

STS-135 SPACE SHUTTLE MISSION REPORT

September 2011



**National Aeronautics and
Space Administration**

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

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STS-135
SPACE SHUTTLE MISSION REPORT

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STS-135 SPACE SHUTTLE MISSION REPORT

INTRODUCTION

The Space Transportation System (STS) -135 Space Shuttle Mission documents the final Space Shuttle Mission for the Space Shuttle Program (SSP). The final 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 135th mission of the Space Shuttle Program.

The purposes of this mission were as follows:

1. Dock with the International Space Station (ISS);
2. Install the Multi-Purpose Logistics Module (MPLM) to the ISS;
3. Transfer critical cargo items;
4. Return the MPLM to the Shuttle payload bay for return to Earth;
5. Transfer the remaining ascent cargo items and transfer return cargo items to meet minimum MPLM return;
6. Install the failed Pump Module (PM) in the payload bay for return;
7. Transfer oxygen, nitrogen, and water to the ISS;
8. Support Pico-Satellite Solar Cell (PSSC) deployment; and
9. Perform five Station Development Test Objectives (SDTO's).

The STS-135 mission was launched on the 33rd and final SSP mission of the *Atlantis* vehicle, and the 37th and final mission to the ISS. STS-135 was the 22nd mission since the return-to-flight following the STS-107 mission.

The flight vehicle consisted of the OV-104 Orbiter; the ET, which was a Super Lightweight Tank (SLWT), designated ET-138; three Block II SSMEs that were designated as Serial Numbers (S/Ns) 2047, 2060, and 2045 in positions 1, 2 and 3, respectively; and two RSRBs that were designated BI-146. The two RSRMs were designated flight set RSRM-114. The individual RSRMs were S/N 360W114A (left) and S/N 360W114B (right). Launch pad 39A and Mobile Launch Platform (MLP) -3 were used as the platform for launch of the STS-135 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, RSRB, 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. Appendix E is a listing of individuals who supported this final Space Shuttle mission in the Mission Evaluation Room (MER).

The four crewmembers that were on the STS-135 flight were Christopher J. Ferguson, Captain, U.S. Navy (Retired), Commander; Douglas G. Hurley , Colonel, USMC, Pilot; Sandra H. Magnus PhD, NASA, Mission Specialist 1; and Rex Walheim, Colonel (Retired), USAF, Mission Specialist 2.

STS-135 was the third flight for the Commander, the third flight for the Mission Specialist 1 and Mission Specialist 2, and the second flight for the Pilot.

MISSION SUMMARY

Pre-Launch

The objectives of the STS-135 mission include docking with the International Space Station (ISS), installation of the Multi-Purpose Logistics Module (MPLM) and performance of one Extravehicular Activity (EVA).

During prelaunch operations, two lightning strikes occurred near the vehicle. One strike hit the water tower and the second hit occurred on a nearby beach. After a review of Orbiter telemetry and Modular Auxiliary Data System (MADS) data for both strikes, no impacts to the vehicle were identified. The Ultra-High Frequency (UHF) communications system was active at the time of the strikes. The UHF system did respond to the electrical energy during the strike timeframe and the system did recover, which is typical of an Amplitude Modulation (AM) receiver.

Flight Day 1

The launch countdown was stopped at T-31 sec by the automatic system. There was a 2 min 18 sec hold in the countdown when a computer reported the Gaseous Oxygen (GOX) vent arm was not fully retracted. A camera was used to verify that the arm was fully retracted and the launch countdown resumed.

The STS-135 mission was launched at 189/15:29:03.996 Greenwich Mean Time (GMT) on July 8, 2011, on the thirty-third and final Space Shuttle Program (SSP) mission of the Atlantis vehicle and the thirty-seventh and final mission to the ISS.

The Backup Flight System (BFS) quantities in the left Reaction Control System (RCS) fuel and oxidizer tanks were erratic during ascent. This signature has been seen on previous missions. The measurement returned to a nominal condition and did not impact ascent operations.

The Reusable Solid Rocket Booster (RSRB) separation was visible. A nominal Orbital Maneuvering System (OMS) assist maneuver was performed following RSRB separation. Ignition occurred at 189/15:31:17 GMT [00/00:02:13 Mission Elapsed Time (MET)], and the maneuver was 83.2 sec in duration.

Main Engine Cutoff (MECO) occurred at 189/15:37:28 GMT (00/00:08:24 MET). The External Tank (ET) separated from the Orbiter at 189/15:37:49 GMT (00/00:08:45 MET).

A nominal OMS-2 maneuver was performed at 189/16:06:49.1 GMT (00/00:37:45 MET). The maneuver was 64.4 sec in duration and the Differential Velocity (ΔV) was 97.0 ft/sec. The resulting orbit was 85.2 by 123.9 nautical miles (nmi).

The payload bay doors were opened at 189/17:03:20 GMT (00/01:34:16 MET). The Ku-Band antenna was deployed and the self-test was completed with satisfactory results.

The Shuttle Remote Manipulator System (SRMS) on-orbit initialization was completed at 189/18:28 GMT (00/02:59 MET) and the power-up was completed at 189/22:06 GMT (00/06:37 MET). The SRMS checkout was completed at 189/22:58 GMT (00/07:29 MET). The SRMS was returned to the Pre-cradle position at 189/23:06 GMT (00/07:37 MET). No anomalies were noted during any of the SRMS activities.

The Nominal Correction (NC) 1 OMS-3 maneuver was performed at 189/19:08:38.0 GMT (00/3:39:34 MET) with the cutoff 94.1 sec later at 189/19:10:12.1 GMT (00/3:41:08 MET). The maneuver was a dual OMS engine, straight-feed firing with a ΔV of 144.6 ft/sec. The resulting orbit was 120.9 by 168.7 nmi, and the engine performance was nominal.

Flight Day 2

The main activities for Flight Day (FD) 2 included the Orbiter Boom Sensor System (OBSS) unberthing, the survey of the Thermal Protection System (TPS), the Orbiter Docking System (ODS) ring extension and the rendezvous tools checkout.

The NC2 OMS-4 maneuver was a right-engine firing that occurred at 190/10:18:07 GMT (00/18:49:03 MET) with the engine cutoff 11.0 sec later at 190/10:18:18 GMT (00/18:49:14 MET). The resulting ΔV was 8.3 ft/sec and the resulting orbit was 121.2 by 172.8 nmi. Engine performance was nominal.

The OBSS was unberthed by the SRMS at 190/11:05 GMT (00/19:35 MET).

During the setup for the TPS surveys, the crew reported an issue with the in-cabin cable between the Laser Camera Computer (LCC) and the Orbiter Patch Panel (OPP) (IFA STS-135-V-06). The crew reported that moving the cable caused communications between the LCC and the LCS to drop out. The crew secured the cable and operations continued. A spare cable is available in the event that the condition of the original cable worsens.

The Starboard Reinforced Carbon-Carbon (RCC) survey of the TPS began at 190/12:21 GMT (00/20:52 MET) and was completed at 190/13:31:10 GMT (00/22:02 MET). The Nose cap survey began at 190/13:53 GMT (00/22:24 MET) and was completed at 190/14:24 GMT (00/22:55 MET). The Port survey began at 190/14:28 GMT (00/22:59 MET) and was completed at 190/16:09 GMT (01/00:40 MET).

The ODS was powered on at 190/18:57:06 GMT (01/03:28:02 MET). The ring extension was completed in 3 min 38 sec at 190/19:00:44 GMT (01/03:31:40 MET). The power was on the ODS for 7 min 02 sec and the ODS performed nominally.

The NC3 maneuver was a +X RCS firing that occurred at 190/19:47:01 GMT (01/04:17:57 MET). The firing duration was 5.6 sec with a ΔV of 1.3 ft/sec. The resulting orbit was 121.7 by 173.5 nmi.

Wing Leading Edge Impact Detection System (WLEIDS) sensor 1080 failed to respond correctly to multiple programming and diagnostic commands when preparing for Port Wing Group 1 Micrometeoroid/Orbital Debris (MM/OD) monitoring during the NC3 maneuver (IFA STS-135-V-01). Further attempts to recover communications with the sensor were ultimately successful.

All imagery from the FD 2 surveys was down-linked. The RCC and TPS Damage Assessment Teams (DATs) were reviewing the imagery.

Flight Day 3

The main activities on FD 3 included rendezvous and docking with the ISS, and OBSS Handoff.

A simultaneous supply and waste-water dump was started at 191/08:03:04 GMT (01/16:34:00 MET) and completed at 191/08:37:30 GMT (01/17:08:26 MET). A total of 137.5 lb of supply water and 55 lb of waste-water were dumped.

When activating General Purpose Computer (GPC) 3 during the Group-B power-up prior to rendezvous, GPC 3 joined the common set then subsequently went to Halt. GPC 3 was used for the rendezvous. An Initial Program Load (IPL) was reloaded to regain GPC 3.

The crew switched the Ku-Band System to Communications (COMM) mode at 191/09:46:16 GMT (01/18:17:12 MET) and the system operated nominally. The crew switched the system to RADAR mode for rendezvous at 191/11:44:48 GMT (01/20:15:44 MET) and detected the ISS at a range of 144,000 ft. The Ku-Band RADAR mode operated as expected.

The Nominal Height (NH) OMS-5 maneuver, a dual-engine firing, was completed satisfactorily. Ignition occurred at 191/10:08:06 GMT (01/18:39:02 MET). The firing duration was 38.3 sec with a ΔV of 60.0 ft/sec. The resulting orbit was 122.5 by 207.4 nmi.

The NC4 OMS-6 maneuver, a dual-engine firing, was completed satisfactorily. Ignition occurred at 191/10:55:27 GMT (01/19:26:23 MET). The firing duration was 89.8 sec with a ΔV of 143.7 ft/sec. The resulting orbit was 203.2 by 207.9 nmi.

The OMS-7 Terminal Initiation (TI) maneuver was completed using the left engine. Ignition occurred at 191/12:29:04 GMT (01/21:00:00 MET). The duration of the maneuver was 8.5 sec with a ΔV of 9.0 ft/sec, and the Orbiter was placed into a 206.8 by 210.6 nmi orbit. Engine performance was nominal.

The Midcourse Correction (MC) 1 maneuver was an +X RCS firing using two thrusters. Ignition occurred at 191/12:49:04 GMT (01/21:20:01 MET). The ΔV delivered was 0.24 ft/sec and the resulting orbit was 206.3 by 210.2 nmi. The MC2 maneuver was a multi-axis RCS firing using 11 primary thrusters. Ignition occurred at 191/13:21:54 GMT (01/21:52:51 MET). The ΔV delivered was 0.8 ft/sec and the resulting orbit was 206.3 by 210.3 nmi. The Out-of Plane null maneuver was not required. MC3 maneuver was a multi-axis RCS firing using seven primary thrusters. Ignition was at 191/13:38:54 GMT (01/22:09:51 MET) and the ΔV delivered was 0.8 ft/sec. The MC4 maneuver was a multi-axis RCS firing using nine primary thrusters. The ignition occurred at 191/13:48:54 GMT (01/22:19:51 MET). The ΔV delivered was 1.6 ft/sec and the resulting orbit was 207.2 by 212 nmi.

The Rendezvous Pitch Maneuver (RPM) began at 191/14:05:20 GMT (01/22:36:16 MET) and was completed satisfactorily.

The crew returned the Ku-Band to COMM mode at 191/14:49:40 GMT (01/23:20:36 MET) at a range of 197 ft.

The ODS was powered on at 191/14:35:46 GMT (01/22:36:17 MET). Atlantis made initial contact with the ISS at 191/15:07:15 GMT (01/23:38:12 MET). The hook-drive command was initiated at 191/15:15:47 GMT (01/23:46:44 MET). The hard-mate was completed at 191/15:18:08 GMT (01/23:49:05 MET), and the ODS was powered off at 191/15:19:39 GMT (01/23:50:36 MET).

The hatch was opened at 191/16:34 GMT (02/01:04:57 MET).

The OBSS was grappled and unberthed by the Space Station Remote Manipulator System (SSRMS) following release of the starboard Manipulator Release Latches (MRLs) at 191/19:17 GMT (02/03:48 MET). The OBSS was maneuvered to the OBSS Handoff position where it was grappled by the SRMS at 191/19:42 (02/04:13 MET). The SRMS was then moved to the MPLM Viewing position.

The crew filled and transferred one Contingency Water Container (CWC). CWC no. 1 was filled with 93 lb of water at 191/19:26:19 GMT (02/03:57:15 MET).

After docking, the Orbiter had issues synchronizing data with the ISS through the Orbiter Interface Unit (OIU). The ground exchanged the data bus being used to transfer data from the ISS and this resolved the issue.

The WLEIDS sensor 1111 prematurely dropped out of the On-Orbit Monitoring (OOM) mode twice (IFA STS-135-V-03). All attempts to reset and reprogram the unit were unsuccessful. No further attempts will be made to recover the unit.

The RCC Damage Assessment Team (DAT) completed their review of the FD 2 imagery and recommended clearing the RCC, which the Mission Management Team (MMT) accepted. The Orbiter Project Office (OPO) accepted the TPS DAT

recommendation that no Focused Inspection (FI) would be required. The DAT team did identify five Regions of Interest (ROI) that pre-existing tile and blanket damage criteria (IFA STS-135-V-02); however, these ROI's were not an impact to the flight and no FI was necessary.

Flight Day 4

The main activities for FD 4 will include the installation and ingress of the MPLM.

Prior to unberthing the MPLM by the SSRMS at 192/09:37:39 GMT (02/18:08:35 MET), the Payload Retention Latch Assembly (PRLA) System-A microswitch did not indicate OPEN (IFA STS-135-V-04) during PRLA unlatch. The PRLA System-B microswitch did indicate OPEN and the System-A motor ran for single-motor time, which provided confidence that the latch was indeed open.

GPC 3 was successfully recovered after reloading the IPL.

The crew filled and transferred three CWCs. CWC no. 2 was filled with 94 lb of water at 192/10:10:37 GMT (02/18:41:33 MET). CWC no. 3 was filled with 94 lb of water at 192/11:34:01 GMT (02/20:04:57 MET). CWC no. 4 was filled with 97 lb of water at 192/13:30:04 GMT (02/22:01:00 MET).

The crew ingressed the MPLM at 192/16:26 GMT (03/00:57 MET).

The DAT presented a status of the tile and blanket imagery analysis to the MMT in support of the recommendation that a Focused Inspection was not required. The MMT subsequently accepted that recommendation.

The MMT also made the decision to add a day to the mission making the mission duration now 13+0+2 days.

Flight Day 5

The main activity for FD 5 was the one, and only, planned EVA.

The crew filled and transferred CWC no. 5 with 93.9 lb of water at 193/11:52 GMT (03/20:23 MET).

The EVA began with the hatch opening at 193/13:21:44 GMT (03/21:52:40 MET). The planned EVA activities, which were completed, included installing the Contingency Operations Large Adapter Plate Assembly (LAPA) Tool (COLTS), removing the Pump Module (PM) from the External Stowage Platform (ESP) 2 and installing the PM on the Lightweight Multi-Purpose Experiment Support Structure (MPESS) Carrier (LMC), installing the Robotics Refueling Mission (RRM) on the Enhanced ORU Temporary Platform (EOTP), and installing the Materials International Space Station Experiment (MISSE) Optical Reflector Materials Experiment (ORMatE). The get-ahead tasks

completed were the Pressurized Mating Adapter (PMA) 3 cover installation, clearing of the Functional Cargo Block (FGB) Power and Data Grapple Fixture (PDGF) grounding wire, installation of a gap-spanner on Laboratory nadir handrails, and retrieval of the Large Cutter from the Airlock (A/L) Tool Box. The hatch was closed at 193/20:05:42 GMT (04/04:36:38 MET). The duration of the EVA was 6 hr 31 min.

The Nitrogen (N₂) repressurization was initiated at 193/15:37 GMT (04/04:36:38 MET) and terminated at 193/18:29:39 GMT (04/03:00:35 MET). A total of 26.7 lb of N₂ was transferred.

Both Inertial Measurement Units (IMUs) were aligned, and drift compensations were uplinked. The largest drift compensation was one-half sigma for the Z axis on IMU 3.

Flight Day 6

The main activities on FD 6 were Middeck and MPLM transfer, and a Public Affairs Office (PAO) event.

The crew began filling CWC no. 6 at 194/08:59:58 GMT (04/17:30:54 MET) and terminated at 194/10:37:48 GMT (04/19:08:44 MET) with 96.2 lb of water transferred to the ISS.

A N₂ repressurization was initiated at 194/14:20:47 GMT (04/22:51:43 MET) and terminated at 194/18:10:44 GMT (05/02:41:40 MET). A total of 29 lb of N₂ was transferred.

Flight Day 7

The main activities for FD 7 were the Removal and Replacement (R&R) of the Treadmill with Vibration Isolation and Stabilization (TVIS) Gyro, MPLM transfer, PAO Events and crew off duty.

The crew filled and transferred two CWCs. CWC no. 7 was started at 195/08:48:56 GMT (05/17:19:52 MET) and terminated at 195/09:42:41 GMT (05/18:13:37 MET) with 94.2 lb of water. CWC no. 8 started at 195/09:51:42 GMT (05/18:22:38 MET) and terminated at 195/10:45:36 GMT (05/19:16:32 MET) with 93.2 lb of water.

