRESS) Logistics Carrier (ELC) 3, performing four Extravehicular Activities (EVAs) and the transfer of critical items.

### **Pre-Launch**

The launch was scrubbed on April 29, 2011, because of a Launch Commit Criteria (LCC) violation that was the result of the Auxiliary Power Unit (APU) 1 Fuel Test Line and Fuel Service Line 'B' heaters failing to activate during the STS-134 pre-launch operations (IFA STS-134-V-01). The failure persisted with both the ground command and the panel switch activation. It was determined that the APU 1 heater circuit was non-functional in the Aft Logic Control Assembly (ALCA) 2. The ALCA was removed and replaced. The ALCA Line Replaceable Unit (LRU) and component analysis indicated that a driver was exposed to a short circuit and responded nominally. The failed driver was replaced and the LRU tested nominally including vibration testing. Vehicle wiring was nominal during Hi-Potential (Hi-Pot) testing. New wire and splices were installed from ALCA 2 to the heater strings to mitigate an undetected transient short. The B-system heaters tested nominally during continuity and 450 Vdc isolation testing. The heaters were functionally tested with Ground Support Equipment (GSE) power and the replacement ALCA 2 performed nominally. Data review from a June 2010 heater test revealed a 2-msec, 18-Ampere (A) current spike during testing of thermostat S12B. The thermostat was found to have an exposed conductor on the vendor lead. The problem was classified as an Unexplained Anomaly (UA) at the time; however, the exposed conductor is considered the most probable cause of the anomaly.

### **Ascent and Flight Day 1**

At 136/12:56:00 Greenwich Mean Time (GMT) [Launch (L) minus 28 sec], the right Nose Landing Gear (NLG) tire pressure 2 instrumentation was erratic until 136/12:58:03 GMT [00/00:01:35 Mission Elapsed Time (MET)], and then again between 136/13:17:30 GMT (00/00:21:02 MET) and 136/13:18:19 GMT (00/00:21:51 MET) (IFA STS-134-V-03). The pressure increased by approximately 10-psi during the first erratic period and by approximately 1.5-psi during the second period. During all other periods, the instrumentation was consistent with the right NLG tire pressure no. 1 instrumentation. Both measurements stem from the same pressure transducer, but have independent signal conditioning.

The STS-134 mission was launched at 136/12:56:27.994 GMT on May 16, 2011, on the thirty-sixth Space Shuttle Program (SSP) mission to the International Space Station (ISS).

At 136/12:57:00 GMT (00/00:00:32 MET), the Vernier Reaction Control System (VRCS) thruster R5D chamber pressure ( $P_c$ ) did not drop to vacuum as expected during ascent. The expected behavior for this pressure is to drop from ground ambient (approximately 15 psia) to 0 psia within approximately 90 sec. In R5D's case, the  $P_c$  dropped much more slowly from an indicated pressure of 16.9 psia to 5 psia over approximately 1 hr and then remained at 5 psia up to the first firing of the R5D thruster. This behavior is consistent with a possible blockage in the thruster nozzle or  $P_c$  sense tube. The R5D thruster was first fired during Operations (OPS) 201 VRCS activation. The firing response was nominal:  $P_c$  rise rate, maximum value, and shutdown transient were nominal with  $P_c$  returning to 0 psia.

The Reusable Solid Rocket Booster (RSRB) performed nominally and separation was visible. A nominal Orbital Maneuvering System (OMS) assist maneuver was performed following RSRB separation. Ignition occurred at 136/12:58:42 GMT (00/00:02:14 MET), and the maneuver was 164.24 sec in duration.

At 136/13:02:38 GMT (00/00:06:11 MET), the Space Shuttle Main Engine (SSME) -1 Low Pressure Fuel Turbopump (LPFTP) pressure Channel-B instrumentation experienced a data drop-out for 0.1 sec (IFA STS-134-E-001). This caused the SSME controller to post a Failure Identifier (FID) and disqualify that measurement. The SSME uses this transducer for the Liquid Hydrogen ( $LH_2$ ) flow-rate calculation on the center engine. It continued to use the Channel-A pressure data for that calculation. The FID did not affect any other SSME operation. This transducer is not used after Main Engine Cutoff (MECO).

MECO occurred at 136/13:04:49 GMT (00/00:08:21 MET). The External Tank (ET) was separated from the Orbiter at 136/13:05:10 GMT (00/00:08:42 MET).

A nominal OMS-2 maneuver was a dual engine, straight-feed firing with the ignition occurring at 136/13:33:25 GMT (00/00:37:58 MET) and the cutoff at 136/13:36:14 GMT (00/00:40:47 MET). The firing time was 168.6 sec with a Differential Velocity ( $\Delta V$ ) of 259.2 ft/sec. The resulting orbit was 124.3 by 175.8 nautical miles (nmi).

The payload bay doors were opened at 136/14:26:29 GMT (00/01:30:01 MET). The Ku-Band antenna was deployed and the self-test was completed with satisfactory results.

A nominal OMS-3 maneuver was performed at 136/15:48:38.1 GMT (00/02:52:11 MET) with cutoff at 136/15:49:44.8 GMT (00/02:53:17 MET). The firing duration was 66.7 sec with a  $\Delta V$  of 93.6 ft/sec. The resulting orbit was 175.6 by 178.4 nmi.

The Shuttle Remote Manipulator System (SRMS) on-orbit initialization was completed at 136/15:54 GMT (00/02:58 MET) and the power-up was completed at 136/16:09 GMT (00/03:13 MET). The SRMS checkout was completed at 136/17:16 GMT (00/04:20 MET). The SRMS payload bay survey was completed at 136/17:36 GMT (00/04:40 MET) and the maneuver to Pre-Cradle position was completed at 136/17:48 GMT (00/04:52 MET).

When driving the Wrist Roll (WR) joint during the SRMS direct-drive test, a fault message was received. The message was determined to be known nuisance alarm caused by a timing issue between the General Purpose Computer (GPC) and the Manipulator Controller Interface Unit (MCIU). This was a recurrence of the alarm on STS-118. There were no impacts to operations and the SRMS remained fully functional.

At 136/19:00 GMT (00/06:03 MET), the downlink of Sequential Still Video (SSV) from multiple cameras and test pattern did not work. Ground stations were verified to be locked onto the SSV encoder signal being downlinked from the Orbiter. However, no video was present. The crew changed the SSV-to-Payload Data Interface Panel (PDIP) cable with a spare cable, cycled the SSV power, and SSV began operating nominally.

At approximately 136/19:09 GMT (00/06:12 MET), the crew reported that the Forward Mission (FWD MSN) timer MET was off by 4 hr (IFA STS-134-V-02). The GMT was reported to be correct. At approximately 137/14:11 GMT (01/01:14 MET), the crew was asked to provide a read-out of the FWD MSN timer for both MET and GMT. This time the GMT was off by 4 hr and the MET was correct. The FWD MSN timer was power cycled at the circuit breaker, but the power cycle did not correct the problem.

## **Flight Day 2**

The main activities for Flight Day (FD) 2 were the survey of the Reinforced Carbon-Carbon (RCC) Thermal Protection System (TPS), checkout of the Extravehicular Activity (EVA) suits, and Orbiter Docking System (ODS) ring extension.

A nominal OMS-4 maneuver was performed at 137/06:22:52 GMT (00/17:26:25 MET) with cutoff at 137/06:23:06 GMT (00/17:26:39 MET). The firing duration was 14.4 sec with a  $\Delta V$  of 11.2 ft/sec. The resulting orbit was 176.1 by 182.5 nmi.

The RCC TPS survey was completed satisfactorily. The Starboard survey of the RCC TPS began at 137/08:31 GMT (00/19:33 MET) and was completed at 137/09:43 GMT (00/20:46 MET). The Nose Cap survey began at 137/10:12 GMT (00/21:15 MET) and was completed at 00/10:42 GMT (00/21:46 MET). The Port survey began at 137/11:23 GMT (00/22:26 MET) and was completed at 137/12:37 GMT (00/23:41 MET).

The SRMS grappled the ELC 3 at 137/13:57 GMT (01/01:01 MET).

The ODS was powered on at 137/14:26:18 GMT (01/01:29:50 MET). The ring extension was completed in 3 min 44 sec at 137/14:35:49 GMT (01/01:39:21 MET). The power was on the ODS for 11 min 04 sec and the ODS performed nominally.

Checkout of the rendezvous tools was completed successfully.

At approximately 137/16:15 GMT (01/03:18 MET), Multiple Headset Adapter (MHA) Ports J1 and J2 were reported as not transmitting (IFA STS-134-V-04). The Flight Deck

MHA is a communications box that allows for three headsets (at ports J1, J2, and J3) to plug in and communicate.

### **Flight Day 3**

The main activities on FD 3 were rendezvous and docking with the ISS, hatch opening, installation of the ELC 3 and Oxygen (O<sub>2</sub>) transfer.

A nominal OMS-5 Nominal Correction (NC) 4 maneuver was performed at 138/06:07:27 GMT (01/17:10:59 MET) with cutoff at 138/06:07:38 GMT (01/17:11:10 GMT). The firing duration was 10.6 sec with a  $\Delta V$  of 9.6 ft/sec. The resulting orbit was 180.8 by 183.0 nmi.

The crew switched the Ku-Band System to COMM mode at 138/04:45:42 GMT (01/15:49:14 MET) and the system operated nominally. The crew switched the system to RADAR mode for rendezvous at 138/06:53:26 GMT (01/17:56:58 MET) and detected the ISS at a range of 140,000 ft. The Ku-Band RADAR mode operated as expected. The crew returned the Ku-Band to COMM mode at 138/09:54:24 GMT (01/20:57:56 MET) at a range of 147 ft.

The OMS-6 NC4 maneuver was completed satisfactorily using the left engine, and ignition occurred at 138/06:07:27.4 GMT (01/17:11:00 MET). The firing duration was 10.6 sec with a  $\Delta V$  of 8.2 ft/sec. The resulting orbit was 180.8 by 183 nmi.

The OMS-7 Terminal Initiation (TI) maneuver was a two-engine straight-feed firing. Ignition occurred at 138/07:38:13 GMT (01/12:41:35 MET). The duration of the maneuver was 10.8 sec with a  $\Delta V$  of 8.6 ft/sec, and the Orbiter was placed into a 183 by 185.8 nmi orbit. Engine performance was nominal.

The Midcourse Correction (MC) 1 maneuver was an +X RCS firing using two thrusters. Ignition occurred at 138/07:58:14.5 GMT (01/19:01:47 MET). The  $\Delta V$  delivered was 0.54 ft/sec and the resulting orbit was 183.9 by 186.6 nmi. The MC2 maneuver was a multi-axis RCS firing using five thrusters. Ignition occurred at 138/08:32:15.1 GMT (01/19:35:47 MET). The  $\Delta V$  delivered was 0.96 ft/sec and the resulting orbit was 183.0 by 185.9 nmi. The Out-of Plane null maneuver was not required. Also, no MC3 maneuver was required. The MC4 maneuver was a multi-axis Reaction Control System (RCS) firing using six primary thrusters. The ignition occurred at 138/08:59:15.1 GMT (01/20:02:47 MET). The  $\Delta V$  delivered was 1.7 ft/sec and the resulting orbit was 183.8 by 187.3 nmi orbit.

During rendezvous, the Trajectory Control Sensor (TCS) lost track with the Pulsed laser and did not transition from Pulse mode to Continuous Wave (CW) mode at the expected range (IFA STS-134-V-05). The Loss of Tracking (LOT) events occurred at 138/09:05:53 GMT (01/20:09:25 MET) at 1020 ft for a duration of approx 28 sec, and at 138/09:07:04 GMT (01/20:10:36 MET) at 895 feet for a duration of 2 min 45 sec. The transition from Pulse to CW generally occurs prior to the R-bar Pitch Maneuver (RPM)

at approximately 950 ft. The transition from Pulse to CW occurred after the RPM at 138/09:23:26 GMT (01/20:26:58 MET) at a distance of 648.29 feet. The CW laser did not lose tracking after the acquisition.

The RPM began at 138/09:15:31 GMT (01/20:19:03 MET) and was completed satisfactorily.

The ODS was powered on at 138/09:40:22 GMT (01/20:43:54 MET). *Endeavour* made initial contact with the ISS at 138/10:13:52 GMT (01/21:17:24 MET). The hook-drive command was initiated at 138/10:22:52 GMT (01/21:26:24 MET). The hard mate was completed at 138/10:26:47 GMT (01/21:30:19 MET), and the ODS was powered off at 138/10:27:22 GMT (01/21:30:54 MET).

The SRMS unberthed the ELC 3 at 138/13:14 GMT (02/00:18 MET) and maneuvered the ELC 3 to the Hover Position.

The Orbiter/ISS hatch opening occurred at 138/12:36 GMT (01/23:40 MET). All operations were nominal.

The SRMS successfully handed off the ELC 3 to the Space Station Remote Manipulator System (SSRMS) at 138/14:57:12 GMT (02/02:00:44 MET) and the SRMS was then maneuvered to the ELC 3 Installation Viewing Position. The ELC 3 was installed on the Port 3 (P3) UCCAS.

A total of 8.5 lb of O<sub>2</sub> were transferred to the ISS.

#### **Flight Day 4**

The main activities on FD 4 were cargo transfer, EVA preparation and procedure review, EVA campout, Gaseous Nitrogen (GN<sub>2</sub>) transfer, installation of AMS-02 and a Public Affairs Office (PAO) event.

The RCC and TPS Damage Assessment Team (DAT) imagery review was completed and seven tile issues were identified. Five of these issues were cleared using standard analysis tools. The DAT completed the analysis of a sixth site on the starboard inboard elevon and that site was cleared at the following Mission Management Team (MMT) meeting. However, based on the imagery review, the DAT and Orbiter Project Office determined that a Focused Inspection (FI) was required for one damage site. The area of interest was on the starboard side between the Main Landing Gear (MLG) door and the ET door.

The crew filled and transferred two Contingency Water Containers (CWCs). The first CWC was filled with 97 lb of water at 139/06:29:35 GMT (02/17:33:07 MET). The second CWC was filled with 99.6 lb at 139/08:38:19 GMT (02/19:41:51 MET).

The AMS-02 installation was successfully completed at 139/09:34 GMT (02/20:38 MET) and the AMS-02 was successfully activated at 139/09:53 GMT (02/20:57 MET).

The transfer of GN<sub>2</sub> continued to proceed satisfactorily.

## **Flight Day 5**

The main planned activity for FD 5 was the first EVA.

The crew filled and transferred the third CWC with 88 lb of water at 140/06:59:42 GMT (03/18:03:14 MET).

Crew egress for the first EVA was approximately 140/07:09 GMT (03/18:12 MET). Hatch opening was 12 min early. During the EVA, the crew retrieved the Materials International Space Station Experiment (MISSE) 7A and 7B, installed the Crew and Equipment Translation Aid (CETA) cart light on the Starboard (S) 3 truss, setup the cooling-loop ammonia fill, installed the external wireless communications antenna and installed the MISSE 8. As a result of a Carbon Dioxide (CO<sub>2</sub>) sensor issue in one of the EVA suits, the crew completed all but one of the nominal tasks and no get-ahead tasks were completed. The hatch was closed at 140/13:28 GMT (04/00:32 MET) and the total duration of the EVA was 6 hr 19 min.

## **Flight Day 6**

The main activities for FD 6 were the unberthing and handoff of the Orbiter Boom Sensor System (OBSS) for the FI, EVA preparations and procedure review, CWC fill and transfer, and a PAO event with the Pope.

The crew filled the fourth CWC with 92.5 lb of water at 141/04:44:00 GMT (04/15:47:32 MET) and transferred the CWC to the ISS.

The SSRMS grappled the OBSS at 141/04:49:40 GMT (04/15:53:12 MET). The OBSS was grappled by the SRMS at 141/05:21:40 GMT (04/16:25:12 MET). The FI was delayed for approximately 1 hr due to the Laser Camera System (LCS) display not being received through the Still Sequential Video (SSV) system. This issue was resolved prior to the FI. The FI started at 141/07:34:16 GMT (04/18:37:48 MET).

The transfer of GN<sub>2</sub> was terminated at 141/09:50 GMT (04/21:12 MET).

## **Flight Day 7**

The main activities for FD 7 were the second EVA and mid-deck transfer.

The DAT completed their review of the FI imagery. Based on the analysis of the large damage site, the DAT and Orbiter Project Office (OPO) recommended clearing the TPS for entry and the MMT accepted the recommendation.

The crew filled and transferred the fifth CWC with 97.7 lbm of water at 142/05:17:38 GMT (05/16:21:10 MET)

The second on-orbit fuel cell purge was performed, beginning at 142/07:07 GMT (05/18:10 MET). During the 114-hour purge interval, the approximate voltage decay was 0.22 Vdc in fuel cell 1, 0.24 Vdc in fuel cell 2, and 0.17 Vdc in fuel cell 3.

The crew egress for the second EVA was approximately 11 min ahead of schedule at 142/06:05:30 GMT (05/17:09:02 MET). The crew completed all nominal tasks including the lubrication of the port Solar Alpha Rotary Joint (SARJ), installation of the Special Purpose Dexterous Manipulator (SPDM) camera cover, lubrication of the SARJ latching end-effector and installation of the radiator grapple bar stow beam on the Starboard (STBD) 1 truss. There were some issues with various bolts during some of the tasks which delayed the completion of the EVA. The hatch was closed at 142/14:06 GMT (06/01:09 MET) and the total duration of the EVA was 8 hr 7 min.

## **Flight Day 8**

The main activities for FD 8 were crew off-duty time, preparations for the Soyuz 25S undocking, cargo transfer, and a PAO event.

At approximately 143/05:30 GMT (06/16:34 MET) the crew was playing back High Definition (HD) Flight Deck camcorder video and the ground was seeing video dropouts every 30 to 50 sec. After the crew swapped the optical cable from Multiplexer (MUX) Channel 2 to Channel 1, the video downlink dropouts did not recur.

The SRMS maneuvered the OBSS at 143/13:40 GMT (07/00:43 MET) from the Undocking Position to the Sensor Protect Position at 143/13:55 GMT (07/00:58 MET). Sensor Package 1 was configured later by ground control to protect the surfaces from possible contamination during the subsequent Soyuz undocking from the ISS.

During FD 8 crew sleep, the K-band File Transfer (KFX) Payload General Support Computer (PGSC) dropped off the onboard network at 143/21:00 GMT (07/08:03 MET) (IFA STS-134-S-001). After crew wake, the crew was asked to move the hard drive from the KFX PGSC into a spare PGSC. Moving the hard drive did not resolve the issue. The spare PGSC's original hard drive was reinstalled and the KFX function was then reassigned to the spare PGSC.

The Soyuz undocked from the ISS at 143/21:35:53 GMT (07/08:39:25 MET).

## **Flight Day 9**

The main activities for FD 9 were EVA tool configuration and preparations, and the installation of parts in the Oxygen Generator System (OGS).

The SRMS maneuvered the OBSS at 144/03:36 GMT (07/14:39 MET) from the Sensor Protect Position to the Undocking Position at 144/03:47 GMT (07/14:50 MET).

When the ISS ground command was sent to provide power to the Station-to-Shuttle Power Transfer System (SSPTS), the Orbital Power Converter Unit (OPCU) convertor 1A volts and temperature measurements remained off-scale low. As a result, the SSPTS experienced a fault isolator shutdown. A data review revealed no anomalous signatures on OPCU convertor 1A. Recycling of the power-up procedure recovered the OPCU convertor 1A and the OPCU convertor 1A voltage was returned to its maximum value.

The crew filled and transferred CWC no. 6 with 90.2 lb of water at 144/08:48:30 GMT (07/19:52:02 MET).

During the final Laser Dynamic Range Imager (LDRI) checkout, the mode timers did not increment as expected at 144/16:14 GMT (08/03:17:32 MET). To verify no impacts to the LDRI sensor performance, a procedure similar to a flat-field inspection was performed during crew sleep on FD 10. Analysis of the imagery did not show any issues with the LDRI.

During FD 9 crew sleep, a momentary loss of power to the APU 2 A-heater and APU controller occurred, but recovered after 4.5 min. Two System Management (SM) alerts were annunciated at 144/19:10:52 GMT (08/06:14:24 MET) (IFA STS-134-V-06). Following crew wakeup, the crew reconfigured the APU 2 to the B heaters.

## **Flight Day 10**

The main activity for FD 10 was the third EVA.

At approximately 145/02:38 GMT (08/13:42 MET), the ground could not hear a call from the Mission Specialist (MS) Audio Terminal Unit (ATU) through the flight-deck Multiple Headset Adapter (MHA) (IFA STS-134-V-04). This condition was suspected to be a repeat of the MHA problems reported on FD 2. The crew exchanged the flight deck MHA with the middeck MHA, but the communication could not be heard on the ground. With the Crew Communications Umbilical (CCU) still powered, the crew demated and then remated the MHA at the flight deck position and good communications were reported. The configuration of the two MHAs remained in the new configuration until further troubleshooting could be performed later in the mission.

The crew filled and transferred CWC no. 7 with 97.4 lb of water at 145/05:06 GMT (08/16:10 MET).

Crew egress for the third EVA was approximately 5 min ahead of schedule at 145/05:43 GMT (08/16:46 MET). The crew completed the In-Suit Light Exercise (ISLE) pre-breath protocol rather than camping out in the ISS airlock overnight. This is the first time this protocol was used. The crew installed and hooked up the Power Data and Grapple



Fixture (PDGF) on the Zarya module, installed the video signal converter on the Zarya module, and installed the jumper cables between the Harmony node, Unity node, and the Zarya module. The crew completed the planned tasks and the get-ahead task of tucking in the Multilayer Insulation (MLI) on the ELC 3 Cargo Transport Container (CTC). The hatch was closed at 145/12:37 GMT (08/23:41 MET). The duration of the third EVA was 6 hr 54 min.

## **Flight Day 11**

The main activities on FD 11 were the docked late inspection of the RCC, the fourth EVA procedure review and EVA campout.

The crew began the docked late inspection approximately 1 hr ahead of schedule at 146/01:48 GMT (09/12:52 MET). The Flat Field Calibration began at 146/01:58 GMT (09/13:02 MET) and was completed 6 min later. The Starboard RCC survey began at 146/02:31 GMT (09/13:35 MET) and was completed at 146/04:28 GMT (09/15:32 MET). The Nose Cap survey began at 146/04:51 GMT (09/15:54 MET) and was completed 17 min later. The Port RCC survey began at 146/05:30 GMT (09/16:34 MET) and was completed at 146/06:15 GMT (09/17:19 MET). The OBSS was maneuvered to the Hand-off Position at 146/06:21 GMT (09/17:23 MET) and the maneuver was completed 10 min later.

