NASA-CR-197233

NSTS-08289

# STS-60 SPACE SHUTTLE MISSION REPORT

(NASA-CR-197233) STS-60 SPACE SHUTTLE MISSION REPORT (Lockheed Engineering and Mgmt. Services Co.) 44 p

N95-26189

Unclas

G3/16 0048154

APRIL 1994



NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

NSTS-08289

# STS-60

# SPACE SHUTTLE

# MISSION REPORT

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April 1994

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# INTRODUCTION

The STS-60 Space Shuttle Program Mission Report summarizes the Payload activities as well as the Orbiter, External Tank (ET), Solid Rocket Booster (SRB), Redesigned Solid Rocket Motor (RSRM), and the Space Shuttle main engine (SSME) systems performance during the sixtieth flight of the Space Shuttle Program and eighteenth flight of the Orbiter vehicle Discovery (OV-103). In addition to the Orbiter, the flight vehicle consisted of an ET designated at ET-61 (Block 10); three SSME's which were designated as serial numbers 2012, 2034, and 2032 in positions 1, 2, and 3, respectively; and two SRB's which were designated BI-062. The RSRMs that were installed in each SRB were designated as 360L035A (lightweight) for the left SRB, and 360Q035B (quarterweight) for the right SRB.

This STS-60 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement as documented in NSTS 07700, Volume VIII, Appendix E. That document requires that each major organizational element supporting the Program report the results of their hardware evaluation and mission performance plus identify all related in-flight anomalies.

The primary objectives of the STS-60 mission were to deploy and retrieve the Wake Shield Facility-1 (WSF-1), and to activate the Spacehab-2 payload and perform on-orbit experiments. Secondary objectives of this flight were to activate and command the Capillary Pumped Loop/Orbital Debris Radar Calibration Spheres/Breman Satellite Experiment/Getaway Special (GAS) Bridge Assembly (CAPL/ODERACS/BREMSAT/GBA) payload, the Auroral Photography Experiment-B (APE-B), and the Shuttle Amateur Radio Experiment-II (SAREX-II).

The STS-60 mission was planned as a nominal eight-day mission with two contingency days available should Orbiter contingency operations or weather avoidance be required. The sequence of events for the STS-60 mission is shown in Table I. The official Orbiter Project Office Problem Tracking List is shown in Table II. The official Government Furnished Equipment (GFE) Problem Tracking List is shown in Table III, and the official MSFC Problem Tracking List is shown in Table IV. In addition, the Integration and Payload in-flight anomalies are referenced in the applicable sections of the report. Appendix A lists the sources of data, both formal and informal, that were used in the preparation of this document. Appendix B provides the definition of acronyms and abbreviations used in this document. All times are given in Greenwich mean time (G.m.t.) as well as mission elapsed time (MET).

The six-person crew for this sixtieth flight of the Space Shuttle Program consisted of Charles F. Bolden, Jr., Col., U. S. Marine Corps, Commander; Kenneth S. Reightler, Jr., Capt. U. S. Navy, Pilot; N. Jan Davis, Ph.D., Civilian, Mission Specialist 1; Ronald M. Sega, Ph.D., Civilian, Mission Specialist 2; Franklin R. Chang-Diaz, Ph.D. Civilian, Mission Specialist 3; and Sergei Konstantinovich Krikalev, Civilian and Russian Cosmonaut, Mission Specialist 4. STS-60 was the fourth space flight for the Pilot and Mission Specialist 3, the second space flight for the Pilot and Mission Specialist 1; the first space flight for Mission Specialist 2; and the first U. S. space flight for Mission Specialist 4; however, Mission Specialist 4 has flown on two Soyuz/Mir missions.

## MISSION SUMMARY

The countdown for the STS-60 launch was completed with no unplanned holds, and this resulted in an on-time launch on a 57-degree inclination at 034:12:10:00.000 G.m.t. (7:10 a.m. e.s.t.) on February 3, 1994, from launch complex 39A. Evaluation showed that all SSME and RSRM start sequences occurred as expected, and the launch phase performance was satisfactory in all respects. SRB separation, entry, deceleration, and water impact occurred as anticipated with no anomalies noted. Performance of the SSMEs, ET, and main propulsion system (MPS) was nominal. A determination of overall vehicle performance during ascent was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine Isp, as determined for the time period between SRB separation and start of 3-g throttling, was 452.47 seconds as compared to an MPS tag value of 452.63 seconds.

As a result of the nominal ascent vehicle performance on the direct insertion trajectory, no orbital maneuvering subsystem (OMS) 1 maneuver was required. A nominal OMS 2 maneuver was performed at 034:12:52:16 G.m.t. (00:00:42:16 MET), and all OMS parameters indicated normal subsystem performance. OMS 2 was 163.5 seconds in duration and imparted a differential velocity ($\Delta V$) of 268.7 ft/sec. The orbit achieved as a result was 191.4 by 189.6 nmi.

The payload bay doors were opened by 034:13:41:20 G.m.t. (00:01:31:20 MET) in a normal manner.

During Spacehab activation, a procedure which consisted of removing a diffuser cap from the middeck floor air duct fitting and placing it on the tunnel adapter floor fitting was to be performed. However, because of the lack of sufficient clearance between the tunnel adapter floor fitting and the tunnel adapter floor, nominal positioning of the diffuser cap could not be completed. The diffuser cap was grey-taped into position and functioned as intended for the remainder of the mission.

Major activities for flight day 3 included Wake Shield Facility (WSF) unberthing and a subsequent reberthing after the WSF deployment was waved off. Difficulties were encountered commanding the WSF, and another deployment attempt was performed on flight day 4.

Following the supply water dump at 036:09:44 G.m.t. (01:21:34 MET), 10 discrete instances of supply-water dump-valve leakage were noted. The leakage occurred over a 16-hour 33-minute period which included the time during which the WSF was being maneuvered by the remote manipulator system (RMS). Following the post-sleep activities on flight day 4, the crew purged the supply dump line; Subsequent supply water dumps were performed with the WSF berthed and were followed by a supply water dump line purge. Similar leakage has been noted on previous OV-103 flights (STS-48, STS-53, and STS-56). However, the leakage occurrences on STS-60 were more numerous and encompassed a longer time period than those experienced on previous flights.

The major activity for flight day 4 was a second attempt to deploy the WSF. Problems were encountered with the WSF attitude control system and the deployment was again waved off. The WSF remained attached to the end of the RMS where many of its planned science operations were completed.

While the WSF remained on the RMS, excess supply water (95 lb) was transferred to a contingency water container (CWC) at 037:22:31 G.m.t. (03:10:21 MET). This action was performed to prevent WSF contamination, which could occur during a water dump.

The final berthing of the WSF was completed at 040:12:18:27 G.m.t. (06:00:08:27 MET). Also, deployment of six Orbital Debris Radar Calibration Spheres (ODERACS) occurred at 040:14:53:24 G.m.t. (06:02:43:24 MET), and deployment of the Bremen Satellite (BREMSAT) was completed at 040:19:23:17 G.m.t. (06:07:13:17 MET).

On flight day 8, the flight control system (FCS) checkout and the reaction control subsystem (RCS) hot-fire test were performed with no anomalies noted. Auxiliary power unit (APU) 1 ran for 6 minutes 8 seconds during the FCS checkout, and all thrusters operated satisfactorily during the RCS hot-fire test.

All stowage activities in preparation for entry were completed. The payload bay doors were closed at 042:14:09:17 G.m.t. (08:01:59:17 MET) and latched at 042:14:10:30 G.m.t. (08:02:00:30 MET). Because the weather conditions at the KSC Shuttle Landing Facility (SLF) were unacceptable for landing operations, the first landing opportunity was waived. However, the weather improved and conditions were acceptable for landing on the second opportunity. The deorbit maneuver was initiated at 042:18:14:50 G.m.t. (08:06:04:50 MET). The maneuver was approximately 234.4 seconds in duration and the $\Delta V$ was 407.0 ft/sec. Entry interface occurred at 042:18:47:51 G.m.t. (08:06:37:51 MET).

Main landing gear touchdown occurred at the SLF on concrete runway 15 at 042:19:19:22 G.m.t. (08:07:09:22 MET) on February 11, 1994. The Orbiter drag chute was deployed satisfactorily at 042:19:19:32.5 G.m.t., and nose landing gear touchdown occurred 9.5 seconds after drag chute deployment. The drag chute was jettisoned at 042:19:19:54.9 G.m.t. with wheels stop occurring at 042:19:20:13 G.m.t. Indications are that the rollout was normal in all respects. The flight duration was 08 days 07 hours 09 minutes 22 seconds. All three APU's were powered down by 042:19:35:38.80 G.m.t. The crew completed the required postflight reconfigurations and departed the Orbiter landing area.

# PAYLOADS

## SPACEHAB SYSTEM PERFORMANCE

The Spacehab Flight Unit-2 Module and its systems exhibited the same near-flawless performance on STS-60 as Flight Unit-1 demonstrated on STS-57. There were no Spacehab Launch Commit Criteria (LCC) violations during the countdown, and performance of the Spacehab was nominal throughout the launch phase.

During Spacehab activation, a procedure which consisted of removing a diffuser cap from the middeck floor air duct fitting and placing it on the tunnel adapter floor fitting was to be performed. However, because of the lack of sufficient clearance between the tunnel adapter floor fitting and the tunnel adapter floor, nominal positioning of the diffuser cap could not be completed (Flight Problem STS-60-V-01). The diffuser cap was grey-taped into position and functioned as intended for the remainder of the mission.

During activation, a cross-talk problem was noted between the intercommunications loops and the Spacehab caution and warning system that was heard on the air-to-ground communications. This problem is discussed in the Communications and Tracking section of this report.

The Spacehab module interior temperature was more closely controlled on this mission, and the crew was kept more comfortable throughout the flight. Calibration of the thermal control system after STS-57 allowed the active control of module interior temperature on STS-60 by controlled mixing of the hot and cold water upstream of the module heat exchangers. Performance of the thermal control system components was nominal during the mission.

The only significant problem that affected Spacehab systems occurred on flight day 3 when the flight crew noted that the flexible rubber duct connecting the Orbiter environmental control and life support system (ECLSS) supply line to the Spacehab floor fitting was partially collapsed. Subsequent troubleshooting identified the cause as blockage of the Spacehab atmospheric revitalization system (ARS) fan inlet debris screen in the fan inlet muffler. This blockage increased the suction in the ECLSS supply line and collapsed the duct. An in-flight maintenance (IFM) procedure was successfully performed on flight day 4 to clean the debris screen and reinforce the flexible duct by inserting a flight data file cover (plastic) inside the flexible duct. The Spacehab ARS fan performance was restored to nominal levels. The module electrical power and command and data systems performed nominally throughout the mission with no anomalies or evidence of performance degradation noted.

## SCIENTIFIC RESULTS OF SPACEHAB EXPERIMENTS.

### Astroculture-3

Performance of the Astroculture (ASC-3) plant growth system was nearly perfect. Some scientific parameters were downlinked through the portable audio data modem (PADM). Final results will be determined through postflight hardware and data analysis. Results of this experiment will be published in separate documentation.

## Bioserve Pilot Laboratory

The Bioserve Pilot Laboratory (BPL) processed perfectly all but one of the bioprocessing modules (BPMs). Upon activation of that one BPM, the crew noticed a drop of fluid in the vicinity of the sample valve. The BPM, which was already double-bagged for containment, was stowed immediately, according to the plan. Subsequent to the mission, the fluid at the valve was determined to have been residual water from a preflight leak check of the BPM. The BPL experiment results will be determined through postflight analysis of all BPMs, and these results will be reported in separate documentation.