A N₂ repressurization was initiated at 195/08:56:41 GMT (05/17:27:37 MET) and terminated at 195/12:17:44 GMT (05/20:48:40 MET). A total of approximately 33 lb of N₂ was transferred.

At 195/22:07:18 GMT (06/06:38:14 MET), the crew was awakened by a Master Alarm that was annunciated by a GPC 4 failure (IFA STS-135-V-08). GPC 4 was assigned as the Primary Avionics Software System (PASS) Systems Management (SM) GPC at the time of the failure. The crew was asked to re-assign GPC 2 as the PASS SM GPC which returned the Data Processing System (DPS) to a stable configuration.

Flight Day 8

The main activities for FD 8 were MPLM transfer, data downloads from GPCs 1 and 4, and IPL reload of GPC 4.

A N₂ repressurization was initiated at 196/07:42:02 GMT (06/16:12:58 MET) and terminated at 196/10:30:04 GMT (06/19:01:00 MET). A total of approximately 20 lb of N₂ was transferred.

The crew filled and transferred three CWCs. CWC no. 9 was started at 196/07:45 GMT (06/16:16 MET) and terminated at 196/08:36 GMT (06/17:07 MET) with 95.3 lb of water. CWC no. 10 was started at 196/09:00 GMT (06/17:31 MET) and terminated at 196/09:54 GMT (06/18:25 MET) with 97.1 lb of water. CWC no. 11 was started at 196/14:54 GMT (06/23:25 MET) and terminated at 196/15:46 GMT (07/00:17 MET) with 93.7 lb of water.

Data downloads from GPCs 1 and 4 were performed to allow ground analysis of the GPC failure that occurred during crew sleep. GPC 4 was recovered after an IPL reload. GPC 4 was subsequently put into the “freeze-dry” state.

The crew reported that one of the latches of the Atmospheric Revitalization System (ARS) Lithium Hydroxide (LiOH) Service Door would not release when the pinch tabs were pressed (IFA STS-135-V-05). The effect of this failure was that the LiOH canisters could not be changed out. An In-Flight Maintenance (IFM) procedure was developed to open the door. The procedure was uplinked for the crew to perform on FD 9.

Flight Day 9

The main activities on FD 9 were the MPLM transfer and the ARS LiOH Service Door IFM.

The crew performed the IFM to open the ARS LiOH Service Door and the door was successfully opened. The crew reported that one of the latches had become completely unthreaded from the rod on the aft-most release. The crew removed that latch and spring. The door was operational using the remaining pull latch.

A N₂ repressurization was initiated at 197/09:59 GMT (07/18:30 MET) and terminated at 197/12:30 GMT (07/21:01 MET). A total of approximately 19 lb of N₂ was transferred.

The crew filled and transferred three CWCs. CWC no. 12 was started at 197/10:00 GMT (07/18:31 MET) and terminated at 197/10:51 GMT (07/19:22 MET) with 93.7 lb of water. CWC no. 13 was started at 197/10:52 GMT (07/19:23 MET) and terminated at 197/11:45 GMT (07/20:16 MET) with 94.6 lb of water. CWC no. 14 was started at 197/12:15 GMT (07/20:46 MET) and terminated at 197/13:09 GMT (07/21:40 MET) with 93.3 lb of water.

GPC 4 was added to the Guidance Navigation and Control (GN&C) redundant set to give the GPC some run time. It operated nominally for several hours after which it was returned to the “freeze-dry” state. Analysis of the data downloaded from GPCs 1 and 4 was completed. While the data was insufficient to definitively isolate the root cause of the GPC 4 issue, evidence was consistent with a transient failure condition.

Flight Day 10

The main activities on FD 10 were MPLM transfer, a PAO event and crew off-duty.

An Oxygen (O₂) repressurization was initiated at 198/05:20 GMT (08/13:51 MET) and terminated at 198/06:13 GMT (08/14:44 MET). A total of approximately 16 lb of O₂ was transferred.

The crew filled and transferred five Payload Water Reservoirs (PWRs). PWR no. 1 was started at 198/05:23 GMT (08/13:54 MET) and terminated at 198/05:43 GMT (08/14:14 MET) with 20.1 lb of water. PWR no. 2 was started at 198/05:49 GMT (08/14:20 MET) and was terminated during a Loss Of Signal (LOS) with 17.9 lb of water. PWR no. 3 was started at 198/06:27 GMT (08/14:58 MET) and terminated at 198/06:48 GMT (08/15:19 MET) with 19.9 lb of water. PWR no. 4 was started at 198/06:49 GMT (08/15:20 MET) and terminated at 198/07:15 GMT (08/15:46 MET) with 19.9 lb of water. PWR no. 5 was started at 198/07:16 GMT (08/15:47 MET) and terminated at 198/07:30 GMT (08/16:01 MET) with 14.2 lb of water.

The crew filled and transferred one CWC-Iodine-treated (CWC-I) water container. The filling of the CWC-I no. 1 was started at 198/12:25 GMT (08/20:56 MET) and terminated at 198/12:26 GMT (08/20:57 MET) with 36 lb of water.

GPC 4 was reassigned as the SM GPC to return the GPC's to the standard flight configuration.

Flight Day 11

The main activities on FD 11 were the MPLM uninstall and return to the payload bay, the hatch closure and the Rendezvous Tools Checkout.

The crew filled and transferred five CWC-I's. CWC-I no. 2 was started at 199/05:23 GMT (09/13:54 MET) and terminated at 199/05:33 GMT (09/14:04 MET) with 36.4 lb of water. CWC no. 3 was started at 199/05:37 GMT (09/14:08 MET) and terminated at 199/05:48 GMT (09/14:19 MET) with 37.4 lb of water. CWC no. 4 was started at 199/05:52 GMT (09/14:23 MET) and terminated at 199/06:03 GMT (09/14:34 MET) with 38.3 lb of water. CWC no. 5 was started at 199/07:25 GMT (09/15:56 MET) and terminated at 199/07:36 GMT (09/16:07 MET) with 38.3 lb of water. CWC no. 6 was started at 199/07:44 GMT (09/16:15 MET) and terminated at 199/07:56 GMT (09/16:27 MET) with 40.1 lb of water.

An O₂ repressurization was initiated at 199/05:28 GMT (09/13:59 MET) and terminated at 199/06:20 GMT (09/14:51 MET). A total of approximately 14 lb of O₂ was transferred.

The MPLM uninstall from the ISS and return to the payload bay with the SSRMS was completed at 199/11:48:29 GMT (09/20:19:25 MET).

The hatch between the ISS and the Orbiter was closed at approximately 199/13:59 GMT (09/22:30 MET) and the vestibule was leak-checked successfully.

The OBSS was maneuvered to the Undock position at 199/14:39 GMT (09/23:10 MET).

Rendezvous Tools Checkout was nominal.

Flight Day 12

The main activities on FD 12 were the undocking, the flyaround and the late inspection RCC surveys.

The Orbiter resumed attitude control with the Digital Autopilot (DAP) in the automatic-mode at 200/04:56:30 GMT (10/13:27:56 MET) and the maneuver to the undocking attitude was initiated at 200/04:57:29 GMT (10/13:28:25 MET). The maneuver was completed satisfactorily in approximately 33 min. The DAP was commanded to Free Drift at 200/06:25:04 GMT (10/14:56:00 MET) for the undocking.

The command to undock from the ISS was initiated at 200/06:25:45 GMT (10/14:56:41 MET). The total drive time was approximately 2 min and 15 sec. Hook Groups 1 and 2 operated nominally. The ODS performed nominally for undocking. Physical separation occurred at 200/06:27:57 GMT (10/14:58:53 MET).

The fly-around the ISS was initiated with RCS +X pulse of the L1A and R1A thrusters at 200/07:27:40 GMT (10/15:58:36 MET).

Prior to the separation 1 maneuver, the Ku-Band was taken to the RADAR mode at 200/07:44:13 GMT (10/16:15:09 MET) and locked on to the ISS at an approximate range of 558 ft. The Ku-Band was configured back to the Communications (COMM) mode at 200/08:15:27 GMT (10/16:46:23 MET) at a range of approximately 4535 ft.

The separation 1 maneuver was initiated with RCS +X pulse for 6.32 sec using thrusters L1A and R1A at 200/07:50:32.68 GMT (10/16:21:29 MET). The separation 2 maneuver was performed at 200/08:18:43.3 GMT (10/16:49:39 MET). This was a 42.72 sec RCS -X maneuver using thrusters F2F and F3F.

A simultaneous supply-water and waste-water dump was started at 200/09:03:17 GMT (10/17:34:13 MET) and completed at 200/09:53 GMT (10/18:24 MET). A total of 134.8 lb of supply water and 108 lb of waste water were dumped.

The starboard RCC survey began at 200/10:49 GMT (10/19:20 MET) and was completed at 200/11:55 GMT (10/20:26 MET). The nose-cap survey was initiated at 200/12:28 GMT (10/20:59 MET) and was completed at 200/12:58 GMT (10/21:29 MET). The port RCC survey was initiated at 200/13:21 GMT (10/21:52 MET) and was completed at 200/14:16 GMT (10/22:47 MET).

The OBSS was returned to the starboard Manipulator Positioning Mechanisms (MPMs) and latched down at 200/14:48 GMT (10/23:19 MET). The SRMS was cradled, latched and powered down at 200/15:16 GMT (10/23:47 MET).

All imagery from the surveys was downlinked. The RCC Damage Assessment Team (DAT) began their review of the imagery.

Flight Day 13

The main activities on FD 13 were the Flight Control System (FCS) checkout, the RCS Hotfire, the deployment of the Pico-Satellite Solar Cell (PSSC) experiment, PAO event and cabin stow.

The separation 3 maneuver was initiated with a RCS +X pulse for 25.9 sec using thrusters L1A and R1A at 201/05:04:06.2 GMT (11/13:35:02 MET).

The FCS checkout was initiated at 201/05:07:13 GMT (11/13:38:09 MET). Auxiliary Power Unit (APU) 1 was started at 201/05:16:36 GMT (11/13:47:32 MET) and ran for 4 min 26 sec, and used 14 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 RCS hot-fire procedure was initiated at 201/06:04:25 GMT (11/14:35:21 MET) and terminated at 201/06:12:53 GMT (11/14:43:49 MET). All 38 RCS thrusters were fired at least once. The hot-fire was completed nominally and no anomalies were observed.

The PSSC experiment was deployed at 201/07:49:04 GMT (11/16:20:00 MET) and was the 180th successful payload deployment from a Shuttle payload bay.

The port MPMs were stowed at 201/08:05 GMT (11/16:36 MET). The starboard MPMs were stowed at 201/08:07 GMT (11/16:38 MET).

The Ku-band antenna was stowed nominally using dual-motors at 201/15:32:34 GMT (12/00:03:30 MET).

The RCC DAT completed analysis of the imagery and the DAT recommend to the MMT that the RCC be cleared for entry, which the MMT accepted.

Flight Day 14

The main activity for FD 14 was deorbit preparation, the deorbit maneuver, entry and landing at Kennedy Space Center (KSC), Florida.

Both Payload Bay Doors (PLBDs) were closed nominally by 202/06:16:35 GMT (12/14:47:31 MET) in preparation for landing.

The deorbit maneuver for the first landing opportunity at KSC, a dual-engine straight-feed firing, was performed on orbit 200 at 202/08:49:04.2 GMT (12/17:20:00 MET). The maneuver was 198.2 sec in duration with a ΔV of 333.1 ft/sec. The orbit after the deorbit maneuver was 25.5 by 209.6 nmi.

Entry interface occurred at 202/09:25:13 GMT (12/17:56:09 MET).

The main landing gear touchdown occurred on KSC runway 15 at 202/09:56:58 GMT (12/18:27:54 MET). The drag chute was deployed at 202/09:57:03.6 GMT. The nose gear touchdown occurred at 202/09:57:12 GMT. Drag chute jettison occurred at 202/09:57:35 GMT. Wheels stop occurred at 202/09:57:53 GMT. The rollout was normal in all respects.

The last APU was shut down at 202/10:18:01.505 GMT.

The STS-135 mission was successfully completed on July 21, 2011, and the flight duration was 12 days 18 hr 27 min 04 sec.

Post-Landing Activities

During the post-landing operations, the Left RCS Oxidizer Manifold 5 Valve failed (IFA STS-135-V-07). When the Left Manifold 5 Oxidizer Isolation valve was cycled to open, the open-indication came on while the closed indication also remained on. Following coordination with the Johnson Space Center (JSC) personnel, the decision was made to have the crew cycle the valve panel switch again in an attempt to clear the anomaly; however, the cycling was not successful. Nearly an hour later, the anomalous closed indication cleared.

During the post-landing inspection and evaluation on the runway, the nose-cap expansion seal on the Right-Hand (RH) side was noted to have SiC damage (IFA STS-135-V-09). The damage was due to the mechanical-loading induced by a minimum-gap condition, and was similar to the damage noted on the Left-Hand (LH) side post during the STS-115 inspection of the OV-104 vehicle.

HISTORY OF SPACE SHUTTLE ATLANTIS

The choice of the name *Atlantis* carries on a tradition drawn from many historic Earth-bound exploring ships of the past. *Atlantis* was named after the primary research vessel from 1930 to 1966 for the Woods Hole Oceanographic Institute in Massachusetts. The two-masted, 460-ton ketch was the first U.S. vessel to be used for oceanographic research. Such research was considered to be one of the last bastions of the sailing vessel as steam-and-diesel-powered vessels dominated the waterways. The ship had a 17-member crew and accommodated up to five scientists who worked in two onboard laboratories, examining water samples and marine life.

The Space Shuttle *Atlantis* was the fourth orbital vehicle manufactured following the *Columbia*, *Challenger*, and *Discovery*. Construction of *Atlantis*, referenced internally by its airframe number OV-104, began in March 1980 at the Palmdale, CA. manufacturing plant. It was transported to Kennedy Space Center in March 1985 where the *Atlantis* was prepared for its maiden voyage on the STS-51J mission, which was a dedicated Department of Defense Mission that was launched on October 3, 1985.

The Space Shuttle *Atlantis* served as a symbol of American pride and leadership in human space flight. *Atlantis* served as the in-orbit launch site for many noteworthy spacecraft, including the planetary probes Magellan and Galileo, as well as the Compton Gamma Ray Observatory. Starting with STS-71, *Atlantis* pioneered the Shuttle-*Mir* missions to dock with the Russian space station. When linked, *Atlantis* and *Mir* together formed the largest spacecraft in orbit at the time.

The Space Shuttle *Atlantis* finished its career with the distinction of being the last Space Shuttle to visit the ISS. *Atlantis* accumulated 307 days during its 33 missions and completed 4848 orbits travelling a total of 125,935,769 statute miles. *Atlantis* docked seven times with the Russian *Mir* space station and 12 times with the ISS.

On April 12, 2011, it was announced that *Atlantis* would be put on display at the Kennedy Space Center Visitor Complex in Florida.

PAYLOADS AND EXPERIMENTS

MISSION OVERVIEW

The primary purpose of the mission was to deliver to the International Space Station (ISS) utilization and logistics supplies stowed within the middeck and the Multipurpose Logistics Module (MPLM) 'Raffaello'. Also, the ISS spent utilization and logistics supplies were returned in the middeck and the MPLM 'Raffaello'. In addition, the second major objectives of the mission were to return the failed External Thermal Control System (ETCS) Pump Module (PM) on the Lightweight Multipurpose Experiment Support Structure Carrier (LMC), and to launch of the Robotics Refueling Mission (RRM) payload on the LMC.

The pre-planned mission duration was for a 12 + 0 day mission. On Flight Day (FD) 4, July 11, 2011, the Mission Management Team (MMT) approved the International Space Station Program (ISSP) MMT's request to extend the mission one day, because of the adequate margin in available consumables, to a 13+0 day mission duration with 9 docked days. The additional day was used to accommodate several get-ahead tasks and logistics transfer activities.

CREW ACTIVITY SUMMARY

The Orbiter docking to the ISS was completed at 10:09 Central Daylight Time (CDT) [01/23:38:12 Mission Elapsed Time (MET)]. The hatch was opened at approximately 02/01:04:57 MET, and transfer activities were started after the crew welcome and safety briefings were completed.

The DTO-701A TriDAR payload was activated and collected data during the rendezvous operations on FD 3.

The MPLM was unberthed on FD 4 from the Shuttle Payload Bay and installed on the ISS Node 2 nadir using the SSRMS. After a successful pressurization and leak check of the Node 2-to-MPLM vestibule, the crew removed the Multi-Layered Insulation (MLI) thermal cover and installed the power-and-data jumper. The MPLM was configured for ingress by equalizing the pressure and installing the Inter-Module Ventilation (IMV) ducts. The IMV valves were opened, the Positive Pressure Relief Assembly (PPRA) valves were closed and the lights were powered. The crew ingressed the MPLM at 03/00:57 MET.

Equipment lock preparations were completed and the Extravehicular Activity (EVA) tool configuration was verified. The ISS Waste and Hygiene Compartment (WHC) Urine Receptacle (Urine Hose) and Insert Filter were removed and replaced. A functional test was performed and the WHC was successfully activated.