All of the imagery from the docked late inspection was downlinked.

The crew filled and transferred CWC no. 8 with 102.8 lb of water at 146/03:49 GMT (09/14:52 MET). The filling and transfer of the ninth CWC was completed at 146/08:14 GMT (09/19:17 MET).

The Nitrogen (N<sub>2</sub>) repressurization was terminated at 146/05:03 GMT (09/16:11 MET). The Oxygen (O<sub>2</sub>) repressurization was initiated at 146/07:09 GMT (09/18:13 MET).

## **Flight Day 12**

The main activities on FD 12 were the fourth and final EVA and the installation of the OBSS on the S1 Truss.

The Extravehicular (EV) crewmembers began the fourth EVA at 147/04:15 GMT (10/15:18 MET) and completed the EVA at 147/11:39 GMT (10/23:42 MET). The duration was 7 hr 24 min. The exchange of the Electrical Flight Grapple Fixture (EFGF) with the PDGF was completed. The EFGF was planned to be stowed in the Tool Stowage Assembly (TSA) in the Shuttle payload bay; however, the EFGF was brought inside the ISS because of time constraints.

The OBSS was successfully transferred to the ISS at 147/04:47 GMT (10/15:50 MET), and this was the last piece of the ISS assembly. The SRMS was stowed at 147/13:01

GMT (11/00:04 MET) and powered down at 147/13:05 GMT (11/00:08 MET). No SRMS activities were planned through the end of the mission.

The transfer of O<sub>2</sub> was continued after the completion of the EVA.

The Leading Edge Subsystem (LESS) Problem Resolution Team (PRT) recommended that the vehicle was “Go” for entry based on analysis of the docked late inspection imagery. The MMT accepted that recommendation.

### **Flight Day 13**

The main activities for FD 13 were the post-EVA Extravehicular Mobility Unit (EMU) reconfiguration, Carbon Dioxide Removal Assembly (CDRA) Bed Removal and Replacement (R&R) and middeck transfer.

The crew performed communications checks to continue the troubleshooting of the Multiple Headset Adapters (MHAs). The crew continued to have transmission issues. As a result, an alternate configuration was implemented to maximize crew communications during entry.

### **Flight Day 14**

The main activities on FD 14 were a reboost of the ISS, filling and transfer of Portable Water Reservoir (PWRs), completion of middeck transfers, stowage operations, rendezvous tool checkout and hatch closure.

A total of four PWRs were filled and transferred to ISS. With the addition of these PWRs, a total of 1121.79 lb of water was transferred to the ISS.

Handoff to Orbiter attitude control occurred at 149/04:41:44 GMT (12/15:45:17 MET) with the 14-degree maneuver to the reboost attitude beginning at 149/04:47:28 GMT (12/15:51:01 MET). The 14-min duration Vernier Reaction Control System (VRCS) reboost began at 149/05:03:27 GMT (12/16:07:00 MET) with a  $\Delta V$  of 2.0 ft/sec resulting in a 0.6 nmi increase in altitude. The 15-degree maneuver back to Torque Equilibrium Attitude (TEA) began at 149/05:23:50 GMT (12/16:27:23 MET) and was completed at 149/06:07:27 GMT (12/17:11:00 MET).

Orbiter Docking System (ODS) hatch closure occurred at 149/11:45:49 GMT (12/22:49:22 MET).

Rendezvous tool checkout was completed successfully.

## Flight Day 15

The main activities on FD 15 were the undocking from the ISS, the fly-around, the Sensor Test for Orion Relative Navigation Risk Mitigation (STORRM) Detailed Test Objective (DTO) which involved a re-rendezvous with the ISS, and a water dump.

The Orbiter resumed attitude control with the Digital Autopilot (DAP) in the automatic-mode at 150/02:35:28 GMT (13/13:39:00 MET).

The maneuver to the undocking attitude began at 150/02:46:28 GMT (13/13:50:00 MET) and was completed at 150/03:18:31 GMT (13/14:22:03 MET). The FREE drift mode was selected at Undocking minus 3 min, which was at 150/03:52:28 GMT (13/14:56:20 MET).

The undocking from the ISS was initiated with the hook-drive command at 150/03:53:08 GMT (13/14:57:20 MET). The total drive time was approximately 2 min and 7 sec and Hook Groups 1 and 2 operated nominally. The ODS performed nominally for undocking.

The fly-around maneuver was initiated with RCS +X-axis pulses of the L1A and R1A thrusters at 150/04:20 GMT (13/25:22 MET).

Prior to the separation 1 maneuver, the Ku-Band was taken to the RADAR mode at 150/04:49:20 GMT (13/15:52:52 MET) and locked on to the ISS at an approximate range of 600 ft. The Ku-Band was configured back to the Communications (COMM) mode at 150/09:09:27 GMT (13/20:12:59 MET) at a range of approximately 21,900 ft.

The separation 1 RCS maneuver was initiated with a 6.48-sec +X-axis pulse of L1A and R1A thrusters at 150/05:06:02 GMT (13/16:09:34 MET). The separation 2 RCS maneuver was performed at 150/05:34:06 GMT (13/16:37:38 MET), and was a 5.2-sec multi-axis firing using the F2F, F3F, F2D, F1D, L2D, L3D, R2D, and R3D thrusters.

During fuel cell performance monitoring at 150/05:45:39 GMT (13/16:49:11 MET), Fuel Cell 2 substack 1 failed its self-test (IFA STS-134-V-07). The next self-test was nominal. Substack 1 continued to fail the self-test a number of times through the remainder of the mission. A Main-B-to-Main-C bus tie was performed as a precaution and all parameters were nominal.

The STORRM DTO was initiated with the Nominal Height (NH) 2 maneuver. The maneuver was performed at 150/06:39:38 GMT (13/17:43:10 MET) with a 6.72-sec multi-axis firing using the L1A, R1A, L2U, R2U and F1U thrusters.

The STORRM DTO Mid-course Correction (MC) 5 maneuver was initiated at 150/06:59:08 GMT (13/18:02:40 MET) and was a 1.6-sec multi-axis firing using the L1A, R1A, L2U, R2U, L2D, L3D, R2D, R3D, F1D and F2D thrusters.

A Nominal Slow Rate (NSR) firing placed the Orbiter in a co-elliptic orbit, and the maneuver was initiated at 150/07:24:08 GMT (13/18:27:40 MET). The maneuver was a 9.12-sec multi-axis firing using the F2F, F3F, F1D, F2D, L2D, L2U, R2D and R2U thrusters.

The STORRM DTO MC6 firing was not required.

The Terminal Phase Initiation (TPI) maneuver was initiated at 150/07:57:34 GMT (13/19:01:06 MET). The maneuver was an 11.6-sec multi-axis firing using the F2F, F3F, F1D, F2D, L2D, L2U, L3D, R1R, R2D, R2U and R3D thrusters.

The Transition to Docking Axis (TDA) maneuver was not required. The closest approach, Center-of-Gravity (CG) to CG, was 955 ft at 150/08:24:25 GMT (13/19:27:57 MET).

The Separation 3 maneuver was initiated at 150/08:38:36 GMT (13/19:43:08 MET) as a 3.68-sec multi-axis firing using the F2F, F3F, F1D, F2D, L2D, L2U, L3D, R2D, R2U and R3D thrusters.

A supply water dump was initiated at 150/09:32:38 GMT (13/20:36:10 MET) and the dump was completed at 150/10:31:09 GMT (13/21:34:28 MET). The total amount of supply water dumped was 148.04 lb.

The waste water dump began at 150/09:40:40 GMT (13/20:44:12 MET) and the dump was completed at 150/10:38:19 GMT (13/21:41:51 MET). The total amount of waste water dumped was 115.8 lb.

A dedicated thruster firing in support of the Maui Analysis of Upper-atmospheric Injections (MAUI) payload of opportunity was initiated at 150/11:43:18 GMT (13/22:46:50 MET) with a multi-axis firing using the F3L, F4R, L1A, L1L, R1A, R1R, F5L, R5D, and L5L thrusters. The customer confirmed that they were able to see the firing thrusters.

## **Flight Day 16**

The main activities on FD 16 were a PAO event, the Flight Control System (FCS) Checkout, the RCS hot-fire, a waste water dump, and cabin stow.

Communications-Security false-lock indications occurred three times during the 24-hr period of S-band operations to meet File IX requirements. This condition is a random occurrence that has previously been observed on this vehicle since its initial flight.

The FCS Checkout was initiated at 151/02:24:36 GMT (14/13:28:38 MET). Auxiliary Power Unit (APU) 1 was started at 151/02:29:16 GMT (14/13:32:48 MET), ran for 4 min 40 sec, and used 15 lb of fuel. The APU and the Hydraulic/Water Spray Boiler (HYD/WSB) systems operated nominally throughout the FCS checkout. The FCS

checkout procedure was completed nominally and all flight control surfaces responded as expected.

The crew reported a successful self-test of the Heads-Up Display (HUD). However, after exiting the self-test, the crew reported that the Commander's (CDR's) HUD display returned to NORM while the Pilot's (PLT's) HUD remained in the TEST mode. The HUDs of both the CDR and PLT performed satisfactorily during entry.

The RCS hot-fire procedure was initiated at 151/03:30:57 GMT (14/13:28:08 MET) and terminated at 151/03:34:24 GMT (14/14:37:56 MET). All 38 RCS thrusters were fired at least once. The hot-fire was completed nominally and no anomalies were observed.

A dedicated thruster firing in support of the Ram Burn Observation (RAMBO) payload of opportunity was performed at 151/07:33:10 GMT (14/18:36:42 MET). This was a set of three 10-sec +X firings using the L1A and R1A thrusters.

A waste water dump and a condensate CWC dump were performed. The waste dump was initiated with the waste-valve opening at 151/08:05:44 GMT (14/19:09:16 MET) and terminated at 151/08:16:46 GMT (14/19:20:18 MET). A total of 35.5 lb was dumped. The CWC dump was completed in one-nozzle temperature cycle, beginning at 151/08:35:37 GMT (14/19:39:09 MET) and terminating at 151/08:42:46 GMT (14/19:46:18 MET).

The stowing of the Ku-Band using dual motors was performed nominally at 151/10:38:16 GMT (14/21:41:48 MET).

### **Flight Day 17 and Landing**

The STS-134 mission was successfully completed with a landing at Kennedy Space Center (KSC), Florida.

Both Payload Bay Doors (PLBDs) were closed nominally by 153/02:48:23 GMT (15/13:54:16 MET) in preparation for landing.

The deorbit maneuver for the first landing opportunity at KSC, a dual-engine firing, was performed on orbit 248 at 152/05:29:03 GMT (15/16:32:35 MET). The burn was 158.3 sec in duration with a  $\Delta V$  of 298.4 ft/sec. The resulting orbit was 23.2 by 188.5 nmi.

Entry Interface (EI) occurred at 152/06:03:06 GMT (15/17:06:38 MET).

The main landing gear touchdown occurred on KSC runway 15 at 152/06:34:50 GMT (15/17:38:12 MET) on June 1, 2011. The drag chute was deployed at 152/06:34:53 GMT. The nose gear touchdown occurred at 152/06:35:00 GMT. Drag chute jettison occurred at 153/06:35:19 GMT. Wheels stop occurred at 152/06:35:33 GMT. The last APU was shutdown 20 min 24 sec after landing.

The flight duration was 15 days 17 hr 38 min 22 sec.

### **Post-landing**

During analysis of post-landing imagery, a brief fire was observed between the left Main Landing Gear (MLG) tires shortly after the drag chute was jettisoned (IFA STS-134-V-08). It appeared to extinguish itself quickly. Detailed visual inspections, material analysis, and landing gear systems testing were performed in an effort to determine the root cause of the fire. However, no definitive root cause could be determined.

During the Orbiter Processing Facility (OPF) inspection of the umbilical cavities on OV-105, one of the hydraulic ET umbilical actuators (LO<sub>2</sub> Forward Outboard) was found to not be fully retracted into the mechanical locks (IFA-STS-134-V-09). This anomaly is similar to anomaly IFA STS-119-V-13 that was recorded after the STS-119 mission.

## **HISTORY OF SPACE SHUTTLE ENDEAVOUR**

The Space Shuttle OV-105, *Endeavour*, finished its career with the distinction of delivering the final major component to the ISS, AMS-2, as well as the final US assembly component, the OBSS. *Endeavour* accumulated 299 days during its 25 missions and completed 4671 orbits travelling a total of 122,883,151 statute miles. *Endeavour* docked once with the Russian Mir space station and 12 times with the ISS.

OV-105 was authorized by Congress in August 1987 as a replacement for space shuttle *Challenger*. For the first time, a national competition involving students in elementary and secondary schools produced the name of the new Orbiter, which was announced by President George H.W. Bush in 1989. The choice of the name *Endeavour* carries on a tradition drawn from many historic Earth-bound exploring ships of the past. The last addition to NASA's orbiter fleet, *Endeavour* was named after the first ship commanded by James Cook, the 18<sup>th</sup>-century British explorer, navigator and astronomer. On the sailing ship *Endeavour's* maiden voyage in August 1768, Cook sailed to the South Pacific to observe and record the infrequent event of the planet Venus passing between Earth and the sun. Determining the transit of Venus enabled early astronomers to find the distance of the sun from Earth, which then could be used as a unit of measurement in calculating the parameters of the universe.

The Space Shuttle *Endeavour* served as a symbol of American pride and leadership in human space flight. *Endeavour* arrived at Kennedy Space Center on May 7, 1991, and flew its first mission, STS-49, exactly one year later on May 7, 1992. The STS-49 mission was highlighted by the dramatic rescue of a stranded Intelsat communications satellite. The commitment to succeed led to a three-man EVA to capture Intelsat by hand when the specially designed capture bar would not snap in place. The EVA succeeded and the STS-49 mission set the tone for future *Endeavour* missions over the next 19 years, including the delivery of the first US component to start assembly of the ISS.

On April 12, 2011, it was announced that *Endeavour* would be put on display at the California Science Center in Los Angeles, California.

## **PAYLOADS AND EXPERIMENTS**

The STS-134 mission was the 36<sup>th</sup> SSP mission to the ISS, the 25<sup>th</sup> and final flight of OV-105 (*Endeavour*), and the 134<sup>th</sup> Space Shuttle flight. Highlights of the mission included:

1. Berth and activate the AMS-02 and the ELC 3.
2. Transfer middeck cargo and consumables to ISS.
3. Perform STORRM DTO activities.
4. Perform high priority science payload activities located on Shuttle middeck and ISS.
5. Remove and Replace (R&R) Node 3 Air Revitalization Carbon Dioxide Removal Apparatus (CDRA) back bed.
6. Perform Oxygen Generation Assembly (OGA) remediation.
7. Departure of 25S Soyuz during Shuttle docked-operations, and
8. Four EVAs to:
  - a. Install MISSE 8;
  - b. Retrieve MISSE 7a and 7b;
  - c. Install External Wireless Communication (EWC) laboratory antennas;
  - d. Refill P6 radiator with ammonia;
  - e. Lubricate Port Solar Alpha Rotary Joint (SARJ) race ring;
  - f. Install Starboard (S)1 radiator grapple bar stowage beams;
  - g. Install Functional Cargo Block (FCB) Power Data Grapple Fixture (PDGF) and Y-power cables;
  - h. Transfer OBSS to ISS S1 Orbit Support Equipment (OSE); and
  - i. Replace OBSS Electrical Flight Releasable Grapple Fixture (EFGF) with the P6 PDGF.

## **LAUNCH PACKAGE OVERVIEW**

The ISS ULF-6 launch package consisted of the AMS-02, ELC3, and MISSE 8 in the Payload Bay along with two powered middeck science payloads. A non-ISS launch package item in the Payload Bay (PLB) was the STORRM DTO.

## **CREW ACTIVITY SUMMARY**

On FD 2, the crew performed the TPS port and starboard wing leading edge (WLE) and nose-cap surveys to check for ascent debris damage.

A successful rendezvous and docking to the ISS occurred on FD 3, on 138/10:14 Greenwich Mean Time (GMT) (01/21:18 MET). Prior to docking, the Orbiter RPM was performed and the ISS crew performed photo imagery of the Orbiter. The STORRM DTO was successfully activated prior to FD 3 approach and docking operations. After docking, the ELC 3 (previously grappled at the end of FD 2 by the SRMS) was



unberthed, handed over to the Space Station Remote Manipulator System (SSRMS), and installed on ISS P3 UCCAS.

On FD 4, the AMS-02 was unberthed, handed over to the SSRMS, and installed on the ISS S3 Payload Attachment System (PAS). Analysis of FD 2 TPS inspection and RPM photography indicated that a FI was required.

On FD 6, the FI was performed, which resulted in clearing the tile for entry.

On FD 8 after the Shuttle crew sleep period started, the 25S Soyuz (TMA-20) undocked with three ISS crewmembers. The ISS was reoriented after undocking to allow the Flight Engineer (FE) -5 to photograph the ISS with the Orbiter docked and AMS-02 and ELC 3 deployed.

On FD 11, the OBSS was used to inspect the port and starboard WLE and nose-cap for micrometeoroid/orbital debris (MM/OD) damage and no damage was discovered. The vehicle was cleared for entry based on the evaluation of the OBSS docked late inspection. Also, the OGA remediation was completed.

On FD14, the CDRA R&R was completed.

During the docked timeframe, the crew performed four scheduled EVAs, utilization payload activities, Russian and US segment IVA activities, PAO) events, and middeck/ consumables transfer operations.

On FD 15, *Endeavour* was undocked from the ISS at the beginning of the crew day, May 30<sup>th</sup> at 150/03:55 GMT (13/14:59 MET). The fly-around and STORRM re- rendezvous activities were successfully conducted after undocking. The MAUI data- take was performed on FD 15 at 150/11:40:00 GMT (013/22:43:32 MET) for the Air Force Maui Optical and Supercomputing Site (AMOS) ground-site. The Orbiter firings were a total of 144 sec using the Primary Reaction Control System (PRCS) and Vernier Reaction Control System (VRCS).

On FD 16, the RAMBO-2 data take was initiated at 151/07:33:10 GMT (14/18:36:42 MET) using three dedicated PRCS firings.

The Orbiter landed at KSC/Orbit 248 on its first landing opportunity of the day on FD17, June 1, 2011 at 2:35 a.m. Central Daylight Time (CDT) (152/06:35:23 GMT) (15/17:38 MET).

## **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 <sub>m</sub>	From ISS, lb <sub>m</sub>
Cargo Bay	29,374	180
Middeck	1536	1601
<b>Totals</b>	<b>30910</b>	<b>1781</b>

1. **Water** – Total amount of water transferred was 1126.6 lb<sub>m</sub>. A total of 11 CWC transferred 1047.8 lb<sub>m</sub>. Four PWRs transferred 78.8 lb<sub>m</sub>. Two CWCs were filled with 109 lb<sub>m</sub> of condensate, which was transferred for processing.
2. **Oxygen** – A total of 16.5 lb<sub>m</sub> of transferred to the airlock High Pressure Gas Tank (HPGT) on ISS. A total of 90 lb was transferred via ISS cabin repressurization and 188 lb<sub>m</sub> for ISS/Shuttle for crew metabolic.
1. **Nitrogen** – A total of 17.5 lb<sub>m</sub> was transferred to ISS airlock tanks. A total of 64 lb<sub>m</sub> was transferred for repressurization of the ISS stack.
2. **Lithium Hydroxide** – The Shuttle transferred 12 unused canisters and 6 used canisters to ISS. ISS transferred 18 used canisters to the Shuttle.
3. **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 AND LASTS

### SIGNIFICANT FIRSTS

The STS-134 mission was the first flight of the AMS-02, which was provided by a consortium lead by Nobel Laureate and Massachusetts Institute of Technology (MIT) Professor Dr. Samuel Ting.

This was the first time that a Soyuz vehicle undocked while the Space Shuttle was docked with the ISS.

### SIGNIFICANT LASTS

This mission was the last for the Space Shuttle *Endeavour* vehicle. This mission was also the last flight of a foreign-based astronaut, the last EVA performed by a Shuttle-based crew, and the last flight to conduct ISS assembly operations.

## SIGNIFICANT ISS ANOMALIES

All ISS subsystems performed nominally during the mission with no significant anomalies. The following problems were noted:

On FD 3, the Mobile Transporter (MT) stopped short during the translation from Worksite no. 7 (WS) 7 to WS 2. The MT translated approximately 33 meters and stopped about 2 centimeters short of the planned translation. The ground controllers resolved the issue and then successfully latched and mated the MT to WS 2. The Mobile Servicing System (MSS) components were repowered successfully with several hours of thermal clock margin remaining.

The node 3 condensate sampling was not initially completed due to a leaking laboratory quick-disconnect on FD 4. The issue was resolved with samples successfully taken on FD 5 and FD 6.

The ISS Global Positioning System (GPS) 2 receiver failed on FD 5 and troubleshooting (several power cycles) was unable to regain the unit. The GPS 1 provided good state vector information and the Russian state vector was available as backup.

On FD 5 during the first EVA, the EV2 crewmember's suit Carbon Dioxide (CO<sub>2</sub>) sensor stopped functioning. The sensor was successfully recovered after completion of a dry-out procedure. The cause was due to moisture buildup during the EVA.

On FD 7, during the second EVA, the EV1 crewmember could not mate the Early Ammonia System (EAS) vent jumper back to its stowage location due to a stuck cap. The EVA crew used short wire-ties to stow the vent jumper in accordance with the contingency plan.

On FD 7 during the second EVA Port SARJ race-ring lubrication, the captive fasteners became separated from their retention hardware and generated debris during the SARJ cover removal. One bolt and three retaining washers floated away from the ISS port and were not recovered. The remaining items were recovered, stowed in the EVA trash bag and returned for analysis. The SARJ cover no. 17 was not reinstalled during the EVA due to the lack of fasteners (only one of four fasteners remained). Thermal analysis indicated sufficient margin existed so the cover was not reinstalled.

On FD 8, the Remote Power Control Module (RPCM) tripped, which powered the Starboard (S) 1-1 Crew Equipment Translation Aid (CETA) light. Other loads on this RPCM included the S-Band 1 Transponder, Radio Frequency Group, and Baseband Signal Processor. The loss of this RPCM did not impact to mission operations.

On FD 8, the overhead Crew Quarter (CQ), a dual fan Failure warning message for the overhead CQ was generated twice. The crew did not note any possible sources of blockage in the overhead CQ. The crew adjusted the Overhead CQ fan setting from low to high. Ground teams recommended the filters for this CQ be cleaned.