## Commercial Generic Bioprocessing Apparatus

The Commercial Generic Bioprocessing Apparatus (CGBA) system performed well with no significant anomalies. The monitoring time for one of the group activation packs (GAPs) was reduced, consequently, a small amount (1 - 2 percent) of science results were lost.

## Commercial Protein Crystal Growth

The commercial protein crystal growth (CPCG) experiment hardware operated satisfactorily. The crew reported detection of the beginning of nucleation process on flight day 2. This was the first time that protein nucleation has been detected in space. Because of a delay in reprogramming a temperature profile, the Protein Crystal Facility Light Scattering Unit was paused overnight and reprogrammed approximately 13 hours later. This 13-hour pause and reprogramming resulted in a loss of visibility into the nucleation process. However, later downlinked information confirmed the growth of human-insulin crystals. After completion of sample inspection and other data analysis, the results of this experiment will be published in a separate document.

## Equipment for Controlled Liquid Phase Sintering Experiment - Spacehab

The Equipment for Controlled Liquid Phase Sintering Experiment - Spacehab (ECLIPSE - Hab) met all of its processing objectives, although a brief false-start occurred because of a software discrepancy. Results will be published in a separate document after all analysis and inspections are completed.

## Immunology Experiment-01

The Immunology Experiment-01 (IMMUNE-01) worked well and temperatures remained within the expected band. All of the animals used in the experiment survived the flight, and results of the experiment will be based on laboratory analysis. The results of this experiment will be published in a separate document.

## Organic Separation

The Organic Separation (ORSEP) facility experienced mechanical failure of both sample transfer disks. This resulted in no activation of any of the experiments within the ORSEP facility. The source of the failure was an incompatibility of the sample fluids and sealing grease which resulted in the two rotating plates bonding together. Additionally, there was a failure of the thermal control system on one of the two transfer disks that, although not a safety hazard, did significantly compromise the viability of the experiment. There is an effort underway at the experiment's home institution to try to glean some science from the flight, but no results have as yet been reported.

## Pennsylvania State Biomodule

During the late access/installation, the failure of a circuit board in the Pennsylvania State Biomodule (PSB) caused the loss of a status display panel. Procedures were developed and implemented to allow the crew to control PSB "in the blind" during the mission. However, postflight analysis revealed that the biomodule failed to activate properly on-orbit, thereby minimizing science return on this experiment.

## Space Acceleration Measurement System

The Space Acceleration Measurement System (SAMS) hardware operation was excellent. Only minor data losses occurred, and these were caused by late disk changes.

## Space Experiment Facility

The Space Experiment Facility (SEF) hardware worked well with no anomalies. Due to the unavailability of onboard real-time TV downlink, the Principal Investigator was unable to prevent spurious nucleation of the transparent furnace "A" side semiconductor crystal growth. The "B" side semiconductor crystal, however, appears to have grown exceptionally well and produced a well-formed crystal. The SEF opaque furnace ran according to its pre-programmed profile, and results (dependent on sample analysis) will be reported in separate documentation.

## Stirling Orbiter Refrigerator/Freezer

The Stirling Orbiter Refrigerator/Freezer (SOR/F) performed satisfactorily. Just before the planned switch to refrigerator mode, a small amount of frost in an air duct caused a loss of cooling. Conversion to the refrigerator mode cleared the frost, and the unit operated properly for the remainder of the mission.

## Sample Return Experiment

The Sample Return Experiment (SRE), which is a passive cosmic dust collector, showed no anomalies on downlink television. Results of this experiment will be obtained from laboratory analysis and will be reported in separate documentation.

## Three-Dimensional Microgravity Accelerometer

The Three-Dimensional Microgravity Accelerometer (3-DMA) front panel g-level displays failed to activate. A problem with the experiment prevented data from being downlinked; however, onboard data recording hardware worked properly for on-orbit acceleration measurements. Results of that data will be obtained through ground-data analysis. An operational problem during experiment installation prevented the instrument from recording ascent and descent data.

## WAKE SHIELD FACILITY

The pre-deployment checkout of the WSF and the RMS went well, and as a result, the WSF was grappled at 036:11:13.57 G.m.t. (01:23:03:57 MET) with unberthing at 036:12:23:41 G.m.t. (02:00:13:41 MET). After moving into the ram-cleaning position, the proper configuration became uncertain due to the status lights being masked by the sunlight. Troubleshooting resulted in a loss of communication capability. The WSF free-flyer (FF) was berthed overnight at 036:20:58:21 G.m.t. (02:08:48:21 MET). Evaluation of the events indicated the communication problem was related to near-field radio frequency (RF) multipath interference on the WSF or a payload RF communication problem. On flight day 4, the WSF FF was again grappled at 037:11:14:10 G.m.t. (02:23:04:10 MET) and unberthed at 037:11:53:51 G.m.t. (02:23:43:51 MET). Additional communication losses occurred, but communication was recovered with a hard reboot of the spacecraft computer (SC 2).

During the checkout of the attitude determination and control system (ADACS), the data indicated the inability of the ADACS to properly determine the WSF attitude. Troubleshooting was unsuccessful. At this point in the mission, time prevented accomplishing alternate methods for deployment and retrieval. Therefore, an agreement was reached to not deploy the WSF. With the WSF on the RMS in the Molecular Beam Epitaxy (MBE) growth position, five crystals were grown. The Reflection High Energy Election Diffraction (RHEED) gun filament that monitors the growth rate and surface characteristics of the epitaxially grown material during processing failed. This failure did not inhibit crystal growth. Charge Analysis and Wake Study (CHAWS) data collection followed the crystal growths, but the study was occasionally perturbed by commanding problems. The final berthing of the WSF FF occurred at 040:12:18:27 G.m.t. (06:00:08:27 MET) and the RMS was ungrappled from the WSF at 040:12:45:29 G.m.t. (06:00:35:29 MET).

Approximately four hours after latching the WSF to its carrier, the Payload Latch 2 Release Command indicator changed state to show that the release command was present (Flight Problem STS-60-V-05). The logic power and mechanical power to the latches were off at the time, and the latch microswitches continued to indicate a latched condition. The latches were not powered up again, and multiple inhibits to latch movement were present throughout the remainder of the mission. This problem is discussed in the Avionics and Software Support section of this report.

At 042:13:55 G.m.t. (08:01:45 MET), the Payload Latch 2 latch indication A changed from a latched to a not-latched state. The payload Latch 2 system B indication had transferred 1.6 seconds earlier than system A during WSF latching. This resulted in the system A microswitch being minimally actuated. The failure has been isolated during KSC troubleshooting to payload latch rigging, which will be rigged correctly prior to the next flight. This problem has been assigned to the KSC Payloads group for resolution and documentation.

## CAPL/ODERACS/BREMSAT/GAS BRIDGE ASSEMBLY

### Capillary Pumped Loop

While only nine of the 67 planned tests were completed, much was learned about the use of a capillary system as a thermal control system for spacecraft.

Specifically, the Capillary Pumped Loop (CAPL) science revealed that the ground-verified start-up procedures will not work reliably in zero-g. This information will be incorporated into the design of the Earth Observation System (EOS). The effect of extended time in cold attitudes (experienced during the WSF activities) made start-up even more difficult. A redesign of the CAPL is underway with plans for flying the experiment on a future flight of Space Shuttle.

### Orbital Debris Radar Calibration Spheres

The six Orbital Debris Radar Calibration Spheres (ODERACS) were deployed on time at 040:14:53:24 G.m.t. (06:02:53:24 MET). All tracking stations locked onto the spheres as predicted.

### Bremen Satellite Experiment

After warming the Bremen Satellite Experiment (BREMSAT) up to -12 °C, the BREMSAT was successfully deployed at 040:19:23:17 G.m.t. (06:07:13:17 MET). The ground station at the University of Bremen reported that the spacecraft is healthy with the attitude control system operating nominally. Two experiments' data recording during the first 48 hours of the mission was lost due to a spacecraft malfunction. The atomic oxygen experiment (experiment 6) and the dust detector experiment (experiment 3) are operating nominally and providing good data. Experiments 4 and 5 have not been operated as of this writing. Reactivation of experiments 1 and 2 is planned for the future.

### Getaway Special Bridge Assembly

The Getaway Specials (GAS) experiments located on the bridge assembly in the payload bay were nominally performed by the crew. Data from these experiments was processed after the flight, and the success of these experiments will be determined from postflight data review and analysis. The results will be published in separate documentation.

## AURORAL PHOTOGRAPHY EXPERIMENT-B

The Auroral Photography Experiment-B (APE-B) primary purpose on this flight was to support the WSF CHAWS experiment. Two opportunities were available for additional APE-B operations. Success of these operations will be determined upon examination of the photography during the postflight time frame.

## SHUTTLE AMATEUR RADIO EXPERIMENT

The Shuttle Amateur Radio Experiment (SAREX) was successfully used in making five school contacts. These contacts were with schools in Moscow, Russia; Boise, Idaho; Mars, Pennsylvania; Chariton, Iowa; and Sidney, Maine. In addition, the SAREX was to be used to contact Mir (Russian Space Station) personnel, but all attempts at communicating with the Mir were unsuccessful.

## VEHICLE PERFORMANCE

### SOLID ROCKET BOOSTER

All Solid Rocket Booster (SRB) systems performed as expected. The SRB prelaunch countdown was normal. The right-hand SRB rock hydraulic power unit (HPU) gas generator (GG) bed temperature measurement (primary A) became erratic shortly after GG bed heater activation. The right-hand secondary GG bed temperature sensor was used to control the heater for that system. No SRB LCC or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred.

Both SRBs were successfully separated from the External Tank (ET) 125.1 seconds after liftoff, and reports from the recovery area indicated that the deceleration subsystems performed satisfactorily.

A suspension line and the confluence keeper on the right-hand drogue parachute was severed during drogue parachute deployment. This is a first-time occurrence of this problem. Investigation has concluded that the line twisted during deployment, partially cutting the line on a metal staple used by the manufacturer during sewing operations. The weakened line then broke under the load. Further details can be found in the Space Shuttle STS-60 Flight Evaluation Report, Volume II, MSFC-RPT-2051.

Both SRBs were recovered and towed back to Port Canaveral from where the SRBs were transferred to KSC for disassembly and refurbishment.

### REDESIGNED SOLID ROCKET MOTOR

This thirty-fifth RSRM flight set performed nominally, and no LCC violations occurred. No RSRM anomalies have been identified from the data analysis.

Power-up and operation of all igniter and field-joint heaters was accomplished routinely. The igniter joint heaters operated for 18 hours 14 minutes, with power being applied to the heating element 98 percent of the time to maintain the igniter joints in their normal operating range. The field joint heater power was applied 59 percent of the time during the LCC time frame to keep the joint temperatures within their normal operating range.

The aft skirt $GN_2$ purge was operated intermittently prior to launch for a total of 42 hours and 49 minutes. To ensure that all hazardous gases were removed from the aft skirt compartment, the purge was operated at the high flow-rate prior to launch. As a result of the purge operation, the calculated flex bearing mean bulk temperature was 86 °F.

Propulsion performance data shown in the following table show that the flight performance of both RSRMs was within the contract end item (CEI) specification limits, and was typical of the performance observed on previous flights. The RSRM propellant bulk temperature (PMBT) was 61 °F at liftoff, but for the purposes of evaluation, the PMBT was adjusted to 60 °F standard.