The only EVA was successfully completed on FD 5 in 6 hr, 31 min. This was the first EVA performed by ISS crewmembers during a Shuttle docked mission. The 'In-Suit Light Exercise' (ISLE) pre-breathe protocol was used in preparation for the EVA. Planned tasks as well as get-ahead tasks were completed.

The SSRMS was operated in support of the EVA. After installing an Articulating Portable Foot Restraint (APFR) on the arm's Latching End Effector (LEE), Extravehicular (EV) crewmember 2 boarded the arm to transfer the failed ETCS PM from External Stowage Platform (ESP) -2 to the LMC in the Shuttle payload bay. Following a EV crewmember exchange on the SSRMS APFR, the EV 1 crewmember transferred the Robotic Refueling Mission (RRM) from the LMC to the Special Purpose Dexterous Manipulator (SPDM) Enhanced On-orbit Replacement Units (ORU) Temporary Platform (EOTP) installed on the U.S. Laboratory module. After EV1 egressed from the arm and the APFR was removed, the SSRMS was maneuvered to its park position.

The planned EVA tasks completed are shown in the ISS MISSION PRIORITIES COMPLETION STATUS table later in this section.

The IVA crews began the first of multiple days of cargo transfer between the MPLM and ISS, including transferring the Zero-G Stowage Rack to the Permanent Multipurpose Module (PMM).

Logistics transfer between the MPLM and ISS began on FD 6 as well as the troubleshooting of the Laboratory Major Constituent Analyzer (MCA). Also, Remove and Replace (R&R) activities associated with the Waste and Hygiene Compartment, and the stowage reconfiguration in the PMA 3. The crew was able to restart the Elektron that produces air for the Russian Segment (RS) after it shut down the previous day. The European Drawer Rack (EDR) Protein Crystallization Diagnostics Facility (PCDF) electronic unit was removed from the EDR Rack and pre-packed for return in the MPLM.

The stowage reconfiguration of the PMA 3 included removing the IRED and its base-plate from PMA 3 for return in the Utilization and Logistics Flight (ULF) 7 Multi-Purpose Logistics Module (MPLM). The IRED functionality was replaced on orbit by the Advanced Resistive Exercise Device (ARED), and the IRED had been kept on board as a spare. The removal of this hardware from PMA 3 allowed the Bearing Motor Roll Ring Module (BMRRM), the Electronics Control Unit, Interface Heat Exchanger, and the spare Rotary Joint Motor Controller (RJMC) to be stored inside the PMA 3. While inside the PMA 3, the crew did not observe any evidence of condensation or microbial growth. In addition, the Node 3 (N3) Port Center Disk Cover was installed. The N3 Port Hatch Seal was inspected prior to reclosing the hatch and replacing the stowage in front of the N3 hatch. PMA 3 was last ingressed in March of 2010.

The crew performed standard post-EVA maintenance on FD 7, such as ionic and particulate filtration (scrubbing) and biocides maintenance (iodination) of the Extravehicular Mobility Unit (EMU) and Airlock cooling water loops for the EMUs that were used in FD 5 EVA.

Cleaning of the Node 2 (N2) Starboard Crew Quarters (CQ) exhaust inlet and fan cleaning was completed, as well as the exhaust septum area. Photographs of the areas were downlinked for analysis.

The EMU checkout and resizing was performed on FD 8, which included photographic documentation of the two EMUs used during the FD 5 EVA to record clocking of the upper-arm segment relative to lower-arm segment as well as wire harness routing. This was to rule out any potential EMU mobility issues due to improper clocking and/or wire harness routing on either EMU arm.

Six liters of Water Processing Assembly (WPA) water was transferred from the Potable Water Bus (PWB) into a Payload Water Reservoir (PWR). For Post-Shuttle retirement, it is desirable to use WPA water for the EMU cooling system; otherwise approximately 112 lb of water will have to be delivered by unmanned vehicles and stored on the ISS each year to support eight EVAs per year.

The ARED Pacebook was removed and replaced in an attempt to recover the display, which failed in early June. The replacement was initially unsuccessful in recovering the display but as troubleshooting steps were being performed, the Pacebook display was successfully recovered.

In addition to other PAO events on FD 8, the ISS and Shuttle crewmembers participated in a Very Important Person (VIP) event with President Obama. The President congratulated the crewmembers on mission accomplishments thus far. Other topics included 'Atlantis' last flight, supplies brought to the ISS on the MPLM, current research onboard ISS, and NASA's plans for the future.

On FD 9, Middeck and MPLM transfer operations continued. The required U.S. EVA hardware was gathered to support Russian Segment (RS) EVA 29, which was scheduled for August 3. Crewmembers also created an on-orbit extension of the Rechargeable EVA Battery Assembly (REBA) pull tab for use on the Orlan suits.

The main activities during FD 10 were middeck transfer operations, final MPLM transfer operations and the General Active Cryogenic ISS Experiment Refrigerator (GLACIER) exchange.

The General Luminaire Assemblies (GLAs) were removed from the MPLM for ISS resupply and the Node 2 Controller Panel Assemblies (CPAs) were installed to support preparations for MPLM demate, which was scheduled for FD 11.

Following completion of assembly and checkout activities and a determination that the TVIS motor current was within nominal ranges, ISS crewmembers were given a Go for nominal use of the TVIS treadmill located in the Service Module.

Two Double Coldbag (DCBs) were packed with samples and ice bricks from the Minus Eighty Degree Celsius Laboratory Freezer for ISS (MELFI) for return on the Shuttle. The MPLM "Raffaello" was configured for final closeout and unberthing. Following egress of the MPLM, the N2 nadir hatch was closed at approximately 09/22:30 MET, followed by vestibule depressurization and a 30-min leak check. The SSRMS grappled and demated the MPLM from the Node 2 Nadir Common Berthing Mechanism (CBM) and successfully transferred and berthed the MPLM in the Shuttle payload bay for the last time. The SSRMS was then maneuvered to the stage-park position, ready for 'Atlantis' undocking.

The ISS crew bid farewell to the Shuttle 'Atlantis' crew and thanked them for their work on the MPLM. There were many tributes from all the crewmembers to the Space Shuttle Program for the outstanding work in the assembly of ISS. A small US flag, that was flown on STS-1, was mounted on the PMA 2 hatch and is to be returned by a US astronaut on the next US crew vehicle that docks to ISS. The Shuttle crew egressed ISS and the hatch in PMA 2 between ISS and the Shuttle was closed.

The final middeck transfer activities were successfully completed before closing the hatches between the Orbiter and ISS.

On FD 12, the *Atlantis* undocked from the ISS with physical separation occurring at 1:59 a.m. CDT (10/14:58:53 MET), and moved to a station-keeping attitude approximately 600 ft from the ISS, to allow the ISS to perform a 90-deg yaw maneuver. 'Atlantis' then performed a half-lap fly-around and separated on the -V bar, which allowed engineering-quality views of the sides of the ISS to be obtained by the Shuttle crew. During the undocking operations, the TriDAR Development Test Objective (DTO) 701A was operational.

The Pico-Satellite Solar Cell-2/Miniature Tracking Vehicle (PSSC-2/MTV) Nano-Satellite was successfully deployed from Space Shuttle 'Atlantis' at 11/16:20:00 MET, marking the 180th and final deployment of a satellite by the Space Shuttle Program. PSSC-2/MTV successfully communicated with the ground station in El Segundo. During the pass, the satellite showed healthy temperatures, low rotation rates (less than 1 deg/axis), batteries charging, and they were able to download a partial image file. The satellite continues to collect data.

Single viewing opportunities for RAMBO-2 and Maui were under assessment for FD 13; however, the request was not approved based on the FD 13 crew loading and timeline assessments. There were no acceptable viewing opportunities for SIMPLEX and SEITE secondary payloads during the mission.

Crewmember Rex Walheim, onboard 'Atlantis', read an original poem titled: "One More Satellite"

*One more satellite takes its place in the sky,
The last of many that the Shuttle let fly.
Magellan, Galileo, Hubble, and more
Have sailed beyond her payload bay doors.
There's still science books, and still more to come,
The shuttle's legacy will live on when her flying is done.
We wish Picosat success, in space where it roams,
They can stay up here, but we're goin' home.
Yes soon for the last time we'll gently touch down,
Then celebrate the shuttle with our friends on the ground.*

TRANSFER WEIGHT SUMMARY

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

TOTAL WEIGHT TRANSFERRED DURING THE MISSION

| Parameter | To ISS, lb _m | From ISS, lb _m |
|---------------|-------------------------|---------------------------|
| Cargo Bay | 26,303 | 23,329 |
| Middeck | 2097 | 1377 |
| Totals | 28,400 | 24,706 |

1. **Water** – Total amount of water transferred was 2074 lb_m. A total of 14 Contingency Water Container (CWC) transferred 1651 lb_m. Five Payload Water Reservoirs (PWRs) transferred 93 lb_m. Six Contingency Water Containers-Iodine (CWC-I) transferred 227 lb_m of water. Two CWCs were filled with 102.7 lb_m of condensate, which was transferred for processing.
2. **Oxygen** – A total of 16 lb_m of oxygen was transferred to maintain the required pressurization of the ISS.
3. **Nitrogen** – No nitrogen (N₂) was transferred to ISS airlock tanks. A total of approximately 110 lb_m was transferred for repressurization of the ISS stack.
4. **Lithium Hydroxide** – The Shuttle transferred 27 new canisters to the ISS. The ISS transferred 6 used canisters to the Shuttle.

SIGNIFICANT FIRSTS

The significant firsts and lasts for the STS-135 mission were as follows:

1. 33rd and last flight of the 'Atlantis' (OV-104) vehicle and final Space Shuttle mission;
2. 37th Shuttle mission to the ISS;

3. Four shuttle crew members to ISS.
4. Modified fly-around of the ISS, YVV maneuver for ISS to +Y-axis for port and starboard photo survey;
5. Shuttle crew rescue, if required, would have been a phased return over the following 10 months using Russian Soyuz vehicles;
6. EVA performed by 2 ISS crew members while Shuttle was docked;
7. Two MPLM modules attached to the ISS at the same time; and
8. Three seat-stowage bags containing approximately 3 Middeck Locker Equivalent (MLE) each of stowage volume installed in the middeck.

SIGNIFICANT ISS ANOMALIES

Major Constituent Analyzer (MCA) failed – a new unit was launched in the middeck and was transferred to the ISS for installation. Compound Specific Analyzer (CSA) units were used as a backup for O₂ readings. The Mass Spectrometer (ORU2) was removed on FD10 and returned for post flight analysis.

Chemical/Urine odor was reported on FD 4 throughout the ISS which dissipated when the Urine Processing Assembly (UPA) was stopped. The UPA was inspected on FD 6 and no leaks were detected. The UPA processing occurred for 3 hr 45 min and the crew did not report a recurrence of the previously reported odor.

Treadmill Vibration Isolation System (TVIS) gyro was R&R, but the new gyro would not 'spin-up'. The Russian crew performed troubleshooting and based on procedures developed on the ground, the gyro operated as required and the crew was given the 'GO' for nominal use of the TVIS.

Node 2 Nadir Petal latch did not fully close. It was 4 deg from the fully-closed position, after the MPLM was transferred to the Orbiter payload bay. There was no impact to undocking.

The Carbon Dioxide Removal Assembly (CDRA) in the Laboratory was deactivated due to an erratic temperature sensor which prevented the assembly from entering its half-cycle transition at 199/02:39 GMT. There was no issue for the ISS stack Partial Pressure Carbon Dioxide (PPCO₂) and no impact to Orbiter Lithium Oxide (LiOH) canister usage plans.

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

| | Task | Flight Day Task Completed |
|----|---|---|
| | Category 1 | |
| 1 | Dock Shuttle Flight ULF7 to PMA-2 and perform mandatory crew safety briefing. | FD 3 |
| 2 | Install MPLM on Node-2 nadir port & perform vestibule outfitting / ingress. Install MPLM on Node-2 nadir port & perform vestibule outfitting / ingress. | FD 4 |
| 3 | Transfer critical cargo items | FD 4/5 |
| 4 | Return MPLM to payload bay | FD 11 |
| | Category 2 | |
| 5 | Transfer remaining resupply cargo, plus transfer return items to meet minimum MPLM return VLA mass requirement of 21,000 | FD 4-11 |
| 6 | Remove failed ETCS Pump Module (PM) from ESP2 and install on LMC in PLB [EVA] | FD 5 |
| 7 | Transfer Robotics Refueling Mission (RRM) payload from LMC to SPDM EOTP [EVA] | FD 5 |
| 8 | Deploy MISSE-8 Optical Reflector Materials Experiment – III Ram/Wake (ORMatE-III R/W) on ELC-2 [EVA] | FD 5 |
| | Category 3 | |
| 9 | Perform ISS daily payload status checks as required | Daily |
| 10 | Perform Oxygen and Nitrogen stack repressurization | Daily |
| 11 | Perform daily middeck payloads activities | Daily |
| 12 | Transfer remaining MPLM return cargo items | FD 6-FD 11 |
| 13 | Perform ISS payload research operations | Daily |
| 14 | Deploy Pico-Satellite Solar Cell (PSSC) spacecraft post-undocking | FD 13 |
| 15 | Transfer water from Orbiter to ISS per Transfer Priority List (TPL) | FD 3-FD 11 |
| | Category 4 | |
| 16 | Perform EVA get-ahead tasks on a time-permitting basis. The following tasks do not fit in the existing timeline: Install PMA-3 thermal cover Install and route FGB PDGF 1553 cable Perform FGB PDGF ground-wire reconfiguration Reconfigure port CETA cart Remove S1 FHRC P-clamps (10) Perform EVA tool reconfiguration-retrieval of large cutter Install gap spanner (Lab Nadir Port HR 201-229) | FD 5 Deferred Deferred Deferred |
| 17 | Perform imagery survey of the ISS port and starboard exterior surfaces during Orbiter fly-around after undocking with the ISS in YVV attitude. | FD 12 |
| 18 | Reboost ISS with Orbiter if propellant available and if consistent with trajectory planning | Not Required |
| 19 | Deploy one Zero-gravity Stowage Rack (ZSR) in the Permanent Multipurpose Module (PMM). | FD 4 |

ISS MISSION PRIORITIES COMPLETION STATUS (Concluded)

| | Task | Flight Day Task Completed |
|----|--|---|
| 20 | Perform ISS Russian Orbital Segment (ROS) resupply and maintenance activities including Treadmill with Vibration Isolation and Stabilization (TVIS) gyroscope, Vibration Isolation and Stabilization (VIS) and cable troubleshooting and Remove and Replace | TVIS on FD 7 – FD 9 |
| 21 | Perform Program approved Inter-Vehicular Activity (IVA) get-ahead tasks on a time-permitting basis. Perform Panasonic HDTV 3D Imagery. Remove Ultrasound 1 from HRF1 and Replace with Ultrasound 2 and four 4-Panel Unit (4-PU) drawers | FD 4 –FD 5 |
| 22 | Perform Triangulation and LIDAR Automated Rendezvous & Docking (TriDAR) Autonomous Rendezvous and Docking (AR&D) Sensor DTO-701A | FD 3- FD 12 |
| 23 | Perform SDTO 13005-U, ISS Structural Life Validation and Extension | FD 3, FD 4 and FD-12 |
| 24 | Perform shuttle payloads of opportunity operations if propellant available. RAM Burn Observations - 2 (RAMBO-2) Maui Analysis of Upper Atmospheric Injections (MAUI) Shuttle Exhaust Ion Turbulence Experiments (SEITE) Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) | Not performed due to lack of available timeline |
| 25 | <ol style="list-style-type: none"> 1. Additional cargo returned in the MPLM; 2. Payload operations (CSPINS, GHF Heater, JAXA Diagnostic Kit Checkout, ICV Data Download); 3. IRED Retrieval from PMA3; 4. BMRRM and other spares moved into PMA3 (23.5 CTBE moved into PMA3); 5. OGS Recirculation Loop Sample; 6. 6L WPS Sample; 7. T2 Quarterly Inspection; 8. EMU Loop Scrub; 9. Microbial air Sampling; 10. Partial PMM Cleanout and Unpack; 11. WHC Liquid Indicator Remove and Replace; 12. Crew quarters Battery Change-outs; 13. Partial Node 2 Starboard Crew Quarter Cleaning; 14. Removal of Laboratory MCA ORU 2 for Return; 15. ARED Pacebook Swap; 16. JEM RMS Cable Check and Bus Monitor; 17. JEM Fire Indicator Checkout; and 18. Russian EVA 28 US Tool gather | Tasks accomplished with the additional mission day |

DEVELOPMENT TEST OBJECTIVES

DTO 701A Triangulation and LIDAR Automated Rendezvous and Docking (TriDAR)

This DTO was installed on the Orbiter Docking System (ODS) truss and was designed to demonstrate technologies for autonomous rendezvous and docking in Low Earth Orbit (LEO). The TriDAR provides guidance information that can be used to guide a vehicle during rendezvous and docking operations. It relies on a laser-based 3D sensor and a thermal imager. Geometric information contained in successive 3D images is matched against the known shape of the target object to calculate its position and orientation in real time. The objective of this mission was to demonstrate the real-time 3D tracking technology as well as demonstrate new functionality including real-time tracking from 2D thermal data and demonstration of advanced user interfaces. It was also used to collect 3D and thermal imagery from the Shuttle fly-around of the ISS. The vision system incorporated laser ranging and imaging capability along with software to process the resulting data for determination of six-degree-of-freedom pose, range/bearing, and imaging.