On FD 9, the RPCM R&R by the MS1 crewmember noted a trip after the 25S Soyuz undocked. This RPCM impacted Orbiter Communications Adapter (OCA), International Partner (IP) phone, Net Meeting, payload data/recording, Zone of Exclusion (ZOE) and Multi-Protocol Converter (MPC) down-linking capabilities. AMS-02 was unable to

downlink data during the RPCM failure due to the High Rate Communications Outage Recorder (HCOR) loss of power.

On FD 10 after the third EVA, a grounding wire was observed protruding from the FGB PDGF connector door. No tasks were developed to secure the grounding wire during the fourth EVA; however, the condition will be cleared during the STS-135/ULF7 EVA.

On FD 11, the Russian Segment (RS) Smoke Detector 4 (SD4) alarm was activated. Investigation by the crew concluded no smoke or fire was present. It was theorized dust was disturbed while the crew was active behind panel 412, where the SD4 was located.

During FD 10 and FD 12 Permanent Multipurpose Module (PMM) stowage operations, a total of three CWCs were discovered to be leaking significantly around the valves. Those leaking CWCs were assessed for return on Shuttle but will be disposed of in the ATV-2. Also, a CWC that leaked on STS-133 will be returned in the MPLM on STS-135.

On FD 14 after filling, a leaking PWR was double bagged and temporarily stowed in the PMM.

## 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
<b>Category 1 Tasks</b>		
1	Dock Shuttle Flight ULF6 to Pressurized Mating Adapter (PMA)-2 and perform mandatory crew safety briefing for all crewmembers.	FD 3
2	Transfer and stow critical middeck cargo items to ISS per ULF6 Transfer Priority List (TPL) (including transfer priorities 1-3).	FD 3 & 4
3	Unberth the Alpha Magnetic Spectrometer-02 (AMS-02) from the Payload Bay (PLB) using the SRMS; install on ISS S3 Upper Inboard Payload Attach Site (PAS) using the SSRMS, and provide keep-alive power.	IVA/Ground FD 4
4	Unberth Express Logistics Carrier-3 (ELC-3) from the PLB using the SRMS; install on ISS P3 Upper Unpressurized Cargo Carrier Attach Site (UCCAS) using the SSRMS, and provide keep-alive power with primary and redundant power feeds enabled.	IVA/Ground FD 3
<b>Category 2 Tasks</b>		
5	Transfer mandatory middeck cargo items required for mission success per ULF6 TPL.	IVA FD 4-FD 6

## ISS MISSION PRIORITIES COMPLETION STATUS

Item	Task	Flight Day Task Completed
6	Transfer Oxygen (O2) from the Orbiter to ISS High Pressure Gas Tanks with the plan to have tanks full at Shuttle retirement. <i>(30 lb planned, 8.5 lb completed FD3-4, 8.0 lb completed FD12-13)</i>	IVA FD 3-FD 4 FD 12-13
7	Transfer Materials on International Space Station (MISSE) 7a and 7b Passive Experiment Containers (PECs) from ISS ELC2 to Orbiter PLB.	EVA FD 5-EVA1
8	Transfer MISSE 8 PEC from Orbiter PLB to ISS ELC2.	EVA FD 5-EVA1
9	Activate Space Test Program-Houston3 (STP-H3) on ELC3.	Ground FD 3
10	Activate AMS-02 for experiment operations.	Ground FD 4
11	Perform Development Test Objective (DTO)-703 Sensor Test for Orion Relative Navigation Risk Mitigation (STORRM) activities.  a. Obtain data during Shuttle undocking and re-rendezvous.  b. Obtain data during Shuttle/ISS rendezvous, proximity operations, and docking.  c. Photograph STORRM targets post docking and prior to undock for photogrammetric analysis.	IVA/Imagery /Ground  FD 15  FD 3  FD 3, FD 15

## ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
12	<p>Perform daily middeck activities to support high priority payloads (including cases where Shuttle crew performs payloads on ISS). These items are not listed in priority order.</p> <ul style="list-style-type: none"> <li>a. General Laboratory Active Cryogenic on ISS Experiment Refrigeration (GLACIER)</li> <li>b. Commercial Growth Bioprocessing Apparatus (CGBA)/National Laboratory Pathfinder (NLP)Vaccine-10</li> <li>c. NLP-Cells-6 (Deactivated)</li> <li>d. Double Cold-bag packing</li> <li>e. Cube Lab 7 and 8 (Deactivated)</li> <li>f. Japanese Aerospace Exploration Agency (JAXA) Myco3 (3 ISS crew, 1 Shuttle crew)</li> <li>g. Human Research Program (HRP)/Sleep Short</li> <li>h. HRP/Spinal Elongation (one ISS crew operator, two Shuttle subjects).</li> <li>i. BIOKon In Space (BIOKIS)</li> <li>j. Italian Astronaut Personal Eye (IAPE)</li> <li>k. Italian Electronic Nose for Space Exploration (IENOS)</li> <li>l. Italian Epoxy Resin Solid State Foaming (IFOAM)</li> <li>m. Agenzia Spaziale Italiana (ASI) Night Vision</li> <li>n. Evaluation and Monitoring of Microbial Bio-films inside ISS (VIABLE)</li> <li>o. CGBA Science Insert (CSI)-05 (ISS only)</li> <li>p. Integrated Immune (ISS only)</li> <li>q. Reaction self-test (ISS only)</li> <li>r. 2D Nano Template 2 Minus Eighty-Degree Laboratory Freezer for ISS (MELFI)</li> <li>s. Bisphosphonates (ISS only)</li> <li>t. t. Light Modular Module (LMM) Biology Liver Tissue Assembly</li> </ul>	<p>IVA FD 2- FD 14</p> <p>(Unit swap on)FD 13)</p> <p>(Deactivated) FD 4</p> <p>FD 16</p> <p>FD 14</p> <p>FD 14</p> <p>FD 13</p> <p>FD 13</p> <p>FD 4</p> <p>FD 13</p> <p>FD 9</p> <p>FD 7</p> <p>FD 3</p> <p>FD 4</p> <p>FD 4</p> <p>FD 5</p> <p>FD 4</p> <p>FD 7</p> <p>FD 12</p>
<b>Category 3 Tasks</b>		
13	Perform daily ISS payload status checks as required.	IVA √ FD3-FD14
14	Transfer remaining middeck cargo items per Flight ULF6 TPL.	IVA √ FD5-FD14
15	Transfer Nitrogen (N2) from the Orbiter to ISS Airlock HPGT with the plan to have tanks full at Shuttle retirement. <u>(17.5 lbs out of 30 lbs planned)</u>	IVA √ FD3-FD5
16	Transfer water from Orbiter to ISS as defined in the Flight ULF6 TPL.	IVA FD3-FD14

## ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
16.5	Perform Russian resupply tasks. a. Perform Russian Segment (RS) ISS maintenance. b. Perform Progress 42P unloading. c. Perform bi-annual Treadmill with Vibration Isolation and Stabilization (TVIS) maintenance in the Service Module (SM). d. Perform preparations for Soyuz 25S (#230) descent: <ol style="list-style-type: none"> <li>1. Lower Body Negative Pressure (LBNP) training session 6,10,14,18.</li> <li>2. Complete remaining Soyuz descent OBT.</li> <li>3. Complete pre-pack for Soyuz 25S descent.</li> </ol> e. Perform tasks for RSA program symbolic activity f. Perform inspection and photography of SM windows. g. Perform the program of payload operations.	
16.6	Undock Soyuz 25S and take imagery of ISS.	Imagery/ Ground FD8
17	Perform remaining ISS payload research operations tasks. a. JAXA HAIR (FE-3) b. HRP Nutrition (FE-6) c. HRP Nutrition/Pro K (FE-5) d. ESA Sodium Loading in Microgravity (SOLO) Portable Chemical Blood Analyzer (PCBA) Retrieve Note: Reference the FTSOD and EPAs for all constraints and crew activity requirements.	IVA ( prior to mission launch)
18	Transfer Integrated Boom Assembly (IBA) Orbiter Boom Sensor System (OBSS) from Orbiter to ISS S1 Orbital Support Equipment (OSE).	IVA/SRMS/ SSRMS FD 12- EVA4
19	Refill P6 radiator with ammonia. a. P1-P6 NH3 Jumpers install and N2 vent b. P6 Radiator fill c. P4 NH3 jumper and vent tool stow	EVA/Ground FD 7-EVA 2
20	Route and install Functional Cargo Block (FGB) Y-power feed cables for channels 1/4 and 2/3.	IVA/EVA FD 10-EVA 3
21	Install external lab wireless communication antenna system. (partial completion on EVA1, remainder on EVA3)	EVA FD 5-EVA 1 FD 10-EVA 3
22	Lubricate port Solar Alpha Rotary Joint (SARJ) Race Ring.	EVA FD 7-EVA 2
23	Remove and Replace (R&R) Node 3 Air revitalization Carbon Dioxide Reduction/Removal Assembly (CDRA) rear bed	IVA FD 9,13,14
24	Remove Special Purpose Dexterous Manipulator (SPDM) Dextre spare are Expanding Diameter Fastener (EDF) bolts.	EVA FD 12-EVA 4
25	Install HPGT Flight Releasable Grapple Fixture (FRGF) Multilayer Insulation (MLI).	EVA FD 10-EVA 3

### ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
26	Lubricate SPDM Dextre Latching End Effector (LEE) Snares.	EVA/SSRMS FD 7-EVA 2
27	Reinstall starboard SARJ Cover No. 7.	EVA FD 5-EVA 1
28	Install S1 radiator grapple bar stowage beam assemblies.	EVA FD 7-EVA 2
29	Inspect Orbital Replacement Unit (ORU) Tool Platform (ORT) long-duration tie-down tether and re-cinch, if necessary.	EVA FD 12-EVA 4
30	Install Power Data Grapple Fixture (PDGF) on FGB. a. Install transfer frame with PDGF and FGB cable harness on FGB. b. Tie down fiberglass MLI removed from FGB.	EVA FD10-EVA 3
31	Retrieve P6 PDGF.	EVA FD12-EVA 4
32	Remove Electrical Flight Grapple Fixture (EFGF) and install adapter plate/PDGF on IBA.	EVA FD 12-EVA 4
33	Complete FGB PDGF installation. a. Install Video Signal Converter (VSC) and VSC thermal cover on FGB. b. Install and route external 1553 cables on FGB. (task deferred due to time needed to complete install of external lab wireless communication antenna system task from EVA#1)	EVA FD10-EVA 3
33.5	Obtain infrared imagery of Variable Emissivity Radiator Aerogel Insulation Blanket Dual zone thermal control Experiment suite for Responsive space (VADER) payload on STP-H3.	EVA/Imagery FD 10-EVA 3
34	Perform STP-H3 imagery documentation.	SSRMS FD3
35	The following EVA tasks are deemed to fit within the existing EVA timelines; however, may be deferred if the EVA is behind schedule. The EVA will not be extended to complete these tasks. a. Stow EFGF in the Port Tool Stowage Assembly (TSA). (brought inside ISS due to inadequate time to stow in TSA, will be returned on STS-135/ULF7 or disposed of in ATV2) b. Install S3 Crew and Equipment Translation Aid (CETA) light. c. Install SPDM Dextre base Camera Light Assembly (CLA) cover. d. Provide photos of FGB, PDGF and FGB thrusters. e. Perform EVA tool reconfiguration.	EVA  Deferred  FD 5-EVA 1 FD 7-EVA 2 FD 10-EVA 3 Deferred



## ISS MISSION PRIORITIES COMPLETION STATUS (Continued)

Item	Task	Flight Day Task Completed
<b>Category 4 Tasks</b>		
36	<p>Perform EVA get-ahead tasks if time permits. The following EVA get-ahead tasks do not fit in the existing EVA timeline; however, the EVA team will be trained and ready to perform should the opportunity arise. EVA Mission Operations Directorate (MOD) has the flexibility to select tasks to be completed based on efficiencies gained in performing schedule-required tasks.</p> <p>a. EVA imagery of STP-H3 <b><u>(CHIT 9422)</u></b>  b. Reconfigure Port CETA cart.</p> <p>c. Remove S1 Flex Hose Rotary Coupler (FHRC) P-Clamps (10/12).  d. Reattach ELC3 CTC MLI. <b><u>(CHIT 9604)</u></b></p>	<p>EVA</p> <p>FD10-EVA 3 Not performed</p> <p>Not performed FD0-EVA 3</p>
36.5	Perform Columbus Thermal Control System (TCS) Sampling	IVA Deferred
37	Perform ISS RS preventive maintenance	IVA Deferred
38	<p>Perform imagery survey of ISS exterior during Orbiter fly-around after undocking.</p> <p>a. ATV-2 MLI imagery</p>	<p>IVA FD 15</p>
39	<p>Perform IVA get-ahead tasks if time permits. 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.</p> <p>a. Transfer excess NASA cargo from Japanese Experiment Logistics Module-Pressurized Section (JLP) to Permanent Multipurpose Module (PMM)/Ariane Transport Vehicle 2 (ATV2) and perform ATV2 cargo transfer.  b. Unpack and stow Flight ULF6 cargo in final location.  c. Perform ULF7 EVA prep.  d. Assemble Lego's payload (FE-6).  e. Swap Radiation Monitors (RAM).  f. Inspect rack ground straps.  g. Exchange Japanese Experiment Module (JEM) Multi-Protocol Converter (MPC) Direct Current (DC/DC) power converter.  h. Routing of Space To Ground Antenna (SGANT) cable.  i. Install MELFI electronics unit.  j. Install MELFI panel.  k. Transfer the Russian items, stowed behind the FGB panels, to the Russian Orbit Segment (ROS) area.  l. Scavenge straps for PMM.  m. Perform PMM Resupply Stowage Rack (RSR) door troubleshooting.  n. Locate ExPRESS Rack 8 ground strap.  o. Perform crew quarters troubleshooting.  p. Perform JAXA Kobairo rack troubleshooting.  q. Perform Clean Bench periodic maintenance.</p>	<p>IVA Not performed</p> <p>Chit 9422</p>

## ISS MISSION PRIORITIES COMPLETION STATUS (Concluded)

Item	Task	Flight Day Task Completed
40	Reboost the ISS with the Orbiter if mission resources allow and are consistent with ISS trajectory analysis and planning.	IVA FD 14
41	Perform payload of opportunity operations to support RAMBO-2, SIMPLEX, MAUI and SEITE.	IVA/Ground FD 15-MAUI FD 16- RAMBO-2
42	Perform Station Development Test Objective (SDTO) 13005-U, ISS Structural Life Validation and Extension, during ELC3 berthing to ISS (ISS Wireless Instrumentation System (IWIS) not required if Microgravity Acceleration Measurement System (MAMS)/Station Acceleration Measurement System (SAMS) are available). (IVA)(Ground)	IVA/Ground /Imagery <b>Not manifested</b>
43	Perform STDO 13005-U during Orbiter docking (ISS IWIS required).	IVA/Ground /Imagery FD 3
44	Perform SDTO 13005-U during ISS reboost (IWIS required – Rover (6 <sup>th</sup> ) accelerometer in Orbiter Airlock (A/L) only if crew time available.	IVA/Ground /Imagery FD 14
45	Perform SDTO-13005 during ULF6 Orbiter undocking (IWIS highly desired).	IVA/Ground /Imagery FD 15
46	Perform Russian imagery of RS exterior for historical documentation	Ground /Imagery Not performed

## DEVELOPMENT TEST OBJECTIVES

### DTO 703-Sensor Test for Orion Relative-Navigation Risk Mitigation (STORRM)

DTO 703 was performed during rendezvous/docking, docked data retrieval, and undock/re-rendezvous. Performance was nominal, with Vision Navigation System (VNS) acquisition near the 5.7 km maximum capability of the VNS which exceeded the 5.0 km requirement. Docking camera recorded excellent images of the Earth, ISS, and stars from about 60 km through docking. Possibly due to higher than anticipated operating temperatures, the Data Recording Unit (DRU) 3 failed prior to undocking, so no docking camera views were obtained during undocking and re-rendezvous. Real-time data from the VNS during undock and the re-rendezvous indicated STORRM operated as expected.

### **DTO 854-Boundary Layer Transition (BLT) Flight Experiment**

The BLT flight experiment with 0.5 inch protuberance will gather information on the effect of high Mach number boundary layer transition caused by a protuberance on the Space Shuttle during the re-entry trajectory.

### **DTO 805-Crosswind Landing Performance**

The forecasted crosswinds did not meet the criteria of crosswinds greater than 10 knots so the DTO was not attempted during landing.

### **DTO 900-Shuttle RSRB Chamber Pressure, Strain Gauge, and Acceleration Rates Data Collection**

Pressure data was recorded with hardware located on the top of the solid rocket motors inside the forward skirt. This data will allow future exploration initiative engineers to determine the accelerations and loads that are transferred through the structure due to pressure oscillation forces. The data is downloaded after the boosters are recovered. No crew activity was required to support the DTO.

## **PAYLOADS OF OPPORTUNITY**

### **MAUI ANALYSIS OF UPPER ATMOSPHERIC INJECTION (MAUI)**

The MAUI is a Department of Defense (DoD) Space Test Program (STP) payload of opportunity payload. Images would be analyzed to better understand the interaction between the spacecraft plume and Earth's upper atmosphere. MAUI observations use ground-based sites to observe Orbiter Reaction Control System (RCS) thruster firings. MAUI does not have manifested hardware, but uses propellant resources, crew time and mission support personnel to achieve the observations. MAUI was performed on FD 15 with four Primary RCS firings lasting a total of 144 sec over the AMOS site. Post experiment analysis indicated the AMOS site did detect the Shuttle over-flight. In addition, Orbiter MADS data provided extra insight into Orbiter position and engine thruster firings. Four simulated imaging activities were conducted prior to the actual data take to assure success.

### **RAM BURN OBSERVATIONS (RAMBO) -2**

The RAMBO-2 is a DoD STP payload of opportunity payload using space-based satellites to observe Orbiter thruster firings to predict the plume direction. Understanding spacecraft engine plume direction, or exhaust flow, could be significant to the safe arrival and departure of spacecraft on future missions. RAMBO-2 does not have manifested hardware, but uses propellant resources, crew time and mission support personnel to achieve its observations. The RAMBO-2 data take was initiated on FD 16 at 151/07:33:10 GMT (14/18:36:42 MET) using three dedicated PRCS firings.

### **SHUTTLE EXHAUST ION TURBULENCE EXPERIMENT (SEITE)**

SEITE is a DoD STP payload of opportunity payload using space-based sensors to detect ionosphere turbulence inferred from the radar observations of the OMS firings. SEITE does not have manifested hardware, but uses propellant resources, crew time and mission support personnel to achieve the observations. SEITE was not performed since no observation opportunities occurred during the mission.

### **SHUTTLE IONOSPHERIC MODIFICATION WITH PULSED LOCAL EXHAUST (SIMPLEX)**

The SIMPLEX is a DoD STP payload of opportunity payload. SIMPLEX observations use ground-based sites to observe OMS firings to investigate plasma turbulence. SIMPLEX does not have manifested hardware, but uses propellant resources, crew time and mission support personnel to achieve its observations. SIMPLEX was not performed since no observation opportunities occurred during the mission.

## **VEHICLE PERFORMANCE**

### **LAUNCH DELAY**

The launch was scrubbed on April 29, 2011, because of a LCC violation that was the result of the APU 1 Fuel Test Line and Fuel Service Line 'B' heaters failing to activate during the STS-134 pre-launch operations. The failure persisted with both the ground command and the panel switch activation. It was determined that the APU 1 heater circuit was non-functional in the ALCA 2. The ALCA 2 was replaced. Analysis of the ALCA 2 internal components indicated that the driver was exposed to a short circuit and responded nominally. The driver was replaced and the ALCA was tested including vibration testing and the unit operated nominally. Vehicle wiring was nominal during Hi-Pot testing. However, new wire and splices were installed from ALCA 2 to the heater strings to mitigate any undetected transient short. The B-system heaters tested nominally during continuity and 450 Vdc isolation testing. The heaters were functionally tested with GSE power and the replacement ALCA 2 performed nominally. Data review from a June 2010 heater test revealed a 2-msec, 18-A current spike during testing of thermostat S12B. The thermostat was found to have an exposed conductor on the vendor lead. The problem was classified as an Unexplained- Anomaly (UA) at the time; however, the exposed conductor is considered the most probable cause of the anomaly. As a result, the SSP management reset the launch date to May 16, 2011.

### **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 7.7 knots, wind direction was 264 degrees, temperature was 69 °F, humidity was 65 Percent (%) and ambient pressure was 29.76 inches Hg.

Because of a late predicted change in the wind at approximately 30,000 to 40,000 ft, the I-loads were designed with the L-3:35 Jimsphere. Based on the L-2:20 Day-of-Launch I-Load Update (DOLILU) assessment profile, no exceedances of the May 95<sup>th</sup> percentile database limits were identified for the in-plane or out-of-plane components. The maximum measured wind velocity was 115 ft/sec at 38,000 ft and 292 degrees. There were no wind-shear exceedances.

There were no violations of the in-plane or out-of-plane wind-change redlines from the L-3:35 DOLILU I-Load design wind profile to the final assessments based on the L-2:20 Jimsphere balloon and the 1236 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 1131 Universal Time Code (UTC) South Cape 915 MHz profiler. The maximum measured wind velocity in the roll maneuver region was 50.6 ft/sec at 6,000 ft and 284 degrees.

## **REUSABLE SOLID ROCKET BOOSTERS**

The STS-134 RSRBs, identified as BI-145, performed satisfactorily during the launch countdown and ascent with one In-Flight Anomaly (IFA) identified. Separation was visible through cutoff at 055/21:55:29 GMT (00/00/02:05 MET).

There was one first flight design change for the RSRB for STS-134. This was the first flight for all four RSRB Phase II Fuel Pumps. On STS-133, the Phase II fuel pump was installed in only one of the four APU fuel-pump positions.

No RSRB 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 ET and were recovered and returned to KSC for inspections and disassembly. The post-flight inspection of the RSRB revealed no IFA's or FIDs. However, one off-nominal foam loss was identified on the Right-Hand (RH) RSRB center stiffener ring.

