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STS-50 SPACE SHUTTLE MISSION REPORT

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STS-50

SPACE SHUTTLE

MISSION REPORT

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INTRODUCTION

The STS-50 Space Shuttle Program Mission Report contains a summary of the Orbiter, External Tank (ET), Solid Rocket Booster/Redesigned Solid Rocket Motor (SRB/RSRM), and the Space Shuttle main engine (SSME) subsystem performance during the forty-eighth flight of the Space Shuttle Program, and the twelfth flight of the Orbiter vehicle Columbia (OV-102). In addition to the Columbia vehicle, the flight vehicle consisted of an ET which was designated ET-50 (LWT-43); three SSME's which were serial numbers 2019, 2031, and 2011 in positions 1, 2, and 3, respectively; and two SRB's which were designated BI-051. The lightweight/redesigned RSRM's installed in each SRB were designated 360L024A for the left RSRM and 360M024B for the right RSRM.

The STS-50 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement, as documented in NSTS 07700, Volume VIII, Appendix E, which states that each major organizational element supporting the Program will report the results of its hardware evaluation and mission performance plus identify all related in-flight anomalies.

The primary objective of the STS-50 flight was to successfully perform the planned operations of the United States Microgravity Laboratory (USML-1) payload. The secondary objectives of this flight were to perform the operations required by the Investigations into Polymer Membrane Processing (IPMP), and the Shuttle Amateur Radio Experiment II (SAREX-II) payloads. An additional secondary objective was to meet the requirements of the Ultraviolet Plume Instrument (UVPI), which was flown as a payload of opportunity.

STS-50 was the first flight of OV-102 after completion of the Orbiter Maintenance Down Period (OMDP), which was completed at Palmdale, CA. In addition, STS-50 was the first flight in the Space Shuttle Program of the following:

a. Extended Duration Orbiter (EDO) cryogenics pallet; and

b. Regenerative carbon dioxide removal system.

The sequence of events for the STS-50 mission is shown in Table I and the Official Orbiter and GFE Projects Problem Tracking List is shown in Table II. The STS-50 mission was planned as a 13-day mission; however, because of unsatisfactory weather at the primary landing site (Edwards Air Force Base) the landing was delayed one day. Unsatisfactory weather was still present at the primary landing site and the decision was made to land at Kennedy Space Center on the first extension day of the mission.

The report also discusses each Orbiter, ET, SSME, and SRB/RSRM subsystem anomaly in the applicable section of the report, and a reference to the assigned tracking number is provided when the anomaly is mentioned in the body of the report. All times in the text are given in both Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The crew for this forty-eighth Space Shuttle flight was Richard N. Richards, Capt. USN, Commander; Kenneth D. Bowersox, Lt. Cdr. USN, Pilot; Bonnie J. Dunbar, Ph.D., Civilian, Mission Specialist 1 (Payload Commander); Ellen S. Baker, M.D., Civilian, Mission Specialist 2; Carl J. Meade, Col. USAF, Mission Specialist 3; Eugene H. Trinh, Ph.D., Civilian, Payload Specialist 1; and Lawrence J. Delucas, Ph.D., Civilian, Payload Specialist 2. STS-50 was the third space flight for the Commander and Mission Specialist 1, the second space flight for Mission Specialists 2 and 3, and the first space flight for the Pilot and both Payload Specialists.

MISSION SUMMARY

Lift-off of the STS-50 vehicle from launch complex 39A occurred at 177:16:12:22.997 G.m.t. (12:12:23 p.m. e.d.t.) on June 25, 1992, after a 5-minute 23-second hold at T-9 minutes because of unacceptable weather in the launch-site area. A decision was made to count down to T-5 minutes and hold for acceptable weather; however, while the count was proceeding at approximately T-7 minutes, the weather was declared acceptable for launch and the countdown was continued to lift-off without an additional hold. The orbital inclination was 28.45 degrees. The total vehicle weight at lift-off was 4,519,430 lb, and the Orbiter weight at lift-off was 257,339 lb.

During the T-9 minute hold, the inertial measurement unit (IMU) 3 gyro drift rate exceeded the specification of 0.09 deg/hr by 0.0011 deg/hr during an inertial reference alignment measurement system (IRAMS) filter pass. After the next filter pass, the drift rate was within specification. Since the data were acceptable during the subsequent filter passes, no Launch Commit Criteria (LCC) violations were noted, and the countdown was not held for this problem.

The launch phase was satisfactory in all respects. All SSME and RSRM start sequences occurred as expected and the launch phase performance was satisfactory in all respects. First stage ascent performance was normal with SRB separation, entry, deceleration, and water impact occurring as anticipated. Both SRB's were successfully recovered. Performance of the SSME's, ET, and main propulsion system (MPS) was also normal with main engine cutoff (MECO) occurring approximately 507.2 seconds after lift-off.

The right orbital maneuvering subsystem (OMS) yaw actuator moved approximately 0.24 degree during ascent. The movement began at lift-off and ended shortly after the period of maximum dynamic pressure (max Q). The 0.24-degree movement indicated slippage of the actuator "no-back" device. The Operations and Maintenance Requirements and Specifications Document (OMRSD) File IX limit is 0.20 degree; however, 0.24-degree movement was not a concern for entry. Redundancy management monitors actuator movement and drives the engine back to the stowed position if the movement exceeds 0.7 degree. This precludes the engine nozzle from entering the air stream where engine/nozzle damage could result. On-orbit OMS firing and entry data indicated the no-back device operated properly.