TriDAR was operated during the Shuttle rendezvous and undocking and the detail data analysis is under review. TriDAR operated flawlessly during the undocking and fly-around concluding a very successful STS-135 DTO mission. Shortly after undocking, Commander Chris Ferguson called down congratulations to the TriDAR team on their "great" displays. The TriDAR was operated in 'imaging mode' during the undocking and constantly acquired 3D raster scans of the ISS as the Orbiter performed a half-lap fly-around.

TriDAR has flown successfully on two previous Shuttle mission, STS-128 and STS-131. The system has been selected by Orbital Sciences Corporation to fly on the Commercial Orbital Transportation Services (COTS) Cygnus Pressurized Cargo Module.

DTO 805 Crosswind Landing Performance

This DTO of opportunity was not performed during landing because the crosswind conditions were below the established minimum.

PAYLOADS OF OPPORTUNITY

Maui Analysis of Upper-Atmospheric Injections (MAUI)

The MAUI payload experiment matrix involved dedicated Orbital Maneuvering System (OMS), Primary Reaction Control System (PRCS) and Vernier Reaction Control System (VRCS) thruster firings. Observations of firings in the vicinity of the International Space Station (ISS), particularly ISS-reboost firings, would have been done passively. Shuttle engine exhaust plumes would be observed utilizing optical telescope sensors and all-sky imagers at the Air Force Maui Optical and Supercomputing Site (AMOS) at Maui, Hawaii. Shuttle thruster firings and attitude maneuvers are to be conducted during night passes over AMOS. This was an observational payload of opportunity that contained no flight hardware.

Single viewing opportunities for MAUI were under assessment for FD 13. However, the request was not approved based on the FD 13 crew-loading and timeline assessments.

Shuttle Exhaust Ion Turbulence Experiments (SEITE)

The SEITE utilized the Space Shuttle to investigate plasma turbulence caused by the OMS engine exhaust in the Ionosphere using space-based sensors. Data would have been collected by flying satellites through the plasma turbulence during a conjunction with the Space Shuttle. Observations of density and electric-field disturbances would have been used to develop quantitative models of plasma-turbulence that affects tracking and imaging radars. This was an observational payload of opportunity that contains no flight hardware. However, No SEITE observation opportunities occurred during this mission.

Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX)

The objective of the SIMPLEX activity was to determine the source of Very High Frequency (VHF) radar echoes caused by the Orbiter and its OMS-engine firings when in the Field-Of-View (FOV) of a SIMPLEX-radar or a radio telescope ground-site. The collected data would have been used to examine the effects of orbital kinetic energy on Ionospheric irregularities and to understand the processes that take place with the venting of exhaust materials. No SEITE observation opportunities occurred during this mission.

Ram Burn Observation 2 (RAMBO-2)

The objective of the RAMBO-2 activity was to use the Space Shuttle to acquire data for developing a method to decipher satellite maneuvers from plume observations, and to characterize monopropellant plume radiance. The Ram Burn Observations-2 (RAMBO-2) used two Space Tracking Surveillance System (STSS) satellites to make observations of Space Shuttle Primary Reaction Control

System (PRCS) plumes. Single viewing opportunities for RAMBO-2 were under assessment for FD 13. However, the request was not approved based on the FD 13 crew-loading and timeline assessments.

VEHICLE PERFORMANCE

FINAL INSPECTION

The pre-launch Final Inspection Team (FIT) reported that the External Tank (ET) observations were consistent with environmental conditions. Heavy condensate was noted over the entire ET. Two typical stringer-valley Thermal Protection System (TPS) cracks were observed on the Intertank, with no anomalies observed on the Liquid Hydrogen (LH₂) or Liquid Oxygen (LO₂) tanks. Typical ice/frost was noted on the aft interface hardware. All of the LO₂ feedline bracket TPS closeouts exhibited acceptable ice/frost formations. A typical foam crack was noted on the -Y vertical strut (5" by ¼") with no offset. All observations were acceptable per established National Space Transportation System (NSTS) documentation.

NATURAL ENVIRONMENTS

The lift-off (T₀) (instantaneous) surface conditions (based on measurements at the 60 -foot level of Camera Site 3) were as follows:

1. Wind apex was 12 knots;
2. Wind direction was 167 deg;
3. Temperature was 83 °F;
4. Humidity was 72 percent; and
5. Ambient pressure was 20.94 in. Hg.

The I-loads were designed with the L-4:50 high-resolution balloon due to icing problems with the Jimsphere. One exceedance of the July 95th percentile database limits for the in-plane component was identified at 1400 ft based on the L-3:35 Day-of-Launch I-Load Update (DOLILU) assessment profile. The maximum measured wind velocity was 51.6 ft/sec at 7300 ft and 193 deg. There were no wind-shear exceedances.

No violations of the in-plane or out-of-plane wind change redlines were identified from the L-4:50 DOLILU I-Load design wind profile to the final assessments based on the L-3:35 high resolution balloon, the 1210 UTC 50 MHz Doppler Radar Wind Profiler (DRWP) and the L-1:25 (1356 UTC) high-resolution balloon.

The L-1:08 Jimsphere balloon was used to clear the roll maneuver region and was validated with the 1346 UTC False Cape 915 MHz profiler. The maximum measured wind velocity in the roll maneuver region was 57.4 ft/sec at 4500 ft and 199 deg.

REUSABLE SOLID ROCKET BOOSTERS

All Reusable Solid Rocket Booster (RSRB) systems performed as expected during the launch- countdown and ascent of the STS-135 mission.

No RSRB-related Interim Problem Reports (IPRs) occurred during the countdown (beginning with the commencement of tanking). However, an IPR was taken prior to tanking that resulted in a waiver being accepted during the tanking time-frame. The IPR was taken because of a violation of a 30-day bearing-soak requirement for an RSRB Hydraulic Power Unit (HPU). The waiver rationale included positive pressurization having been maintained downstream of the Fuel Isolation Valve (FIV) fulfilling the intent of the requirement.

No RSRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred once tanking commenced.

All RSRB systems performed as expected during launch countdown and ascent. The RSRB pre-launch countdown was nominal and no potential RSRB or RSRM anomalies were identified.

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

There was no indication of Hold-Down Post (HDP) stud hang-up based on preliminary analysis.

Both RSRBs were successfully separated from the ET, retrieved and returned to Kennedy Space Center (KSC) for inspection and analysis. The deceleration subsystem performed as designed.

REUSABLE SOLID ROCKET MOTORS

The STS-135 Reusable Solid Rocket Motor (RSRM) set performed within established and predicted limits, which was nominal.

No RSRM-related IPRs occurred during the countdown. All RSRM temperatures were maintained within acceptable limits throughout the countdown.

No RSRM LCC or OMRSD violations occurred once tanking commenced.

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.

EXTERNAL TANK

All ET systems performed as expected during launch countdown and ascent.

All ET objectives and requirements associated with propellant loading and flight operations were met. No significant oxygen or hydrogen concentrations were detected in the Intertank or at 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.

No first flight design changes were made to the ET; however, a modification of interest was made to an existing design. The ET LO₂ feedline camera run-time was extended to obtain LO₂ feedline camera imagery during ET entry.

No ET-related IPRs occurred during the countdown, and no ET LCC or OMRSD violations occurred.

ET separation was nominal. The ET impact-point was at latitude 35.871 degrees South and at longitude of 159.695 degrees West, which is approximately 37 nautical miles from the preflight predicted impact point.

SPACE SHUTTLE MAIN ENGINES

Overall, Space Shuttle Main Engine (SSME) systems performed as expected during launch countdown and ascent performance was typical of previous flights. Flight data indicated nominal SSME performance during startup, main-stage, throttling, and shutdown.

The SSME pre-launch countdown was nominal. Engine "Ready" was achieved at the proper time, all LCCs were met, and thrust build-up was nominal. No SSME-related IPRs or SSME LCC or OMRSD violations occurred during the countdown.

The commanded Max Q (dynamic pressure) throttle-down was a single-step throttle bucket to 72-percent Rated Power Level (RPL). Adaptive Guidance Throttle (AGT) was not activated.

Propellant dump operations data were normal and the MECO time was Engine Start plus 512 sec (Launch plus 505 sec).

Review of Advanced Health Monitoring System (AHMS) vibration measurements 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. No OMRSD or LCC violations occurred during the countdown.

All SRSS Safe and Arm (S&A) devices were armed and system inhibits were 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.

LAUNCH DELAY

The launch countdown was stopped at T-31 sec by the automatic countdown system. There was a 2 min 18 sec hold in the countdown when a computer reported the Gaseous Oxygen (GOX) vent arm was not fully retracted. A camera was used to verify that the arm was fully retracted and the launch countdown resumed.

ORBITER SYSTEMS

As a result of the Space Shuttle Program ending, the submitting of Orbiter System reports was optional. The following are those reports that were submitted voluntarily.

Main Propulsion System

All Main Propulsion System (MPS) systems performed as expected during launch countdown and ascent.

There was one MPS-related IPR that occurred after commencement of tanking. During stable replenish, the LO₂ pump A126 temperature was trending downward due to a suspected shaft seal leak. The pump was swapped over to pump A127 for the remainder of loading. The LO₂ ullage pressure recovered resulting in no impact to propellant load.

The maximum Hydrogen (H₂) concentration level in the Orbiter aft compartment, with the normally elevated system backpressure used for fastfill, was 146 ppm (System A was used to determine the maximum concentration). The maximum allowable is 600 ppm.

Data indicate that the MPS system performed as planned. All LH₂ and LO₂ loading parameters were nominal. All LO₂ and LH₂ fill and drain valves performed nominally. The LO₂ and LH₂ ECO sensors passed all pre-flight checkouts and operated nominally through ascent.

The LH₂ pre-pressurization cycle count was 7 cycles; 14 cycles or more violate the LCC criteria.

Pressurization performance was nominal indicating proper operation of the Flow Control Valve (FCV) hardware.

The predicted average SSME specific impulse (I_{SP}) tag value (using the ground-based tag-value method) was 451.78 seconds at 104.5% Rated Power Level (RPL). Indications are that the delivered I_{SP} was within the expected range.

Engine inlet net positive suction pressure requirements were met throughout the flight.

Gas Sample Analysis

The measured sample bottle pressures indicated the redesigned Orbiter Aft Fuselage Gas Sampler System (OAFGSS) were nominal.

The redesigned gas sampler system captured all six samples with two bottles being slightly below the allowable range. The remaining pressures were within the range of

acceptable pressures established by the Propulsion Systems Integration Group (PSIG) Subcommittee.

A summary of bottle pressure and gas concentration for STS-135 is given in the following table.

SUMMARY OF BOTTLE PRESSURES AND GAS CONCENTRATION

| Bottle No. | Position | Pressure, psia | Helium, % | Measured Oxygen, % | Hydrogen, % |
|------------|----------|----------------|-----------|--------------------|-------------|
| 1 | RH 1 | 3.11 | 0.39 | 3.15 | 0.01 |
| 2 | LH 1 | 1.33 | 0.34 | 2.68 | 0.03 |
| 3 | RH 2 | 1.22 | 1.04 | 3.47 | 0.02 |
| 4 | LH 2 | 0.78 | 0.54 | 4.70 | 0.04 |
| 5 | LH 3 | 0.16 | 3.19 | 3.48 | 0.11 |
| 6 | RH 3 | 0.06 | 5.67 | 2.44 | 0.23 |

The Ascent Hazard Analysis indicated the maximum H₂ firing leak rate for STS-135 was 718 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 | 460 |
| 2 | LH 1 | 718 |
| 3 | RH 2 | 465 |
| 4 | LH 2 | 675 |
| 5 | LH 3 | 485 |
| 6 | RH 3 | 390 |

Two of the six measured sample bottle pressures were slightly below the allowable range. The first bottle in the sequence (right-hand no. 1) had a measured pressure of 161 torr and it should be at least 161.81. The bottle in position right-hand no.2 had a measured pressure of 63.3 torr; it should have been at least 64.83 torr. The pressure in the first bottle was in the low range on several recent flights, including being just outside the value that was deemed acceptable. The following is the flight history of the OAFGSS sample bottles on STS-135: It was the second flight of the bottles in positions right-hand no. 2 and right-hand no. 3. It was the third flight for bottles right-hand no. 1, left-hand no. 1, left-hand no. 2 and left-hand no. 3. It was the 22nd flight using the new gas chromatograph/mass spectrometer.

The Hydrogen concentrations were well below the flammability limit in each bottle. The highest estimated leak rate was 718 scim from bottle left-hand no. 1.

The Oxygen concentration was above the flammability limit, and it was bottle left-hand no. 2, which had a measured concentration of 4.70 percent. Argon indicates air as the major source of the oxygen in all six bottles and not Orbiter system leakage.

The highest Helium concentration was 5.67 percent in bottle right-hand no. 3. Through STS-135, the highest previous Helium concentration on OV-104 was 6.53 percent. The average for all bottles is 3.72 percent, but the average for right-hand no. 3 is 3.36 percent. Due to the low pressure at the time the last bottle acquired its sample and the lack of a diluting atmosphere, the last bottle typically has the most variation in Helium concentration.

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

AFT FUSELAGE SAMPLE BOTTLE GAS ANALYSIS

| S/N | Position | Actual pressure, torr | Ar, % | Air from Ar, % | He, % | CO, % | CH ₄ , % | CO ₂ , % | O ₂ from air, % | O ₂ found, % | H ₂ , % | H ₂ pyro corrected, % |
|----------------|----------|-----------------------|-------|----------------|-------|-------|---------------------|---------------------|----------------------------|-------------------------|--------------------|----------------------------------|
| 1126 FLT-3 | RH1 | 161 | 0.14 | 14.45 | 0.39 | <0.01 | <0.01 | 0.01 | 3.04 | 3.15 | 0.01 | 0.01 |
| 1112 FLT-3 | LH1 | 68.9 | 0.08 | 8.35 | 0.34 | <0.01 | <0.01 | 0.01 | 1.75 | 2.68 | 0.03 | 0.03 |
| 1141 FLT-2 | RH2 | 63.3 | 0.15 | 15.95 | 1.04 | <0.01 | <0.01 | 0.01 | 3.35 | 3.47 | 0.02 | 0.02 |
| 1121 FLT-3 | LH2 | 40.4 | 0.20 | 20.88 | 0.54 | <0.01 | <0.01 | 0.01 | 4.38 | 4.70 | 0.04 | 0.04 |
| 1123 FLT-3 | LH3 | 8.5 | 0.15 | 15.95 | 3.18 | 0.02 | <0.01 | 0.01 | 3.35 | 3.48 | 0.12 | 0.11 |
| 1143L FLT-2 | RH3 | 3.1 | 0.15 | 16.06 | 5.67 | <0.01 | <0.01 | 0.02 | 3.37 | 2.44 | 0.24 | 0.23 |

Purge, Vent, and Drain System

The Purge, Vent and Drain (PV&D) system performed satisfactorily and no In-Flight Anomalies (IFAs) were identified from the data.

Reaction Control System

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

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

RCS PROPELLANT LOADING

| Parameter | Forward RCS | | Left RCS | | Right RCS | |
|-----------------------|-------------|--------|----------|--------|-----------|--------|
| | Oxidizer | Fuel | Oxidizer | Fuel | Oxidizer | Fuel |
| Target, % | 82.67 | 81.53 | 100.48 | 100.76 | 100.48 | 100.76 |
| Target, lb | 1343 | 832 | 1523.0 | 962.0 | 1523.0 | 962.0 |
| Calculated, % | 82.96 | 80.58 | 100.35 | 100.66 | 100.25 | 100.56 |
| Advertised, % | 1347.0 | 823.9 | 1521.2 | 961.1 | 1519.9 | 960.3 |
| PASS WHI ^a | 4.3858 | 4.2952 | 4.3619 | 4.2677 | 4.3704 | 4.2540 |
| BFS WHI ^b | 4.3938 | 4.3020 | 4.3692 | 4.2863 | 4.3878 | 4.2665 |

Notes:

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

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

^c Quantities taken from RCS propellant loading sheet.