Diver assessment of one of the three main parachutes for the RH SRB showed evidence of significant damage to the canopy (IFA SRB-B-001). The post-flight assessment of the parachutes at the Parachute Refurbishment Facility (PRF) documented the damage to RH main parachute canopy (S/N 64488). The damage was characterized as a vertical tear within gore 26 failed from the skirt band through the vent band. Onboard imagery from the Data Acquisition System (DAS) showed the canopy rupture occurring subsequent to the second-stage reefing-line severance. The three main parachutes functioned normally through the 1st and 2nd stages until main parachutes no. 3 failed during the second disreefing to full open. The RH estimated water impact velocity was about 92 ft/sec, which is a typical SRB vertical velocity under two inflated main parachutes and is considered to be a hard water impact. The cause of the canopy damage has been attributed to the material rupture to damage incurred during the main parachute deployment. During deployment, evidence indicated that canopy components were dragged across the Main Parachute Support Structure (MPSS) attachment struts. This resulted in a tear within the fabric ribbons of the canopy, which existed prior to the second stage disreefing. Review of the RH SRB DAS video depicts within a single frame the initial tear prior to the second stage disreefing. The existing tear was analogous to a critical flaw size during third stage inflation, resulting in the canopy rupture.

## **REUSABLE SOLID ROCKET MOTORS**

The STS-134 RSRMs set, identified as RSRM-113, performed within established and predicted limits. Data show RSRM ballistic performance appeared nominal and RSRB separation occurred as predicted.

There was also one first flight design change for RSRM. Low-temperature O-ring material was implemented in the RSRM nozzle joint 3. The low-temperature material has flown in field joints since STS-125 and in other nozzle joints since STS-126.

No RSRM LCC or OMRSD violations occurred. Likewise, no IPRs occurred during the launch countdown. The RSRM Predicted Mean Bulk Temperature (PMBT) was 62 °F.

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

There was no indication of hold-down stud hang-up based on preliminary analysis.

## **EXTERNAL TANK**

The STS-134 ET, which was designated as a SLWT-122 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 (GO<sub>2</sub>) and Gaseous Hydrogen (GH<sub>2</sub>) 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 PMBT was 75 °F at launch.

There were no first-flight design changes to the ET. However, ET-122 was the Hurricane Katrina-damaged tank and required significant repair and modifications to become flight worthy. As a result, ET-122 was a unique tank configuration. All of the repairs and changes were thoroughly reviewed and accepted by the SSP management. The same radius block modifications of the LO<sub>2</sub> flange as flown on STS-133/ET-137 were implemented to provide additional structural capability.

No ET LCC or OMRSD violations occurred.

One ET-related IPR was taken during the tanking phase of countdown. During automated ET operations, the ET bellows heater did not turn on. The heater turned on after a manual command was sent. Data review showed that during the last scrub (4/29/11), the automated ET operations were terminated before the ET Bellows heaters were turned off. The heaters were manually unpowered, which inhibited the auto sequencer and inhibited the bellows heater. This IPR was closed.

The Final Inspection Team (FIT) the ET observations were consistent with environmental conditions. Light to moderate condensate was noted on the LO<sub>2</sub> tank

and Intertank, with moderate to heavy condensate on the Liquid Hydrogen (LH<sub>2</sub>) tank. Multiple intertank stringer valley cracks were observed, all typical and acceptable. A typical foam crack was noted on the -Y vertical strut. All of the LO<sub>2</sub> feedline bracket TPS closeouts exhibited acceptable ice/frost formations. A 1-inch diameter thin shell ice-ball was observed at Xt 1871 and was determined to be acceptable per the ice-ball table in NSTS documentation.

All observations were acceptable per NSTS documentation, with the exception of a debris item observed on the ET crossbeam. The debris (0.9-in. by 0.25-in. by 0.125-in.) was consistent in appearance with Room Temperature Vulcanization (RTV) and was in violation of LCC ICE-01 per NSTS documentation. The FIT tank observations were consistent with environmental conditions. Light to moderate condensate was noted on the LO<sub>2</sub> tank and Intertank, with moderate to heavy condensate on the LH<sub>2</sub> tank. Multiple intertank stringer valley cracks were observed, all typical and acceptable. A typical foam crack was noted on the -Y vertical strut (9"x 1/4"). All of the LO<sub>2</sub> feedline bracket TPS closeouts exhibited acceptable ice/frost formations. A one-inch diameter thin shell ice-ball was observed at Xt 1871 and was determined to be acceptable per the ice-ball constraints in Program documentation.

All observations were acceptable per Program documentation, with the exception of a debris item observed on the ET crossbeam. The debris (0.9-in. by 0.25-in. by 0.125-in.) was consistent in appearance with RTV and was in violation of LCC per NSTS documentation. System Engineering and Integration (SE&I) performed a Debris Transport Analysis (DTA) and determined the worst-case damage condition was within Orbiter damage tolerance capability. An LCC waiver was written and approved.

The ET separation was normal. The ET entry and break-up resulted in the ET impact being at 35.535 South Longitude and 158.000 West Latitude, which is approximately 32 nmi up range.

## **SPACE SHUTTLE MAIN ENGINES**

The 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 2059, 2061 and 2057 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 LCC or OMRSD violations occurred. Likewise, no IPRs occurred during the launch countdown.

There was one FID posted on the SSME1 Low Pressure Fuel Turbopump (LPFTP) discharge pressure (channel B) at approximately 7 min, 18 sec after engine start (IFA STS-134-E-001). The measurement momentarily (about 0.1 sec) dropped off-scale-low and was disqualified. The channel "A" sensor read nominally throughout the flight. This



measurement is not a redline measurement; it is used to calculate fuel-density for the mixture-ratio calculation. The engine would have continued to run on the fixed density value that is coded into the software, if the second channel had failed.

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) were not activated.

The predicted average SSME specific impulse (ISP) tag value (using the ground-based tag value method) was 452.07 sec at 104.5% RPL. Indications are that the delivered ISP was within the expected range.

Review of Advanced Health Monitoring System (AHMS) vibration data indicates nominal performance. 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.

## **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. Likewise, no IFAs were identified from the flight or the data review.

The maximum Hydrogen concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fastfill, was 180 ppm. This compares favorably with previous data for this vehicle.

All LH<sub>2</sub> and LO<sub>2</sub> loading parameters were nominal. All LO<sub>2</sub> and LH<sub>2</sub> fill-and-drain valves performed nominally during the flight. The LO<sub>2</sub> and LH<sub>2</sub> Engine Cut off (ECO) sensors passed all pre-flight checkouts and operated nominally through ascent.

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

The GH<sub>2</sub> pre-pressurization cycle count was 10 cycles; 14 cycles or more violates the LCC criteria. The engine inlet Net Positive Suction Pressure (NPSP) requirements were met throughout the flight. All three Flow Control Valves (FCV) performed nominally with 5 cycles on FCV no.1, 2 cycles on FCV no.2 and 5 cycles on FCV no.3. Pressurization performance was nominal indicating proper operation of the 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	8500	6000
Hydrogen	180	32
Oxygen	127	12
LD54/55	0	0

## Gas Sample Analysis

The flight history of the Orbiter Aft Fuselage Gas Sampler System (OAFGSS) sample bottles on STS-134 showed that all of the six bottles were within the acceptable pressure range.

STS-134 was the 21<sup>st</sup> flight using the new gas chromatograph /mass spectrometer at the Kennedy Space Center Materials Science Laboratory.

The Hydrogen concentrations were well below the flammability limit in each bottle. The highest estimated leak rate was 1850 scim from RH bottle no.1.

The Oxygen concentrations were below the flammability limit. The highest concentration was 3.49-percent in RH bottle no. 2. Argon indicates air as the major source of the oxygen in all six bottles and not Orbiter system leakage.

The highest Helium concentration was 4.26-percent in RH bottle no. 3. Through STS-134, the highest helium concentration on OV-105 is 11.90-percent. The average for all bottles is 1.23-percent, but the average for RH bottle no. 3 is 4.11%. 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.

### **SUMMARY OF BOTTLE PRESSURES AND GAS CONCENTRATION**

<b>Bottle No.</b>	<b>Position</b>	<b>Pressure, psia</b>	<b>Helium, %</b>	<b>Measured Oxygen, %</b>	<b>Hydrogen, %</b>
1	RH 1	3.14	0.27	2.05	0.04
2	LH 1	1.43	0.54	1.30	0.06
3	RH 2	1.30	0.51	3.49	0.05
4	LH 2	0.84	0.61	2.56	0.08
5	LH 3	0.18	0.82	1.81	0.10
6	RH 3	0.06	4.26	0.83	0.49

The Ascent Hazard Analysis indicates the maximum hydrogen firing leak rate for STS-134 was 1850 scim. The maximum allowable firing leak rate on ascent is 57,000 scim. The estimated firing leak rates for all sample bottle data from this flight are summarized in the following table.

## HYDROGEN FIRING LEAK RATES

Bottle no.	Position	Hydrogen Firing Leak Rate, scim
1	RH 1	1850
2	LH 1	1490
3	RH 2	485
4	LH 2	865
5	LH 3	457
6	RH 3	845

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 <sub>4</sub> , %	CO <sub>2</sub> , %	O <sub>2</sub> From Air, %	O <sub>2</sub> , % found	H <sub>2</sub> , %	H <sub>2</sub> Pyro. Corrected, %
1110 FLT-3	RH1	162.4	0.09	9.53	0.27	<0.01	0.046	<0.01	2.00	2.05	0.04	0.04
1103 FLT-4	LH1	73.7	0.07	7.92	0.54	<0.01	0.014	<0.01	1.66	1.30	0.06	0.06
1114 FLT-3	RH2	67.4	0.14	14.45	0.51	<0.01	<0.01	<0.01	3.04	3.49	0.05	0.05
1109 FLT-4	LH2	43.3	0.10	10.60	0.61	<0.01	0.018	<0.01	2.23	2.56	0.08	0.08
1111 FLT-3	LH3	9.07	0.07	7.60	0.82	<0.01	0.038	<0.01	1.60	1.81	0.10	0.10
1117 FLT-2	RH3	3.19	0.06	6.32	4.26	<0.01	0.19	0.024	1.33	0.83	0.50	0.49

### Purge, Vent, and Drain System

The Purge, Vent and Drain (PV&D) system performed nominally. Purge flow rates and temperatures were nominal. The payload bay was cooler than normal (mid 70's) due the Alpha Magnetic Spectrometer (AMS) payload requirements.

The post-landing purge was initiated within 30 min (was approximately 26 min) of the upper aft safety assessments. The purge was initiated approximately 59 min after touchdown, which exceeded the 45-min limit. The limit was exceeded as a result of the delay in performing internal hazardous gas checks that required prior to initiation purge.

## Reaction Control System

The Reaction Control System (RCS) performed all functions required for successful completion of the mission. No IFAs were identified from the data; however, two items of interest were identified and will be discussed in later paragraphs.

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, %	68.27	67.52	100.48	100.76	100.48	100.76
Target, lb	1148.6	712.9	1523.0	962.0	1523.0	962.0
Calculated, %	70.48	69.31	100.63	100.72	100.53	100/74
Advertised, %	1178.5	728.1	1525.0	961.6	1523.7	961.8
PASS WHI <sup>a</sup>	4.2991	4.2394	4.3210	4.2175	4.3297	4.2304
BFS WHI <sup>b</sup>	4.3026	4.2421	4.3455	4.2525	4.3733	4.2414

Notes:

<sup>a</sup> PASS WHI – Primary Avionics Software System Initial Weight of Helium Load

<sup>b</sup> BFS WHI – Backup Flight System Initial Weight of Helium Load

All Tyvek covers except F4D and F3F 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)
F4D	Prelaunch	N/A	N/A	N/A
F3F	Prelaunch	N/A	N/A	N/A
F3D	6.8	83	6	-7
F1D	6.9	84	6	-7
F2F	6.9	85	6	-7
F2R	7.2	89	5	-6
F1L	7.5	94	6	-6
F1F	7.7	97	6	-6
F4R	8.0	101	6	-6
F2D	8.5	108	6	-5
F3L	9.	121	7	-5
F2U	9.4	121	7	-5
F1U	9.6	124	7	-5
F3U	10.3	135	8	-4

The F4D and F3F thrusters Tyvek rain covers detached prior to launch and the F2D Tyvek rain cover mostly debonded because of high winds. Since no rain had occurred following loss of the covers, this condition was accepted on a waiver.

The RCS window-protect firing of the F1U, F2U and F3U thrusters was initiated at 136/12:58:31.9 GMT (00/00:02:03 MET) with a total duration of 2.08 sec. The Forward Reaction Control System (FRCS) performance was nominal. The window-protect firing deflects the exhaust from the RSRB separation motors away from windows during RSRB separation.

The ET Separation maneuver was performed at 136/13:05:10 GMT (00/00:08:42 MET) and was a 6-sec 10-thruster translation. The ET Photographic +X firing was initiated at 136/13:06:58 GMT (00/00:10:30 MET) and was a 10.0-sec, four-thruster translation. ET Photo Pitch maneuver was initiated at 136/13:06:58 GMT (00/00:10:30 MET) and completed at 136/13:07:25 GMT (00/00:10:57 MET).

The heaters (including FRCS, Left and Right pods and crossfeed) were configured to the A-strings at 136/13:27:34 GMT (00/00:31:06 MET). The Left and Right RCS helium valves were configured for orbit at 136/13:38:35 GMT (00/00:43:07 MET) (A-GPC, B-CLOSED). Forward RCS helium valves were configured for orbit at 136/13:39:21 GMT (A-GPC, B-CLOSED).

The Vernier RCS thruster R5D chamber pressure (Pc) did not drop to vacuum as expected during ascent. The expected behavior is for this pressure to drop from ground ambient (approximately 15 psia) to 0 psia over approximately 90 sec. In R5D's case, the Pc dropped much more slowly from an indicated pressure of 16.9 psia to 5 psia over approximately 1 hr and then remained at 5 psia until the completion of the first firing of the thruster. The firing response was nominal: the Pc rise rate, maximum value, and shutdown transient were nominal with the Pc returning to 0 psia. Subsequent pulses were all nominal. There was no impact to the mission.

The RCS firings, times initiated,  $\Delta V$ , and firing times are listed in the following table.

### RCS MANEUVERS AND FIRING DATA

Maneuver/Firing	System	Time of Ignition, GMT	$\Delta V$ , ft/sec	Duration, sec
RCS Window Protect	RCS	136/12:58:31.9	N/A	2.08
ET Separation	RCS	136/13:05:10	N/A	6
ET Photo +X	RCS	136/13:05:19	N/A	10.0
ET Photo Pitch	RCS	136/13:06:58		
NC3	RCS	137/15:41:14	2.7	11.5
NCC	RCS	138/06:40:32.5	0.12	
MC1	RCS	138/07:58:14.5	0.54	Not Reported
MC2	RCS	138/08:32:15	0.96	Not Reported
MC4	RCS	138/08:59:15.1	1.7	Not Reported

## RCS MANEUVERS AND FIRING DATA (Concluded)

Maneuver/Firing	System	Time of Ignition, GMT	$\Delta V$ , ft/sec	Duration, sec
R-bar Pitch Maneuver	RCS	138/09:15:31		
TORVA	RCS	138/09:27:39		
Docking	RCS	138/10:13:51		
Reboost Maneuver	RCS	149/05:03:29	2.0	14 minutes
Orbiter Undocking	RCS	150/03:55:22		
ISS Fly Around	RCS	150/04:20:00		
Separation 1	RCS	150/05:06:02		6.48
Separation 2	RCS	150/05:34:06		5.2
NH2 (STORMM DTO)	RCS	150/06:39:38		6.72
NSR (STORMM DTO)	RCS	150/06:59:08		1.6
MC5 (STORMM DTO)	RCS	150/07:24:08		9.12
MC6 (STORMM DTO)	RCS	Not Required		
TPI (STORMM DTO)	RCS	150/07:57:34		11.6
TDA (STORMM DTO)	RCS	Not Required		
Separation 3	RCS	150/08:38:36		3.68
MAUI	RCS	150/11:43:18		
RCS Hotfire	RCS	150/11:43:18		
RAMBO	RCS	151/07:33:10		10.6
Forward RCS Dump	RCS	152/05:45:06.7		11.04

A configuration 3 Vernier Reaction Control System (VRCS) reboost maneuver was performed at 149/05:03:29 GMT (12/16:07:01 MET) with the cutoff at 149/05:17:29 GMT (12/16:21:01 MET), resulting in burn duration of approximately 14 min. The maneuver was performed in straight feed. The reboost delivered a total Differential Velocity ( $\Delta V$ ), including the pre- and post-reboost attitude maneuvers, of 2.0 ft/sec, which resulted in 1.0 Nautical Mile (nmi) increase in altitude. Vernier pulse totals are given in the table below.

### REBOOST FIRING DATA

Thruster Position	Number of Pulses	Seconds Firing Time
F5L	7	713.32
F5R	5	782.16
L5D	3	414.76
L5L	0	0
R5D	3	414.4
RSR	1	34.8

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
	138/10:13:51	DAP FREE DRIFT	Docking / ISS Capture
Orbiter	138/10:30:57		
	138/10:36:19	DAP FREE	
Orbiter	138/10:36:29	DAP AUTO	TEA Maneuver
ISS	138/11:14:03	DAP FREE	
Orbiter	138/11:15:03	DAP AUTO	
Orbiter	138/11:18:33	DAP B	
Orbiter	138/11:19:44	DAP AUTO	
Orbiter	138/11:30:32	DAP B	Collapse Dead band
ISS	138/11:44:18	DAP FREE	
Orbiter	149/04:41:44		Handover For Reboost
Orbiter	149/04:47:32		Maneuver to Reboost Attitude
Orbiter	149/05:03:29		Reboost Ignition
Orbiter	149/05:23:53		Maneuver to post Reboost – TEA Attitude
ISS	149/06:07:27		Handover
Orbiter	150/02:35:28	DAP AUTO -	Maneuver to Undock attitude
ISS	150/03:35:30	DAP FREE DRIFT –	Logic Configuration
Orbiter	150/03:38:49	AUTO	
ISS	150/03:52:28	FREE -	Driver configuration
Orbiter	150/03:53:00	B/ALT/No Low Z	
	150/03:55:22	Undocking	

As part of the undocking preparations, the forward RCS thrusters were reselected at 150/03:18:07 GMT (13/14:21:39 MET), except for F1F and F2F. The maneuver to the undocking attitude was initiated at 150/02:35:28 GMT (13/14:25:18 MET). Undocking was initiated with a +Z pulse at 150/03:55:22 GMT (13/14:58:54 MET). The F1F and F2F thrusters were reselected after undocking at 150/04:00:14 GMT (13/15:03:46 MET). The Fly-Around (full maneuver) was initiated with a +X pulse of L3A and R3A at 150/04:20:00 GMT (13/15:23:32 MET).

The Separation 1 maneuver was a 6.5- sec +X firing of the L1A and R1A thrusters at 150/05:06:02 GMT (13/16:09:34 MET). The Separation 2 maneuver was a 5.2-sec multi-axis maneuver (thrusters F2F, F3F, F2D, F1D, L2D, L3D, R2D, and R3D) was initiated at 150/05:34:06 GMT (13/16:37:38 MET).

The start of Sensor Test for Orion Relative Navigation Risk Mitigation (STORRM) Development Test Objective (DTO) was initiated with the Nominal Height (NH2) maneuver. The maneuver was a 6.72-sec multi-axis firing (L1A, R1A, L2U, R2U



and F1U thrusters) at 150/06:39:38 GMT (13/17:43:10 MET). The Midcourse (MC) 5 maneuver was initiated at 150/06:59:08 GMT (13/18:02:40 MET). This was a 1.6-sec multi-axis firing (L1A, R1A, L2U, R2U, L2D, L3D, R2D, R3D, F1D and F2D thrusters). The NSR maneuver was initiated at 150/07:24:08 GMT (13/18:02:40 MET). This was a 9.12-sec multi-axis firing (F2F, F3F, F1D, F2D, L2D, L2U, R2D and R2U thrusters). The MC6 maneuver was not required. The TPI maneuver was initiated at 150/07:57:34 GMT (13/19:01:06 MET). This was an 11.6-sec multi-axis firing (F2F, F3F, F1D, F2D, L2D, L2U, L3D, R1R, R2D, R2U and R3D thrusters). The TDA firing was not required.

The Separation 3 maneuver was initiated with a 3.68-sec multi-axis firing (F2F, F3F, F1D, F2D, L2D, L2U, L3D, R2D, R2U and R3D thrusters) at 150/08:38:36 GMT (13/19:42:08 MET). The RCS performance during this STORMMM DTO operation was nominal.

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. 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 Vernier RCS thrusters were fired 6421 times for a total of 14915.84 sec. The Primary RCS thrusters were fired 3254 times for a total of 976.04 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 Calculations <sup>a</sup>	
	%	lb	%	lb
Forward Oxidizer	2.6	35	1.9	25.7
Forward Fuel	0.8	7	0.75	6.3
Left Oxidizer	50.0	675	49.1	662.9
Left Fuel	49.2	418	49.2	418.2
Right Oxidizer	47.6	643	47.2	637.2
Right Fuel	48.4	411	48.3	410.6

Note:

<sup>a</sup> 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	925.8	582.8	1.59
Left RCS	695.6	437.9	1.59
Right RCS	719.3	445.9	1.63

### 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) 03	36 <sup>th</sup>	L-OME S/N 107	6 <sup>th</sup> rebuilt flight - 22 <sup>nd</sup> flight
Right Pod (RP) 04	32 <sup>nd</sup>	R-OME S/N 113	6 <sup>th</sup> rebuilt flight 9 <sup>th</sup> flight

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

### OMS MANEUVERS

Maneuver designation	Configuration	Time of ignition, GMT	Firing time, sec	$\Delta V$ , ft/sec/interconnect usage, %
Assist	Dual Engine	136/12:58:43.0	165.4	N/A
OMS-2	Dual Engine	136/13:33:25.3	168.6	259.2
OMS-3 (NC1)	Dual Engine	136/15:48:38.1	66.7	93.6
OMS-4 (NC2)	Right Engine	137/06:22:51.6	14.4	11.2
OMS-5 (NC4)	Left Engine	138/06:07:27.4	10.6	8.2
OMS-6 (TI)	Left Engine	138/07:38:13.0	10.8	8.2
(Deorbit)	Dual Engine	152/05:29:03.1	159.2	296.9

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

## INTERCONNECT USAGE, %/POUNDS

Parameter	Total, %	Total, pounds
Left OMS	2.066	267.56
Right OMS	2.578	333.87

## PROPELLANT USAGE DATA

Parameters	Left OMS pod		Right OMS pod	
	Oxidizer	Fuel	Oxidizer	Fuel
Loaded, lbm	7701	4660	7707	4640
Residual, lbm (aft gage)	638	476	628	365
Residual, lbm (burn time integration)	641	354	743	402
Residual, lbm (SODB flow rate)	542	316	562	319
Residual, lbm MOD chit	594	361	632	371

## Auxiliary Power Unit System

The APU system performance was nominal throughout the STS-134 mission. A total of two IFAs were recorded against the APU system during the STS-134 mission.