RSRM PROPULSION PERFORMANCE

| Parameter | Left motor, 61 °F | | Right motor, 61 °F | |
|---|---|---|---|---|
| | Predicted | Actual | Predicted | Actual |
| Impulse gates | | | | |
| I-20, $10^6$ lbf-sec | 65.19 | 65.28 | 65.35 | 65.44 |
| I-60, $10^6$ lbf-sec | 173.95 | 174.67 | 174.35 | 174.80 |
| I-AT, $10^6$ lbf-sec | 296.67 | 297.59 | 296.91 | 296.97 |
| Vacuum Isp, lbf-sec/lbm | 268.40 | 269.30 | 268.40 | 268.50 |
| Burn rate, in/sec @ 60°F at 625 psia | 0.3695 | 0.3694 | 0.3698 | 0.3703 |
| Burn rate, in/sec @ 72°F at 625 psia | 0.3698 | 0.3697 | 0.3701 | 0.3706 |
| Event times, seconds | | | | |
| Ignition interval | 0.232 | N/A | 0.232 | N/A |
| Web time[a] | 110.4 | 110.1 | 110.2 | 110.2 |
| Separation cue, 50 psia | 120.2 | 120.2 | 120.0 | 119.7 |
| Action time[a] | 122.3 | 122.0 | 122.1 | 122.1 |
| Separation command | 125.1 | 125.1 | 124.9 | 125.1 |
| PMBT, °F | 61.00 | 61.00 | 61.00 | 61.00 |
| Maximum ignition rise rate, psia/10 ms | 90.4 | N/A | 90.4 | N/A |
| Decay time, seconds (59.4 psia to 85 K) | 2.8 | 2.5 | 2.8 | 3.3 |
| Tailoff imbalance Impulse differential, KLBF-sec | Predicted N/A | | Actual 250.5[b] | |

Notes:
[a] All times are referenced to ignition command time except where noted by the letter a. Those items are referenced to lift-off time (ignition interval).
[b] Impulse imbalance = left motor - right motor

All ground environment instrumentation (GEI) and operational flight instrumentation (OFI) performed within established requirements. Postflight inspection of the motors indicated nominal performance. No abnormal insulation erosion was noted. All J-joint (igniter and field) performed as designed.

## EXTERNAL TANK

All objectives and requirements associated with the ET propellant loading and flight operations were met. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operation were monitored, and all performed satisfactorily. No ET LCC or OMRSD violations were identified.

The nose cone purge heater and temperature control system operated successfully. There were no LCC or OMRSD temperature violations, but unusually wide oscillations in heater outlet and nose cone compartment temperatures did occur until the heater reached maximum power.

Typical ice/frost formations were observed on the ET during the countdown. There was light frost, but no ice on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen ($LO_2$) and liquid hydrogen ($LH_2$) feedlines and on the pressurization line brackets, and some frost or ice was present along the $LH_2$ protuberance air load (PAL) ramps. These observations were all acceptable per NSTS-08303. The Ice/Frost "Red Team" reported that there were no anomalous thermal protection system (TPS) conditions.

The ET pressurization system functioned properly throughout engine start and flight. The minimum $LO_2$ ullage pressure experienced during the ullage pressure slump was 12.7 psid.

ET separation was confirmed, and the ET entry and breakup occurred 58 nmi. uprange of the preflight prediction. Post-separation photography of the ET from the Orbiter revealed no anomalous conditions that were visible to the cameras. A more detailed discussion of the ET photography is contained in the Development Test Objective section under the DTO 312 discussion.

## SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine "ready" was achieved at the proper time; all LCC were met; and engine start and thrust buildup were normal.

Flight data indicate that the SSME performance during mainstage, throttling, shutdown, and propellant dump operations was normal. High pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures appeared to be well within the specification limits throughout engine operation. Space Shuttle main engine cutoff (MECO) occurred 512 seconds after liftoff.

An anomalous pressure spike was observed 1.72 seconds after SSME 1 start in the emergency shutdown (EMSD) pressure measurement data (Flight Problem STS-60-E-1). The spike was deemed unreal data and a possible transducer failure. This pressure sensor is not flight critical; however, it is used during chill, start, and main stage to verify the emergency shutdown solenoid function and can cause a scrub or pad abort. During purge sequence 3 (PSN-3) the EMSD pressure is verified to be between 600 and 900 psia. A sensor outside these limits inhibits engine start. From PSN-4 to start enable, the pressure is verified to be less than 50 psia. Again, a sensor above this limit will inhibit engine start. From engine start to the end of mainstage, the EMSD pressure must indicate outside the 600 to 900 psia limits. A sensor indicating between these limits will cause a pad abort before SRB ignition. An EMSD pressure between 600 and 900 psia would indicate that the EMSD solenoid has failed open (deenergized).

## SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits turned off at the appropriate times. All SRSS measurements indicated that the system operated satisfactorily throughout the countdown and flight.

One gage of holddown stud 6 recorded unusual data during SSME thrust buildup. The redundant gage of holddown stud 6 did not show any anomalous behavior, which indicates the stud functioned properly.

As planned, the SRB S&A devices were safed, and SRB system power was turned off prior to SRB separation. The ET system remained active until ET separation from the Orbiter.

## ORBITER SUBSYSTEMS

### Main Propulsion System

The overall performance of the main propulsion system (MPS) was nominal with no OMRSD or LCC violations. $LO_2$ and $LH_2$ loading were performed as planned with no stop-flows or reverts. However, the speed sensors for $LH_2$ recirculation pumps 1 and 3 indicated zero throughout the loading process. Measurements of pump current, pump voltage, and pump $\Delta P$ provided a satisfactory alternate means of determining pump operation. This type of failure has been seen seven times. Previous failures have been attributed to cryogenic fatigue. Subsequent troubleshooting of OV-103 verified the continuity at ambient temperatures, which is needed to satisfy dry-spin tests performed in the Vehicle Assembly Building. As long as the indicators operate at ambient temperatures, no further action will need to be taken.

Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment (occurred shortly after start of fast-fill) was approximately 101 ppm, which compares favorably with previous data for this vehicle.

The $LH_2$ loading operations were normal through chilldown, slow-fill, fast-fill, topping and replenish. Based on an analysis of loading system data, the $LH_2$ load at the end of replenish was 231,739 lbm. A comparison of the actual load with the inventory (predicted) load of 231,853 lb yields a difference of -0.05 percent, which is within the required MPS loading accuracy of $\pm$ 0.37 percent.

The $LO_2$ loading operations were normal through chilldown, slow-fill, fast-fill, topping and replenish. Based on an analysis of loading system data, the $LO_2$ load at the end of replenish was 1,387,917 lbm. A comparison of the actual load with the inventory (predicted) load of 1,387,828 lbm yields a difference of +0.01 percent, which is within the required MPS loading accuracy of $\pm$ 0.43 percent.

Ascent MPS performance was completely normal. Data indicate that the $LO_2$ and $LH_2$ pressurization systems performed as planned, and satisfied all tank ullage pressure requirements. Performance analysis of the propulsion systems during start, mainstage and shutdown operations indicated that performance was nominal and all requirements were satisfied.

The gaseous hydrogen ($GH_2$) flow control valves operated nominally with 71 cycles on SSME 1, 68 cycles on SSME 2, and 37 cycles on SSME 3.

The only problem noted was the rate of MPS pneumatic regulator pressure decay, which was twice the rate expected based on historical data but within specification. Troubleshooting revealed that three-way solenoids LV78, 79, and 84 were leaking excessively. The valves were replaced during turnaround operations.

The MPS helium system performed as expected and met all requirements during powered flight operation as well as propellant dump and vacuum inerting.

All MPS components performed nominally during entry and landing. Helium consumption during entry was 59.0 lbm, which is within the flight history of OV-103.

There were two new MPS configurations on STS-60. The MPS liquid oxygen ($LO_2$) bleed check valves were redesigned and flown for the first time on OV-103. The spring between the flappers was replaced with a 30-degree wedge. All three valves performed nominally and closed as verified by the $LO_2$ inlet pressures. The valves have been replaced on OV-102, OV-103, and OV-105. STS-60 was also the first flight of actual 750-psi regulator calibrations on OV-103.

## Reaction Control Subsystem

The RCS performed nominally throughout the STS-60 mission with no anomalies or problems noted. Propellant consumption from the RCS was 4349.3 lbm. In addition, 2.80 percent of OMS propellant were used from the left OMS pod and 3.41 percent was used from the right OMS pod through the RCS.

The RCS was used for attitude control while the crew was taking pictures of the ET for DTO 312. Approximately 154 lbm of propellant was used in excess of the amount planned.

With the WSF on the RMS during flight day 4, the Orbiter maintained a tail-to-earth gravity-gradient attitude to minimize RCS thruster firings. In this attitude, RCS thruster F5L experienced a cold environment (coupled with no vernier thruster firings) that caused the oxidizer valve temperature to fall below the redundancy management (RM) deselection limit of 130 °F during the crew sleep period. The thruster was deselected by RM at 038:05:48 G.m.t. (03:17:38 MET), along with vernier attitude control. The thruster was reselected after the crew sleep period. Anticipating a similar false "fail-leak" annunciation during the following sleep period, the forward RCS manifold 5 thruster heater switch was turned off to allow both F5L and F5R to annunciate their alarms prior to the sleep period. Following this second crew sleep period, and a subsequent recovery of the injector temperatures to above 130 °F, the two vernier thrusters were reselected.

## Orbital Maneuvering Subsystem

The OMS performed very satisfactorily with a total of 397.9 seconds of firing time during which 15,769.8 lbm of propellants were used. In addition, the OMS was interconnected to the RCS, during which time the RCS used 2.80 percent of the left OMS pod propellants and 3.41 percent of the right OMS propellants. Details of the two maneuvers performed are shown in the following table.

| OMS firing | Engine used | Time, G.m.t./MET | Firing duration, sec | ΔV ft/sec |
|---|---|---|---|---|
| 2 | Both | 034:12:52:16.3 G.m.t.<br>00:00:42:16.3 MET | 163.5 | 268.3 |
| Deorbit | Both | 042:18:14:50.3 G.m.t.<br>08:06:04:50.3 MET | 234.4 | ----- |

OMS problems noted during the data review were that the left forward fuel probe was reading off-scale high, and the left aft fuel probe was indicating high after the deorbit maneuver. These are known recurring problems. All other probes indicated the expected amount of propellant quantities remaining throughout the mission.

## Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed nominally throughout the mission, supplying 2090 lbm of oxygen and 263.3 lbm of hydrogen for fuel cell use and 55 lbm of oxygen for crew breathing. Consumable oxygen and hydrogen remaining at landing would have provided for a 65-hour mission extension at the average power level of 15.2 kW.

The quantity sensor for oxygen tank 2 was erratic and read as much as 4-percent higher than the actual quantity (Flight Problem STS-60-V-04). The erratic readings were present with or without a demand on the tank, as well as with tank quantities as low as 30 percent. This condition was also found in data from previous flights of OV-103 beginning with STS-48 (flight 13). Alternate methods were used to accurately ascertain the oxygen tank 2 quantity. No correlation has been seen between this erratic behavior and vehicle-induced reactions, such as RCS vernier or primary thruster firings, PRSD manifold valve closures or check valve leakages, or tank usage. Failures or problems with the quantity probe or signal conditioner have been investigated, but no cause for this type of behavior could be isolated.

Oxygen tank 4 was satisfactorily depleted to 5.9 percent, which is below the defined residual quantity of 6.5 percent. Likewise, hydrogen tank 4 was also satisfactorily depleted to 2.0 percent, which is below the defined residual quantity of 2.5 percent.

## Fuel Cell Powerplant Subsystem

The fuel cell powerplant performed nominally throughout the mission. The Orbiter electrical power averaged 15.2 kW and the total Orbiter load averaged 498 amperes. For the 199.2-hour mission, the fuel cells produced 3029 kWh of electrical energy and 2,353 lb of potable water. The fuel cells consumed 2,090 lb of oxygen and 263.3 lb of hydrogen. Four fuel cell purges were performed, occurring at approximately 21, 69, 121, and 189 hours MET. The actual fuel cell voltages at the end of the mission were 0.05 volt above the level predicted for fuel cell 1, and as predicted for fuel cells 2 and 3.