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

TYVEK COVER RELEASE TIMES, VELOCITIES AND ALPHA/BETA ANGLES

| Cover | MET (sec) | Velocity (mph) | Alpha (deg) | Beta (deg) |
|-------|-----------|----------------|-------------|------------|
| F2D | 5.1 | 64 | -13 | 2 |
| F4D | 6.3 | 81 | -10 | 1 |
| F1D | 6.4 | 82 | -10 | 1 |
| F3D | 6.9 | 89 | -8 | 0 |
| F4R | 7.0 | 92 | -8 | 0 |
| F3L | 7.0 | 92 | -8 | 0 |
| F1L | 7.7 | 102 | -6 | -1 |
| F2R | 8.2 | 108 | -5 | -1 |
| F3F | 8.3 | 111 | -5 | -2 |
| F2F | 8.5 | 114 | -5 | -2 |
| F1F | 8.6 | 115 | -5 | -2 |
| F3U | 8.9 | 120 | -5 | -3 |
| F1U | 9.5 | 130 | -3 | -4 |
| F2U | 9.6 | 131 | -3 | -4 |

The RCS window-protect firing of the F1U, F2U and F3U thrusters was initiated at 189/15:31:06 Greenwich Mean Time (GMT) [00/00:02:02 Mission Elapsed Time (MET)] for 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 189/15:37:48 GMT (00/00:08:44 MET) and was a 7-sec 10-thruster translation. The ET Photographic +X firing was initiated at 189/15:39:01 GMT (00/00:09:57 MET) and was a 10.8-sec, four-

thruster translation. The ET Photo Pitch maneuver was initiated at 189/15:39:33 GMT (00/00:10:30 MET) and completed at 189/15:39:33 GMT (00/00:10:29 MET).

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

RCS MANEUVERS AND FIRING DATA

| Maneuver/Firing | System | Time of Ignition, GMT | ΔV , ft/sec | Duration, sec |
|----------------------|--------|-----------------------|---------------------|---------------|
| RCS Window Protect | RCS | 189/15:31:06.2 | N/A | 2.08 |
| ET Separation | RCS | 189/15:37:48 | N/A | 7 |
| ET Photo +X | RCS | 189/15:39:01 | N/A | 10.8 |
| ET Photo Pitch | RCS | 189/15:39:33 | | |
| NC3 | RCS | 190/19:47:00.6 | 1.3 | 5.6 |
| NCC | RCS | 191/11:31:23 | 0.38 | |
| MC1 | RCS | 191/12:49:04 | 0.24 | Not Reported |
| MC2 | RCS | 191/13:21:54 | 0.8 | Not Reported |
| MC3 | RCS | 191/13:38:54 | 0.7 | Not Reported |
| MC4 | RCS | 191/13:48:54 | 1.6 | Not Reported |
| R-bar Pitch Maneuver | RCS | 191/14:05:20 | | |
| TORVA | RCS | 191/14:18:00 | | |
| Docking | RCS | 191/15:07:14 | | |
| Orbiter Undocking | RCS | 200/06:28:09 | | |
| ISS Fly Around | RCS | 200/07:27:40 | | |
| Separation 1 | RCS | 200/07:27:40 | | 6.32 |
| Separation 2 | RCS | 200/08:18:43 | | 42.72 |
| Separation 3 | RCS | 201/05:04:06 | | 25.9 |
| RCS Hotfire | RCS | 201/06:04:25 | | |
| Forward RCS Dump | RCS | 202/09:07:13.5 | | 32.64 |

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 ^a | |
|------------------|--------------------------------|-------|--------------------------------------|-------|
| | % | lb | % | lb |
| Forward Oxidizer | 3.6 | 49 | 1.9 | 25.7 |
| Forward Fuel | 0.0 | 0.0 | -0.59 | -5.0 |
| Left Oxidizer | 42.4 | 572.0 | 41.6 | 561.6 |
| Left Fuel | 44.8 | 381.0 | 44.6 | 379.1 |
| Right Oxidizer | 42.8 | 578.0 | 41.2 | 556.2 |
| Right Fuel | 41.0 | 348.0 | 41.3 | 351.1 |

Note:

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

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

RCS PROPELLANT CONSUMPTION

| Parameter | Oxidizer, lb | Fuel, lb | Mixture ratio, Oxidizer/Fuel |
|-------------|--------------|----------|------------------------------|
| Forward RCS | 1094.3 | 689.9 | 1.59 |
| Left RCS | 793.1 | 476.5 | 1.66 |
| Right RCS | 797.2 | 503.7 | 1.58 |

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 |
|------------------------|--------------------|------------------|--------------------------------|
| | 191/15:07:14 | DAP FREE DRIFT | Docking / ISS Capture |
| Orbiter | 191/15:25:03 | DAP LVLH | |
| ISS | 191/15:32:01 | DAP FREE | |
| Orbiter | 191/15:32:19 | DAP AUTO | |
| ISS | 191/15:33:42 | DAP FREE | |
| Orbiter | 191/15:34:19 | DAP LVLH | |
| ISS | 191/15:35:47 | DAP FREE | |
| Orbiter | 191/15:35:55 | DAP AUTO | TEA Maneuver |
| ISS | 191/16:17:55 | DAP FREE | |
| ISS | 191/16:21:17 | DAP AUTO | |
| ISS | 191/16:35:46 | DAP B | Collapse attitude dead bands |
| ISS | 191/16:50:25 | DAP FREE | Station Controlling |
| Orbiter | 200/04:54:51 | DAP to LVLH | Undocking preparations |
| Orbiter | 200/04:56:30 | DAP AUTO | Maneuver to Undocking attitude |
| ISS | 200/05:48:09 | DAP B | Conserve propellant |
| ISS | 200/06:07:58 | DAP FREE DRIFT | Logic Configuration |
| Orbiter | 200/06:09:28 | AUTO | |
| ISS | 200/06:25:04 | FREE | Driver configuration |
| Orbiter | 200/06:25:44 | DAP B/ALT | No Low Z |
| | 200/06:28:09 | | Undocking |

The maneuver to the undocking attitude was initiated at 200/04:56:30 GMT (10/13:27:26 MET). As part of the undocking preparations, the forward RCS thrusters were reselected at 200/05:43:37 GMT (10/14:14:33 MET), except for F1F and F2F. Undocking was initiated with a +Z pulse at 200/06:28:09 GMT

(10/14:59:05 MET). The F1F and F2F thrusters were reselected after undocking at 200/06:33:29 GMT (10/15:04:25 MET). The Fly-Around (full maneuver) was initiated with a +X pulse of L1A and R1A at 200/07:27:40 GMT (10/15:58:36 MET).

The Separation 1 maneuver was a 6.32- sec +X firing of the L1A and R1A thrusters at 200/07:50:32 GMT (10/16:21:28 MET). The Separation 2 maneuver was a 42.7-sec -X maneuver (thrusters F2F and F3F) was initiated at 200/08:18:43 GMT (10/16:49:39 MET). Separation 3 maneuver was initiated with a 25.9-sec multi-axis firing at 201/05:04:06 GMT (11/13:35:02 MET).

The RCS hot-fire was initiated at 201/06:04:25 GMT (11/14:35:21 MET). All 38 RCS thrusters were fired at least twice. Two pulses of at least 0.240 sec per pulse were verified for all 38 thrusters. No fail-off or fail-leak problems were detected during the satisfactory hot-fire.

The Vernier RCS thrusters were fired 8753 times for a total of 13202 sec. The Primary RCS thrusters were fired 3152 times for a total of 1048.02 sec.

During post-landing operations, the manifold 5 isolation-valve Closed- indication remained on after the valve was switched to OPEN (IFA STS-135-V-07). When the left manifold 5 oxidizer isolation valve was cycled to Open, the Open indication came on while the Close-indication also remained on. Following coordination with the Mission Evaluation Room (MER) personnel, the Flight Controllers decided to have the crew cycle the valve again; however, the attempt to clear the anomaly was not successful. Nearly an hour later, the anomalous Closed-indication cleared. Although the RCS valve reconfigurations were occurring at the time by Ground Personnel, the failure cleared. There was no indication that the ground personnel had cycled the manifold 5 switch. This was the first service failure of the "new" manifold 5 isolation valve--a torque motor valve originally developed for the Forward Interconnect System, certified in 2004-2005, and first installed in OV-104/LP04 prior to STS-115 (during Return To Flight). The valve will be decontaminated as part of the pod's manifold drains prior to pod removal. The pod was declared as ready for transport.

Orbital Maneuvering System

The Orbital Maneuvering System (OMS) performed satisfactorily throughout the STS-135 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) 04 | 33 rd | L-OME S/N 108 | 7 th rebuilt flight - 31 st flight |
| Right Pod (RP) 01 | 40 th | R-OME S/N 109 | 12 th rebuilt flight 29 th flight |

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

OMS MANEUVERS

| Maneuver designation | Configuration | Time of ignition, GMT | Firing time, sec | ΔV , ft/sec/ interconnect usage, % |
|-------------------------|---------------|--------------------------|------------------------|--|
| Assist | Dual Engine | 189/15:31:17.4 | 83.2 | N/A |
| OMS-2 | Dual Engine | 189/16:06:49.1 | 64.5 | 97.0 |
| OMS-3 (NC1) | Dual Engine | 189/19:08:38.0 | 144.6 | 94.1 |
| OMS-4 (NC2) | Right Engine | 190/10:18:07.3 | 11.0 | 8.3 |
| OMS-5 (NH) | Dual Engine | 191/10:08:06.6 | 38.7 | 60.0 |
| OMS-6 (NC4) | Left Engine | 191/10:55:27.5 | 91.1 | 143.7 |
| OMS-7 (TI) | Left Engine | 191/12:29:04.3 | 11.8 | 9.0 |
| (Deorbit) | Dual Engine | 202/08:49:04.2 | 198.1 | 333.1 |

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

INTERCONNECT USAGE, %/POUNDS

| Parameter | Total, % | Total, pounds |
|-----------|----------|---------------|
| Left OMS | 0.468 | 60.61 |
| Right OMS | 0.948 | 122.77 |

The propellant usage during the STS-135 mission is shown in the following table.

PROPELLANT USAGE DATA

| Parameters | Left OMS pod | | Right OMS pod | |
|---------------------------------------|--------------|------|---------------|------|
| | Oxidizer | Fuel | Oxidizer | Fuel |
| Loaded, lbm | 7704 | 4650 | 7704 | 4650 |
| Residual, lbm (aft gage) | 644 | 402 | 677 | 450 |
| Residual, lbm Burntime integration | 750 | 456 | 761 | 424 |
| Residual, lbm (SODB flow rate) | 685 | 438 | 681 | 389 |
| Residual, lbm (MOD chit) | 676 | 433 | 669 | 390 |

Power Reactant Storage and Distribution System

The OV-104 Power Reactant Storage and Distribution (PRSD) system performance was nominal during STS-135, and no IFAs were identified from the mission data.

The PRSD system supplied the fuel cells with 2856 lb_m of Oxygen (O₂) and 360 lb_m of H₂ for the production of electrical energy. A 71-hr mission extension was possible at the 13.6 kW mission average power level with the reactants remaining at landing (wheel stop).

The total oxygen supplied to Shuttle/ISS Environmental Control and Life Support System (ECLSS) was 106 lb_m from PRSD, which included 65 lb_m transferred for stack repressurization. The H₂ tank 4 and 5 and O₂ tank 4 and 5 were depleted to residual quantities.

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

PRSD TANK QUANTITIES

Oxygen

| Oxygen | Tank 1, % | Tank 2, % | Tank 3, % | Tank 4, % | Tank 5, % | Total Mass, lb _m |
|---------|--------------|--------------|--------------|--------------|--------------|--------------------------------|
| Loaded | 101.8 | 101.8 | 100.9 | 101.8 | 101.8 | 3968 |
| Launch | 100.5 | 100.5 | 100.1 | 100.5 | 100.5 | 3921 |
| Landing | 31.7 | 33.9 | 40.1 | 5.9 | 5.9 | 959 |

Hydrogen

| Hydrogen | Tank 1, % | Tank 2, % | Tank 3, % | Tank 4, % | Tank 5, % | Total Mass, lb _m |
|----------|--------------|--------------|--------------|--------------|--------------|--------------------------------|
| Loaded | 102.3 | 101.5 | 102.3 | 103.7 | 102.3 | 471.1 |
| Launch | 99.3 | 97.9 | 99.3 | 100.6 | 99.3 | 456.7 |
| Landing | 32.8 | 33.9 | 27.0 | 1.9 | 1.4 | 97.0 |

Fuel Cell System

The overall performance of the OV-104 Fuel Cell (FC) system was nominal for STS-135, and no IFAs were identified from the mission data. The average electrical power level and load was 13.6 kW and 442 Amperes (A). The fuel cells produced 3216 lb_m of potable water and 4159 kWh of electrical energy from 2856 lb_m of O₂ and 360 lb_m of H₂.

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 336:55:22 (hr:min:sec) for fuel cell 1, 336:26:56 for fuel cell 2, and 335:36:19 for fuel cell 3. The end-of-mission accumulated operating times for these fuel cells are 2176, 903, and 2411 hours, respectively.

Six fuel cell purges were performed, occurring at approximately 23, 65, 124, 180, 240, and 298 hr MET. The purge intervals were 42, 59, 56, 60, and 58 hr.

The actual fuel-cell voltages at the end of the mission were 0.5 Volts (V) above predicted for fuel cell 1, 0.10 V for fuel cell 2, and as predicted for fuel cell 3. The voltage margins above the minimum performance curves at 200 A at the end of the mission were 0.74 V above minimum for fuel cell 1, 0.90 V above minimum for fuel cell 2, and 0.74 V above minimum for fuel cell 3.

The prelaunch baseline Cell Performance Monitor (CPM) values for FC 1 were 4, 16, and 18 mV, for FC 2 were 16, 26, and 8 mV, and for FC 3 were 24, 10, and 62 mV. They were established at approximately three hours after the completion of the Fuel Cell High Load Calibration requirement. The Fuel Cells Monitoring System (FCMS) was used to monitor individual cell voltages prelaunch, on-orbit, and postlanding.

Orbiter Docking System

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

The initial application of power to the ODS and ring extension were performed nominally during Flight Day (FD) 2 and the ODS was activated for 7 min 2 sec, and

the avionics hardware was powered for 4 min 33 sec. The docking ring was extended to the normal 76.4 percent position at 190/19:00:44 GMT (01/03:31:36 MET). The system was ready for rendezvous and docking with the ISS.

The application of power for the docking activities was initiated at 191/15:21:43 GMT (01/23:52:39 MET), and the ODS was powered for 65 min 53 sec with power to the avionics hardware for 45 min 6 sec. The initial contact and capture of the ISS occurred at 191/15:07:15 GMT (01/23:38:11 MET). The total damping was 3 min 15 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 191/15:10:30 GMT (01/23:41:26 MET), and was completed in 1 min 8 sec. The capture latches were released at 191/15:18:58 GMT (01/23:49:54 MET).

In preparation for undocking, the ODS was activated at 200/06:00:38 GMT (10/14:31:34 MET). The undocking and separation from the ISS was completed satisfactorily at 200/06:27:58 GMT (10/14:58:54 MET). The ODS was powered for 42 min 37 sec with power to the avionics hardware for 31 min 58 sec for the undocking operations.

Inertial Measurement Unit and Star Tracker

The Inertial Measurement Unit (IMU) and Star Tracker systems performed satisfactorily.

During the mission, the IMU accelerometer compensation values were uplinked one time for all three IMUs. The drift compensation values were also uplinked once for two of the IMUs.

The Star Tracker (ST) system performed satisfactorily. The -Y ST star acquired a navigation star 658 times during the mission, and missed navigation stars 386 times during the mission. The missed stars were caused by bright objects, Orbiter attitudes, Extravehicular Activities (EVAs), docking orientation and Orbiter maneuvers.

The -Z ST performed satisfactorily and showed an even distribution of star acquisitions for both dim and bright stars. The -Z ST acquired a navigation star 46 times and missed the navigation star 80 times. The missed stars occurred during the rendezvous and docking activities with the International Space Station.

Global Positioning System Navigation

Overall, the Global Positioning System (GPS) operation during STS-135 was nominal. There were no Figure of Merit (FOM) chimneys, and no flight anomalies were reported during the mission.

The GPS system was powered ON at 189/10:40:08 GMT, approximately 4 hr 46 min prior to launch. The GPS Age-of-Aiding remained consistent at 240 msec throughout the entire on-orbit phase.

On the entry/landing day (FD 14), the GPS was taken to Auto-Incorporate shortly after transition to the Operations 3 Mode (OPS3). In accordance with the nominal plan, the GPS was inhibited about 72 min later, which was prior to the deorbit maneuver. In accordance with the plan for all 1-String GPS flights, the GPS state-vector was incorporated into both Primary Avionics Software System (PASS) and Backup Flight System (BFS) in Major Mode (MM) 304 after performance confirmation with high-speed C-band tracking. This occurred at approximately 146,000 ft altitude, and simultaneously with the call for incorporation of the TACANs. The effect was that the PASS and BFS navigation state-vector residuals were reduced significantly, as expected.

During, the GPS high-FOM period usually encountered in the Plasma region cleared well before GPS incorporation. The FOM stayed at 1 from slightly before GPS incorporation through rollout. No Data-Invalid" nor FOM Chimneys occurred during the critical phase of entry (below 140,000 ft altitude), where the GPS satellite geometry is less dynamic.

Aerothermodynamics, Integrated Heating and Interfaces

Data indicated that the overall Orbiter Thermal Protection System (TPS) was nominal. The lower-surface structural-temperature data indicated normal entry heating. The recorded structure temperatures were within the flight experience of OV-104. From Modular Auxiliary Data System (MADS) surface thermocouples (T/C), the Boundary Layer Transition (BLT) was symmetric and occurred at Mach 7.0 or 1283 sec after Entry Interface (EI) based on the TCs at $x/L=0.6$ and a pre-flight EOM trajectory.