During the STS-134 launch countdown on April 29, 2011, the APU 1 Fuel Test Line Temperature reading trended below the APU-14 LCC 45 °F minimum limit (IFA STS-134-V-01). At that time, the fuel test/service line B heaters were activated via ground command. When the fuel test line temperature reading dropped to 42 °F, the system was taken to a safe configuration by configuring to the A heater system circuits by ground command. Nominal performance on the A heater circuits was noted. Once personnel were available in the crew compartment, the LCC Preplan Contingency Procedure (PCP) was performed to troubleshoot the heater circuit. The A system heaters were activated by the cockpit-panel switch and nominal performance was noted. As troubleshooting was continued, the B system heaters were activated via the cockpit-panel switch, and the same lack of temperature response was seen. With this the LCC violation confirmed the launch attempt was scrubbed. There was also a lack of temperature response on the APU 1 fuel-feed line of the B system heater-circuit identified during the PCP troubleshooting.

The post-scrub troubleshooting identified a blown fuse in the type III hybrid driver in ALCA 2 that feeds power to the B system heaters. This problem was closed as an UA) A thermostat lead wire short-to-ground during the fuel-feed line over-temperature thermostat testing in June 2010 that exposed the type III driver to a high current

demand was determined to be the most likely failure cause. The ALCA 2 and all wiring downstream of ALCA 2 that was leading up to the affected heaters as well as the thermostats were replaced prior to launch. During the prelaunch operations, both the A and B heater strings were verified operational by ground command.

At 144/19:10:23 GMT (08/06:13:55 MET) during crew sleep on FD 9, the APU 2 gearbox GN<sub>2</sub> pressure and Gas Generator (GG) Bed temperature data showed a step-function drop to Off-Scale Low (OSL) (IFA STS-134-V-06). These data showed this drop for 4 min 30 sec, after which the data returned to the normal condition. The APU 2 gearbox pressure and GG Fuel Pump (FP) System Management (SM) alarms were annunciated. A Table Maintenance Block Update (TMBU) was uplinked to inhibit these limits, and prevent additional nuisance alarms during crew sleep. After the crew awakened, the three APU tank/fuel line/H<sub>2</sub>O system and APU GG fuel pump A heaters were deactivated due to the presence of SM alerts. When these heaters were reactivated, the APU 2 GG/FP heaters were reconfigured to the B system. The APU 2 GG/FP heaters remained on 'B' for the remainder of the mission. Data reviewed during this time period showed that in addition to the sensor reading dropouts, the GG heater was off, which was indicated by a drop in current on Main Bus B (MNB) Aft Power Controller (APC) 5 current and APU 2 GG injector tube temperature reading decrease during this time period. At the time of this anomaly, the APU 2 assembly fuel lines/fuel pump/GG Valve Module (VM) A heaters were off (nominal performance) so it could not be verified if this anomaly affected these heaters. The APU and Electrical Power Distribution and Control (EPDC) teams recommended that no post-flight troubleshooting be performed to isolate the failure cause or to gather additional data for flight rationale for the remaining shuttle flight, since this was the last flight of OV-105. Flight rationale already exists for the failure modes that can cause this signature.

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 (304)	00:18:55	00:04:40	01:04:20	01:27:55
2 (311)	00:19:08	00:00:00	01:30:56	01:50:04
3 (303)	00:19:19	00:00:00	01:04:43	01:24:02

### APU FUEL CONSUMPTION

APU (S/N)	Ascent, lb	FCS Checkout, lb	Entry, lb	Total, lb
1 (304)	49	15	136	200
2 (311)	49	0	178	227
3 (303)	49	0	130	179

## 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. The WSB data for the ascent phase is shown in the following table.

### WATER SPRAY BOILER PGME/H<sub>2</sub>O USAGE DURING ASCENT

WSB	Spray Start Temp (°F)	Spray Start Time	Steady State Temp (°F)	PGME/H <sub>2</sub> O Usage (lb)
System 1	257	136:13:05:27	253	3.6
System 2	257	136:13:06:09	253	2.8
System 3	249	136:13:05:28	247	4.2

The Entry PGME/H<sub>2</sub>O coolant usage on WSB 2 exceeded the File IX specification of No Greater Than (NGT) 50 lb/system for entry usage by 0.6 lb (50.6 lbs total usage versus specification NGT 50 lb). Detailed analysis indicates the slight WSB 2 PGME/H<sub>2</sub>O usage overage was attributable to extended cooling of the hydraulic fluid in Heat Exchanger (HX) mode during Terminal Area Energy Management (TAEM) and post-landing (approximately 21 min total steady-state time in HX mode). All WSB 2 operational parameters indicated nominal operation during the STS-134 entry. A detailed analysis of the WSB 2 PGME/H<sub>2</sub>O coolant usage during entry is covered in the following table.

### WATER SPRAY BOILER PGME/H<sub>2</sub>O DURING ENTRY

WSB	Spray Start Temp, °F	Time, GMT	Steady State Temp, °F	PGME/H <sub>2</sub> O Usage, lb
System 1	255	152:05:57:59	253	38.2
System 2	251	152:05:31:44	251	50.6
System 3	24F	152:05:58:22	247	34.5

During the post-flight hydraulic inspections, it was discovered that the LO<sub>2</sub> Outboard ET Umbilical Retract Actuator was not in the fully retracted and locked position within the mechanical locks (IFA STS-134-V-09). This problem is undetectable during flight, and did not have an effect on STS-134 flight operations.

## **Power Reactant Storage and Distribution System**

The OV-105 Power Reactant Storage and Distribution (PRSD) system performance was nominal during STS-134 and no IFAs were identified from the mission data.

The PRSD system supplied the fuel cells with 2317 lb<sub>m</sub> of O<sub>2</sub> and 292 lb<sub>m</sub> of H<sub>2</sub> for the production of electrical energy. A 106-hr mission extension was possible at the 12.456 kW mission extension average power level with the reactants remaining at landing (wheel stop). A 142-hour mission extension capability existed at landing, based upon the PRSD O<sub>2</sub> (the limiting reactant) tank landing quantities at the average fuel-cell flight-power-level of 9.0 kW.

The total oxygen supplied to Shuttle/ISS Environmental Control and Life Support System (ECLSS) was 345 lb<sub>m</sub> from PRSD. A total of 136.5 lb<sub>m</sub> of the O<sub>2</sub> was supplied for an O<sub>2</sub> tank-to-tank transfer to ISS and 120 lb<sub>m</sub> for ISS crew metabolic use. The H<sub>2</sub> tank 4 and 5 and O<sub>2</sub> tank 4 were depleted to residual quantities.

Two loadings of the PRSD cryogenic tanks were performed. The first was done on April 27, 2011 and the O<sub>2</sub> tanks were offloaded to about 99-percent in each tank. After the launch was scrubbed, a review of the ascent performance margin and minimum lift-off requirement was performed and they plans were revised so that no O<sub>2</sub> offload was required for the next launch attempt. The next loading of the five PRSD tank sets was performed on May 5, 2011.

The following tables show the O<sub>2</sub> and H<sub>2</sub> tank quantities at loading, lift-off and landing.

### **PRSD TANK QUANTITIES**

#### **Oxygen**

<b>Oxygen</b>	<b>Tank 1, %</b>	<b>Tank 2, %</b>	<b>Tank 3, %</b>	<b>Tank 4, %</b>	<b>Tank 5, %</b>	<b>Total Mass, lb<sub>m</sub></b>
Loaded	101.8	101.4	101.4	101.4	101.4	3963
Launch	100.5	100.1	100.1	100.5	100.1	3915
Landing	55.4	50.1	39.2	9.9	5.0	1254

## Hydrogen

Hydrogen	Tank 1, %	Tank 2, %	Tank 3, %	Tank 4, %	Tank 5, %	Total Mass, lb <sub>m</sub>
Loaded	101.9	102.3	101.5	102.3	101.5	468.7
Launch	98.8	99.3	98.4	99.3	98.4	454.7
Landing	58.6	51.5	63.0	2.4	1.5	162.8

## Fuel Cell System

The overall performance of the OV-105 Fuel Cell system was nominal for STS-134, and one IFA was identified from the mission data. The average electrical power level and load was 9.0 kW and 291 A. The fuel cells produced 2609 lb<sub>m</sub> of potable water and 3409 kWh of electrical energy from 2317 lb<sub>m</sub> of oxygen and 292 lb<sub>m</sub> of hydrogen.

Two fuel cell startups were performed. The first started was done on April 29, 2011 with the fuel cells accumulating 18-19 hr of run time. For the mission, the second fuel cell startup was initiated on May 15, 2011 at 135:21:35:02 GMT and was completed at 135:23:49:26 GMT. The startup and prelaunch operations were nominal. Fuel cell operating times, which are the times accumulated on the fuel cells prelaunch, on-orbit, and postlanding, were 404:41:20 (hr:min:sec) for fuel cell 1, 404:06:15 for fuel cell 2, and 403:11:45 for fuel cell 3. The end-of-mission accumulated operating times for these fuel cells are 1765, 807, and 1924 hours, respectively.

The actual Fuel Cell voltages at the end of the mission were 0.14 Volts (V) above predicted for Fuel Cell 1, as predicted for Fuel Cell 2, and 0.05 V above predicted for Fuel Cell 3. The voltage margins above the minimum performance curves at 175 A at the end of the mission were 0.78 V above minimum for Fuel Cell 1, 0.94 V above minimum for Fuel Cell 2, and 0.62 V above minimum for Fuel Cell 3.

During the Fuel Cell 2 Cell Performance Monitor (CPM) Self-Test at 150:05:45 GMT (13/16:48 MET), the Fuel Cell 2, substack 1, Differential Voltage ( $\Delta V$ ) indication went to an Off-Scale High (OSH) reading of 500 mV from a nominal value of approximately 22 mV but returned to nominal readings at the next self-test 7.5 min later (IFA STS-134-V-07). The nominal CPM self-test reading is 50 mV. There were 35 additional occurrences with the last one happening about 1 hr before landing. Systems Management Limit sensing for this parameter was inhibited onboard to prevent nuisance alarms.

Since the CPM was considered suspect, the established Flight Rule was invoked by tying Main Bus B to Main Bus C for the remainder of the flight. A Fuel Cell Monitoring System (FCMS) data recording was performed the following day. All single cell data was nominal. The bus tie was broken prior to entry to relieve the crew from having to

destow and stow the onboard computer used to perform the FCMS data recording each extension day.

### **Station-to-Shuttle Power Transfer System Operation**

STS-134 utilized the SSPTS, with an average power transferred of 6.23 kW, and a total energy transfer of 1718 kWh over 276 hours. This was the sixth flight of SSPTS on OV-105. When combined with the Orbiter, the average electrical power level was 13.58 kW for the mission duration.

During the Soyuz undocking, three of the four SSPTS OPCU channels were powered down. During the four EVAs and other mission operations (reboost), some or all of the power transfer from ISS was lowered as a standard safety practice.

The SSPTS Power Transfer Unit (PTU) performance for the STS-134 mission was flawless as usual with the exception of a fault isolation trip that occurred at 144/00:42:47 GMT, when the ISS switch was closed to reactivate SSPTS OPCU channel 1A. The OPCU Channel 1A telemetry remained OSL indicating that there was no input power. This signature is indicative of a PTU fault isolator trip. The converter was regained by performing the established procedure, and the OPCU operated nominally for the remainder of the flight.

### **Electrical Power Distribution and Control System**

The EPDC system performed nominally during all STS-134 mission phases and no IFAs were identified from the review and analysis of the data.

### **Orbiter Docking System**

The 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 FD 2 and the ODS was activated for 11 min 4 sec, and the avionics hardware was powered for 7 min 57 sec. The docking ring was extended to the normal 74.8 percent position at 137/14:35:43 GMT (01/01:39:15 MET). The system was ready for rendezvous and docking with the ISS.

The application of power for the docking activities was initiated at 138/09:40:21 GMT (01/20:43:53 MET), and the ODS was powered for 51 min 30 sec with power to the avionics hardware for 45 min 6 sec. The initial contact and capture of the ISS occurred at 138/10:13:53 GMT (01/22:45:13 MET). The total damping was 1 min 43 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 138/10:19:35 GMT (01/21:23:07 MET), and was completed in 3



min 24 sec. The drive-start time for the Hooks-Close function was 138/10:22:53 GMT (01/21:26:25 MET). The capture latches were released in 12 min 38 sec.

In preparation for undocking, the ODS was activated at 066/11:36:15 GMT (10/21:26:25 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. After undocking from the ISS, system 2 was configured and used for the remainder of the mission.

An Orbiter-to-ISS tank-to-tank O<sub>2</sub> transfer was performed, the final offload to ISS was 16.5 lb. An Orbiter-to-ISS tank-to-tank N<sub>2</sub> transfer was performed, and the final offload to ISS was 17.5 lb. There were two Orbiter/ISS stack N<sub>2</sub> repressurizations performed prior to undocking using the Orbiter PCS. The repressurizations were performed by opening the payload N<sub>2</sub> valves with restrictors in line that limited the flow to 7 lb/hr for better cabin air mixing. There was one direct O<sub>2</sub> repressurizations performed prior to docking with the ISS. There were 10 O<sub>2</sub> repressurizations performed through ISS using Orbiter O<sub>2</sub> during docked operations.

### **Airlock System**

The Airlock Systems performed nominally throughout the mission, and no Orbiter-based EVAs were performed during this mission. All water line and vestibule heaters were cycled on all systems. The Vestibule was successfully leak checked for docking and undocking operations.

### **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 73 °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 CWC condensate dump. The dump rate for the three dumps was a nominal average dump rate of 1.9 percent/min (3.2 lb/min). The

wastewater dump line temperature was maintained between 55 °F and 77 °F throughout the mission.

A total of 11 CWCs and 4 PWRs were filled with supply water and transferred to the ISS, for a total of 1126.6 lb<sub>m</sub> (1047.8 lb<sub>m</sub> from CWCs and 78.8 lb<sub>m</sub> from PWRs).

Two CWCs were used to collect condensate. The Orbiter condensate CWC was used to collect 34 lb<sub>m</sub> of condensate. It was transferred to ISS to be processed by Russian assets and returned to Shuttle empty. The ISS condensate CWC was used to collect approximately 75 lb<sub>m</sub> of condensate. It was transferred to ISS to be processed and remain on the ISS.

The vacuum vent line temperature was maintained between 81°F and 57 °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/Atmospheric Revitalization System**

The Active Thermal Control System (ATCS) performed satisfactorily throughout the STS-134 mission. No IFAs were identified from the review and analysis of the mission data.

The CO<sub>2</sub> level during the on-orbit mission phase was controlled below the flight rule maximum limit of 5 mmHg. The highest level recorded was 3.27 mmHg on 143/11:42 GMT (12/22:46 MET). There were no limits exceeded during this flight.

Ammonia Boiler System (ABS) B secondary controller was activated at 152/06:44 GMT (15/17:48 MET) and continued ABS operation on system B secondary controller to provide cooling nominally for approximately 36 min, until the start of ground cooling activation at 15/18:28 GMT (15/18:28 MET).

### **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 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-134 mission. One IFA was identified from the flight data during the review and analysis and it is discussed in the following paragraph.

At approximately 136/19:09 GMT (00/06:12 MET), the crew reported that the Forward Mission (FWD MSN) timer MET was off by 4 hr (IFA STS-134-V-02). The GMT was reported to be correct. At approximately 137/14:11 GMT (01/01:14 MET), the crew was asked to provide a read-out of the FWD MSN timer for both MET and GMT. This time the GMT was off by 4 hr and the MET was correct. The FWD MSN timer was power cycled at the circuit breaker, but the power cycle did not correct the problem.

### **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.

The FCS hardware/effector systems performed nominally during ascent through APU shutdown. At all times, the RSRB Thrust Vector Controller (TVC), 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 (RSB) Power Drive Unit (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. Entry performance was nominal from the deorbit preparation through vehicle touchdown. The pre-ignition OMS gimbal profile was as expected with the OMS actuator active and standby channels reaching nominal drive rates. All aerosurface actuators performed normally. Secondary differential pressures for all actuators were well within the equalization threshold, and all actuator positions closely tracked General Purpose Computer (GPC) commands. 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.

ADTA performance during the FCS checkout performance was nominal. Power-on and self-tests were performed with no anomalies. All 16 transducer outputs showed nominal responses.

Entry performance was nominal from the de-orbit maneuver through wheels-stop. All 16 transducers tracked during the pre-probe deployment phase of entry. Air data probes were deployed at approximately Mach 4.9, and deployment timing was within specification at less than 15 sec. The 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.

The Star Tracker (ST) system performed satisfactorily. The -Y ST star acquired a navigation star 798 times during the mission, and missed navigation stars 245 times during the mission. The missed stars are caused by bright objects, Orbiter attitudes, 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 114 times and missed the navigation star 92 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-134 was nominal. The GPS was powered 5 hr 8 min 31 sec prior to launch through ascent. During entry after the Plasma period, no Data Invalid or Figure of Merit (FOM) chimneys occurred during the critical phase of entry (below 140,000 ft). No IFAs were identified from the review and analysis of the flight data.

GPS no. 1 and GPS no. 3 were powered off as part of the Group B Powerdown at 02:21:17 MET into the mission. These two receivers were powered on for the STORRM DTO at 150/03:01:26 GMT (13/14:04:58 MET). GPS no.1 and no.3 were powered down at 150/12:04:05 GMT (13/23:07:37 MET). The two receivers were again powered up just before the FCS C/O the day before landing. Upon powerup, both GPS no. 1 and no. 3 downloaded the daily encryption key and transitioned to Precise Positioning Service (PPS) mode at the expected times. GPS no. 2 remained ON (and in PPS mode) the entire mission.

On entry day, the GPS state vector was incorporated into the PASS and BFS at 9 min 49 sec after going to Major Mode (MM) 301. At 51 min 10 sec prior to the deorbit maneuver, the GPS was inhibited in both PASS and BFS as planned. Once in MM 304 and after performance confirmation with high-speed C-band tracking, the GPS state vector was again set to automatically incorporate into both the PASS and the BFS, which is a standard operational procedure for both 3-string and single-string GPS. This occurred at 20 min 44 sec after Entry Interface at approximately 153,000-ft altitude. The effect was that the PASS and BFS navigation state vector residuals were reduced significantly, as expected. The PASS navigation state vector residuals remained consistently low from GPS incorporation through Microwave Landing System (MLS) incorporation at approximately 16,300 ft altitude.

### **Communications and Tracking System and Navigation Aids**

The communications and tracking systems (S- Band, Ku-Band, NAVAIDS and Antennas/cables performed satisfactory. IFA and one issue were identified and these are discussed in the following paragraphs.

The Ku-Band Radar Radio Frequency (RF) Output Telemetry fluctuations occurred during the ISS rendezvous and undocking radar operations. Although this signature was initially believed to be a telemetry-only problem, confirmation was made that the levels observed did not violate the flight rule or OMRSD requirements. This condition did not impact the mission activities.

The Pilot attempted calls on FD 2 from the Flight Deck Multiple Headset Adapter (MHA) using the Hand-Help Microphone (HHM) with no response from Mission Control Center-Houston (MCCH) (IFA STS-134-V-04). Later troubleshooting revealed that the Flight Deck MHA ports J1 and J2 were not transmitting. On FD 4, the crew checked out the FD MHA using the Headset Interface Unit (HIU)/VL Headset and reported all three ports operated nominally. No further troubleshooting was planned and EVAs 1 and 2 were operated in this configuration with no issues. However, on FD 10 (EVA 3 day), the audio problems recurred. The crew exchanged the FD MHA with the MD MHA. This configuration did not work initially, but began working after a hot-demate and re-mate. EVAs 3 and 4 were operated in this configuration with no issues. For entry, a new configuration was used that bypassed the Flight Deck MHA completely. These conditions did not impact the successful completion of the mission.

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

The Operational Instrumentation (OI) and Modular Auxiliary Data System (MADS) performed satisfactorily. One OI IFA was identified during the mission and after the review of the flight data, and it is discussed in a following paragraph.

At 136/12:56:00 Greenwich Mean Time (GMT) [Launch (L) minus 28 sec], the right Nose Landing Gear (NLG) tire pressure 2 instrumentation was erratic until 136/12:58:03 GMT [00/00:01:35 Mission Elapsed Time (MET)], and then again between 136/13:17:30 GMT (00/00:21:02 MET) and 136/13:18:19 GMT (00/00:21:51 MET) (IFA STS-134-V-03). The pressure increased by approximately 10-psi during the first erratic period and by approximately 1.5-psi during the second period. During all other periods, the instrumentation was consistent with the right NLG tire pressure no. 1 instrumentation. Both measurements stem from the same pressure transducer, but have independent signal conditioning.

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

### **Mechanical and Hatches System**

All STS-134 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.

During analysis of post-landing imagery, a brief fire was observed between the left Main Landing Gear (MLG) tires shortly after the drag chute was jettisoned (IFA STS-134-V-08). It appeared to extinguish itself quickly. Detailed visual inspections, material analysis, and landing gear systems testing were performed in an effort to determine the root cause of the fire. However, no definitive root cause could be determined.

### LANDING PARAMETERS

Parameter	From threshold, ft	Time from MLG touchdown, sec	Speed, keas <sup>a</sup>	Speed, kgs	Sink rate, ft/sec	Pitch rate, deg/sec
Main Landing gear touchdown	3186	0.0	190.6	195.3	1.21	
Drag Chute Deployment	4164	3.04	180.2	184.3		3.81
Drag Chute Disreef	5794	8.59	155.3	159.6		
Nose Landing Gear Touchdown	6000	9.35	149.7	155.0		
Brakes On	7675	16.76	113.5	118.8		
Drag Chute Jettison	9383	28.85	Off Scale Low	45.9		
Wheels Stop	9782	42.47	0.0	0.0		
Parameter			Data			
Brake Initiation Speed, keas			118.8			
Brake On Time, sec			27.7			
Rollout Distance, ft			6596			
Rollout Time, sec			42.5			
Runway Location, Surface and Degrees			KSC/15 (concrete)			
Orbiter Weight at Landing, lb			204,477			
Parameter	Maximum Brake Pressure, psia		Total Brake Energy, Mft/lb			
Left inboard	1534		24.14			
Left outboard	1511		24.30			
Right inboard	1201		18.45			
Right outboard	1055		16.58			

<sup>a</sup>Knots equivalent air speed

### Aerothermodynamics, Integrated Heating and Interfaces

The overall Orbiter TPS performed satisfactorily, and the postflight reports indicated the overall Orbiter TPS looked normal. The lower structural temperature data indicated normal entry heating. The recorded structure temperatures were within the flight experience of OV-105. From MADS surface thermocouples (T/C), Boundary Layer BLT

was asymmetric as well as late and occurred at  $X/L = 0.6$  around Mach 6.8 or 1270 sec after EI on the right side of the vehicle, and Mach 5.8 or 1322 seconds after EI on the left side based on a preflight End of Mission (EOM) trajectory.