## Auxiliary Power Unit Subsystem

The APU subsystem performance was satisfactory with no problems or anomalies identified. The following table shows the run-times for each APU as well as the fuel consumption for each APU.

| Flight Phase | APU 1 (S/N 405) | | APU 2 (S/N 406) | | APU 3 (S/N 404) | |
|---|---|---|---|---|---|---|
| | Time, min:sec | Fuel consumption, lb | Time, min:sec | Fuel consumption, lb | Time, min:sec | Fuel consumption, lb |
| Ascent | 20:32 | 59 | 20:02 | 61 | 20:53 | 51 |
| FCS checkout | 06:08 | 21 | | | | |
| Entry[a] | 60:37 | 129 | 85:48 | 185 | 60:29 | 129 |
| Total[a,b] | 87:17 | 209 | 105:50 | 246 | 81:22 | 180 |

Notes:
[a] APU's 1, 2, and 3 ran for 16 minutes, 19 seconds after landing.
[b] Totals include ascent, FCS checkout, and entry.

The APU Shutdown Test - DTO 414 was performed after ascent with the APU shutdown order being 2, 1, and 3. No unusual data signatures were noted following the shutdown sequence.

Fault detection and annunciation (FDA) alarms occurred at 034:12:30 G.m.t. (00:00:20 MET) when the APU 1 and APU 2 test line temperature decreased below the 48 °F FDA limit. APU 1 and 2 test line temperatures decreased to 46 °F and 48 °F, respectively. The crew activated the heaters and nominal performance was observed. Crew procedures have recently been changed to prevent the alarms by activating the heaters earlier after APU shutdown following ascent. However, on this mission, the new procedure still did not require activation of the heaters early enough to prevent the alarms. Consequently, documentation has been released to change the FDA limits in the Orbiter software.

All three APUs were removed from the vehicle after this flight as the 21-month wetted time limit for the gas generator valve module (GGVM) will be reached prior to the next flight of this vehicle.

## Hydraulics/Water Spray Boiler Subsystem

Performance of the hydraulics/water spray boiler (WSB) subsystem was nominal throughout the mission.

DTO 414 (APU Shutdown Test - Sequence B) was performed to help determine why the hydraulics system 3 supply pressure hung up for about 40 seconds when APU 3 was shut down early during ascent on STS-54. The theory was that the hang-up was caused by back-driving the system 3 rudder speedbrake (RSB) power drive unit (PDU) motors. The DTO was performed with a APU 2, APU 1, and APU 3 shutdown sequence with at least 5 seconds between the shutdown of each individual APU. No anomalous pressure hang-ups or PDU motor back-driving were noted in the data.

On flight day 2 at 35:07:00 G.m.t. (00:18:50 MET) the WSB 3 gaseous nitrogen ($GN_2$) regulator demonstrated an internal leak of 25 sccm for about 30 minutes, and the WSB 3 regulator outlet pressure increased from 26.4 psia to 27.3 psia (Flight Problem STS-60-V-06). At that point, the leak stopped. Termination of the internal leak suggests transient contamination; however, the regulator is an older configuration regulator, and this leak may be an indication of on-going problems in the older configuration hardware.

During entry, WSB 2 had three minor periods of over-cooling with the minimum lube oil temperature observed being approximately 233 °F on the first two instances and 234 °F on the third instance (normal temperature = 252 °F). This condition was very minor and did not impact entry operations.

## Electrical Power Distribution and Control

The electrical power distribution and control (EPDC) subsystem performed satisfactorily throughout the mission. No problems or anomalies were noted from the data review.

## Environmental Control and Life Support System

The ECLSS performed nominally during the STS-60 mission with two anomalies identified.

During Spacehab activation, a nominal procedure consisted of removing a diffuser cap from the middeck floor air duct fitting and then placing it in the tunnel adapter floor fitting to prevent air suction from that tunnel adapter section. Insufficient clearance existed between the tunnel adapter floor fitting and the tunnel adapter floor; consequently, nominal placement of the diffuser cap was unsuccessful (Flight Problem STS-60-V-01). The diffuser cap was taped in place and performed the intended function satisfactorily. The postflight tests at KSC revealed that the duct was not configured in accordance with the drawing, and the duct configuration was corrected.

The active thermal control system (ATCS) performed nominally. At 034:13:37 G.m.t. (00:01:27 MET), approximately 15 minutes after radiator flow initiation, the flash evaporator system (FES) primary A controller shut down in the full-up mode. The FES was restarted, only to shut down again when the crew cycled the primary controller off and then on. At 034:13:47 G.m.t. (00:01:37 MET), the crew successfully restarted the FES and it functioned normally for the remainder of the mission. The first shutdown was caused by a known phenomenon in the OV-103 FES, which has a unique midpoint-sensor block design. The unique design introduces a thermal lag into the control system that results in outlet-temperature oscillations which may cause the FES to shut down. The second shutdown has been attributed to a combination of a low heat load on the FES and the thermal lag of the midpoint temperature sensor block. This phenomenon is not a problem.

The radiator coldsoak provided cooling during entry through touchdown plus 11 minutes when ammonia system A was activated. Ammonia system A controlled the Freon evaporator outlet temperature to 37 °F using the unique OV-102/OV-103 procedures to prevent under-temperature operation of the boiler. System A operated for 28 minutes before it was depleted, after which System B was activated. System B operated at 37 °F for 10 minutes before the ground cooling was activated.

The supply water and waste management systems performed adequately. Supply water was managed through the use of the overboard dump system and the FES. Five supply water dumps were performed at an average dump rate of 1.47 percent/minute (2.43 lb/minute). One supply water dump was also made to a CWC because of the payload constraints on dumping water. This dump was performed at an average dump rate of 2.54 percent/minute (4.20 lb/min). The CWC was later dumped overboard via the waste water dump line at an average rate of 0.80 percent/min (1.32 lb/min). The supply water dump line temperature was maintained between the satisfactory levels of 64 °F and 106 °F throughout the mission with the operation of the line heater.

Waste water was gathered at approximately the predicted rate. Four waste water dumps were performed at an average rate of 1.9 percent/minute (3.13 lb/min). The waste water dump line temperature was maintained between the satisfactory levels of 56 °F and 86 °F throughout the mission with the operation of the line heater.

Following the supply water dump at 036:09:44 G.m.t. (01:21:34 MET), 10 discrete instances of supply-water dump-valve leakage were noted (Flight Problem STS-60-V-02). The leakage occurred over a 16-hour 33-minute period which included the time during which the WSF was being maneuvered by the RMS. Following the post-sleep activities on flight day 4, the crew purged the supply dump line, and subsequent supply water dumps were performed with the WSF berthed and were followed by a supply water dump line purge. This "burping" phenomenon has occurred on STS-53, STS-48, STS-44, STS-56, and STS-51 prior to this mission, and is suspected to have occurred on previous flights of OV-103 and OV-104. However, the leakage occurrences on STS-60 were more numerous and encompassed a longer time period than those experienced on previous flights.

Corrective actions from the previous flights have included removing and replacing the supply water dump line and valve (STS-48), and rewrapping the dump line heater (STS-53). It is theorized that the intermittent leakage (burping) from the supply water dump valve may have been caused by ice formation at the valve outlet bellows. The scenario for this condition is that after termination of the dump, some water remains trapped in the outlet bellows convolutions; the water then freezes causing the outlet bellows to expand; this makes the bellows shaft move which unseats the poppet, thus allowing water to leak (burp); the leakage water is warmer, therefore causing the ice to melt and the poppet to reseat. The process could repeat depending on the conditions of each dump.

The waste collection system (WCS) performed normally during the mission. One transient shutdown of the WCS fan separator occurred; however, it is suspected to be due to inadvertent switch operation because the WCS performed satisfactorily for the remainder of the mission.

The ARS performed nominally; however, the water coolant loop bypass valve on system 2 responded slowly. This is an acceptable condition for OV-103.

The atmospheric revitalization pressure control system (ARPCS) performance was nominal. During the period of the mission when WSF operations were ongoing, the cabin pressure reached 15.2 psia, the alarm limit for overpressurization, at 039:23:05 G.m.t. (05:10:55 MET). During the flight day 6 sleep period, the alarm limit was raised to 15.4 psia to preclude nuisance alarms, and the oxygen supply to the oxygen bleed orifice was inhibited to prevent additional gas flow into the cabin. After inhibiting the oxygen bleed orifice, the cabin pressure remained stable at 15.04 psia overnight. The cabin pressure alarm was caused by a combination of factors which included the following:

a. The closed WCS vacuum vent valve (to prevent WSF contamination while on the RMS) resulted in reduced overboard venting by 6.0 lb/day;

b. Small amount of Orbiter, tunnel adapter, and Spacehab structural leakage;

c. Partial pressure of oxygen was slowly increasing and that was indicative of the oxygen bleed orifice flowing at a slightly higher rate than the 6-man metabolic consumption rate;

d. Normal venting of $GN_2$ into the cabin as the water tanks filled (minimal effect);

e. Cabin humidity increase and warmer air temperatures in the avionics bays because of warmer water loop temperatures caused by high evaporator outlet temperatures; and

f. $GN_2$ freezer in middeck venting 0.912 lb/day of nitrogen into the crew compartment.

Based on these factors, it has been concluded that no out-of-specification leakage existed in the Orbiter ARPCS. After resuming normal cabin operations, the cabin pressure returned to its normal control band (14.7 $\pm$0.2 psia).

## Smoke Detection and Fire Suppression Subsystem

The smoke detection and fire suppression system monitoring parameters indicated nominal performance and no smoke generation during the mission. Use of the fire suppression subsystem was not required.

## Airlock Support System

All airlock support system parameters indicated normal performance throughout the flight. No extravehicular activity was performed, consequently, the airlock support components were not used.

## Avionics and Software Support System

The integrated guidance, navigation and control subsystem performed nominally as also did the flight control system and star trackers.

The inertial measurement units (IMUs), which were all KT-70s, performed nominally. New compensation values were uplinked to the IMUs three times during the mission. These KT-70 units will be replaced with high accuracy inertial navigation system (HAINS) units prior to the next flight of this vehicle.

One item of interest was noted at 040:14:35 G.m.t. (06:02:25 MET), when an IMU 2 BITE (Built In Test Equipment) occurred at IMU 2 deselect. The BITE occurrence is believed to have been caused by an I/O (input/output) reset. This condition has occurred in the past and is not an IMU problem.

At 034:12:18 G.m.t. (00:00:08 MET), display electronics unit (DEU) 3 experienced a symbol generator character parity error, as indicated in the backup flight system (BFS) software error buffer. Further BFS keystrokes were normal (no parity error). The crew did not report any cathode ray tube (CRT) display anomalies or tripping of the DEU BITE flag. CRT 3 was powered off in accordance with nominal on-orbit procedures, and this configuration was maintained until flight day 8 when DEU 3 and CRT 3 were powered up for 1 hour 42 minutes to support FCS checkout. Both units performed satisfactorily during the checkout. This condition is characterized as a single event upset and is not a concern.