The quick-look runway report and post-flight inspection pictures indicated that overall the vehicle looked satisfactory. The gap between the tiles 191011-131/-132 which was identified as the potential site of the launch-gap filler liberation was indeed empty, but no charred filler bar noted. Blanket protrusion on the port-side OMS pod noted during on-orbit imagery was still present, but did not appear to have propagated. The tile damage on the outboard of the port ET door noted during on-orbit imagery appeared to be the same size and in the same condition.

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

ENTRY MAXIMUM TEMPERATURE AND MAXIMUM TEMPERATURE RISE DATA

| Thermal Sensor Location | Maximum Temperature, °F | Maximum Temperature Rise, °F |
|---|-------------------------|------------------------------|
| Lower fuselage forward center (B1) | 148.2 | 124.4 |
| Lower fuselage forward left-hand (B2) | 187.8 | 169 |
| Lower fuselage forward mid left-hand (B3) | 179.8 | 176.4 |
| Lower fuselage mid center (B4) | 158.7 | 147.7 |
| Lower fuselage mid aft center (B5) | 171.9 | 153.2 |
| Lower fuselage aft center (B6) | 185.1 | 151 |
| Left-wing center (LW) | 124.7 | 131.4 |
| Right wing center (RW) | 127.3 | 136.5 |
| Port side FRCS forward (P1) | 137.7 | 103.6 |
| Port side fuselage forward center (P2) | 101.2 | 90.1 |
| Port side fuselage forward mid center (P3) | 93.4 | 84.9 |
| Port side fuselage mid aft center (P4) | 70.1 | 61.6 |
| Port side fuselage aft center (P5) | 93.4 | 64.4 |
| Starboard side FRCS Forward (S1) | 135.1 | 101 |
| Starboard side fuselage forward center (S2) | 122 | 116.1 |
| Starboard side fuselage forward mid center (S3) | 103.8 | 82.5 |
| Starboard side fuselage mid-aft center (S4) | 64.6 ^a | 71.7 ^a |
| Starboard side fuselage aft center (S5) | 88.2 | 79.7 |
| Left-hand OMS pod side forward (LP) | 75.3 | 54.0 |
| Right-hand OMS pod side forward (RP) | 67.5 | 69.2 |
| Lower body flap center | 129.9 | 100.9 |
| Right-hand PLBD forward | 64.9 ^a | 134.8 ^a |
| Left-hand PLBD forward | 67.5 ^a | 109.7 ^a |
| Right-hand PLBD aft | 75.3 ^a | 122.5 ^a |
| Left-hand PLBD aft | 80.5 | 102.4 |
| Right wing upper center | 90.8 ^a | 112.8 ^a |
| Left wing upper center | 88.2 ^a | 79.7 |
| Forward RCS center | 88.2 ^a | 66.9 ^a |
| Forward fuselage upper center | 67.5 | 79.3 |

Notes

^a Maximum temperature occurred 30 min after wheel stop.

^b Maximum temperature ever experienced on the OV-105 vehicle.

Thermal Protection System and Post-Landing Assessment

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

SUMMARY OF IMPACT SITES FOR EACH ORBITER SURFACE

| Orbiter Surface | Impacts greater than 1 in. | Total impacts |
|------------------------|-----------------------------------|----------------------|
| Lower surface | 14 | 83 |
| Upper Surface/Window | 0 | 8 |
| Right OMS pod | 1 | 5 |
| Left OMS pod | 2 | 7 |
| Totals | 17 | 103 |

EXTRAVEHICULAR ACTIVITY

One Extravehicular Activity (EVA) was performed nominally on the International Space Station (ISS) during the STS-135/ULF-7 mission. The EVA was performed on Flight Day (FD) 5, July 12, 2011, and all planned activities were completed. The EVA was performed by two Increment 28 crewmembers (Mike Fossum/Extravehicular (EV) 1 and Ron Garan/EV2), and the duration of the EVA was 6 hr 31 min.

The EVA started with both crewmembers transferring the failed Pump Module (PM) from External Stowage Platform -2 (ESP-2) to the Orbiter Payload Bay Lightweight Multipurpose Carrier (LMC) for return to the ground for analysis and troubleshooting. The EV1 crewmember was the free-floater and EV2 on the Space Station Remote Manipulator System (SSRMS). The crew then transferred the Robotic Refueling Mission (RRM) payload to the Enhanced Orbital Replacement Unit Temporary Platform (EOTP) located on the Special Purpose Dexterous Manipulator (SPDM). For this part of the EVA, the EV1 crewmember was on the SSRMS and the EV2 crewmember was the free-floater. Following STS-135/ULF7, the SPDM will transfer the RRM to the External Logistics Carrier-4 (ELC 4).

Following the RRM transfer, the EV2 crewmember installed the Optical Reflector Materials Experiment III – Ram/Wake (ORMatE-III R/W) on the Materials in ISS Experiment-8 (MISSE-8) located on Express Logistics Carrier (ELC) 2. This completed all planned tasks of the EVA.

After removing and stowing the Articulating Portable Foot Restraint (APFR) from the Space Station Remote Manipulator System (SSRMS), the EV1 crewmember translated over the Functional Cargo Block (FCB) Power Data Grapple Fixture (PDGF) to clear a grounding-wire that was protruding from the J4 Channel B power connector door (Get-Ahead Task). The EV1 crewmember successfully cleared and re-secured the grounding wire, but due to time constraints the crewmember was not successful in investigating the status of the grounding wire located behind the J3 Channel-A power connector door.

The next task of the EVA was installation of the Pressurized Mating Adapter-3 (PMA-3) thermal cover (Get-Ahead Task). Both the EV1 and EV2 crewmembers worked together to successfully completed this task.

Two other Get-Ahead tasks were completed during the EVA. These tasks were the installation of an EVA Gap-Spanner between two Laboratory nadir handrails and retrieval of the Large EVA Tool Cutter from the Airlock Tool Box.

REMOTE MANIPULATOR SYSTEM AND ORBITER BOOM SENSOR SYSTEM

The Shuttle Remote Manipulator System (SRMS) performed nominally. The SRMS On-orbit Initialization began at 189/18:16 GMT [00/02:46 Mission Elapsed Time (MET)] on Flight Day (FD) 1. The port and starboard Manipulator Positioning Mechanisms (MPMs) were deployed and the SRMS shoulder brace was released. SRMS power-up began at 189/21:45 GMT (00/06:15 MET) and was completed at 189/22:06 GMT (00/06:36 MET).

On FD 2, the SRMS grappled the Orbital Boom Sensor System (OBSS) at 190/10:58 GMT (00/19:28 MET) and maneuvered it to the OBSS Hover Position at 190/11:06 GMT (00/19:36 MET). After unberthing the OBSS, the SRMS maneuvered to the Flat-Field position at 190/11:47 GMT (00/20:17 MET). The Starboard Survey began at 190/12:21 GMT (00/20:51 MET) and was completed 70 min later. The Nose Cap RCC Survey began at 190/13:53 GMT (00/22:23 MET) and was completed 31 min later. The Port Survey began at 190/14:48 GMT (00/23:18 MET) and was completed 20 min later. The SRMS was maneuvered to the OBSS Hover position at 190/16:32 GMT (01/01:02 MET). The OBSS was berthed in the starboard MPMs at 190/16:52 GMT (01/01:22 MET) and the SRMS maneuvered to the Pre-cradle Position.

After docking on FD 3, the SRMS began its maneuver to OBSS Pre-Grapple at 191/18:20 GMT (02/02:50 MET). The Space Station Remote Manipulator System (SSRMS) grappled the OBSS and unberthed it before handing it off to the SRMS at 191/19:42 GMT (02/04:12 MET). The SRMS maneuvered the OBSS to the MPLM Viewing Position at 20 min after the SRMS grappled the OBSS.

On Flight Days 4 to 10, there were no SRMS activities.

On FD 11, the SRMS maneuvered to the undocking position at 199/14:56 GMT (09/23:26 MET).

On FD 12, after undocking from the ISS, the inspection of the Starboard Wing Reinforced Carbon-Carbon (RCC) began at 200/10:40 GMT (10/19:10 MET) and the survey was completed at 200/11:55 GMT (10/20:25 MET). The Nose-Cap survey began at 200/12:28 GMT (10/20:58 MET) and was completed 1 hr later. The Port-Wing RCC survey began at 200/13:21 GMT (10/21:51 MET) and was completed 68 min later. Following the surveys, the SRMS was maneuvered to the Hover Position and the OBSS was berthed at 200/14:49 GMT (10/23:19 MET). After berthing the OBSS, the SRMS maneuvered to the Pre-Cradle position at 200/15:01 GMT (10/23:31 MET) and was cradled and latched 11min later.

On FD 13, the Port MPMs were stowed at 201/08:06 GMT (11/16:36 MET) and the Starboard MPMs were stowed 1 min later.

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.

During the setup for the Thermal Protection System (TPS) surveys, the crew reported an issue with the in-cabin cable between the Laser Camera System (LCS) Control Computer (LCC) and the Orbiter Patch Panel (OPP). The crew reported that moving the cable caused communications between the LCC and the LCS to drop out. The crew secured the cable and operations continued. A spare cable was available in the event that the condition of the original cable worsens.

While trying to program the Wing Leading Edge Impact Detection System (WLEIDS) Sensor Serial Number (S/N) 1080 for Port Wing Group 1 Micro Meteoroid/Orbital Debris (MM/OD) monitoring during the NC-3 maneuver period, the unit failed to complete the command and provided a local time-out error message. Diagnostic file commands were then uplinked to sensor 1080 in an effort to help determine if the unit had programmed successfully; however, the diagnostic attempt failed 3 consecutive times and returned with a local time-out error message each time. A sensor reset command was submitted and the unit returned a local time-out error message. Then a Cancel command was sent and it successfully processed. A diagnostic command was then submitted again and it also returned a local time-out error message. On Flight Day (FD) 3, the unit was then successfully programmed for Group 1 Start 1 monitoring to cover the elevated MM/OD Reinforced Carbon-Carbon (RCC) risk period during the dump, R-bar Pitch Maneuver (RPM) and Docking period. A diagnostic command was sent to the unit after it had been programmed and it also successfully went through. During the first hourly On-Orbit Summary check, the unit experienced another local time-out error message. The controllers were able to regain solid communication with WLE Sensor 1080. It monitored its planned Group 1 Start 1 monitoring period without any issues. There were no further plans to use this sensor for the remainder of the mission.

An issue occurred with sensor S/N 1111, which monitors the Starboard wing 7 and 8, 9 and 10, 11 and 12 RCC Panel Interfaces. The unit dropped out of the on-orbit mode prematurely during the planned Group 1 Start 1 MM/OD monitoring for the water dump, NH, NC4 and Ti maneuvers and the RPM and Docking periods. It was scheduled to monitor starting at 191/07:25:00 GMT [2:25 a.m. Central Daylight Time (CDT)] and stop at 192/04:55:00 GMT. After the initial drop-out of the unit, the ground controllers programmed the sensor again to monitor and it dropped out prematurely a second time. The exact time at which the unit dropped out initially was unknown, but ground support engineers did know it was successfully monitoring during the third hourly trigger status at 191/10:15:00 GMT. After the third hourly trigger status, use of the prime and back-up laptop was lost for communication to the system and communication was regained to the system during the ninth hourly trigger check at which point sensor S/N 1111 showed as out of on-orbit mode.

POST-LAUNCH PAD INSPECTION

The post-launch inspection of the Mobile Launcher Pad (MLP) -3, Pad A Fixed Service Structure (FSS), and Pad A apron/infield was conducted on July 8th, 2011. The inspection proceeded relatively quickly while Safing Teams secured the Pad. The entire PAD, FSS, MLP, and SRB Flame trench were inspected. SRB throat plug material was the only flight hardware found.

Orbiter lift-off lateral acceleration data indicated a maximum of 0.12g. Hold-down stud hang-ups are typically noted with lateral accelerations above 0.19g.

Reusable Solid Rocket Booster Hold-Down Posts (HDP) Inspection

HDP No. 1 The EA934 poured sidewalls were nominal with moderate acceptable pitting. The Phenolic shim was nominal. 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. The northeast Inconel flange top surface had what appeared to be Room Temperature Vulcanizing (RTV) -type material contamination.

HDP No. 2 The EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim was nominal. No evidence of either firing line was present. Approximately 2-ft 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.

HDP No. 3 The HDP showed nominal indications of erosion on the RTV-coated blast shield with proper closure.

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

HDP No. 5 The EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim was nominal. 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. The northwest Inconel-flange-top surface had what appeared to be RTV-type contamination.

HDP No. 6 The EA934 poured sidewalls were nominal with minor acceptable pitting. The Phenolic shim was nominal. One ft 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 northeast Inconel-flange-top surface had what appeared to be RTV-type contamination.

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

HDP No. 8 The HDP showed nominal indications of erosion on the RTV-coated blast shield with proper closure.

GN₂ Purge Lines Inspection

1. The Left-Hand (LH) probe was erect and slightly bent South. Protective tape was present with no exposed braiding. No O-ring was present.
2. The Right Hand (RH) probe was erect and bent Southwest. 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. All four frangible bolt halves were present.
2. The RH SRB T-0 GCAs appeared to be in nominal condition with proper demate.
 - a. Several connector housings had broken sidewalls.
 - b. The 4J1 pins and sockets were raised higher than nominal.
 - c. All four frangible bolt halves were present.

LO₂ and LH₂ Tail Service Masts Inspection

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

MLP Deck Inspection

- 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. Unsecured pip-pins were noted on baskets 1 and 5.

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

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

3. The External Tank (ET) GUCP 7-in. GH₂ 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 4- and 24-ft. flexible-line suffered blast damage.
7. The LH and RH pivot assembly electrical bond jumpers had nominal separation.

Gaseous Oxygen Vent Arm (255-ft level) Inspection

1. The Gaseous Oxygen (GO₂) 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. Three rail pip-pins were unsecured and hanging by their tethers.

PAD Facility and North RSRB Flame-Trench Inspection

Pad A appeared to be in very good condition and exceptionally clean. Several pieces of Fondue Fyre approximately 1-ft by 1-ft by 2-in. in dimension were present in the exit of the SRB Flame Trench.

Debris Items Found

1. At the 255-ft level, a 2-in. by 3-in. piece of aluminum was found. The door on side 1 corner had 3 of 6 unsecured latches.
2. At the 195-ft level, two Oxygen (O₂) analyzer doors had 3 of 6 latches unsecured.
3. At the 155-ft level, a 6-in. by 6-in. aluminized thermal blanket material found. The team suspected that the Gaseous Hydrogen (GH₂) vent line was part of the arresting-cable-deceleration system.
4. The inspection of the MLP Deck west gutter identified a 3-in. bolt with washer. Tie-wrap was found in the Northeast corner near the RH SRB flame trench.
5. Pad Surface:
 - a. The inspection of the Southeast Apron found several pieces of rust scale, 2-in. bolt, 10-in. metal clip band, 8-in. by 8-in. plastic plate, and a 10-in. long platform strut retaining pin were found.
 - b. The inspection of the Northeast Apron found several pieces of rust scale, 4-in. by 4-in. plastic plate. The cross-country feed-line trench had several bolts and washers, as well as a metal rod that were not able to be retrieved.
 - c. The inspection of the West Apron found a hose clamp by the RSS truck 2; a grating clip just north of RSS truck; a 2-in. bolt, KC fitting, screw head, 2 pieces of bolt with head missing, conduit locknut, RF cable cap, grating clip, pipe clamp, self-taping sheet metal screw, portion of plastic shower rinse sign, small bolt, and a large metal washer.

LAUNCH PHOTOGRAPHY AND TELEVISION ANALYSIS

The launch photography provided excellent views of areas requested. 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 (DAT) to determine the condition of the Thermal Protection System (TPS). A total of 627 photographs were analyzed by the DAT.

ET TPS losses were observed at Xt 1123 on LH₂ intertank-flange outboard of the cable tray. The time of this occurrence was not provided.

An External Tank (ET) TPS crack was noted on the aft face of the starboard bipod closeout. The time of the occurrence was not provided.

An ET TPS loss was identified on the -Z side aft of the LH₂ Intertank flange. A divot was noted at +112 degrees.

At minus 2.940 sec prior to lift-off, debris was observed falling near the Space Shuttle Main Engines (SSMEs) during ignition. The debris first appears between the SSME nozzles and the Orbiter body flap.

At 0.847 sec, debris was released from Holddown Post (HDP) M7 Debris Containment System (DCS) stud hole during lift-off.

At 0.871 sec, lift-off debris and possible vapors coming from the flame trench appear to impact the right Solid Rocket Booster (SRB) in the aft skirt area.

At 4.100 sec during lift-off, an Orbiter gap filler was observed protruding on the lower surface of the port wing, approximately 2 ft. inboard of Reinforced Carbon-Carbon (RCC) panel 14 L.

At 24.7 sec, debris spray was observed near the Orbiter port wing lower surface and travelled aft during ascent. There was no observed debris impact to the Orbiter. The SRB imagery will be evaluated for additional information on this observation.

At 35.056 sec, debris was observed near the left vertical strut during ascent. The debris appears to impact the Orbiter aft and port lower surface and travelled aft. No visible damage occurred to the Orbiter.