The large tile damage at the aft of the RH MLGD noted during on-orbit imagery appeared unchanged from the FI images. The BLT flight experiment protuberance was still present and in good condition with some glazing on the tip. The experiment has succeeded in BLT onset around Mach 18.9 using a protuberance height of 0.5 inch.

The following table shows the maximum temperatures 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)	143	121.7
Lower fuselage forward left-hand (B2)	201	174.6
Lower fuselage forward mid left-hand (B3)	171.9	160.8
Lower fuselage mid center (B4)	145.6	139.6
Lower fuselage mid aft center (B5)	182.5	166.3
Lower fuselage aft center (B6)	185.1	148.5
Left-wing center (LW)	119.4	128.7
Right wing center (RW)	119.4	131.2
Port side FRCS forward (P1)	129.9	108.6
Port side fuselage forward center (P2)	103.8	95.3
Port side fuselage forward mid center (P3)	85.6	79.6
Port side fuselage mid aft center (P4)	67.5	71.7
Port side fuselage aft center (P5)	72.7	59.1
Starboard side FRCS Forward (S1)	137.7	113.9
Starboard side fuselage forward center (S2)	106.4	115.7
Starboard side fuselage forward mid center (S3)	88.2**	74.6
Starboard side fuselage mid-aft center (S4)	59.8*	61.4*
Starboard side fuselage aft center (S5)	70.1	59
Left-hand OMS pod side forward (LP)	83	74.5
Right-hand OMS pod side forward (RP)	67.5*	56.4*
Lower body flap center	109.0*	77.5*
Right-hand PLBD forward	67.5*	56.4*
Left-hand PLBD forward	83	74.5
Right-hand PLBD aft	59.8*	107.0*
Left-hand PLBD aft	59.8*	109.5*
Right wing upper center	72.7	104.8
Left wing upper center	75.3*	109.9*
Forward RCS center	83.0*	105.0*
Forward Fuselage Upper Center	59.8	102.5*

<sup>a</sup> 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 the data.

## 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**

<b>Orbiter Surface</b>	<b>Impacts greater than 1 in.</b>	<b>Total impacts</b>
Lower surface	21	104
Upper Surface/Window	0	8
Right OMS pod	1	7
Left OMS pod	0	2
<b>Totals</b>	<b>22</b>	<b>121</b>

### **Tile and Blanket Flight Assessment**

The overall performance of the TPS was satisfactory, and the overall damage not during the post-flight was minimal.

There was tile damage on the RH nose landing gear door that appeared 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 that was possibly induced by the drag chute.

The ET LH<sub>2</sub> umbilical had a wad of dark brown tape on the forward edge of the umbilical periphery. It appeared 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 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**

Four EVAs were performed nominally on the ISS during the STS-134/ULF-6 mission. The total time of the four EVAs was 24 hr and 44 min.

### **FIRST EXTRAVEHICULAR ACTIVITY**

The first EVA was performed on FD 5, May 20, 2011 and all planned activities were completed with the exception of the EWC cable installation during the 6 hr 19 min EVA.

The EVA started with both crewmembers translating to the ELC 2 for the MISSE 7 removal. The MISSE 7 Payload Equipment Containers (PECs) were closed and connectors were demated. Once the PECs were removed, the crewmembers translated to the Shuttle payload bay to install the MISSE 7 on the Shuttle Sidewall Carriers (SWCs). The Extra-Vehicular (EV) 1 crewmember (Drew Feustel) translated to the MISSE 8 and removed it from its SWC. The EV 1 crewmember translated back to ELC 2 and installed MISSE 8, mated its connectors and opened the PEC.

The EV 2 crewmember (Greg Chamitoff) installed the S3 CETA light and the S3 SARJ Multi-Layer Insulation (MLI) cover no. 7.

Both crewmembers then performed the P1-P6 preparation tasks required for the fill to be performed during the second EVA. Both crewmembers removed the P3-P4 ammonia jumper from the P4 stowage location and routed it across the SARJ and mated the connectors at P3 and P4. The EV 1 crewmember used the vent tools to vent the N<sub>2</sub> pad from the P1-P5 lines and then from the P6 EAS jumper. Finally, EV 2 crewmember temporarily stowed the P4 side of the P3-P4 jumper to allow the SARJ to rotate between EVAs.

The crewmembers then started on the External Wireless Communication (EWC) task. The EV 1 crewmember performed the EWC cable routing on the Laboratory while the EV 2 crewmember removed the two on-orbit installed handrails (OIHs) that would be replaced with the antenna mounted OIHs launched on ULF-6. During this task, the EV 2 received the CO<sub>2</sub> Sensor Bad message and the EVA had to be cut short. The crew completed all EWC tasks with the exception of removing the Micrometeoroid/Orbital MM/OD shield to mate/demate the connectors under the shield. This task was deferred and completed during the third EVA.

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, and had a duration 8 hr 7 min EVA. One anomaly was identified that impacted the EVA. The anomaly is discussed in a following paragraph.

The two crewmembers [Drew Feustel (EV 1) and Mike Fincke (EV 2)] translated to the P3/P4 worksite for the P1-P6 Ammonia fill task. The P3-P4 ammonia jumper was mated on the P4 side. The jumpers and the P1 ATA were configured for the fill and the fill was initiated. Then EV 1 set up the ammonia vent tools for the first of two ammonia vents required. Once the fill was complete, EV 1 configured the jumpers for the ammonia vent. While the vent was commanded, EV 1 translated to the Port SARJ to assist in Port SARJ lubrication task.

EV 2 had multiple issues with the SARJ MLI fasteners during the removal of the SARJ MLI covers, and was identified as an anomaly. The original plan was to remove 6, but since multiple washers and bolts were lost, so the real-time plan changed to the removal of only 4 covers (9, 13, 16 and 17). Only 3 covers were reinstalled (16, 9 and 13). Cover 17 was brought inside since it had only 1 of 4 bolts remaining; Cover 16 cover had 2 of 4 bolts remaining. There were no issues with covers 9 and 13.

EV 1 then reconfigured the ammonia vent tool for the second vent and translated back to the Port SARJ to assist EV 2. Once the ammonia vent was completed, EV1 stowed the P3-P4 jumper in its permanent stowage location and reconfigured the jumpers to the nominal configuration.

EV 2 installed the S1 Radiator Grapple Bar Stowage Beams. EV 2 performed the SPDM Latching End Effector (LEE) lubricant and installed the SPDM LEE camera cover.

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

### **THIRD EXTRAVEHICULAR ACTIVITY**

The third EVA was performed on FD 10, and all planned activities were completed during the 6 hr 54 min EVA. All planned activities were completed with the exception of the Functional Cargo Block (FCB) 1553 cable installation.

Both crewmembers translated to the FCB to prepare the worksite for the PDGF and Video Signal Converter (VSC) installation. The crew was to remove 5 MLI covers and temporarily stow them on the FCB using wire-ties and remove the Russian FCB caps. The crew found no caps and the MLI was out of the expected configuration. One of the MLI covers turned out to be 3 separate covers. All were temporarily stowed together. The crew returned to the airlock to retrieve the PDGF, which was been installed IVA on the PDGF stand. The crewmembers were able to "leapfrog" the PDGF and the PDGF Stand hardware to the worksite. The PDGF and VSC hardware was installed as well as all the associated cables, with the exception of the 1553 cable, which was deferred.

The crew routed the FCB Ch 1/4 and Ch 2/3 Y-jumpers and mated the connectors. The final task on the FCB was to take EVA digital imagery of the FCB PDGF worksite and the FCB thrusters.

The crewmembers then returned to complete the External Wireless Communication (EWC) cable installation task that had been deferred from the first EVA. The MM/OD shield was removed to demate the EWIS cable and mate the connectors of the EWC cable under the shield.

Both crewmembers then translated to ELC 3. EV 2 installed the HPGT FRGF MLI and EV 1 completed the EVA Infrared (IR) imagery of the STP-H3 VADER experiment, which was a new task added the week prior to launch. At ELC 3, the crew tucked the CTC MLI, which was a get-ahead task added during the docked timeframe. The EVA glove inspections and post-EVA photographs indicated no glove damage had been incurred during the third EVA.

## **FOURTH EXTRAVEHICULAR ACTIVITY**

The fourth EVA was performed on FD 12, and all planned activities were completed with the exception of the EFGF that was not stowed in the TSA, which was considered lower priority than the FGB 1553 cable installation task deferred from the third EVA. Both tasks were not completed. The duration of the fourth EVA was 7 hr 24 min.

Both crewmembers performed the stowing of the OBSS on the S 1 truss. The crew then translated to the P6 truss to retrieve the P6 PDGF. The PDGF Universal MCF Adapter Assembly (PUMMA) was installed and the PDGF was removed from P6 and taken to the OBSS EFGF worksite. The crew removed the bolts on the EFGF, cut the cable and replaced it with the PDGF Adapter Assembly (PAA), then finally the PDGF.

The EV 1 (Mike Fincke) then translated to the ELC3 SPDM Arm Flight Support Equipment (FSE) worksite to release the 3 Expandable Diameter Fasteners (EDFs). The center EDF and one other EDFs were removed without the use of the SPDM Pry Rod, which was launched on ULF-6 for this task. The last of the EDFs required use of the SPDM Pry Rod for removal.

EV 2 (Greg Chamitoff) inspected the Orbital Replacement Unit (ORU) Tool Platform (OTP) Long Duration Tethers (LDTs) and re-cinched them, as planned. The crew then took the EVA digital imagery of the STP-H3 payload.

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

## **REMOTE MANIPULATOR SYSTEM AND ORBITER BOOM SENSOR SYSTEM**

The SRMS performed nominally during the mission. STS-134 was the 90th flight of the Shuttle Remote Manipulator System (SRMS), the 23rd flight of SRMS S/N 201, the 21st flight of the OBSS, and the 7th flight of Inspection Boom Assembly (IBA) S/N 202.

The SRMS on-orbit Initialization began at 136/15:42 GMT (00/02:45:32 MET) on 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 136/15:58 (00/03:01 MET) and was completed at 11 min later. The SRMS checkout began at 136/16:13 GMT (00/03:16 MET) and was completed at 136/17:16 GMT (00/04:19:32 MET). During the Direct Drive Test of the Wrist Roll joint, a WR ABE BITE fault message and SM alert was annunciated. The crew re-performed the Direct Drive Test on the Wrist Roll joint successfully. This was defined as a recurrence from a previous flight. Following the SRMS checkout, the crew performed a PLB survey before maneuvering to the Pre-Cradle Position.

On FD 2, the SRMS grappled the OBSS at 137/06:50 GMT (00/17:53 MET) and maneuvered the OBSS to the hover-position at 15 min later. After unberthing the OBSS, the SRMS maneuvered to the flat-field position at 137/07:52 GMT (00/18:55 MET). The Starboard Survey began at 137/08:30 GMT (00/19:33 MET) and was completed 1 hr 13 min later. The Nose Cap RCC Survey began at 137/09:56 GMT (00/20:59 MET) and was completed 47 min later. The Port Survey began at 137/10:52 GMT (00/21:55 MET) and was completed 1hr 44 min later. The SRMS maneuvered to the OBSS Hover position at 137/13:01 GMT (01/00:04 MET). The OBSS was berthed in the starboard MPMs at 137/13:27 GMT 901/00:30 MET) and the SRMS was maneuvered to grapple the ELC 3 30 min later.

On FD 3, Endeavour docked with the International Space Station (ISS). After docking, the SRMS unberthed the ELC 3 at 138/13:17 GMT (02/00:20 MET) and handed off to the SSRMS at 138/14:44 GMT (02/01:47 MET). The SRMS maneuvered to the ELC 3 Install Viewing Position 22 min later.

On FD 4, The SRMS maneuvered to the AMS-2 Pre-Grapple at 139/6:13 GMT and grappled the AMS at 139/06:29 GMT (02/17:32 MET). The SRMS unberthed the AMS-2 to the Hover Position before maneuvering to the Handoff Position at 139/07:22 GMT (02/18:25 MET), where the SSRMS grappled the AMS 28 min later. After releasing the AMS, the SRMS maneuvered to the AMS Install Viewing Position at 139/08:12 GMT (02:19:15 MET). The SRMS maneuvered to the Pre-Cradle Position at GMT 139/13:17 (03/00:29 MET).

No SRMS activities occurred during FD 5.

On FD 6, the SSRMS grappled the OBSS at 141/04:37 GMT (04/15:40 MET) and handed it off to the SRMS 36 min later to perform the Focused Inspection. The Focused Inspection was completed at 141/08:45 GMT (04/19:48 MET), and the SRMS/OBSS maneuvered to the OBSS Handoff/Undock Position 5 min later.

No SRMS activities occurred during FD 7.

On FD 8, the SRMS maneuvered to the OBSS Sensor Protect Position at 143/13:55 GMT (07/00:58 MET) prior to the Soyuz undocking and the SRMS maneuvered back to the Orbiter undocking-position at 144/03:47 GMT (07/14:50 MET) on FD 9.

There were no SRMS activities on FD 10.

On FD 11, the Docked Late Inspection of the Starboard Wing Reinforced Carbon-Carbon (RCC) began at 146/02:31 GMT (09/13:34 MET) and was completed at 146/04:28 GMT (09/15:31 MET). The Nose Cap Survey began 24 min later and was completed at 146/05:08 GMT (09/16:11 MET). The Port Wing RCC Survey began at 20 min later and was completed at 146/06:15 GMT (09/17:18 MET). Following the surveys, the SRMS was maneuvered to the OBSS Handoff for Stow Position.

On FD 12, the SRMS handed off the OBSS to the SSRMS at 147/04:47 GMT (10/15:50 MET). After the fourth EVA, the SRMS maneuvered to the Pre-Cradle Position at 147/12:45 GMT (10/23:48 MET). The SRMS was cradled and latched 13 min later.

On FD 13 through 16, there were no SRMS activities with the exception of stowing the Manipulator Positioning Mechanisms (MPMs) on FD 15.

# 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 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 FD 2 OPO. This is because it was not confirmed to be an impact to the lower surface of the RCC, for which the Damage Likelihood would be Category I. The ascent impact location analysis in combination with corroborating imagery from the 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 <sup>a</sup>		Location			Magnitude		Criteria						Impact <sup>b</sup>		Damage Likelihood Category
MET, sec	DET, hr	Wing	RCC	Unit-Channel	Max Grms	Max G	Transient	Non-Mission	Spectral	Shock	Damping	Multi-Sensor	In-Flight	Postflight	
106.6	115.8	Stbd	10	1057-J2	1.01	4.07	+	+	+	+	+	+	P	P	1
115.1	124.3	Stbd	8	1048-J1	1.84	13.6	+	+	+	+	+	+	P	P	1

<sup>a</sup> Data Analysis Findings: P=Possible;

<sup>b</sup> Category assessed from ascent data (I:<1/1000, II:<1/1000 to 1/500, III: <1/500 to 1/200, <IV:1/200 to 1/100, IV:> 1/100)



Automated scanning of post-flight data acquired from MET 10-500 seconds revealed a total of 50 possible ascent debris impacts on the wing leading edge (25 on the port and 25 on the starboard wing) ranging from 0.08 to 1.84 Grms.

## 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	Location			Magnitude	Criteria					Impact <sup>b</sup>	
	Wing	RCC	Unit-Channel	Measured G Peak	Transient	Non-Mission	Spectral	Shock	Multi-Sensor	In-Flight	Postflight
056/22:20:30	Port	19/20	1022-J3	0.41	+	o	-	-	-	A	A

<sup>a</sup>Adjusted to correct for known differences between the onboard laptop and actual GMT times.

<sup>b</sup>A = 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 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 OBSS survey visually inspected the WLE after the Orbiter undocked from the 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. All planned objectives for the equipment were met.

On FD 2, the downlink of SSV from multiple cameras as well as the test pattern did not work. Ground stations were able to lock onto the SSV encoder signal that was being down linked from the Orbiter. However, no video was present. Crew removed the SSV to PDIP cable with install a spare cable and cycled the SSV power switch. The SSV began operating nominally.

The cables were returned to Johnson Space Center (JSC) for standard post-flight testing. Both cables passed the standard post-flight testing. Additional testing is being developed and scheduled.

During the STS-134 rendezvous, the TCS unit lost track with the Pulsed laser and did not transition from Pulse mode to CW mode at a range of 300 Meters as expected (IFA STS-134-V-05). The LOT events occurred at 138/09:05:53 GMT (01/20:09:25 MET) at 311meters (1020 ft) for a duration of 28 sec, and at 138/09:07:04 GMT (01/20:10:36 MET) at 273 meters (895 feet) for duration of 2.45 min. The transition from Pulse to CW generally occurs prior to the RPM at approximately 290 meters (950 ft). The transition from Pulsed-to-CW occurred at 138/09:23:26 GMT (01/20:26:58 MET) at a distance of 197.6 meters (648.29 feet) after the RPM. The CW did not lose tracking after the acquisition at 197.6 meters (648.29 feet) to docking.

During FD 8 crew sleep, the K-band File Transfer (KFX) Payload General Support Computer (PGSC) dropped off the onboard network at 143/21:00 GMT (07/08:03 MET) (IFA STS-134-S-001). After crew wake, the crew was asked to move the hard drive from the KFX PGSC into a spare PGSC. Moving the hard drive did not resolve the issue. The spare PGSC's original hard drive was reinstalled and the KFX function was then reassigned to the spare PGSC.

## **POST-LAUNCH PAD INSPECTION**

The post-launch inspection of the MLP-2 Pad A Fixed Service Structure (FSS), the Pad-A apron, the infield, and the flame trench was conducted on May 16, 2011. The inspection proceeded quickly while Safing Teams secured the Pad. The entire PAD, FSS and MLP were inspected. The RSRB flame trench was unable to be inspected because of the high levels of HCL. A piece of RSRB throat-plug material was the only flight hardware found during the inspection.

The Orbiter lift-off lateral acceleration data indicated a maximum of 0.09g. Hold-down stud hang-ups are typically noted with lateral accelerations above 0.19g.

### **RSRB Hold-down Posts (HDP) Inspection**

**HDP No. 1** – EA934 poured sidewalls were nominal with moderate acceptable pitting Phenolic shim had minor blistering. No firing lines were present. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down.

**HDP No. 2** – EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim was nominal. No evidence of either firing line was present. Approximately 10 in. of Range Safety System (RSS) cable remained past the tie-off point. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down. The inboard Inconel flange appeared to have 2 machine marks.

**HDP No. 3** – The inspection showed nominal indications of erosion on the 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** – EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim was nominal. Five inches of one firing line was present. No galling or chatter marks were noted in the chamfer of the through-hole and the stud was set down. The inboard Inconel flange appeared to have a corner machined off.

**HDP No. 6** – EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim had an oval-shaped blister that was 5 in. by 3 in. No evidence of firing lines was present. 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 a RSS cable was missing.

### **GN2 Purge Lines Inspection**

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

2. The Right Hand (RH) probe was erect and bent Southeast. 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 (GCA's) appeared to be in nominal condition with proper demate.
  - a. Several connector housings had broken sidewalls.
  - b. 5J1 and 3J1 pins and sockets were raised higher than nominal.
  - c. All 4 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 LO<sub>2</sub> and LH<sub>2</sub> Tail Service Masts (TSMs) appeared to be undamaged and both bonnets appeared to have closed properly.

### **MLP Deck Inspection**

- 1 The MLP deck was in nominal condition.
- 2 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 inspection noted unsecured pip pins on baskets 2, 4, and 5.
4. The grating clips between baskets 1 and 2 were detached.

### **Gaseous Hydrogen Vent Line Ground Umbilical Carrier Plate (215-ft level) Inspection**

1. The GH<sub>2</sub> vent line was latched on the eighth tooth (of eight) on the latching mechanism.
2. The GH<sub>2</sub> vent line was latched nominally and had a nominal arresting cycle. The inspection of the GUCP LH and RH pivot assemblies indicated a nominal separation.

3. The ET GUCP 7-in. GH<sub>2</sub> 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.
7. Circular abrasions were noted on the left inboard pivot assembly.

### **Gaseous Oxygen Vent Arm (255-ft level) Inspection**

1. The GOX vent arm and hood appeared undamaged.
2. Hood windows and purge ducts appeared to be in nominal condition and the latch mechanism locked properly.
3. Southwest door had an unsecured pip pin.

### **PAD Facility Inspection**

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

### **North RSRB Flame-Trench Inspection**

The NASA Flame Trench was not inspected due to high levels of HCL. NASA Flame trench engineering completed the Debris portion of this walk down when the levels were acceptable.

### **Debris Items Found**

1. At the 275-ft level, an empty cigarette pack was found in the northeast corner; and a clamp vibrated loose on south side.
2. At the 195-ft level- 8" piece of nylon rope in front of elevators; Rust scale found in northwest corner; metal washer found on east side; Lower RH side of O<sub>2</sub> analyzer box had two disengaged clamps.
3. At the 155-ft level, a large bolt was found protruding from the top of -Y Orbiter Work Platform (OWP) structure. A bond strap was found on the east side, and a washer was found on east side.
4. At the 75-ft level, a bent tube with a P-clamp associated fastener missing
5. 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.
6. On the Pad surface, a 1-in. long bolt was found near the OIS box. A nut and bolt were found under the MLP north of the flame effector. A chain was loose on the Southwest corner of the MLP, and a bond- strap found near RSS truck 1 and several pieces of small concrete were found near the west FSS stairwell. A clamp was found on the west-side pad surface, and rust scale was found near the pivot point of the RSS.

## **LAUNCH PHOTOGRAPHY AND TELEVISION ANALYSIS**

The launch photography provided excellent views of areas requested. One RSRB camera that was aimed at the ET did not record video of the thrust panel. However, the other five cameras 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 TPS.

1. At 4.905 sec, lift-off debris was observed from the 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 LO<sub>2</sub> 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 LO<sub>2</sub> 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 RCC leading edge panel. This event may correlate to the 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 LH<sub>2</sub> tank acreage above EB-8.
9. At 220.9 sec, debris appeared to impact the Orbiter forward of the bipod and then travel aft 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. ET TPS had a loss at the base of the feedline bracket. The loss was noted on the inboard side of the Liquid Oxygen (LO<sub>2</sub>) 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 LO<sub>2</sub> TSM. Facility debris observed exiting from the Firex nozzle.
2. At minus 3.461 sec, lift-off debris was observed near the LO<sub>2</sub> TSM. Facility rust falls from the LO<sub>2</sub> TSM.
3. At minus 4.307 sec, lift-off debris was observed to fall from the Liquid Hydrogen LH<sub>2</sub>TSM during the SSME ignition. Facility rust falls from the TSM after SSME ignition.