Several hours after WSF operations on the RMS were completed and the WSF was latched into its carrier, a latch 2 release indicator [multiplexer/demultiplexer (MDM) operational forward (OF) 2 discrete input high (DIH) card 4 channel 0 bit 16] changed state at 40:16:07 G.m.t. (06:03:57 MET) to indicate the release command was present (Flight Problem STS-60-V-05). The logic power and mechanical power to the latches were off at the time, and the latch microswitches continued to indicate a latched condition which was verified by the crew. This was not a problem that could impact operations as the latch was powered off. Postflight troubleshooting at KSC was performed after the Orbiter was powered down. When the vehicle was powered back up, the anomaly was no longer present. The switch was cycled several times and did not exhibit any anomalous characteristics. MDM troubleshooting is in progress as this report is being written; however, the hardware involved including the MDM will remain on the vehicle unless further anomalous behavior is demonstrated.

## Communications and Tracking Subsystems

The communications and tracking subsystems performed nominally except for the two anomalies and two occurrences discussed in the following paragraphs.

When the crew transitioned to the on-orbit communications configuration (very lightweight headsets), the Pilot's HIU failed (Flight Problem STS-60-V-03). The crew switched to a backup HIU. The failed headset was marked for postflight testing which will be performed at JSC upon return of the headset.

The closed circuit television (CCTV) camera B was noted to have burned-in spots and a curved line in the upper part of the image. This condition was visible in the lens when the iris was fully closed at 40:20:43 G.m.t. (06:08:33 MET). Standard postflight camera processing tests and checkout will be performed.

Instances of intercommunications (ICOM), air-to-ground (A/G) 2, and Spacehab caution and warning tone "bleedover" onto the A/G 1 channel were noted. The bleedover was at a very low volume level and did not impact the use of A/G 1. After Spacehab power down, the "bleedover" condition was not observed. Procedures are being developed to test for "bleedover" during integrated vehicle testing on Spacehab and Spacelab flights.

## Structures and Mechanical Subsystems

The structures and mechanical subsystems performed nominally. The landing and braking data are presented in the following table.

LANDING AND BRAKING PARAMETERS

| Parameter | From threshold, ft | Speed, keas | Sink rate, ft/sec | Pitch rate, deg/sec |
|---|---|---|---|---|
| Main gear touchdown | 2463 | 204.1 | ~2.0 | n/a |
| Nose gear touchdown | 7455 | 134.6 | n/a | 3.52 |

| | |
|---|---|
| Braking initiation speed | 111.6 knots (keas) |
| Brake-on time | 26.6 seconds (sustained) |
| Rollout distance | 7,771 feet |
| Rollout time | 49.8 seconds |
| Runway | 15 (concrete) at KSC SLF |
| Orbiter weight at landing | 216,594.5 lb (landing estimate) |

| Brake sensor location | Peak pressure, psia | Brake assembly | Energy, million ft-lb |
|---|---|---|---|
| Left-hand inboard 1 | 1097 | Left-hand outboard | 13.19 |
| Left-hand inboard 3 | 1057 | Left-hand inboard | 16.68 |
| Left-hand outboard 2 | 1018 | Right-hand inboard | 18.90 |
| Left-hand outboard 4 | 1084 | Right-hand outboard | 15.25 |
| Right-hand inboard 1 | 1176 | | |
| Right-hand inboard 3 | 1282 | | |
| Right-hand outboard 2 | 1150 | | |
| Right-hand outboard 4 | 1097 | | |

Drag chute performance was satisfactory. The STS-60 drag chute deployment successfully demonstrated the effect of the recent refinements to increase the vehicles' directional stability. As with STS-47, the chute system was initiated at the beginning of nose wheel derotation with the main parachute fully inflated prior to nose gear touchdown. For STS-60, no lateral directional corrections were required and the vehicle did not deviate because of chute forces. (During STS-47, the chute caused the Orbiter to stray approximately 27 feet from the runway centerline.) The effect of the chute was very evident as an effective tool in bringing the vehicle to a stop.

At 041:15:55 G.m.t. (07:03:45 MET), the Commander reported that the crew felt a shudder in conjunction with hearing a loud noise, similar to the sound of a primary RCS thruster firing. However, the phenomenon was not associated with a primary RCS thruster firing. A review of data for all subsystems indicated no anomalies, and there were no measured accelerations associated with the phenomenon. The most likely cause of the phenomenon was load relief of the Spacehab retention hardware with the noise and shudder being transmitted to the crew cabin through the tunnel adapter structure. The Commander of STS-57 (first Spacehab mission) reported a similar phenomenon, and the Spacelab modules/tunnels have a known similar phenomenon of load relief on-orbit. There was no concern for entry.

At 042:13:55 G.m.t. (08:01:45 MET), the payload latch 2 latch indication A changed from a latch to a not-latched state. The payload latch 2 system B indication had transferred 1.6 seconds earlier than system A during WSF latching. This results in the system A microswitch being minimally actuated. The failure has been isolated during KSC troubleshooting to payload latch rigging. This anomaly has been transferred to the KSC Payloads Group for resolution and documentation.

## Integrated Aerodynamics, Heating and Thermal Interfaces

The ascent and entry aerodynamics were nominal with no problems, anomalies, or unexpected conditions identified in the data. The aerodynamic and plume heating were nominal during ascent and the aerodynamic heating to the SSME nozzles during descent was nominal. The prelaunch analysis of the thermal interfaces showed no temperatures in excess of limits. In addition, the gaseous helium and gaseous nitrogen ET/Orbiter electrical disconnect pressures were within limits, and the aft compartment helium concentration was within the experience base.

## Thermal Control Subsystem

The performance of the thermal control subsystem (TCS) was nominal during all phases of the mission, and all Orbiter subsystem temperatures were maintained within acceptable limits.

One item of interest was that the APU 3 fuel pump drain line temperature 1 cycled near to the lower FDA limit of 48 °F while on-orbit. The lower FDA limit was changed to 43 °F to ensure that temperatures remained within limits. Additional details on this problem are found in the Auxiliary Power Unit Subsystem section of this report.

## Aerothermodynamics

The acreage heating was nominal during entry, and no unusual local heating was noted. The heating to a one-foot radius sphere showed that the trajectory was slightly higher in peak heating rate and load than previously experienced on OV-103, but within the experience base for all Orbiters. The thermocouples reflected this with a slight increase in temperature. Boundary layer transition on the lower surface was late, at Mach 7.3, but within both OV-103 and all Orbiters' experience. The surface temperatures of the left and right OMS pods were within the experience data base, not showing any significant heating asymmetry due to the 0.5-degree sideslip.

An initial report, which showed an off-nominal aileron excursion around a relative velocity of 10,000 ft/sec, was incorrect in that the large negative Y c.g. of this flight required up-aileron to trim. Therefore, as the elevon schedule moved the elevon more negative around 10,000 ft/sec, the more up-elevator was less aerodynamically effective resulting in a further up deflection, thus resulting in the aileron excursion during entry.

## Thermal Protection Subsystem

The thermal protection subsystem (TPS) performed satisfactorily. Structural temperature response data show that the entry heating was above average, and the TPS performed as designed in preventing heating damage effectively during ascent and entry. The overall boundary layer transition from laminar flow to turbulent flow occurred 1235 seconds after entry interface on the forward centerline and the aft centerline of the vehicle. Transition was symmetric from right to left on the vehicle.

During flight day 6 activities, the crew observed a damaged TPS blanket on the upper forward RCS module just aft of the F1U thruster. An RMS video camera inspection showed that the outer cover material of an advanced flexible reusable surface insulation (AFRSI) blanket had torn and was protruding. The blanket was identified as a part of part number V070-391134-050 blanket, which is 6 in. by 5 in. long, and is bonded to an aluminum carrier panel. The torn section was approximately 4 in. by 1.5 in. in size, and was later determined to be a degraded patch repair. The blanket batting material was intact. This type of damage is typical for AFRSI blankets in this location. A review of this particular blanket's history revealed several minor repairs had been performed on the blanket as well as having been patched. The blanket covered a carrier plate and no critical subsystems were located immediately below this area. A worst-case thermal analysis that assumed a complete loss of the blanket, but with the room-temperature vulcanizing (RTV) adhesive intact, predicted that the maximum carrier plate temperature would be 385 °F (positive margin-of-safety) during entry with the only anticipated damage being to the blanket itself. It is not uncommon for this particular blanket to see wear damage.

Orbiter debris damage was less than average with only 106 hits, of which 15 had a major dimension of one inch or greater. However, this number does not include the numerous hits on the base heat shield that were caused by the flame arrestment sparkler system. Of the 106 total hits, 48 were on the lower surface, 28 were on the upper surface, 2 were on the right side, 4 were on the left side, 7 were on the right OMS pod, and 17 were on the left OMS pod. The distribution of hits on the vehicle, especially the lower surface, does not suggest a single source of ascent debris, but indicates a shedding of ice and TPS debris from random sources. Furthermore, the postflight inspection showed that none of the tile damage resulted from micrometeorites or on-orbit debris, and none of the damage was attributed to material from the wheels, tires, or brakes.

The main landing gear door (MLGD) thermal barriers were in good condition overall, although minor damage was noted on some of the thermal barriers from both the left and right main gear areas. The ET door thermal barriers were in excellent condition overall. Damage to the ET door tiles was minor, and the elevon cove and elevon gap tiles and thermal barriers were all in good condition.

The engine dome-mounted heat shield blankets were in good condition with minor fraying to the SSME 3 lower closeout pillow. No damage occurred to tiles as a result of drag chute deployment.

Orbiter windows 3 and 4 exhibited moderate hazing with some streaks. Only a very light haze was present on the other windows. Surface wipes were taken from all the windows for chemical analysis sampling.

The Shuttle thermal imager (STI) was used to measure the surface temperature of several areas of the vehicle. The Orbiter nosecap reinforced carbon carbon (RCC) temperature was 170 °F 24 minutes after landing. The leading edge temperature of RCC panel 9 was 104 °F 27 minutes after landing, and panel 17 was 99 °F at that same time.

The potential identification of debris damage sources for STS-60 will be based on the laboratory analysis of Orbiter postlanding microchemical samples, inspection of the recovered SRB components, and film analysis (including on-orbit photography of the ET). The results of these analyses will be documented in the STS-60 Ice/Debris/TPS Assessment and Integrated Photographic Analysis Report (NASA Technical Memorandum 109193).

## REMOTE MANIPULATOR SYSTEM

The RMS performed satisfactorily in support of Wake Shield Facility activities, and no RMS anomalies were identified.

The RMS checkout was performed at 35:11:30 G.m.t. (00:23:30 MET), and all signatures were nominal. At the end of the checkout, the RMS remained in use to conduct a premission planned CCTV survey of the payload bay. The survey was shortened, however, to protect the timeline for the planned Spacehab operations. The RMS was cradled and latched at 35:13:28 G.m.t. (01:01:18 MET).

The RMS activities began with the grapple of the berthed WSF at 36:11:13:57 G.m.t. (01:23:03:57 MET). By 36:12:37 G.m.t. (02:00:27 MET), the WSF was maneuvered to a position placing the experiment carrier on the WSF into the velocity vector of the Orbiter for cleaning by atomic oxygen impact. WSF communications difficulties were encountered prior to its planned deployment as a free-flyer. The deployment procedures were replaced with a series of payload troubleshooting measures. WSF performance did not warrant a deployment on flight day 3, and the WSF was reberthed in the Orbiter at 36:20:58:21 G.m.t. (02:08:48:21 MET) after which the RMS was cradled and latched.

The WSF deployment was attempted again on flight day 4. After the RMS was powered and uncradled, grapple with WSF was completed at 37:11:14:10 G.m.t. (02:23:04:10 MET). The WSF was maneuvered to the cleaning position using the normal deployment procedures. At 37:14:45 G.m.t. (03:02:35 MET), the WSF was driven by RMS auto-sequence to a preplanned checkout position prior to deployment. Again, however, communications and WSF attitude control system problems prevented deployment. After a second series of troubleshooting maneuvers, the decision was made to place the RMS/WSF in a contingency overnight parking configuration. During the crew sleep period that followed, crystal growth was initiated on the WSF.