At approximately 79 sec, a single piece of debris appears to originate near the Liquid Oxygen (LO₂) feedline at Xt 1958 and then it falls aft.

At approximately 109 sec, a single piece of debris was first seen near the LH₂ intertank flange and fell aft toward the starboard wing leading edge. Further evaluation was inconclusive in determining whether this event correlated with the Wing Leading Edge Impact Detection System (WLEIDS) event at 109.6 sec MET event.

At 208.1 sec, a single piece of debris was observed near the port side of the intertank. The debris travelled in the +Z direction.

At approximately 269 sec, multiple pieces of ET TPS debris appear to originate near the Liquid Hydrogen (LH₂) intertank flange outboard of the cable tray. The debris travelled aft and outboard over the starboard wing. No Orbiter impact was observed.

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APPENDIX A **STS-135 MISSION EVENTS**

| EVENT | DESCRIPTION | ACTUAL GMT |
|--|--|--|
| APU Activation | APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure | 189/15:21:56.458 189/15:21:57.672 189/15:21:58.775 |
| 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 | 189/15:28:36.216 189/15:28:36.376 189/15:28:36.536 189/15:28:36.696 |
| Main Engine Start | SSME-3 Start Command Accepted SSME-2 Start Command Accepted SSME-1 Start Command Accepted | 189/15:28:57.442 189/15:28:57.564 189/15:28:57.691 |
| SRB Ignition | SRB Ignition Command | 189/15:29:03.996 |
| Throttle Up 104.5 Percent | SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted | 189/15:29:07.838 189/15:29:07.840 189/15:29:07.847 |
| Throttle Down to 72 Percent | SSME-2 Command Accepted SSME-1 Command Accepted SSME-3 Command Accepted | 189/15:29:42.720 189/15:29:42.727 189/15:29:42.729 |
| Maximum Dynamic Pressure (Max Q) | Derived Ascent Dynamic Pressure | 189/15:29:24 |
| Throttle Up to 104.5 Percent | SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted | 189/15:30:00.799 189/15:30:00.801 189/15:30:00.808 |
| Both SRMs at 50 psia | LH SRM Chamber Pressure RH SRM Chamber Pressure | 189/15:31:02.506 189/15:31:02.666 |
| End SRM Action | LH SRM Chamber Pressure RH SRM Chamber Pressure | 189/15:31:04.696 189/15:31:04.796 |
| SRB Separation Command | SRB Separation Command Flag | 189/15:31:07 |
| SRB Physical Separation | LH APU B Turbine Loss of Signal LH APU A Turbine Loss of Signal RH APU B Turbine Loss of Signal RH APU A Turbine Loss of Signal | 189/15:31:07.036 189/15:31:07.076 189/15:31:07.076 189/15:31:07.116 |
| OMS Assist Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 189/15:31:17.3 189/15:31:17.4 |
| OMS Assist Cutoff | R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position | 189/15:32:40.8 189/15:32:40.9 |
| Throttle Down for 3g | SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted | 189/15:36:26.088 189/15:36:26.089 189/15:36:26.094 |
| 3G Acceleration | Total Load Factor (g) | 189/15:36:31.8 |
| Throttle down to 67 percent for Cutoff | SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted | 189/15:37:21.449 189/15:37:21.450 189/15:37:21.455 |
| SSME Shutdown | SSME-3 Command Accepted SSME-2 Command Accepted SSME-1 Command Accepted | 189/15:37:27.809 189/15:37:27.810 189/15:37:27.815 |
| Main Engine Cutoff (MECO) | MECO Command Flag MECO Confirmed Flag | 189/15:37:28 189/15:37:28 |
| ET Separation | ET Separation Command Flag | 189/15:37:49 |

APPENDIX A **STS-135 MISSION EVENTS**

| EVENT | DESCRIPTION | ACTUAL GMT |
|---|--|--|
| APU Deactivation | APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure | 189/15:43:17.638 189/15:43:29.632 189/15:43:37.075 |
| OMS 1 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | Not Required |
| OMS 1 Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | Not Required |
| OMS 2 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 189/16:06:49.1 189/16:06:49.2 |
| OMS 2 Cutoff | R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position | 189/16:07:53.8 189/16:07:53.9 |
| Payload Bay Doors Open | Right Payload Bay Door Open 1 Left Payload Bay Door Open 1 | 189/17:02:02 189/17:03:21 |
| OMS 3 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 189/19:08:38.1 189/19:08:38.1 |
| OMS 3 Cutoff | R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position | 189/19:10:12.3 189/19:10:12.9 |
| OMS 4 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 190/10:18:07.4 |
| OMS 4 Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 190/10:18:18.6 |
| OMS 5 Ignition | R Engine Bipropellant Valve Position L Engine Bipropellant Valve Position | 191/10:08:06.5 191/10:08:06.7 |
| OMS 5 Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 191/10:08:45.5 191/10:08:45.5 |
| OMS 6 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 191/10:55:27.5 191/10:55:27.5 |
| OMS 6 Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 191/10:56:58.9 191/10:56:58.9 |
| OMS 7 Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 191/12:29:04.3 |
| OMS 7 Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 191/12:29:16.3 |
| Docking | Capture | 191/15:19:22 |
| Undocking | Undocking Complete | 200/06:27:59 |
| Flight Control System Checkout – APU 1 Start | APU-1 Gas Generator Chamber Pressure | 201/05:16:35.308 |
| APU 1 Stop | APU-1 Gas Generator Chamber Pressure | 201/05:20:59.368 |
| Payload Bay Door Close | Left Payload Bay Door Close Right Payload Bay Door Close | 202/06:13:52 202/06:15:57 |
| APU Activation | APU-3 Gas Generator Chamber Pressure APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure | 202/08:44:06.185 202/09:12:13.248 202/09:12:15.362 |
| Deorbit Maneuver Ignition | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 202/08:49:04.2 202/08:49:04.2 |
| Deorbit Maneuver Cutoff | L Engine Bipropellant Valve Position R Engine Bipropellant Valve Position | 202/08:52:22.6 202/08:52:22.6 |

APPENDIX A
STS-135 MISSION EVENTS

| EVENT | DESCRIPTION | ACTUAL GMT |
|--|--|--|
| Entry Interface | Orbital Altitude Referenced to Ellipsoid | 202/09:25:13 |
| Blackout End | Data Locked (High Sample Rate) | NO BLACKOUT |
| Terminal Area Energy Management (TAEM) | Major Mode Code (305) | 202/09:50:29 |
| Main Landing Gear Contact | Main Landing Gear Left Hand Tire Pressure Main Landing Gear Right Hand Tire Pressure | 202/09:56:56 202/09:56:56 |
| Main Landing Gear Weight on Wheels | Main Landing Gear Left Hand Weight on Wheels Main Landing Gear Right-Hand Weight on Wheels | 202/09:56:58 202/09:57:00 |
| Drag Chute Deployment | Drag Chute Deploy 1 CP Volts | 202/09:57:03.6 |
| Nose Landing Gear Contact | Nose Landing Gear Right Hand Tire Pressure 1 | 202/09:57:11 |
| Nose Landing Gear Weight on Wheels | Nose Landing Gear Weight on Wheels | 202/09:57:12 |
| Drag Chute Jettison | Drag Chute Jettison 1 CP Volts | 202/09:57:35.0 |
| Wheels Stop | Velocity with respect to Runway | 202/09:57:53 |
| APU Deactivation | APU-1 Gas Generator Chamber Pressure APU-2 Gas Generator Chamber Pressure APU-3 Gas Generator Chamber Pressure | 202/10:17:35.578 202/10:17:51.582 202/10:18:01.505 |

APPENDIX B

STS-135 IN-FLIGHT ANOMALIES

INTRODUCTION

This appendix contains listings and discussions of each of the In-Flight Anomalies (IFAs) that were identified for the STS-135 mission.

1. Orbiter

No STS-135 IFAs were defined for the following areas.

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

APPENDIX B
STS-135 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES

| IFA Number | Title | Comments |
|--------------|---|---|
| STS-135-V-01 | WLES Sensor Unit 1080 Communications Issues | <p>While trying to program the Wing Leading Edge Impact Detection System (WLEIDS) Sensor S/N 1080 for Port Wing Group 1 Micro Meteoroid/Orbital Debris (MM/OD) monitoring during the NC-3 period, the unit failed to complete the command and provided a local time-out error message. Diagnostic file commands were uplinked to sensor 1080 in an effort to help determine if the unit had programmed successfully; however, the diagnostic attempt failed three consecutive times and returned with a local time-out error message each time. A sensor reset command was submitted and the unit returned a local time out error message. Next a Cancel command was sent and it successfully processed. A diagnostic command was then submitted again and it also returned a local time-out error message. On Flight Day (FD) 3, the unit was then successfully programmed for Group 1 Start 1 monitoring to cover the elevated MM/OD Reinforced Carbon-Carbon (RCC) risk period during the dump, R-bar Pitch Maneuver (RPM) and Docking period.</p> <p>A diagnostic command was sent to the unit after it had been programmed and it successfully went through. During the first hourly On-Orbit Summary check, the unit experienced another local time-out error message.</p> <p>Ground personnel were able to regain solid communication with WLE Sensor S/N 1080. It monitored its planned Group 1 Start 1 monitoring period without any issues and there was no further use of this sensor for the remainder of the mission.</p> <p>Post-flight Plan: Request the unit be removed post-flight and returned to JSC.</p> |
| STS-135-V-02 | Tile and Blanket Anomalies | <p>A complete listing of the Thermal Protection System (TPS) tile and blanket Regions of Interest (ROIs) evaluated by the Tile Damage Assessment Team are documented in the TPS Imagery Inspection Management System (TIIMS) Database located at: http://isal-web1.jsc.nasa.gov/tiims/TIIMS.htm.</p> <p>Five items were identified in-flight which exceeded pre-defined screening criteria and were entered into the TIIMS Database. No focused inspection for these items was required. The five items are as follows:</p> <ol style="list-style-type: none"> 1. D-135-AFD-550-001 - Small Fray or Protrusion on Blanket or Patch Repair; 2. D-135-AFD-550-002 - Small Fray or Protrusion on Blanket; 3. D-135-AFD-550-003 - Blanket Closeout Frayed Around Vent; 4. D-135-RPM-130_6-001 - Frayed/Lifted Blanket Forward of Star Tracker; and 5. D-135-RPM-700_2-001 - Tile is Damage Outboard of ET Door. <p>Post-flight Plans: TBD repairs for retirement ferry flight.</p> |

APPENDIX B
STS-135 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES

| IFA Number | Title | Comments |
|--------------|--|--|
| STS-135-V-03 | WLES Sensor Unit 1111 Dropped Out of OOM Prematurely | <p>An issue occurred with Wing Leading Edge System (WLES) sensor S/N 1111, which monitored the Starboard wing sensors 7 through 12 RCC panel Interfaces. The unit dropped out of the on-orbit mode prematurely during the planned Group 1 Start 1 for MM/OD monitoring for the Dump, NH, NC4 and Ti maneuvers, as well RPM and Docking periods. The schedule had been to monitor starting at 191/07:25:00 GMT and stop at 192/04:55:00 GMT. After the initial drop-out of the unit, the sensor was programmed again to monitor and it dropped out prematurely a second time. The exact time at which the unit dropped is not known, but it was known that the sensor was successfully monitoring during the third hourly trigger status at 191/10:15:00 GMT. After the third hourly trigger status, the prime and back-up laptop use for communication to the system was lost, but regained communication to the system during the ninth hourly trigger check at which point sensor S/N 1111 showed as out of on-orbit mode.</p> <p>Post-flight plans: Request the unit be removed post-flight and returned to JSC.</p> |
| STS-135-V-04 | PRLA 3 Sys A Microswitch Failed to Indicate Open | <p>During the Multi-Purpose Logistics Module (MPLM) payload unberthing, the bay 12 port Payload Retention Latch Assembly (PRLA) system 1 release indication failed to change state from OFF to ON. The System 2 release indication showed nominal PRLA release. System 1 power to the PRLA was removed by the crew per procedure. If an MPLM payload contingency jettison is required, and if the release switch remains failed, the bay 12 port PRLA will open (release) as it did for payload unberthing. System 1 power would again need to be removed by the crew per procedure. On FD 11 when the MPLM was unberthed, the PRLAs all operated nominally.</p> <p>Post-flight plans: None</p> |
| STS-135-V-05 | ARS LiOH Service Door Won't Open | <p>The crew could not open the Air Revitalization System (ARS) service door. This door provides access to the ARS Lithium Hydroxide (LiOH) servicing location (not the storage location). The middeck latch is free floating. The spring that keeps tension on the latch is suspected to be loose so that the latch won't release. An In-Flight Maintenance (IFM) procedure was completed to open the ARS LiOH Servicing Door and was uploaded to the crew to review and execute on FD 9. The ARS LiOH door latch IFM was performed successfully. The pull-rod became completely unthreaded from the latch pawl. The spring and latch pawl were removed and bagged. The door remained operational using the remaining pull latch. The crew commented that pulling up the floor panel was easy and did not require the pry bar. The crew also commented that the entire procedure took no time at all. Crew tagged and bagged removed parts.</p> <p>Post-flight Plans: Standard LiOH can removal. No unique post-flight processing requirements. The anomaly is closed.</p> |

APPENDIX B
STS-135 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES

| IFA Number | Title | Comments |
|--------------|--|--|
| STS-135-V-06 | OPP-to-LCS Cable Not Seating Properly | <p>The crew called down with an intermitted communication issue with the Orbiter Patch Panel (OPP) Laser Camera System (LCS) Control Computer (LCC) OPP-to-LCS Ethernet cable. The communication issues were dependent on cable movement/position. The Ground controller called up the location of the spare cable. The crew secured the OPP-to-LCS cable with tape and did not swap it out with the spare cable (prior to start of inspection). There are 2 OPP-to-LCC cables currently on-orbit. Also, the TriDAR cable is the same cable and could also be used.</p> <p>On FD 3, the TriDAR had similar communication issues. TriDAR used the same laptop, but a different cable. The cables are the same design.</p> <p>The LCS was activated for Orbiter Boom Sensor System (OBSS) Handoff. No communication issues with the LCS. The crew did not report how they secured the OPP-to-LCC cable for that activity. It is also assumed that the crew did not swap the OPP-to-LCC cable with the spare or that they switched the laptop. On FD 12, no reports from the crew on whether any communication issues encountered as part of Late Inspection.</p> <p>Post-flight Plan: Post-flight , the cables were removed. The anomaly is closed.</p> |
| STS-135-V-07 | LRCS Oxidizer Manifold 5 Valve Failure during post-flight valve test | <p>When the Left Manifold 5 Oxidizer Isolation valve was cycled to open, the Open indication came on while the Closed indication also remained on. Following coordination, the crew was asked to cycle the valve panel switch again in an attempt to clear the anomaly, but with no success. Nearly an hour later at 202/11:26:01 GMT, the anomalous closed indication cleared. Although RCS valve reconfigurations were occurring by Ground Personnel at the time the failure cleared, there was no indication that Ground Personnel had cycled the manifold 5 switch (no change in RPC status).</p> <p>This is the first service failure of the "new" manifold 5 isolation valve--a torque motor valve originally developed for the Forward Interconnect System, certified in 2004-2005, and first installed in OV-104/LP04 during Return to Flight (RTF) activities. The valve has separate OPEN and CLOSED Valve Position Indication (VPI) switches, so having both VPI indications (and correct RPC indications) suggests a problem was most likely caused by an issue with the CLOSED VPI switch on the valve. This cannot be determined without postflight ground testing.</p> <p>Post-Flight Plan: No ground troubleshooting is planned; it is unknown whether down-mission processing will even require the valve to be cycled again prior to closing the valve as part of configuring the pod for the shipment to White Sands Test Facility (WSTF). The PRT's decision was to call this failure in to PRACA for documentation purposes and disposition it as safe for transport. It will be decontaminated as part of the pod's manifold drains prior to pod removal.</p> |

**APPENDIX B
STS-135 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

| IFA Number | Title | Comments |
|--------------|-------------------------|--|
| STS-135-V-08 | GPC 4 (PASS SM) Fail | <p>At 195/22:07:18 GMT, General Purpose Computer (GPC) 4 failed. At the time of the failure, GPC 1 was configured as the single G2 GPC and GPC 4 was the System Management (SM). At the time of the failure, GPC 1 annunciated an On-Board Fault Summary (OFS) message against GPC 4 "GPC 4 1" as well as a U-fail. No GPC or I/O errors were annunciated by GPC 1. GPC 4's data went static and no errors (I/O or GPC) were logged prior to it failing. After GPC 4 failed, the GPC synchronizer fail pointer on GPC 1 changed to (SSIP SYNC FAIL). Previously, the synchronizer fail pointer was 8FAB (Norm MODE to STBY/HALT). GPC 1's view of GPC 4's duty cycle was static at 44-percent after the failure.</p> <p>The crew powered GPC 4 off and GPC 2 was configured as the new SM GPC. No dumps or recovery actions were taken at that time in order to get the crew back to bed.</p> <p>Data dumps from GPC 1 and GPC 4 were performed for ground analysis. GPC 4 was re-IPL'ed and recovered. It was subsequently put into a "freeze-dry" state until such a time that it was needed. GPC 4 operated nominally for several hours after which it was returned to the "freeze-dry" state.</p> <p>Analysis of the data downloaded from GPCs 1 and 4 was completed. While the data were insufficient to definitively isolate the root cause of the GPC 4 issue, evidence was consistent with a transient failure condition.</p> <p>On FD 9, GPC 4 was added to the Guidance Navigation and Control (GNC) redundant set to give it some run time. On FD 10, GPC 4 was reassigned as the Systems Management (SM) GPC.</p> <p>On FD 12, the Flight Software (FSW) team reported that further analysis of the core dump identified a memory position where a single bit flip could have caused the GPC failure signature. While not conclusive, it does provide additional information that the possible cause might have been due to a Single Event Upset (SEU). SE&I FSW considers this a hardware issue and will therefore not be taking an integrated IFA on this item.</p> <p>Post-flight plans: None and the anomaly is closed</p> |