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## **APPENDIX A**

### **STS-134 MISSION EVENTS**

<b>EVENT</b>	<b>DESCRIPTION</b>	<b>ACTUAL GMT</b>
APU Activation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	136/12:51:40.745 136/12:51:41.959 136/12:51:43.102
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	136/12:55:59.874 136/12:55:59.964 136/12:56:00.124 136/12:56:00.284
Main Engine Start	SSME-3 Start Command Accepted SSME-2 Start Command Accepted SSME-1 Start Command Accepted	136/12:56:21.439 136/12:56:21.564 136/12:56:21.677
SRB Ignition	SRB Ignition Command	136/12:56:27.994
Throttle Up 104.5 Percent	SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted	136/12:56:32.134 136/12:56:32.135 136/12:56:32.140
Throttle Down to 72 Percent	SSME-2 Command Accepted SSME-1 Command Accepted SSME-3 Command Accepted	136/12:57:07.495 136/12:57:07.495 136/12:57:07.501
Throttle Up to 104.5 Percent	SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted	136/12:57:19.335 136/12:57:19.335 136/12:57:19.341
Maximum Dynamic Pressure (Max Q)	Derived Ascent Dynamic Pressure	136/12:57:28
Both SRMs at 50 psi	LH SRM Chamber Pressure RH SRM Chamber Pressure	136/12:58:27.944 136/12:58:28.304
End SRM Action	LH SRM Chamber Pressure RH SRM Chamber Pressure	136/12:58:30.494 136/12:58:30.894
SRB Separation Command	SRB Separation Command Flag	136/12:58:33
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	136/12:58:32.718 136/12:58:32.798 136/12:58:32.838 136/12:58:32.838
OMS Assist Ignition	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	136/12:58:43.0 136/12:58:43.1
OMS Assist Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	136/13:01:28.5 136/13:01:28.6
Throttle Down for 3g	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	136/13:03:47.979 136/13:03:47.986 136/13:03:47.991
3G Acceleration	Total Load Factor (g)	136/13:04:28.2
Throttle down to 67 percent for Cutoff	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	136/13:04:42.700 136/13:04:42.708 136/13:04:42.712
SSME Shutdown	SSME-3 Command Accepted SSME-1 Command Accepted SSME-2 Command Accepted	136/13:04:49.100 136/13:04:49.108 136/13:04:49.112
Main Engine Cutoff (MECO)	MECO Command Flag MECO Confirmed Flag	136/13:04:49 136/13:04:49
ET Separation	ET Separation Command Flag	136/13:05:10



## **APPENDIX A**

### **STS-134 MISSION EVENTS**

<b>EVENT</b>	<b>DESCRIPTION</b>	<b>ACTUAL GMT</b>
APU Deactivation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	136/13:10:32.625 136/13:10:46.849 136/13:10:59.132
OMS 1 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	Not Required
OMS 1 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	Not Required
OMS 2 Ignition	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	136/13:33:25.4 136/13:33:25.5
OMS 2 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	136/13:36:14.1 136/13:36:14.2
Payload Bay Doors Open	Right Payload Bay Door Open 1 Left Payload Bay Door Open 1	136/14:25:10 136/14:26:31
OMS 3 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	136/15:48:45.1 136/15:48:45.1
OMS 3 Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	136/15:49:44.9 136/15:49:45.3
OMS 4 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	137/06:22:51.7
OMS 4 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	137/06:23:06.3
OMS 5 Ignition	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	138/06:07:27.5
OMS 5 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	138/06:07:38.5
OMS 6 Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	138/07:38:13.1
OMS 6 Cutoff	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	138/07:38:24.3
Docking	Capture	138/09:40:21
Undocking	Undocking Complete	150/03:55:13
Flight Control System Checkout – APU 1 Start	APU-1 Gas Generator Chamber Pressure	151/02:24:35.135
APU 1 Stop	APU-1 Gas Generator Chamber Pressure	151/02:29:12.265
Payload Bay Door Close	Left Payload Bay Door Close Right Payload Bay Door Close	152/02:48:24 152/02:49:45
APU Activation	APU-2 Gas Generator Chamber Pressure APU-1 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	152/05:24:07.189 152/05:50:26.985 152/05:50:29.702
Deorbit Maneuver Ignition	L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position	152/05:29:03.2 152/05:29:03.2
Deorbit Maneuver Cutoff	R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position	152/05:31:42.8 152/05:31:43.0
Entry Interface	Orbital Altitude Referenced to Ellipsoid	152/06:03:06
Blackout End	Data Locked (High Sample Rate)	No Blackout
Terminal Area Energy Management (TAEM)	Major Mode Code (305)	152/06:28:21

**APPENDIX A**  
**STS-134 MISSION EVENTS**

<b>EVENT</b>	<b>DESCRIPTION</b>	<b>ACTUAL GMT</b>
Main Landing Gear Contact	Main Landing Gear Right Hand Tire Pressure Main Landing Gear Left Hand Tire Pressure	152/06:34:50 152/06:34:51
Drag Chute Deployment	Drag Chute Deploy 1 CP Volts	152/06:34:52.9
Main Landing Gear Weight on Wheels	Main Landing Gear Left Hand Weight on Wheels Main Landing Gear Right-Hand Weight on Wheels	152/06:34:50 152/06:34:55
Nose Landing Gear Contact	Nose Landing Gear Left Hand Tire Pressure 1	152/06:35:00
Nose Landing Gear Weight on Wheels	Nose Landing Gear Weight on Wheels	152/06:35:00
Drag Chute Jettison	Drag Chute Jettison 2 CP Volts	152/06:35:18.7
Wheels Stop	Velocity with respect to Runway	152/06:35:33
APU Deactivation	APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure	152/06:54:45.185 152/06:55:00.209 152/06:55:11.012

## **APPENDIX B**

### **STS-134 IN-FLIGHT ANOMALIES**

#### **INTRODUCTION**

This appendix contains listings and discussions of each of the In-Flight Anomalies (IFAs) that were identified for the STS-134 mission.

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

## APPENDIX B STS-134 IN-FLIGHT ANOMALIES

### ORBITER ANOMALIES

IFA Number	Title	Comments
STS-134-V-01	APU 1 Fuel Test Line Temperature Trended Below the LCC limit	<p>During pre-launch operations on April 29, Auxiliary Power Unit (APU) 1 Fuel Test Line and Fuel Service Line 'B' heaters failed to activate (temperature trended below the Launch Commit Criteria (LCC) limit of 45 ° F in LCC APU-14) with both ground command and panel switch activation. This was a violation of the LCC and resulted in a scrub of the first launch attempt. The APU 1 heater circuit was non-functional in Aft Logic Control Assembly (ALCA) 2, and the ALCA was replaced. The ALCA Line Replaceable Unit (LRU) and component analysis indicated that the driver was exposed to a short circuit and responded nominally. The driver was replaced and the LRU tested nominally including during vibration testing. Vehicle wiring was nominal during Hi-Potential (Hi-POT) testing. New wire and splices were installed from ALCA 2 to the heater strings to mitigate an undetected transient short. The B system heaters tested nominally during continuity and 450 Vdc isolation testing. Heaters were functionally tested with Ground Support Equipment (GSE) power and the replacement ALCA 2 performed nominally. Data review from the June 2010 heater testing revealed a 2 msec 18 Ampere (A) current spike during testing of thermostat S12B. The thermostat was found to have exposed conductor on the vendor lead. The problem is classified a Unexplained Anomaly (UA); however, the exposed conductor is considered the most probable cause of the anomaly.</p> <p><b>Post-flight plan:</b> None</p>
STS-134-V-02	FWD Mission Timer MET Off by 4 hours	<p>At approximately 136/19:09Greenwich Mean Time (GMT), the crew reported that the Forward Mission (FWD MSN) timer Mission Elapsed Time (MET) was off by 4 hr. The GMT was reported to be correct. At approximately 137/14:10 GMT, the crew was asked to provide a read out of the FWD MSN timer for both MET and GMT. The results were that the GMT was incorrect and off by 4 hr and MET was correct. The FWD MSN timer was power cycled at the circuit breaker on panel O14:B. This power cycle did not correct the initial problem. The GMT hr was still off by 4 hr. The FWD MSN Timer would not display the correct hours for either MET or GMT when the hours value is supposed to be 4, 5, 6, 7, 14, 15, 16, 17. When the hour is supposed to read those values it will be 4 hours behind. Other time sources were used for GMT/MET (CRT timers, AFT Mission Timer).</p> <p><b>Post-Flight Plans:</b> None</p>

**APPENDIX B  
STS-134 IN-FLIGHT ANOMALIES  
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-134-V-03	Right NLG Tire P2 Transducer Erratic	<p>The right Nose Landing Gear (NLG) tire pressure 2 instrumentation was erratic between 000/00:00:28 MET and 000/00:01:35 MET and then again between 000/00:21:02 MET and 000/00:21:51 MET. The pressure increased by approximately 10 psi during the first erratic period and by approximately 1.5 psi during the second period. During all other periods, the instrumentation was consistent with the right NLG tire-pressure-1 instrumentation. Both measurements stem from the same pressure transducer but have independent signal conditioning. The crew was made aware of the condition, and Table Maintenance Block Update (TMBU) was uplinked to inhibit the BFS FDA limit prior to entry to prevent nuisance alarms. The subject separation harness is destroyed on the runway at NLG touchdown during spin-up of the nose tires.</p> <p><b>Post-Flight Plans:</b> None.</p>

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-134-V-04	Multiple Head Set Adapter Ports J1 and J2 Not Transmitting	<p>FD02 - PLT attempts calls using HHM (Hand Held Microphone) (s/n 5038) from the FD MHA (Flight Deck Multiple Headset Adapter) (s/n 0011) with no response from MCC-H. Later troubleshooting revealed FD Multiple Headset Adapter (MHA) Ports J1 and J2 were not transmitting.</p> <p>FD04 - Crew checked out the FD MHA (s/n 11) using the Headset Interface Unit /Very Lightweight Headset (HIU/VLHS) shortly after crew wake and reported no issues. All three ports worked nominally. EVA 1 and 2 were operated in this config with no issues. Crew did not use the hand held mic for the test FD4, but ground did not believe a hand held mic issue (e.g., bent pin) since it worked after the original anomaly.</p> <p>FD10 - Audio problems again. Crew did comm checks with FD HHM (s/n 5038) plugged directly into MS ATU and PS ATU with joy. Crew then swapped FD MHA (s/n 0011) with MD MHA (s/n 0009). At first this swap was no joy, but the crew left the CCU power ON, de-mated and re-mated the MHA into the CCU, and all 3 ports worked nominally.</p> <p>FD11 - Crew performed comm checks with the new MD MHA (s/n 0011) and MD HHM (s/n 5041), and all 3 ports worked nominally.</p> <p>FD12 - In an effort to get in the best config for Entry, it was decided that the original FD MHA (s/n 0011) would be mounted in the MD for Entry. Also FD HHM (Hand Held Microphone) (s/n 5038) and MD HHM (s/n 5041) would be swapped.</p> <p>FD13 - Crew performed HHM swap, MD MHA re-installation, and confirmed QDMs (Quick Don Masks) were connected to MD MHA (s/n 0011). Crew reported MD MHA (s/n 0011) comm checks were nominal. The ground was unsure which audio equipment was used for comm checks, which were performed on ICOM, not the Air-to-ground loops. Later the crew had audio issues again with the MD MHA (s/n 0011) using the original FD HHM (s/n 5038). All 3 ports were tested with no joy. The crew did a 'hot' de-mate, re-mate which worked, but only for 2 hours until issues occurred again. The crew then plugged the HHM (s/n 5038) directly into MD CCU bypassing the MD MHA (s/n 0011) all together. The MD remained in this config until reconfig for Entry.</p> <p><b>Post-flight plans:</b> HHMs and MHAs destowed for troubleshooting.</p>

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-134-V-05	TCS Late Transition from Pulse to CW	<p>During STS-134 Rendezvous, the TCS unit (S/N 1010) lost track with the Pulsed laser and did not transition from Pulse mode to CW mode at a range of 300 meters as expected. The Loss of Tracking (LOT) events occurred at 1/20:09:25 MET at 311 meters (1020 ft) for a duration of approximately 28 sec, and at 01/20:10:36 MET at 273 meters (895 feet) for a duration of 2 min 45 sec. The transition from Pulse to CW generally occurs prior to the R-bar Pitch Maneuver (RPM) at approximately 290 meters (950 ft). The transition from Pulsed to CW occurred at 01/20:26:58 MET at a distance of 197.6 meters (648.29 feet) after the RPM. The CW laser did not lose tracking after the acquisition at 197.6 meters (648.29 feet) to docking.</p> <p><b>Post-Flight Plans:</b> This is the last flight for TCS S/N 1010. No additional post-flight actions are planned.</p>
STS-134-V-06	APU SM Alerts	<p>During Flight Day (FD) 9 crew sleep, two System Management (SM) alerts were annunciated at 144/19:10:52 GMT. Review of telemetry showed that the Auxiliary Power Unit (APU) 2 parameters took a step function from approximately 20 psig and 365 ° F, respectively, to Off Scale Low (OSL) for a 4 min 30 sec period starting 144/19:10:23 GMT. Both parameters fully recovered and returned to nominal. A Table Maintenance Block Update (TMBU) was uplinked at 144/19:29:03 GMT to inhibit these limits, and prevent additional nuisance alarms during crew sleep.</p> <p>These sensors are powered through instrumentation power supply C in the APU 2 controller. Data from main bus B Aft Power Controller (APC) no. 5 current measurement indicated a drop in current at the same time the data was lost, and APU 2 Gas Generator (GG) injector tube temperature reading showed that the GG heater was off. At the time of this anomaly, the APU 2 assembly fuel lines/fuel pump/GGVM 'A' heaters were off (nominal S17A thermostat performance) so it could not be verified if this anomaly affected these heaters.</p> <p>After the crew awake, the APU 2 GG/FP heater circuits were reconfigured to 'B' at. No switch to the GG/FP 'B' heaters was performed during the failure event so it could not be determined if this anomaly affected both GG heater circuits.</p> <p><b>Post-Flight Plans:</b> No post-flight troubleshooting planned.</p>

**APPENDIX B  
STS-134 IN-FLIGHT ANOMALIES  
ORBITER ANOMALIES**

IFA Number	Title	Comments
STS-134-V-07	Fuel Cell 2 Substack 1 CPM Intermittent Self-Test Fail	<p>During a Cell Performance Monitor (CPM) self-test at 150/05:45 GMT (013/16:48 MET), Fuel Cell (FC) 2 substack 1 delta volts indication transitioned from a nominal value of approximately 22 mv to an Off-Scale High (OSH) value. At the next self- test event 7minutes, 38 seconds later, the substack 1 delta volts measurement returned to a nominal value of approximately 24 mV. An associated onboard SM alert message was annunciated. SM limit sensing for this parameter was inhibited onboard to prevent nuisance alarms. There was several additional occurrences throughout the remainder of the mission</p> <p>A main bus tie B to C was performed as a backup method to monitor relative FC performance per Flight Rules. The bus tie was broken prior to entry. Additionally, the Flight Rule mandated a daily Fuel Cell Monitoring System (FCMS) data recording and downlink. The data takes were performed and indicated nominal FC performance.</p> <p><b>Post Flight Plan:</b> None</p>



## APPENDIX B STS-134 IN-FLIGHT ANOMALIES

### ORBITER ANOMALIES

IFA Number	Title	Comments
STS-134-V-08	Left Hand Main Landing Gear Observed Fire	<p>A brief fire was observed between the left Main Landing Gear (MLG) tires shortly after the drag chute was jettisoned. It apparently extinguished itself quickly. Overall, the tires looked good. The Left-Hand (LH) outboard did show a bit of an unusual spin-up patch as compared to the others. There was tread cord exposed around the circumference of the tire. However, the cord exposed around the circumference was “stringy”. This means the typical wide spin-up patch that is seen where the vehicle initially touches down did not go completely around the circumference of the tire. There were a small number of “single” tread cords that were exposed around the circumference of the tire.</p> <p>The 200 °F temp labels on the LH Outboard Tire did trip. The 150 ° F temp labels tripped on the others. There seemed to be no evidence of a fire on the runway from personnel who have performed visuals with good lighting.</p> <p>Landing data does show high-brake energies late in the roll-out (approximately 40 knots), which correlates to the short roll-out time of 42 sec.</p> <p>Samples were taken and were followed by rolling resistance checks and wheel removal on the LMG. The rolling resistance on the LH OTBD was 300 in-lb, which was 100 in-lb lower than the pre-flight value. The LH INBD was 350 in-lbs, 70 in-lbs lower than pre-flight. After removal of the wheels, a inspection of the brakes and inner wheel halves was performed. Overall, there was no evidence of a fire on the LH INBD brake. Other than a slightly higher than normal amount of brake dust on the upper surfaces (especially the INBD brake), there was nothing unusual. It was noted that some of the dust had formed into flakes which accumulated on the upper surface of the stators. That was observed on both of the LH brakes, and this condition has been seen before. There was no evidence of any abnormal wear or other problems. There was also no evidence of fire from the grease on the axle or in the wheel bearings, and there was no hydraulic fluid contamination observed.</p> <p>Inspections of the inner wheel halves noted more darkening of the heat shield on the INBD wheel. The INBD wheel heat shield was almost uniformly blackened on the inner surface, where the OTBD was fairly clean toward the inner edge. This may have been due to the higher amount of brake dust on the INBD, or it could be soot/residue from the fire.</p> <p>Samples were taken from the wheels to be analyzed. Hydraulic pressure was applied to the LH brakes to check for any hydraulic fluid leaks and no leaks were detected.</p> <p>To date, no definitive cause has been determined.</p>
STS-134-V-09	ET/Orbiter Umbilical LO <sub>2</sub> Fwd Outboard Actuator did not Retract into Mechanical Locks	<p>During OPF inspection of the umbilical cavities on OV-105, 1 of the hydraulic External Tank (ET) umbilical actuators (LO<sub>2</sub> Forward Outboard) was found to not be fully retracted into the mechanical locks. There was a similar occurrence on STS-119.</p>

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**REUSABLE SOLID ROCKET BOOSTER ANOMALIES**

IFA Number	Title	Comments
STS-SRB-B-001	Right Hand (RH) SRB Main Parachute Gore 26 Failure Failed from the Skirt Band through the Vent Band	Diver assessment of one of the three main parachutes for the RH SRB showed evidence of significant damage to the canopy. The post-flight assessment of the parachutes at the Parachute Refurbishment Facility (PRF) documented the damage to RH main parachute canopy (S/N 64488). The damage was characterized as a vertical tear within gore 26 failed from the skirt band through the vent band. Onboard imagery from the Data Acquisition System (DAS) showed the canopy rupture occurring subsequent to the second-stage reefing-line severance. The three main parachutes functioned normally through the 1st and 2nd stages until main parachutes no. 3 failed during the second disreefing to full open. The RH estimated water impact velocity was about 92 ft/sec, which is a typical SRB vertical velocity under two inflated main parachutes and is considered to be a hard water impact. The cause of the canopy damage has been attributed to the material rupture to damage incurred during the main parachute deployment. During deployment, evidence indicated that canopy components were dragged across the Main Parachute Support Structure (MPSS) attachment struts. This resulted in a tear within the fabric ribbons of the canopy, which existed prior to the second stage disreefing. Review of the RH SRB DAS video depicts within a single frame the initial tear prior to the second stage disreefing. The existing tear was analogous to a critical flaw size during third stage inflation, resulting in the canopy rupture.

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**REUSABLE SOLID ROCKET MOTOR ANOMALIES**

No anomalies were identified from the data and inspection of the SRB.

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**SPACE SHUTTLE MAIN ENGINE ANOMALIES**

IFA Number	Title	Comments
STS-134-E-01	Low Pressure Fuel Pump Discharge Pressure Sensor Channel B Disqualification during Ascent	<p>At Engine Start plus 371.65 sec, the channel B :Low Pressure Fuel Pump Pressure sensor measurement went Off-Scale Low ((OSL)for approximately 0.1 sec and then recovered. A Failure Identifier (FID) was posted and the measurement was permanently disqualified for mixture ratio control calculations. In addition, post-flight data review identified a simultaneous 100 psia (1.25 percent) decrease on the High Pressure Oxidizer Turbopump (HPOTP)pre-burner boost pump discharge pressure (HPOTP boost stage discharge pressure)sensor measurement follows the LPFP discharge measurement digitized in the controllers input Electronics read sequence.</p> <p><b>Post-flight Actions:</b> This anomaly is not resolved and is still in the evaluation and testing phase.</p>

**APPENDIX B  
STS-134 IN-FLIGHT ANOMALIES**

**EXTERNAL TANK ANOMALIES**

No anomalies were identified from the data and inspection of the SRB.