On flight day 5, the WSF was berthed in the Orbiter payload bay at 38:17:21:32 G.m.t. (04:05:11:32 MET) to protect its experiment packages from contamination during a required Orbiter supply and waste water dump. The WSF was again unberthed at 38:20:51:29 G.m.t. (04:08:41:29 MET) and for the second time parked in the contingency crystal growth position for overnight.

A supply water dump was also required on flight day 6, during which time the WSF was berthed at 39:11:59:05 G.m.t. (04:23:49:05 MET) and unberthed at 39:14:34:49 G.m.t. (05:02:24:49 MET). Following unberthing, the WSF was placed in a preplanned configuration for a CHAWS activity. At 39:20:30 G.m.t. (05:08:20 MET), troubleshooting of the WSF attitude control system involved firing its main thruster while on the end of the RMS. The low-impulse firing caused no noticeable RMS movement. At 39:21:19 G.m.t. (05:09:09 MET), the RMS/WSF was once more placed in the overnight park crystal growth position.

The final berthing of the WSF occurred on flight day 6 with the WSF latched in the payload bay at 40:12:18:27 G.m.t. (06:00:08:27 MET). After ungrappling from the WSF at 40:12:45:29 G.m.t. (06:00:35:29 MET), the RMS was used to perform Tile Survey H of the Orbiter's forward fuselage prior to cradling and latching the RMS which occurred at 40:14:08 G.m.t. (06:01:58 MET). The manipulator positioning mechanisms (MPMs) were then rolled in and STS-60 RMS operations were complete.

## FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

The crew reported that the ac power cable was not connected to the back of the thermal impulse printer system (TIPS) (Flight Problem STS-60-F-01). The crew had to remove the printer from its locker to make the connection.

During flight day 2 activities, the crew asked for the stowage location of the tunnel adapter stowage net that had been used during training. A check of the stowage documentation revealed that this net was not onboard as expected by the crew (Flight Problem STS-60-F-02).

At 039:22:15 G.m.t. (05:10:05 MET), the crew reported that Hasselblad camera (s/n 1002) had shutter pieces floating around in the 250-mm lens which was jammed on the camera (Flight Problem STS-60-F-03). Two additional Hasselblad cameras were onboard and were used by the crew in place of the failed camera.

## CARGO INTEGRATION

Cargo integration hardware performed nominally; however, one anomaly was identified in this area. During Spacehab activation, a diffuser cap could not be installed on the tunnel adapter floor fitting and had to be taped in place (Flight Problem STS-60-V-01). A more detailed discussion of this problem is contained in the Environmental Control and Life Support System section of this report.

# DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

A total of 14 DTOs and 10 detailed supplementary objectives (DSOs) were assigned to the STS-60 mission. Data were not collected for two DTOs and one DSO.

## DEVELOPMENT TEST OBJECTIVES

DTO 301D - Ascent Structural Capability Evaluation - Data were recorded during ascent for this DTO. The data have been given to the sponsor for analysis, and the results of the analysis will be reported in separate documentation.

DTO 305D - Ascent Compartment Venting Evaluation - Data were recorded during ascent for this DTO. The data have been given to the sponsor for analysis and evaluation, and the results of that effort will be reported in separate documentation.

DTO 306D - Descent Compartment Venting Evaluation - Data were recorded during descent for this DTO. The data have been given to the sponsor for analysis, and the results of the analysis effort will be reported in separate documentation.

DTO 307D - Entry Structural Capability - Data were recorded during entry for this DTO. The data have been given to the sponsor for analysis, and the results of the analysis effort will be reported in separate documentation.

DTO 312 - ET TPS Performance (Method 3) - Thirty-seven excellent quality photographs of the ET (after separation) were acquired using a Nikon camera with a 300-mm lens and a 2X extender (Method 3). The photographs were taken by crew member Sergei Krikalev (Soviet Cosmonaut). All sides of the ET were photographed, although the +Y (right) side of the ET did not come into view until near the end of the film sequence when the ET was much further away. The first picture was taken at 034:12:23:54 G.m.t. (00:00:13:54 MET) and the last picture was taken approximately 11 minutes later.

The photographic evaluation showed the ET to be in excellent condition. The usual SRB booster separation motor (BSM) burn scars and charring of the TPS on the aft dome and the $LH_2$ tank (aft) are visible. A small light-colored mark is visible on the -Y (left) side of the $LO_2$ tank TPS just above the intertank area. A second mark is visible nearby on the $LO_2$ tank-to-intertank closeout flange. A third mark is visible on the intertank TPS below and to the left of the left SRB forward attach point.

Fifteen minutes of excellent quality video of the ET (after separation) was also taken by crew member Jan Davis. A camcorder with a 2X extender and a 15 to 1 zoom lens was used to image the ET. All sides of the ET were imaged. The video analysis showed the ET to be in the expected good condition. No significant ET surface features were observed that were not seen in the 35 mm film.

DTO 319D - Shuttle/Payload Low Frequency Environment - Data were recorded for this DTO, and these data have been given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DTO 414 - APU Shutdown Test, Sequence B - This DTO was performed at APU shutdown after ascent with the shutdown sequence being APU 2, APU 1, and APU 3, respectively. No PDU back-driving was noted, and all pressure slope changes corresponded to switching-valve changes of state as expected. Final results of this DTO will be published in separate documentation.

DTO 623 - Cabin Air Monitoring - Data were collected for this DTO. These data have been given to the sponsor for analysis. The results of that analysis will be documented in other publications.

DTO 656 - Payload General Support Computer (PGSC) Single Event Upset Monitoring - Data were collected for this DTO. These data are being analyzed by the sponsor, and the results will be published in separate documentation.

DTO 664 - Cabin Temperature Survey - Temperature data were collected during the mission, and these data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DTO 670 - Evaluation of Passive Cycle Isolation System - The DTO was not performed as the hardware required for the investigation was removed prior to launch.

DTO 700-2 - Laser Range and Range Rate Device - This DTO was not performed since the WSF deployment and rendezvous were canceled because of operational problems. As a result, the laser was only used to obtain range and range rate data on the BREMSAT following its deployment. The major activity for this DTO was to be in conjunction with the rendezvous with the WSF.

DTO 700-7 - Orbiter Data for Real-Time Navigation Evaluation - The primary objective of the DTO was not accomplished because of the cancellation of the WSF rendezvous and plume tests experiment. However, the hardware for this DTO did enable an onboard PGSC pulse code modulation master unit (PCMMU) interface during the WSF CHAWS activities, providing the crew with downlink data, thereby enhancing the operations and air-to-ground communications.

DTO 805 - Crosswind Landing Performance - This DTO was to be performed if environmental (crosswind) conditions at landing met the minimum criteria for the DTO. Crosswinds were below the minimum requirements of the DTO, therefore it was not performed.

## DETAILED SUPPLEMENTARY OBJECTIVES

DSO 200 - Joint U.S./Russian Investigation: Radiobiological Effects - The Tissue Equivalent Proportional Counter (TEPC) and the U. S. and Russian dosimeters were set up to collect data according to premission planning. These data have been given to the sponsors for evaluation, and the results of that evaluation will be published in separate documentation.

DSO 201 - Joint U.S./Russian Sensory-Motor Investigations - Most of the science objectives for the voluntary head movements (VHM) and Optokinetic Nystagmus (ON) were met. The activities required more time than expected; therefore, some deletions of tests were necessary to fit within the tight timeline. Approximately 30 to 50 percent of the science was estimated to have been lost over what was planned premission. Autonomic and Gastric Function activities were completed as planned. Postflight, the data were given to the sponsors for analysis to determine scientific return. The results of the analysis will be published in separate documentation.

DSO 202 - Joint U.S./Russian Investigations: Metabolic - All activities in support of this DSO were completed, and the scientific return from this DSO is expected to be very significant. The data have been given to the sponsors for analysis, and the results of that analysis will be published in separate documentation.

DSO 204 - Joint U.S./Russian Investigations: Visual Observations from Space - All activities in support of this DSO were completed according to premission plans. The data obtained during the DSO observations have been given to the sponsor for analysis, and the results of that analysis will be published in separate documentation.

DSO 325 - Dried Blood Method for In-Flight Storage (Protocol 1) - This DSO was not performed because of timeline constraints.

DSO 326 - Window Impact Observations - Observations in support of this DSO were made and the results of those observations have been given to the sponsor for analysis. The results of the analysis will be published in separate documentation.

DSO 487 - Immunological Assessment of Crewmembers - Data for this DSO were collected during preflight and postflight activities. These data have been given to the sponsor for analysis. The results of that analysis will be published in separate documentation.

DSO 901 - Documentary Television - Many Public Affairs Office (PAO) events occurred on this flight and have been documented on video tape. These special events included:

a. First live hookup between the Orbiter and Mir via 'Good Morning America';

b. A conference with President Bill Clinton;

c. A conference with the Director General of the Russian Space Agency, Mr. Yuri Koptev;

d. A conference with Russian Prime Minister Chernomyrdin;

e. An interview with Ron Sega and Sergei Krikalev on CNN; and

f. An interview with Charles Bolden and Franklin Chang-Diaz on BET.

DSO 902 - Documentary Motion Picture Photography - Motion picture photography obtained for this DSO have been turned over to the sponsor for analysis. The results of that analysis will be reported in separate documentation.

DSO 903 - Documentary Still Photography - Still photographs were obtained in support of this DSO. These data have been given to the sponsor for analysis. The results of that analysis will be reported in separate documentation.

# PHOTOGRAPHY AND TELEVISION ANALYSES

## LAUNCH PHOTOGRAPHY AND VIDEO ANALYSIS

On launch day, 24 videos of the launch were screened, and no anomalies were noted. Following the launch day, 54 of the planned 55 films of the launch were reviewed, and no potential anomalies were noted. The film from camera E-222 was not delivered.

Multiple pieces of debris were photographed falling aft of the Shuttle vehicle at liftoff, throughout the roll maneuver, and beyond on the launch tracking views. Most of the debris sightings were apparently either paper that is used to cover the RCS thrusters during prelaunch operations or ice from the ET/Orbiter umbilicals. During ascent, multiple pieces of debris exited the SRB exhaust plume between 65 and 80 seconds after liftoff. None of the debris was observed to strike the vehicle.

## ON-ORBIT PHOTOGRAPHY AND VIDEO ANALYSIS

On-orbit video of the ODERACS experiment deployment was screened to determine the velocity of the metal spheres as the spheres departed the GAS canister. The calculated velocity of these spheres ranged from 1.53 to 3.34 meters/second. An analysis was also performed to determine the separation angles between spheres following deployment.

The results of the on-orbit photography of the ET in support of DTO 312 are presented in the Development Test Objective section of this report.

## LANDING PHOTOGRAPHY AND VIDEO ANALYSIS

Eleven videos of the approach and landing phase plus NASA Select, (which uses multiple views in real-time) were screened, and no anomalies were noted. In addition, 16 landing films were also reviewed, and again, no anomalies were noted.