**APPENDIX B
STS-135 IN-FLIGHT ANOMALIES
ORBITER ANOMALIES**

| IFA Number | Title | Comments |
|--------------|------------------------|--|
| STS-135-V-09 | OV-104 Nose Cap Damage | <p>During the [post-landing runway inspection and evaluation on post landing, the OV-104 Nose Cap expansion seal on the R/H side was noted to have SiC damage. Damage was due to mechanical loading induced by a minimum gap condition, and was similar to the damage noted on the L/H side after STS-115 on OV-104. The damage is unrelated to the RCC root cause spallation effort for WLE panel joggle region.</p> <p>The following are PRT Observations:</p> <ol style="list-style-type: none"> 1. SiC coating was not liberated until after landing during runway team evaluation; 2. Coating was not recovered but no evidence of visible oxidation to black carbon substrate; 3. Damage is new and not a previous repair. Pre-flight Infrared (IR) thermography images reviewed and no evidence of any subsurface issues were evident. The Chin Panel to Nose Cap gap in this area was 0.010" (criteria is 0.016 in. to 0.086 in.; 4. Preflight gap measurements were within specification. The expansion seal(s) may have shifted slightly; 5. Chin Panel was removed and re-installed during STS-132 processing – flown twice; 6. Damage scenario - supported by the post flight observations; <ol style="list-style-type: none"> a. During entry, the chin panel to nose cap gap closes up due to RCC expansion from thermal effects; b. Contact occurred at this localized area initiating a stress riser causing a SiC coating crack; c. Late in entry; post-peak heating; the Type A sealant starts to solidify thus fusing the nose cap/chin panel together; d. Upon landing, the heat-soak reaches the STR opening up the chin panel/nose cap gap; e. Upon gap opening, the Type A pulled the SiC chip away from the nose cap expansion seal causing the event. <p>The Problem Resolution Team (PRT) discussed the most likely approach in the event of another flight would be to repair the nose cap;</p> <ol style="list-style-type: none"> a. L/H side repair is performing nominally; b. Would require Chin Panel removal; c. Repair would be "fail-safe" like other side – no burn-through predicted in the event of a failure due to part geometry/thickness in this area <p>The damage was the result of a minimum gap condition. The damage was unrelated to the infamous WLE RCC root-cause spallation failure mode observed at the joggle region. No change in the root cause team's recommendations or SSP's accepted risk. The PRT recommendation was to close this action, with no constraint to OV-104 display activities or previous RCC root cause risk acceptance.</p> <p>Post-Flight Plan: None.</p> |

APPENDIX C

STS-135 DOCUMENT SOURCES

MER DAILY REPORTS

The following STS-135 MER Daily Reports by David S. Moyer, Lead MER Manager:

- Launch and First Daily Report, dated July 8, 2011
- Second Daily Report, dated July 9, 2011
- Third Daily Report, July 10, 2011
- Fourth Daily Report, dated July 11, 2011
- Fifth Daily Report, dated July 12, 2011
- Sixth Daily Report, dated July 13, 2011
- Seventh Daily Report, dated July 14, 2011
- Eighth Daily Report, dated July 15, 2011
- Ninth Daily Report, dated July 16, 2011
- Tenth Daily Report, dated July 17, 2011
- Eleventh Daily Report, dated July 18, 2011
- Twelfth Daily Report, dated July 19, 2011
- Thirteenth Daily Report, dated July 20, 2011
- Landing Plus 2 Hour Report, dated July 21, 2011
- Mission Summary Report, dated July 25, 2011

ET/SRB/RSRM/SSME REPORTS

- STS-135 ET Impact Coordinates, David W. Morr, USA-Huntsville, August 8, 2011
- STS-135 HOSC Console Flash Report, David W. Morr, USA-Huntsville, July 8, 2011
- STS-135 RSRM Flash Report, Robert Zahl, ATK, July 8, 2011
- STS-135 SRB Open Assessment, Thomas F. Ford, NASA-KSC, July 13, 2011

ORBITER REPORTS

- STS-135 Shuttle Remote Manipulator System, Nik Doshewnek, MDA-Houston, July 25, 2011
- STS-135 Orbiter Docking System Summary, Robert E. Davis, NASA-JSC, August 5, 2011
- STS-135 OMS Report, Edward J. Fitzgerald, Boeing-Houston, August 5, 2011
- STS-135 RCS Mission Report, Edward J. Fitzgerald, Boeing-Houston, August 5, 2011
- STS-135 Postflight Aeroheating Report, Dennis C. Chao, Boeing-Houston, August 26, 2011
- STS-135 Fuel Cells Mission Report, Kenneth D. Adams, Boeing-Houston, August 4, 2011
- STS-135 Power Reactant Storage and Distribution, Kenneth D. Adams, Boeing-Houston, August 4, 2011
- STS-135 Global Positioning System Report, Ray W. Nuss, NASA-Houston, July 21, 2011
- STS-135 Final Mission Events List, Vernon C. Hill, ESCG-Houston, July 25, 2011

OTHER REPORTS

- STS-135 Post Launch Report, Jeffrey S. Thon, NASA-KSC, July 8, 2011
- STS-135 CSR Final Report, Phyllis Grounds, NASA-JSC, August 17, 2011
- STS-135 Final Landing Debris Runway Report, Thomas F. Ford, NASA-KSC, August 12, 2011
- STS-135 Pre- and Post-EVA No. 1 Data, Samuel D. Hamilton Sundstrand, July 12, 2011
- STS-135 Final Extravehicular Activity Report, William W. West, Hamilton Sunstrand, August 9, 2011
- STS-135 Post-Launch Debris Report, Jeffrey S. Thon, NASA-KSC, July 8, 2011
- STS-135 prop30 Mass Properties Report, R. R. Mark, NASA-JSC, July 22, 2011

STS-135 Imagery Reports, Imagery Integration Group, NASA-JSC, July 8, 2011 through July 14, 2011
STS-135 Ascent Hazard Analysis Final Report, Lillian P. Gibson, Boeing-Houston, August 1, 2011
STS-135 Flight Operations/MOD Anomalies, Gregory A. Lange, August 26, 2011
STS-135 Descent Postflight Summary, Christopher M. Re USA-Houston, July 26, 2011
STS-135 Final Numbers History, Kyle Herring, NASA-Houston, August 9, 2011
STS-135 Launch + 2 Day Report, Lionel J. Russell, USA-Houston, July 13, 2011
STS-135 Government Furnished Equipment/Flight Crew Equipment, Kenneth L. Brown, NASA-JSC,
September 1, 2011

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|--------------------------|--|
| A | Ampere |
| AGT | Adaptive Guidance Throttle |
| AHMS | Advanced Health Monitoring System |
| A/L | Airlock |
| AM | Amplitude Modulation |
| AMOS | Air Force Maui Optical Supercomputing Site |
| APFR | Articulating Portable Foot Restraint |
| APU | Auxiliary Power Unit |
| ARED | Advanced Resistive Exercise Device |
| ARS | Atmospheric Revitalization System |
| BFS | Backup Flight System |
| BFS WHI | Backup Flight System Initial Weight of Helium Load |
| BLT | Boundary Layer Transition |
| BMRRM | Bearing Motor Roll Ring Module |
| CBM | Common Berthing Mechanism |
| CDR | Commander |
| CDRA | Carbon Dioxide Recycling Assembly |
| CDT | Central Daylight Time |
| CO ₂ | Carbon Dioxide |
| COLTS | Contingency Operations Large Adapter Plate Assembly (LAPA) Tool |
| COMM | Communications |
| CPA | Controller Panel Assemblies |
| CPM | Cell Performance Monitor |
| CQ | Crew Quarter |
| CSA | Compound Specific Analyzer |
| CSR | Customer Support Report |
| CWC | Contingency Water Container |
| CWC-I | Contingency Water Container-Iodine |
| DAP | Digital Autopilot |
| DAT | Damage Assessment Team/Debris Assessment Team |
| DCS | Debris Containment System |
| DCB | Double Cold Bag |
| DOLILU | Day of Launch I Load Update |
| DPS | Data Processing System |
| DRWP | Doppler Radar Wind Profile |
| ΔV | Differential Velocity |
| ECLSS | Environmental Control and Life Support System |
| ECO | Engine Cut-off |

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|----------------------------------|---|
| EDR | European Drawer Rack |
| EI | Entry Interface |
| EMU | Extravehicular Mobility Unit |
| EOTP | Enhanced ORU Temporary Platform |
| ESP | External Stowage Platform |
| ET | External Tank |
| ETCS | External Thermal Control System |
| EV | Extravehicular (Crewmember) |
| EVA | Extravehicular Activity |
| FCMS | Fuel Cell Monitoring System |
| FCS | Flight Control System |
| FCV | Flow Control Valve |
| FD | Flight Day |
| FGB | Functional Cargo Block |
| FI | Focused Inspection |
| FID | Failure Identifier |
| FIT | Final Inspection Team |
| FIV | Fuel Isolation Valve |
| FOM | Figure of Merit |
| FOV | Field of View |
| 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 |
| GH ₂ | Gaseous Hydrogen |
| GLA | General Luminaire Assembly |
| GLACIER | General Active Cryogenics ISS Experiment Refrigerator |
| GMT | Greenwich Mean Time |
| GN ₂ | Gaseous Nitrogen |
| GN&C | Guidance Navigation and Control |
| GO ₂ /GOX | Gaseous Oxygen |
| GPC | General Purpose Computer |
| GPS | Global Positioning System |
| GUCP | Ground Umbilical Carrier Plate |
| H ₂ | Hydrogen |
| HDP | Hold Down Post |
| HPFTP | High Pressure Fuel Turbo Pump |

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|--------------------------|---|
| HPU | Hydraulic Power Unit |
| HYD | Hydraulic |
| IDS | Impact Detection System |
| IFA | In-Flight Anomaly |
| IFM | In-Flight Maintenance |
| IMU | Inertial Measurement Unit |
| IMV | Inter-Module Ventilation |
| IPL | Initial Program Load |
| IPR | Interim Problem Report |
| IREDD | Interim Resistive Exercise Device |
| I_{SP} | Specific Impulse |
| ISLE | In-suit Light Exercise |
| ISS | International Space Station |
| ISSP | International Space Station Program |
| IVA | Inter-Vehicular Activity |
| JSC | Johnson Space Center |
| KSC | Kennedy Space Center |
| L | Launch |
| LCC | Launch Commit Criteria/Laser Camera Computer |
| LCS | Laser Camera System |
| LEE | Latching End Effector |
| LEO | Low Earth Orbit |
| LH | Left Hand |
| LH ₂ | Liquid Hydrogen |
| LiOH | Lithium Hydroxide |
| LMC | Lightweight Multi-Purpose Experiment Support Structure Carrier/Lightweight Multi-Purpose Carrier |
| LO ₂ LOX | Liquid Oxygen |
| LOS | Loss of Signal |
| LPFTP | Low Pressure Fuel Turbo Pump |
| MADS | Modular Auxiliary Data System |
| MAUI | Maui Analysis of Upper Atmospheric Modification |
| MC | Midcourse Correction |
| MCA | Major Constituent Analyzer |
| MECO | Main Engine Cutoff |
| MELFI | Minus Eighty Degree Celsius Laboratory Freezer for ISS |
| MER | Mission Evaluation Room |
| MET | Mission Elapsed Time |
| MISSE | Materials International Space Station Experiment |
| MLE | Middeck Locker Equivalent |

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|----------------------------------|---|
| MLI | Multi-Layer Insulation |
| MLP | Main Launch Platform |
| MM | Major Mode |
| MM/OD | MicroMeteoroid/Orbital Debris |
| MMT | Mission Management Team |
| MPESS | Lightweight Multi-Purpose Experiment Support Structure |
| MPLM | Multi-Purpose Logistics Module |
| MPM | Manipulator Positioning Mechanism |
| MPS | Main Propulsion System |
| MRL | Manipulator Release Latches |
| N ₂ | Nitrogen |
| NASA | National Aeronautics and Space Administration |
| NC | Nominal Correction |
| NH | Nominal Height |
| NSTS | National Space Transportation System |
| O ₂ | Oxygen |
| OAA | Orbiter Access Arm |
| OAFGSS | Orbiter Aft Fuselage Gas Sample System |
| OBSS | Orbiter Boom Sensor System |
| ODS | Orbiter Docking System |
| OIU | Orbiter Interface Unit |
| OME | Orbital Maneuvering Engine |
| OMRSD | Operational Maintenance and Requirements Specification Document |
| OMS | Orbital Maneuvering System |
| OOM | On-Orbit Monitoring |
| OPO | Orbiter Project Office |
| OPP | Orbiter Patch Panel |
| OPS | Operations |
| ORMatE | Optical Reflector Materials Experiment |
| ORU | Orbital Replacement Unit |
| OV | Orbiter Vehicle |
| PAO | Public Affairs Office |
| PASS | Primary Avionics Software System |
| PASS WHI | PASS With Initial Helium Load |
| PCDF | Protein Crystallization Diagnostics Facility |
| PDGF | Power Data and Grapple Fixture |
| PLBD | Payload Bay Door |
| PM | Pump Module |

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|----------------------------------|--|
| PMA | Pressurized Mating Adapter |
| PMM | Permanent Multipurpose Module |
| PPRA | Positive Pressure Relief Assembly |
| PRCS | Primary Reaction Control System |
| PRLA | Payload Retention Latch Assembly |
| PRSD | Power Reactant Storage and Distribution System |
| PSIG | Propulsion System Integration Group |
| PSSC | Pico-Satellite Solar Cell |
| PV&D | Purge, Vent and Drain |
| PWB | Potable Water Bus |
| PWR | Payload Water Reservoir |
| QD | Quick Disconnect |
| RAMBO | Ram Burn Observations |
| RCC | Reinforced Carbon-Carbon |
| RCS | Reaction Control System |
| REBA | Rechargeable EVA Battery Assembly |
| RH | Right Hand |
| RJMC | Rotary Joint Motor Controller |
| ROI | Regions of Interest |
| RPL | Rated Power Level |
| RPM | R-Bar Pitch Maneuver |
| R&R | Remove and Replace |
| RRM | Robotics Refueling Station |
| 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 |
| SDFS | Smoke Detection and Fire Suppression |
| STDO | Station Development Test Objective |
| 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 |
| S/N | Serial Number |
| SPDM | Special Purpose Dexterous Manipulator |

APPENDIX D

STS-135 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

| Acronym/ Abbreviation | Explanation |
|----------------------------------|---|
| SRMS | Shuttle Remote Manipulator System |
| SRSS | Shuttle Range Safety System |
| SSME | Space Shuttle Main Engine |
| SSP | Space Shuttle Program |
| SSRMS | Space Station Remote Manipulator System |
| SSTS | Space Tracking Surveillance System |
| ST | Star Tracker |
| STS | Space Transportation System |
| T/C | Thermocouple |
| TEA | Torque Equilibrium Attitude |
| TI | Terminal Initiation /Transfer Initiation |
| TMBU | Table Maintenance Block Update |
| T _o | Liftoff |
| TPL | Transfer Priority List |
| TPS | Thermal Protection System |
| TRIDAR | Triangulation and LIDAR Automated Rendezvous and Docking |
| TSM | Tail Service Mast |
| TVIS | Treadmill with Vibration Isolation and Stabilization |
| UCCAS | Upper Outboard Unpressurized Cargo Carrier Attach System |
| UHF | Ultra High Frequency |
| ULF | Utilization Logistics Flight |
| UPA | Urine Processing Assembly |
| UTC | Universal Time Code |
| VIP | Very Important Person |
| VNS | Visual Navigation System |
| VRCS | Vernier Reaction Control System |
| WHC | Waste and Hygiene Compartment |
| WLE | Wing Leading Edge |
| WLE IDS | Wing Leading Edge Impact Detection System |
| WPA | Water Processing Assembly |
| WSB | Water Spray Boiler |

APPENDIX D

STS-135 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 |
| hr | hour |
| In. | inch |
| inHg | Inch of Mercury |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| lb | pound |
| lb _m /lbm | pound mass |
| min | minute |
| msec | millisecond |
| mv | millivolt |
| nmi | nautical mile |
| ppm | parts per million |
| scim | Standard cubic inches per minute |
| sec | second |
| torr | Unit of pressure (ratio of 760 to one standard atmosphere) |
| V | Volt |