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**SYSTEM ENGINEERING AND INTEGRATION ANOMALIES**

IFA Number	Title	Comments
STS-134-I-001	Unexpected Debris/Expected Debris Exceeding Mass Allowable Prior to Pad Clearance (Lift-off Debris)	<p>STS-134 experienced unexpected debris and expected debris exceeding the mass allowable prior to pad clearance. The Closure Rationale went to the SICB on June 14, 2011. SR 4933 provided rationale for closure of STS-134-I-001. The recommendation was accepted and the IIFA closed.</p> <p>Risk Assessment indicated that given the proposed mitigations, 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 IDBR-01 cause AD. Unexpected lift-off debris from KSC Facilities/GSE is transferred from IDBR-01 cause AJ to LL-0077, which is classified as infrequent catastrophic. Debris release has been mitigated for identified potential sources of critical debris by performing repairs and adding inspections for system-level components (e.g. Unistrut clamp hardware, grounding straps, control handles, grating clips, and removable handrail kick plates). Mitigations include the removal of the unused safety slide hardware on top of the Orbiter Weather Protection. Ongoing mitigations include Foreign Object Damage (FOD) awareness, attrition-based removal of hardware, routine inspections and monitoring for facility hardware and corrosion. Main Launch Platform (MLP) -3 Tail Service Mast (TSM) Side Panel drainage was mitigated to prevent debris liberations exceeding the NSTS-60559 Risk Assessment Mass due to corrosion debris experienced on STS-133. No updates to NSTS 60559 are recommended as part of this IIFA closure.</p>

## APPENDIX B STS-134 IN-FLIGHT ANOMALIES

### SYSTEM ENGINEERING AND INTEGRATION ANOMALIES

IFA Number	Title	Comments
STS-134-I-002	Cylindrical Debris Observed Near +Y Thrust Panel During RSRB Separation	<p>At approximately 125 seconds Mission Elapsed Time (MET), the External Tank (ET) Observation Camera in the right Reusable Solid Rocket Booster (RSRB), designated SRF110, observed a cylindrically shaped object traversing the field of view for approximately 0.12 sec. The observation was recorded as reportable 134-034. The object appeared to be metallic. The same object could not be identified in the recorded imagery from any other camera. Other objects characterized as debris are also seen liberating around this point in time, however, none appear to impact the Orbiter. Due to the very large depth of field of the camera and observed motion blur in the imagery, analysis was inadequate to identify the object or to determine if the object was relatively closer to the camera (in the RSRB) or the ET. The investigation approach was two-fold: First, attempt to identify source of object and outline potential mitigations, and second, determine risk for STS-135. An integrated fault tree was developed establishing potential sources as Foreign Object Debris (FOD) and ET and RSRB flight hardware. Ground Operations, ET Project, and RSRB Project, and their contractors supported the integrated team in assessing the causes. The Orbiter and Space Shuttle Main Engine causes were not developed due to assessment that there was no credible transport from those elements to the location where the object was observed. Investigation of the ET did not identify any flight hardware potential sources. Review of separation imagery and vehicle performance data verified all ET hardware was intact. Ground Operations with support from ET and RSRB conducted an extensive investigation, which included reviews of all integrated work conducted on the vehicle in the Vertical Assembly Building (VAB) and at the Pad including work document review, tool box checks, parts- kits checks, PRACA searches, close-out imagery review, and Baseline Configuration Imagery (BCI) review. For potential liberation of flight hardware, analysis has indicated only two objects that match the physical description of the object observed on STS-134. Both objects, a ground strap coupler and a lock pin, are RSRB hardware and have been assessed to be unexpected debris. Only one of the two objects, the coupler, fits the estimated Ballistic Number of the time correlated radar observation. Testing and analysis by RSRB has demonstrated that the coupler will remain attached to either the RSRB or ET side ground strap pin and will not be liberated. Debris transport analysis of an object similar to the coupler shows liberation must occur within a short exposure window on the order of tenths of a second immediately after RSRB separation to result in impact and damage to the Orbiter. There is residual risk that if there is a metallic object liberated from the E/B area within the exposure window, transport is possible to Orbiter RCC and tile and can cause significant damage.</p>

**APPENDIX B  
STS-134 IN-FLIGHT ANOMALIES**

**SYSTEM ENGINEERING AND INTEGRATION ANOMALIES**

<b>IFA Number</b>	<b>Title</b>	<b>Comments</b>
STS-134-I-002 (Continued)	Cylindrical Debris Observed Near +Y Thrust Panel During RSRB Separation	Assessment by the Orbiter Project is that damage caused by an object similar to the coupler would be detectable by on-orbit inspections. The Integrated Hazard Report was reviewed for possible controls and/or accepted risk associated with the occurrence of this IIFA. If the debris were flight hardware, it is most likely unexpected debris from RSRM or RSRB. If this is FOD, it is unexpected debris during lift-off/ascent due to KSC facilities/GSE. No update to Integrated Hazard Report IDBR- 01 is required.



**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**FLIGHT SOFTWARE ANOMALIES**

IFA Number	Title	Comments
STS-134-S-001	KFX PGSC Failure	<p>During the middle of Flight Day (FD) 8 crew sleep, the Orbiter Communication Adapter (OCA) noticed that the KFX PGSC machine (STS 3) dropped off the network. The crew later mentioned that they had stopped hearing the fan running on STS 3. After crew wakeup, Ground personnel had the crew perform a A31P Device Changeout &amp; A31p Hard Drive Changeout with the former AMS PGSC (STS8), using the old KFX Hard Drive and Ultra-bays. Crew then called down that the new KFX machine (STS8) still wasn't booting up, so the crew then replaced the old KFX hard-drive with the former AMS hard-drive. The OCA then went onboard and deleted the AMS startup shortcut from the Startup folder on the new KFX machine.</p> <p>Because of the loss of the original KFX Hard-drive, the crew lost access to their old Personal Outlook folders and any messages that may have been created in the time after the last mail synchronization with the ground right around crew sleep. Crew also lost access to any old messages, Transfer Lists, and News from Home.</p> <p>The Ultra-bay drive E from KFX was no longer available with the new configuration for backup of the image cards. Only drive D Ultra-bay will retain a copy of the image cards.</p> <p><b>Post-Flight Plans:</b> Standard destow and return to JSC</p>

**APPENDIX B**  
**STS-134 IN-FLIGHT ANOMALIES**  
**FLIGHT OPERATIONS AND INTEGRATION ANOMALIES**

No Flight Operations and Integration anomalies were identified during the STS-134 Mission.

## **APPENDIX C**

### **STS-134 DOCUMENT SOURCES**

#### **MER DAILY REPORTS**

The following STS-134 MER Daily Reports by Michael D. Wright, Lead MER Manager:

Launch and First Daily Report, dated May 16, 2011  
Second Daily Report, dated May 17, 2011  
Third Daily Report, May 18, 2011  
Fourth Daily Report, dated May 19, 2011  
Fifth Daily Report, dated May 20, 2011  
Sixth Daily Report, dated May 21, 2011  
Seventh Daily Report, dated May 22, 2011  
Eighth Daily Report, dated May 23, 2011  
Ninth Daily Report, dated May 24, 2011  
Tenth Daily Report, dated May 25, 2011  
Eleventh Daily Report, dated May 26, 2011  
Twelfth Daily Report, dated May 27, 2011  
Thirteenth Daily Report, dated May 28, 2011  
Fourteenth Daily Report, dated May 29, 2011  
Fifteenth Daily Report, dated May 30, 2011  
Sixteenth Daily Report, dated May 31, 2011  
Landing Plus 2 Hour Report, dated June 1, 2011  
Mission Summary Report, dated June 6, 2011

#### **ET/SRB/RSRM/SSME REPORTS**

STS-134 In-Flight Anomalies, David W. Morr, USA-Huntsville, July 17, 2011  
STS-134 HOSC Console Flash Report, David W. Morr, USA-Huntsville, June 8, 2011  
STS-134 RSRM Flash Report, Robert Zahl, ATK, May 14, 2010  
STS-134 SRB Open Assessment, Thomas F. Ford, NASA-KSC, July 8, 2011  
STS-134 ET Impact Data, David W. Morr, USA-Huntsville, July 9, 2011

#### **ORBITER REPORTS**

STS-134 Landing Parameters, Chip C. Heinol, Boeing-Houston, June 20, 2011  
STS-134 Final Descent Postflight Quick Look Report, David A. Kyle, USA-Houston, June 29, 2011  
STS-134 Communications and Tracking Report, Charles J. Stafford, Boeing-Houston, June 16, 2011  
STS-134 Shuttle Remote Manipulator System, Charles Arnoldi, MDA-Houston, June 9, 2011  
STS-134 HYD/WSB System Report, Charles A. Rittrivi, Boeing-Houston, June 22, 2011  
STS-134 Main Propulsion System Report, Trina A. Martingano, Boeing-Houston, June 22, 2011  
STS-134 Auxiliary Power Unit System, Christopher N. Adi, Boeing-Houston, June 14, 2011  
STS-134 Data Processing System Integrated Report, Lynna L. Wood, Boeing-Houston, June 17, 2011  
STS-134 EPDC Mission Report, William D. Peterson, Boeing-Houston, June 16, 2011  
STS-134 ATCS and ARS Post-Flight Mission Report, Carmelo S. Asuncion, Boeing-Houston, June 30, 2011  
STS-134 Wing Leading Edge Impact Detection System, Jennifer C. Hodge, Boeing-Houston, July 8, 2011,  
STS-134 Life Support System Report, Jamie M. Haynes, Boeing-Houston, June 16, 2011  
STS-134 Orbiter Docking System Summary, Thomas I Hoffman, Boeing-Houston, June 28, 2011  
STS-134 OMS Report, Eric N. Duncan, Boeing-Houston, June 17, 2011

STS-134 RCS Mission Report James M. Garza, Boeing-Houston , June 23, 2011  
 STS-134 Postflight Aeroheating Report, Dennis C. Chao, Boeing-Houston, June 16, 2011  
 STS-134 Fuel Cells Mission Report, Kenneth D. Adams, Boeing-Houston, June 17, 2011  
 STS-134 Power Reactant Storage and Distribution, Kenneth D. Adams, Boeing-Houston, June 17, 2011  
 STS-134 Global Positioning System Report, Ray W. Nuss, NASA-Houston, June 6, 2011  
 STS-134 Flight Control System and ADTA Mission Report, Donald E. Marquith, Boeing-Houston,  
 June 7, 2011  
 STS-134 Final Mission Events List, Vernon C. Hill, ESCG-Houston, March 14, 2011  
 STS-134 SE&I In-Flight Anomalies, Carla A. Santiago, NASA-JSC, July 22, 2011  
 STS-134 Windows Report, Orlando Torres, Boeing-KSC, July 20, 2011  
 STS-134 Purge, Vent and Drain Report, C. C. Heinol, Boeing-Houston, June 28, 2011  
 STS-134 Mechanical Systems, Link Salvador, Boeing-Houston, June 20, 2011  
 STS-134 Station-to-Shuttle Power Transfer System, William D. Peterson, Boeing-Houston,  
 May 16, 2011  
 STS-134 Government Furnished Equipment, Kenneth L. Brown, NASA-Houston, June 23, 2011

## **OTHER REPORTS**

STS-134 CSR Final Report, Shelby Lawson, NASA-JSC, July 9, 2011  
 STS-134 Final Landing Debris Runway Report, Thomas F. Ford, NASA-KSC, June 9, 2011  
 STS-134 Final Debris Maps, Thomas F. Ford, NASA-KSC, June 1, 2011  
 STS-134 Post-EVA No. 1 Data, Sandra Peterson, Hamilton Sundstrand, May 20, 2011  
 STS-134 Post-EVA Report for EVA 1, Rolland J. Daley, Hamilton Sunstrand, May 20, 2011  
 STS-134 Pre-EVA No. 2 Data, Jeff Outlaw, Hamilton Sundstrand, May 22, 2011  
 STS-134 Post-EVA Report for EVA 2, Sandra Peterson, Hamilton Sunstrand, March 2, 2011  
 STS-134 EVA 3 Pre-Breathe and Egress, Jeff Outlaw, Hamilton Sunstrand, May 25, 2011  
 STS-134 EVA 3 Ingress and Post-EVA Report, Sandra Peterson, Hamilton Sunstrand, May 21, 2010  
 STS-134 EVA 4 Preparation and Egress, Jeff Outlaw, Hamilton Sunstrand, May 27, 2011  
 STS-134 EVA 4 Post EVA Report, Sandra Peterson, Hamilton Sunstrand, May 27, 2011  
 STS-134 Final Extravehicular Activity Report, Maria Tullar, NASA-JSC, June 15, 2011  
 STS-134 Post-Launch Debris Report, Jeffrey S. Thon, NASA-KSC, May 16, 2011  
 STS-134 prop30 Mass Properties Report, R. R. Mark, NASA-JSC, June 2, 2011  
 STS-134 Imagery Reports, Imagery Integration Group, NASA-JSC, May 16, 2011 through  
 June 2, 2011  
 STS-134 Ascent Hazard Analysis Final Report, C. C. Heinol, Boeing-Houston, June 16, 2011  
 STS-134 Flight Operations/MOD Anomalies, Gregory A. Lange, July 26, 2011  
 STS-134 Descent Postflight Summary, Rosalyn H. Mark, USA-Houston, June 30, 2011  
 STS-134 Endeavour History, Kyle Herring, NASA-Houston, June 6, 2011  
 STS-134 Launch + 2 Day Report, Henry Domingo, Boeing-Houston, May 17, 2011  
 STS-134 SRB Open Assessment, Thomas F. Ford, NASA-KSC, May 19, 2011

## APPENDIX D

### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
A	Ampere
AA	Accelerometer Assembly
ABS	Ammonia Boiler System
ADTA	Air Data Transducer Assembly
AGT	Adaptive Guidance Throttle
AHMS	Advanced Health Monitoring System
ALCA	Aft Logic Control Assembly
AMOS	Air Force Maui Optical Supercomputing Site
AMS	Alpha Magnetic Spectrometer
APC	Aft Power Controller
APU	Auxiliary Power Unit
ARPCS	Atmospheric Revitalization Pressure Control System
ATCS	Active Thermal Control System
ATU	Audio Terminal Unit
ATV	Automated Transfer Vehicle
BFS	Backup Flight System
BFS WHI	Backup Flight System Initial Weight of Helium Load
BLT	Boundary Layer Transition
CCU	Crew Communications Umbilical
CDR	Commander
CDRA	Carbon Dioxide Recycling Assembly
CETA	Crew and Equipment Translation Aid
C/O	Checkout
CO <sub>2</sub>	Carbon Dioxide
COMM	Communications
CPM	Cell Performance Monitor
CQ	Crew Quarter
CSR	Customer Support Report
CTC	Cargo Transport Container
CW	Continue Wave
CWC	Contingency Water Container
D & C	Display and Control
DAP	Digital Autopilot
DAT	Damage Assessment Team
DDU	Data Display Unit
DET	Data Elapsed Time
DOD	Department of Defense
DOLILU	Day of Launch I Load Update
DPS	Data Processing System

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
DRWP	Doppler Radar Wind Profile
DRU	Data Recording Unit
DTA	Debris Transport Analysis
DTO	Development Test Objective
$\Delta V$	Differential Velocity
EAS	Early Ammonia System
ECLSS	Environmental Control and Life Support System
ECO	Engine Cut-off
EDF	Expanding Diameter Fastener
EFGF	Flight Releasable Grapple Fixture
EI	Entry Interface
ELC	Express Logistics Carrier
EMU	Extravehicular Mobility Unit
EPDC	Electrical Power Distribution and Control
ET	External Tank
EV	Extravehicular (Crewmember)
EVA	Extravehicular Activity
EWC	External Wireless Communication
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
FE	Flight Engineer
FGB	Functional Cargo Block
FI	Focused Inspection
FIT	Final Inspection Team
FID	Failure Identifier
FOM	Figure of Merit
FP	Fuel Pump
FRCS	Forward Reaction Control System
FSS	Fixed Service Structure/Flight Support System
FWd MSN	Forward Mission
g/G	Gravity
GCA	Ground Carrier Assembly
GFE	Government Furnished Equipment
GG	Gas Generator
GH <sub>2</sub>	Gaseous Hydrogen

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
GMT	Greenwich Mean Time
GN <sub>2</sub>	Gaseous Nitrogen
GN&C	Guidance Navigation and Control
GO <sub>2</sub> /GOX	Gaseous Oxygen
GPC	General Purpose Computer
GPS	Global Positioning System
GSE	Ground Support Equipment
GUCP	Ground Umbilical Carrier Plate
H <sub>2</sub>	Hydrogen
H <sub>2</sub> O	Water
HCOR	High Rate Communications Outage Recorder
HD	High Definition
HDP	Hold Down Post
HF	High Frequency
Hi-POT	High Potential
HPFTP	High Pressure Fuel Turbo Pump
HPGT	High Pressure Gas Tank
HPOTP	High Pressure Oxidizer Turbopump
HRP	Human Research Program
HTV	H-II Transfer Vehicle
HYD	Hydraulic
Hx	Heat Exchanger
IBA	Integrated Boom Assembly
IDS	Impact Detection System
IFA	In-Flight Anomaly
IFOAM	Italian Epoxy Resin Solid State Foaming
IFE	Ice/Frost Ramp
IMU	Inertial Measurement Unit
IP	International Partner
IPR	Interim Problem Report
ISP	Integrated Stowage Platform
I <sub>SP</sub>	Specific Impulse
ISLE	In-suit Light Exercise
ISS	International Space Station
JSC	Johnson Space Center
KSC	Kennedy Space Center
KFX	K-band File Transfer
L	Launch
LCC	Launch Commit Criteria
LCS	Laser Camera System

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
LDRI	Laser Dynamic Range Imager
LDT	Long Duration Tethers
LEE	Latching End Effector
LESS	Leading Edge Subsystem
LF	Low Frequency
LH	Left Hand
LH <sub>2</sub>	Liquid Hydrogen
LiOH	Lithium Hydroxide
LO <sub>2</sub>	Liquid Oxygen
LOT	Loss of Tracking
LP	Launch Package
LPFTP	Low Pressure Fuel Turbo Pump
LRU	Line Replaceable Unit
MADS	Modular Auxiliary Data System
MAUI	Maui Analysis of Upper Atmospheric Modification
MAX Q	Maximum Dynamic Pressure
MC	Midcourse Correction
MCIU	Manipulator Controller Interface Unit
MECO	Main Engine Cutoff
MEDS	Multifunction Electronics Display System
MET	Mission Elapsed Time
MHA	Multiple Headset Adapter
MISSE	Materials International Space Station Experiment
MIT	Massachusetts Institute of Technology
MLG	Main Landing Gear
MLGD	Main Landing Gear Door
MLI	Multi-Layer Insulation
MLP	Main Launch Platform
MLS	Microwave Landing System
MM	Major Mode
MM/OD	MicroMeteoroid/Orbital Debris
MMT	Mission Management Team
MNB	Main Bus B
MPM	Manipulator Positioning Mechanism
MPS	Main Propulsion System
MS	Mission Specialist
MSS	Mobile Servicing System
MT	Mobile Transporter
MUX	Multiplexer
N <sub>2</sub>	Nitrogen



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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
NASA	National Aeronautics and Space Administration
NAVAID	Navigation Aids
NC	Nominal Correction
NGT	No Greater Than
NH	Nominal Height
NLG	Nose Landing Gear
NPSP	Net Positive Suction Pressure
NSR	Nominal Slow Rate
O <sub>2</sub>	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
OGS	Oxygen Generator System
OI	Operational Instrumentation/Operational Increment (Software)
OIH	On-Orbit Installed Handrails
OME	Orbital Maneuvering Engine
OMRSD	Operational Maintenance and Requirements Specification Document
OMS	Orbital Maneuvering System
OPCU	Orbital Power Converter Unit
OPF	Orbiter Processing Facility
OPO	Orbiter Project Office
OPS	Operations
ORGA	Orbiter Rate Gyro Assembly
ORU	Orbital Replacement Unit
OSE	Orbit Support Equipment
OSH	Off-Scale High
OSL	Off-Scale Low
OV	Orbiter Vehicle
OWP	Orbiter Work Platform
PA	Power Amplifier
PAA	PDGF Adapter Assembly
PAO	Public Affairs Office
PAS	Payload Attach System
PASS	Primary Avionics Software System
PASS WHI	PASS With Initial Helium Load
P <sub>c</sub>	Chamber Pressure

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
PCM	Pulse Code Modulation
PCP	Preplan Contingency Procedure
PCS	Pressure Control System
PDIP	Payload Data Interface Panel
PDGF	Power Data and Grapple Fixture
PDU	Power Drive Unit
PEC	Passive Experiment Containers
PGME	Propylene Glycol Monomethyl Ether
PGSC	Payload General Support Computer
PLB	Payload Bay
PLBD	Payload Bay Door
PMM	Permanent Multipurpose Module
PMBT	Predicted Mean Bulk Temperature
ppm	parts per million
PRCS	Primary Reaction Control System
PRSD	Power Reactant Storage and Distribution System
PRT	Problem Resolution Team
PTU	Power Transfer Unit
PUMMA	PDGF Universal MCF Adapter Assembly
PV&D	Purge, Vent and Drain
PWR	Payload Water Reservoir
PWR	Portable Water Reservoir
QD	Quick Disconnect
RAMBO	Ram Burn Observations
RCC	Reinforced Carbon-Carbon
RCS	Reaction Control System
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

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
R&R	Remove and Replace
RS	Russian Segment
RSB	Rudder Speed Brake
RSRB	Reusable Solid Rocket Booster
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTV	Room Temperature Vulcanizing (material)
S	Starboard
S&A	Safe and Arm
SARJ	Solar Alpha Rotary Joint
SD	Smoke Detector
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
SM	System Management
SMRD	Spin Motor Rotation Detector
S/N	Serial Number
SPDM	Special Purpose Dexterous Manipulator
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulator System
SRSS	Shuttle Range Safety System
SSR	Solid State Recorder
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
SSPTS	Station-to-Shuttle Power Transfer System
SSRMS	Space Station Remote Manipulator System
ST	Star Tracker
SSV	Sequential Still Video
STBD	Starboard
STORMM	Sensor Test for Orion Relative Navigation Risk Mitigation
STP	Space Test Program
STS	Space Transportation System
SSV	Sequential Still Video
SWC	Shuttle Sidewall Carrier
TAEM	Terminal Area Energy Management
T/C	Thermocouple
TCS	Thermal Control System/Trajectory Control Sensor
TDA	Transition to Docking Axis

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### STS-134 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

<b>Acronym/ Abbreviation</b>	<b>Explanation</b>
TEA	Torque Equilibrium Attitude
THC	Translation Hand Controller
TI	Terminal Initiation /Transfer Initiation
TMBU	Table Maintenance Block Update
TPI	Terminal Phase Initiation
TPL	Transfer Priority List
TPS	Thermal Protection System
TSA	Tool Stowage Assembly
TSM	Tail Service Mast
TVC	Thrust Vector Controller
TWT	Travelling Wave Tube
UA	Unexplained Anomaly
UCCAS	Upper Outboard Unpressurized Cargo Carrier Attach System
ULF	Utilization Logistics Flight
UTC	Universal Time Code
VM	Valve Module
VNS	Visual Navigation System
VRCS	Vernier Reaction Control System
VSC	Video Signal Converter
WLE	Wing Leading Edge
WLE IDS	Wing Leading Edge Impact Detection System
WR	Wrist Roll
WSB	Water Spray Boiler
ZOE	Zone of Exclusion

## APPENDIX D

### STS-134 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
hr	hour
In.	inch
keas	knots estimated air speed
kgs	knots ground speed
kW	Kilowatt
kWh	Kilowatt hour
lb	pound
lb <sub>m</sub> /lbm	pound mass
lb/hr	Pound per hour
MHz	Mega Hertz
min	minute
mmHg	Millimeters of Mercury
mph	miles per hour
mv	millivolt
nmi	nautical mile
%	percent
ppm	parts per million
psi	pound per square inch
psia	pound per square inch absolute
scim	Standard cubic inches per minute
sec	second
torr	Unit of pressure (ratio of 760 to one standard atmosphere}
V	Volt
Vdc	Volt direct current