TABLE I.- STS-60 SEQUENCE OF EVENTS

| Event | Description | Actual time, G.m.t. |
|---|---|---|
| APU Activation | APU-1 GG chamber pressure | 034:12:05:10.87 |
| | APU-2 GG chamber pressure | 034:12:05:12.27 |
| | APU-3 GG chamber pressure | 034:12:05:13.71 |
| SRB HPU Activation[a] | LH HPU system A start command | 034:12:09:32.120 |
| | LH HPU system B start command | 034:12:09:32.280 |
| | RH HPU system A start command | 034:12:09:32.440 |
| | RH HPU system B start command | 034:12:09:32.600 |
| Main Propulsion System Start[a] | Engine 3 start command accepted | 034:12:09:53.446 |
| | Engine 2 start command accepted | 034:12:09:53.567 |
| | Engine 1 start command accepted | 034:12:09:53.695 |
| SRB Ignition Command (lift-off) | SRB ignition command to SRB | 034:12:10:00.000 |
| Throttle Up to 104 Percent Thrust[a] | Engine 3 command accepted | 034:12:10:04.246 |
| | Engine 2 command accepted | 034:12:10:04.247 |
| | Engine 1 command accepted | 034:12:10:04.256 |
| Throttle Down to 70 Percent Thrust[a] | Engine 3 command accepted | 034:12:10:25.686 |
| | Engine 2 command accepted | 034:12:10:25.688 |
| | Engine 1 command accepted | 034:12:10:25.696 |
| Maximum Dynamic Pressure (q) | Derived ascent dynamic pressure | 034:12:10:52 |
| Throttle Up to 104 Percent Thrust[a] | Engine 3 command accepted | 034:12:10:57.207 |
| | Engine 2 command accepted | 034:12:10:57.208 |
| | Engine 1 command accepted | 034:12:10:57.217 |
| Both SRM's Chamber Pressure at 50 psi[a] | LH SRM chamber pressure mid-range select | 034:12:11:59.520 |
| | RH SRM chamber pressure mid-range select | 034:12:12:00.040 |
| End SRM Action[a] | LH SRM chamber pressure mid-range select | 034:12:12:02.190 |
| | RH SRM chamber pressure mid-range select | 034:12:12:02.320 |
| SRB Separation Command | SRB separation command flag | 034:12:12:05 |
| SRB Physical Separation[a] | LH rate APU A turbine speed LOS | 034:12:12:05.080 |
| | RH rate APU A turbine speed LOS | 034:12:12:05.080 |
| 3g Acceleration | Total load factor | 034:12:17:27.8 |
| Throttle Down for 3g Acceleration[a] | Engine 3 command accepted | 034:12:17:27.932 |
| | Engine 2 command accepted | 034:12:17:27.936 |
| | Engine 1 command accepted | 034:12:17:27.944 |
| Throttle Down to 67 Percent Thrust[a] | Engine 3 command accepted | 034:12:18:25.852 |
| | Engine 2 command accepted | 034:12:18:25.857 |
| | Engine 1 command accepted | 034:12:18:25.865 |
| MECO | Command flag | 034:12:18:32 |
| Engine Shutdown[a] | Engine 3 command accept | 034:12:18:32.052 |
| | Engine 2 command accept | 034:12:18:32.057 |
| | Engine 1 command accept | 034:12:18:32.065 |
| MECO | Confirm flag | 034:12:18:33 |

[a]MSFC supplied data

TABLE I.- STS-60 SEQUENCE OF EVENTS (Continued)

| Event | Description | Actual time, G.m.t. |
|---|---|---|
| ET Separation | ET separation command flag | 034:12:18:52 |
| OMS-1 Ignition | Left engine bi-prop valve position | Not performed - direct insertion trajectory flown |
| | Right engine bi-prop valve position | |
| OMS-1 Cutoff | Left engine bi-prop valve position | |
| | Right engine bi-prop valve position | |
| APU Deactivation | APU-2 GG chamber pressure | 034:12:25:12.88 |
| | APU-1 GG chamber pressure | 034:12:25:42.35 |
| | APU-3 GG chamber pressure | 034:12:26:06.60 |
| OMS-2 Ignition | Left engine bi-prop valve position | 034:12:52:16.3 |
| | Right engine bi-prop valve position | 034:12:52:16.6 |
| OMS-2 Cutoff | Left engine bi-prop valve position | 034:12:55:00.4 |
| | Right engine bi-prop valve position | 034:12:55:00.4 |
| Payload Bay Doors Open | PLBD right open 1 | 034:13:40:02 |
| | PLBD left open 1 | 034:13:41:20 |
| Wake Shield Facility | | |
| Grapple | Payload captured | 036:11:13:57 |
| Unberth | Payload latch 2A released | 036:12:23:41 |
| Berth | Payload latch 2A latched | 036:20:58:21 |
| Ungrapple | Payload captured | 036:21:03:19 |
| Grapple | Payload captured | 037:11:14:10 |
| Unberth | Payload latch 2A released | 037:11:53:51 |
| Berth | Payload latch 2A latched | 038:17:21:32 |
| Ungrapple | Payload captured | 038:17:24:31 |
| Grapple | Payload captured | 038:17:24:54 |
| Unberth | Payload latch 2A released | 038:20:51:29 |
| Berth | Payload latch 2A latched | 039:11:59:05 |
| Unberth | Payload latch 2A released | 039:14:34:49 |
| Berth | Payload latch 2A latched | 040:12:18:27 |
| Ungrapple | Payload captured | 040:12:45:29 |
| ODERACS deployment | Voice call | 040:14:53:24 |
| BREMSAT deployment | Video call | 040:19:23:17 |
| Flight Control System Checkout | | |
| APU Start | APU-1 GG chamber pressure | 041:12:29:20.77 |
| APU Stop | APU-1 GG chamber pressure | 041:12:35:28.77 |
| Payload Bay Doors Close | PLBD left close 1 | 042:14:06:56 |
| | PLBD right close 1 | 042:14:09:17 |

TABLE I.- STS-60 SEQUENCE OF EVENTS (Concluded)

| Event | Description | Actual time, G.m.t. |
|---|---|---|
| APU Activation For Entry | APU-2 GG chamber pressure | 042:18:09:49.95 |
| | APU-1 GG chamber pressure | 042:18:34:58.99 |
| | APU-3 GG chamber pressure | 042:18:35:09.75 |
| Deorbit Maneuver Ignition | Right engine bi-prop valve position | 042:18:14:50.3 |
| | Left engine bi-prop valve position | 042:18:14:50.3 |
| Deorbit Maneuver Cutoff | Right engine bi-prop valve position | 042:18:18:45.0 |
| | Left engine bi-prop valve position | 042:18:18:45.0 |
| Entry Interface (400K) | Current orbital altitude above reference ellipsoid | 042:18:47:51 |
| Blackout Ends | Data locked at high sample rate | No blackout |
| Terminal Area Energy Management | Major mode change (305) | 042:19:12:45 |
| Main Landing Gear Contact | LH MLG tire pressure | 042:19:19:22 |
| | RH MLG tire pressure | 042:19:19:22 |
| Main Landing Gear Weight On Wheels | LH MLG weight on wheels | 042:19:19:22 |
| | RH MLG weight on wheels | 042:19:19:22 |
| Drag Chute Deploy | Drag chute deploy 1 CP Volts | 042:19:19:32.5 |
| Nose Landing Gear Contact | NLG tire pressure | 042:19:19:41 |
| Nose Landing Gear Weight On Wheels | NLG WT on Wheels -1 | 042:19:19:41 |
| Drag Chute Jettison | Drag chute jettison 1 CP Volts | 042:19:19:54.9 |
| Wheels Stop | Velocity with respect to runway | 042:19:20:13 |
| APU Deactivation | APU-1 GG chamber pressure | 042:19:35:36.37 |
| | APU-2 GG chamber pressure | 042:19:35:37.70 |
| | APU-3 GG chamber pressure | 042:19:35:38.80 |

TABLE II.- STS-60 ORBITER PROBLEM TRACKING LIST

| Number | Title | Reference | Comments |
|---|---|---|---|
| STS-60-V-01 | Unable to Place Diffuser Cap Into Tunnel Adapter Floor Fitting (LEVEL III CLOSURE) | 034:17:38 G.m.t.<br>IM 60RF01<br>MVO-519A-2-0004 | During Spacehab activation, a nominal procedure consisted of removing a diffuser cap from the middeck floor air duct fitting and then placing it in the tunnel adapter floor fitting to prevent air suction from that tunnel adapter section. Due to insufficient clearance between the tunnel adapter floor fitting and the tunnel adapter floor, nominal placement of the diffuser cap was unsuccessful.<br>KSC: KSC personnel found the duct to be not per print. KSC to return the duct to print. JSC and RI-Downey personnel to take corrective measures to prevent recurrence. |
| STS-60-V-02 | Supply Water Dump Valve "Burps" | 036:10:38 G.m.t.<br>CAR 48 RF04<br>IM 60RF05 | There were several supply water valve "burps" (10) after the second water dump and one other indication by the nozzle temperatures that water was moving through the nozzle. OV-103 and OV-103 have exhibited similar burps on previous missions. For this mission, the dump line will be purged after all supply water dumps to prevent further burping. JSC is evaluating further analysis/corrective action options.<br>KSC: No action required. |
| STS-60-V-03 | Pilot HIU Failure (LEVEL III CLOSURE) | 034:13:00 G.m.t.<br>IM 60RF02<br>PR MV0027A-3-0038 | When the crew transitioned to orbit communications configuration (very lightweight headsets), the Pilot's HIU failed. Crew switched to the backup HIU. The crew taped/tagged the failed unit for postflight analysis. KSC to return hardware to NSLD for repair. |
| STS-60-V-04 | Oxygen Tank 2 Quantity Erratic (LEVEL III CLOSURE) | 034:09:32 G.m.t.<br>IM 60RF03<br>IPR 64V-0003 | Cryogenic oxygen tank 2 quantity sensor measurement (V45Q1205A) was erratic. Similar behavior has been noted on previous flights.<br>KSC: Verify wiring integrity. |
| STS-60-V-05 | A) WSF Latch 2 Switch Indicates Release | 040:16:07 G.m.t.<br>IM 60RF04<br>IPR 64V-0005 | A) Payload retention latch switch 2 position indication shows RELEASE and should be OFF.<br>KSC: Performed the troubleshooting plan after the Orbiter was powered down. When the vehicle was powered back up, the anomaly was no longer present. The switch was cycled several times and did not exhibit any anomalous characteristics. MDM OF2 troubleshooting is to be scheduled. |
| | B) Loss of Payload System 2A Latch Indication (TRANSFERRED TO PAYLOADS) | 042:13:15 G.m.t.<br>IPR 64V-0010 | B) The payload latch 2 latch indication A changed from a latched to an unlatched state.<br>KSC: Problem isolated to the payload latch rigging. Problem transferred to KSC Payload Group for final disposition and closure. |
| STS-60-V-06 | Internal Leakage Through Water Spray Boiler (WSB) 3 $GN_2$ Regulator | 035:07:00 G.m.t.<br>IM60RF06<br>HYD-3-19-0687 | On flight day 2, the WSB 3 gaseous nitrogen regulator demonstrated an internal leak of 25 sccm for about 30 minutes; the WSB 3 regulator outlet pressure increased from 26.4 to 27.3 psia. At that point the leak stopped. Termination of the internal leak suggests transient contamination.<br>This is an old configuration regulator. The leak could be an indication of ongoing problems in the old configuration regulators. |

TABLE III.- STS-60 GFE PROBLEM TRACKING LIST

| Number | Title | Reference | Comments |
|---|---|---|---|
| STS-60-F-01 | TIPS power cable unplugged | 034:15:15 G.m.t. | The crew reported that the ac power cable was not connected to the back of the Thermal Impulse Printer System (TIPS). The crew reported that they had to remove the printer from the locker to make the connection. TIPS operated normally for the remainder of the mission. |
| STS-60-F-02 | Tunnel Adapter Stowage Net Net Not Stowed | 035:08:15 G.m.t. | The crew asked for the stowage location of the tunnel adapter stowage net. The crew expected the net to be onboard. The net was verified to not be onboard. |
| STS-60-F-03 | Failure of Hasselblad Camera and 250-mm Lens (LEVEL III CLOSURE) | 039:22:15 G.m.t. | The crew reported that Hasselblad camera (S/N 1002) had shutter pieces floating around in the lens which was jammed on the camera. There are a total of three Hasselblad cameras stowed onboard the vehicle. The crew can use the remaining two good cameras. |

TABLE IV.- MSFC ELEMENTS PROBLEM TRACKING LIST

| Problem/Title | Element | Description | Comments/Status |
|---|---|---|---|
| STS-60-B-1 Right SRB Drogue Parachute Suspension Line Failure | SRB (USBI) A15861 | During drogue parachute deployment of the right SRB, parachute line #45 failed. | Each drogue chute has twelve suspension line bundles, comprised of five suspension lines each. Each bundle is retained in a confluence keeper which attaches the two outside lines by tabs. The failed suspension line was one of the outside lines adjacent to the keeper. This keeper also failed due to effects of the broken suspension line.<br><br>Physical inspection of the hardware revealed two key pieces o evidence relative to the failure. The failed suspension line had twisted within the confluence keeper, exposing the opposite side of the line to the keeper. The inspection also revealed two staples inside the keeper which were installed as manufacturing aids.<br><br>The failure scenario involves the twisting of the suspension line and contact between the suspension line and the staples. The twist was introduced during drogue chute deployment, exposing the opposite side of the suspension lines to the staples. The staples reacted with the extreme vibrations in the line and cut approximately 60% through the line which subsequently failed due to operating loads. Failure of the suspension line is attributed to a combination of cuts introduced by the staples and twisting during drogue chute deployment.<br><br>Inspection of all lines identified eight of 140 bundles which had staples installed. All staples were removed from these lines. All drogue parachutes have been inspected, except for those installed on STS-59. STS-59 is the only flight remaining which may potentially have staples installed.<br><br>A failure analysis was conducted which demonstrated that a fail safe condition exists should one line per bundle fail, provided no two adjacent outside lines fail. The failure of two adjacent outside lines could result in the loss of an SRB. The statistical probability of success based on required failure of two adjacent suspension lines due to this condition provided 0.9999 reliability. This failure is contingent upon the staples being present, the lines twisting, and two adjacent outside lines both failing. |
| STS-60-E-01 SSME-1 Emergency Shutdown (EMSD) Pressure Sensor Spike | Space Shuttle Main Engine (RKDN) A15814 (A032841) | At approximately 1.72 seconds after the engine start command (ESC), the SSME-1 (E2012) EMSD pressure sensor exhibited a positive spike on channel A of up to 523.8 psia. | No other EMSD pressure sensor anomalies were noted during the chill, mainstage, and post-shutdown phases. Three consecutive data points must be between the 600-900 psia range to register a Failure Identification (FID). The two anomalous data points reported within the spike were not between the pressure sensor limits, therefore, no violation occurred. The sensor (P/N RES7001-207, S/N 41793) had experienced seven starts and 2,920 seconds of hot-fire time prior to the STS-60 mission. |

TABLE IV.- MSFC ELEMENTS PROBLEM TRACKING LIST

| Problem/Title | Element | Description | Comments/Status |
|---|---|---|---|
| | | | Pressure sensor spikes have been attributed to sensor failure on four previous flights and have been documented/tracked on four separate IFAs (IFA no. STS-50-E-01, STS-47-E-01, STS-53-E-01, and STS-54-E-02). All of these spikes were caused by contamination introduced during the manufacturing process that resulted in short-circuit signatures. The SSME Project has currently underway a sensor screening plan that will include Particle Impact Noise Detection (PIND) testing of all flight pressure sensors. IFA no. STS-54-E-02 will remain open until implementation of the flight sensor screening plan is complete.<br><br>SSME pressure sensors of this design have been categorized into two families; the -100 and -200 series sensors. The -200 sensors have been either modified and/or re-identified since the original build. Statistical analyses have identified a higher failure rate for the -200 series sensors, and their use is restricted to non-flight critical locations. The -200 sensors, however, are allowed in two locations that can cause a pad abort; one being the discussed EMSD pressure; and the other location being the LPFP discharge pressure which requires two bridges to fail (remote possibility) for a pad-abort condition.<br><br>Although the EMSD pressure sensor is not flight critical, it is used during the chill, start, and mainstage phases to verify the EMSD solenoid function. During purge sequence (PSN)-3, the EMSD pressure is verified to be between 600 and 900 psia. A sensor outside these limits results in a FID, and a major component failure (MCF) is posted by the controller which issues an inhibit, preventing engine start. From PSN-4 (+2 seconds) to start enable, the pressure is verified to be less than 50 psia. Again, a sensor indication above this limit results in a FID, and the MCF is posted along with the issued inhibit, preventing engine start. From ESC to the end of mainstage, the EMSD pressure must indicate outside of the 600 to 900 psia limits. A sensor indicating between these limits results in a FID, an MCF, and an on-pad abort (only if between ESC and $T_o$ SRB ignition command). An EMSD pressure between 600 and 900 psia would indicate that the EMSD solenoid has failed open (deenergized). All SSME LCC and sensor redundancy management are currently under review by a Level II working group to attempt to assess risk and improve launch probability.<br><br>Postflight testing of the sensor, controller, and harness will be completed after engine removal from the vehicle. |

## DOCUMENT SOURCES

In an attempt to define the official as well as the unofficial sources of data for this mission report, the following list is provided.

1. Flight Requirements Document
2. Public Affairs Press Kit
3. Customer Support Room Daily Reports
4. MER Daily Reports
5. MER Mission Summary Report
6. MER Quick Look Report
7. MER Problem Tracking List
8. MER Event Times
9. Subsystem Manager Reports/Inputs
10. MOD Systems Anomaly List
11. MSFC Flash Report
12. MSFC Event Times
13. MSFC Interim Report
14. Crew Debriefing comments
15. Shuttle Operational Data Book

## ACRONYMS AND ABBREVIATIONS

The following is a list of the acronyms and abbreviations and their definitions as these items are used in this document.

| | |
|---|---|
| 3-DMA | Three-Dimensional Microgravity Accelerometer |
| ADACS | attitude determination and control system |
| A/G | air-to-ground |
| APE-B | Auroral Photography Experiment-B |
| APU | auxiliary power unit |
| ARPCS | atmospheric revitalization pressure control system |
| ARS | atmospheric revitalization system |
| ASC-3 | Astroculture-3 |
| ATCS | active thermal control system |
| BFS | backup flight system |
| BITE | built-in test equipment |
| BPL | Bioserve Pilot Laboratory |
| BPM | bioprocessing module |
| BREMSAT | Bremen Satellite Experiment |
| BSM | booster separation motor |
| CAPL | Capillary Pumped Loop |
| CCTV | closed circuit television |
| CEI | Contract end item |
| c.g. | center of gravity |
| CGBA | Commercial Generic Bioprocessing Apparatus |
| CHAWS | Charge Analysis and Wake Study |
| CPCG | Commercial Protein Crystal Growth |
| CRT | cathode ray tube |
| CWC | contingency water container |
| DEU | display electronics unit |
| DIH | discrete input high |
| DSO | Detailed Supplementary Objective |
| DTO | Development Test Objective |
| ΔP | differential pressure |
| ΔV | differential velocity |
| ECLIPSE-HAB | Equipment for Controlled Liquid Phase Sintering Experiment-Spacehab |
| ECLSS | Environmental Control and Life Support System |
| EMSD | Emergency Shutdown |
| EOS | Earth Observation System |
| EPDC | electrical power distribution and control subsystem |
| e.s.t. | eastern standard time |
| ET | External Tank |
| FCS | flight control system |
| FDA | fault detection annunciation |
| FES | flash evaporator system |
| FF | free flyer |
| FPB | fuel preburner |
| ft/sec | feet per second |
| GAPS | group activation packs |
| GAS | Getaway Special |
| GBA | Getaway Special Bridge Assembly |

| | |
|---|---|
| GEI | ground environment instrumentation |
| GFE | Government furnished equipment |
| GGVM | gas generator valve module |
| $GH_2$ | gaseous hydrogen |
| G.m.t. | Greenwich mean time |
| $GN_2$ | gaseous nitrogen |
| GPC | general purpose computer |
| HAINS | High Accuracy Inertial Navigation System |
| HIU | headset interface unit |
| HPFTP | high pressure fuel turbopump |
| HPOTP | high pressure oxidizer turbopump |
| ICD | Interface Control Drawing |
| ICOM | intercommunications |
| IFM | in-flight maintenance |
| IMMUNE-01 | Immunology Experiment-01 |
| IMU | inertial measurement unit |
| I/O | input/output |
| Isp | specific impulse |
| JSC | Johnson Space Center |
| keas | knots equivalent air speed |
| KSC | Kennedy Space Center |
| kW | kilowatt |
| kWh | kilowatt hours |
| lbm | pound mass |
| LCC | Launch Commit Criteria |
| LESC | Lockheed Engineering and Sciences Company |
| $LH_2$ | liquid hydrogen |
| $LO_2$ | liquid oxygen |
| lube | lubrication |
| MBE | Molecular Beam Epitaxy |
| MDM | multiplexer/demultiplexer |
| MECO | main engine cutoff |
| MET | mission elapsed time |
| Mir | Russian Space Station |
| MPM | manipulator positioning mechanism |
| MPS | main propulsion system |
| MSFC | George C. Marshall Space Flight Center |
| NASA | National Aeronautics and Space Administration |
| nmi. | nautical mile |
| NPSP | net positive suction pressure |
| NSTS | National Space Transportation System |
| ODERACS | Orbital Debris Radar Calibration Spheres |
| OF | operational forward |
| OFI | operational flight instrumentation |
| OMRSD | Operations and Maintenance Requirements and Specifications Document |
| OMS | orbital maneuvering subsystem |
| ON | Optokinetics Nystagmus |
| ORSEP | Organic Separation |
| PADM | portable audio data modem |
| PAO | Public Affairs Office |
| PAL | protuberance air load |
| PCMMU | pulse code modulation master unit |
| PDI | payload data interleaver |

| | |
|---|---|
| PDU | power drive unit |
| PGSC | Payload General Support Computer |
| PMBT | propellant mean bulk temperature |
| ppm | parts per million |
| PRSD | power reactant storage and distribution |
| PSB | Pennsylvania State Biomodule |
| RCC | reusable carbon carbon |
| RCS | reaction control subsystem |
| RF | radio frequency |
| RHEED | Reflection High Energy Election Diffraction |
| RM | redundancy management |
| RMS | remote manipulator system |
| RSRM | Redesigned Solid Rocket Motor |
| RSB | rudder speedbrake |
| S&A | safe and arm |
| SAMS | Space Acceleration Measurement System |
| SAREX | Shuttle Amateur Radio Experiment |
| SC-2 | spacecraft-2 computer |
| SEF | Space Experiment Facility |
| SLF | Shuttle Landing Facility |
| s/n | serial number |
| SOR/F | Stirling Orbiter Refrigerator/Freezer |
| SOYUZ | Russian spacecraft |
| SRB | Solid Rocket Booster |
| SRE | Sample Return Experiment |
| SRSS | Shuttle Range Safety System |
| SSME | Space Shuttle main engine |
| STI | Shuttle Thermal Imager |
| STS | Space Transportation System |
| TCS | Thermal Control System |
| TEPC | Tissue Equivalent Proportional Counter |
| TIPS | Thermal Impulse Printer System |
| TPS | thermal protection subsystem |
| VHM | voluntary head movements |
| WCS | Waste Collection System |
| WSB | water spray boiler |
| WSF/ WSF-1 | Wake Shield Facility |

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