No OMS 1 maneuver was required, and the OMS 2 maneuver was performed at 177:16:52:13.7 G.m.t. (00:39:51 MET). The firing time for the OMS 2 maneuver was 141.6 seconds with a resultant differential velocity (ΔV) *of 222.0 ft/sec.* The Orbiter was in a 160-nmi. circular orbit at the completion of the OMS-2 maneuver.

The payload bay door opening sequence was initiated at 177:17:37:38 G.m.t. (00:01:25:15 MET) and the doors were fully open approximately three minutes later. The Ku-band antenna was satisfactorily deployed at 177:17:46 G.m.t. (00:01:34 MET).

The Spacelab facility was activated at 177:20:42 G.m.t. (00:04:30 MET), about 10 minutes ahead of schedule.

The power reactant storage and distribution (PRSD) subsystem oxygen tank 2 pressure indicated a decrease at the rate equivalent to approximately 1 lb/hr. Leakage from this tank did not impact mission duration or entry as the tank 2 management plan called for 125 lb of oxygen to be used from this tank early in the mission to ensure that the 13-day plus 2-day contingency capability was preserved in the remaining PRSD tanks.

The Extended Duration Orbiter (EDO) pallet tanks began supplying hydrogen and oxygen about 24 hours into the flight, and satisfactorily met all requirements throughout the mission. This was the first flight of the EDO pallet in the Space Shuttle Program.

The reaction control subsystem (RCS) thruster L1U heater was declared failed on at 177:23:42 G.m.t. (00:07:30 MET). The crew turned off the heater when it was declared failed. Five other thrusters were also affected by turning off heater power (R1U, R1R, R1A, L1L, and L1A). The crew managed the thruster heaters manually to maintain temperatures within the 60° F to 160° F range for all thrusters. This was the same plan that was used on STS-49 to manage a similar failure. Later in the mission (approximately flight day 2), a subsequent failure within the heater controller limited the power to the L1U heater. As a result of this second failure, the temperature of the thruster was maintained at approximately 135° F for the remainder of the mission with no further manual cycles required.

STS-50 was the first flight of the regenerable CO_2 removal subsystem (RCRS). The RCRS was activated shortly after orbital insertion and operated satisfactorily for the first 25 hours of the mission. The RCRS uses regenerable solid amine to adsorb CO_2 and water from the Orbiter cabin environment instead of non-regenerable lithium hydroxide (LiOH).

Beginning at 178:20:26 G.m.t. (01:04:14 MET), the RCRS experienced a total of six shutdowns, and the RCRS was deactivated about two hours later at 01:06:06 MET and fresh LiOH canisters were installed in the Spacelab and in the Orbiter.

An in-flight maintenance (IFM) procedure was developed for regaining single-string operation of the RCRS. Development included duplicating the failure condition in the Environmental Test Article (ETA) facility, performing the IFM procedure, and verifying the RCRS operation by a two-hour verification run. The procedure was initiated onboard the Orbiter beginning at approximately

182:12:12 G.m.t. (04:20:00 MET). The procedure required about 4 hours and 45 minutes to complete after which the RCRS was powered up at 182:16:57 G.m.t. (05:00:45 MET), after which it operated satisfactorily for the remainder of the mission.

The oxygen purge valve on fuel cell 3 failed to close after completion of the eighth purge at approximately 181:11:43 G.m.t. (03:19:31 MET). The valve subsequently reseated after being manually cycled open and then closed by the crew. As a result, a decision was made to not purge fuel cell 3 for the rest of the mission unless excessive degradation of the electricity-producing capability occurred. Fuel cell 3 performance degradation was less than 0.4 volt during the remainder of the mission, and no additional purges of fuel cell 3 were required after the problem occurred.

The Orbiter was maneuvered into a bottom-solar-inertial attitude a number of times during the mission for thermal conditioning of the tires. The main landing gear (MLG) tire temperatures were maintained at satisfactory levels throughout the mission. Prior to entry, the lowest tire pressure indicated was 349 psia, well above the 337 psia lower limit.

On flight day 8, the crew removed the tunnel duct cap, which is redundant to the payload isolation valve and allows better air circulation between the Spacelab and the crew module. The partial pressure of CO_2 in the Spacelab dropped from approximately 6.7 mmHg to 6.2 mmHg within two hours of the cap removal, and the CO_2 level in the crew cabin experienced a corresponding rise from approximately 4.2 mmHg to 5.0 mmHg. This cap should have been removed during Spacelab activation; however, the crew was not aware of this requirement as there were no written procedures that required the cap to be removed.

Data from a series of six recharges of the hydraulic system 2 accumulator indicated a leak of gaseous nitrogen (GN_2) from the system 2 bootstrap accumulator. The first four recharges showed nominal GN_2 pressures of approximately 2500 psi. However, the fifth recharge at approximately 188:15:44 G.m.t. (10:23:32 MET) and the sixth recharge 7 hours 15 minutes later showed pressures of 2356 and 2127 psi, respectively. Continuous manual operation of the circulation pump began at 189:06:03 G.m.t. (11:13:51 MET) after the recharge was initiated under general purpose computer (GPC) control. The concern was that loss of GN_2 pressure could result in loss of head pressure to the main hydraulic pump. Main pump start with loss of reservoir/bootstrap pressure is uncertified. Head pressure was maintained with manual circulation pump 2 operation.

The flight control system (FCS) checkout was performed at 189:12:02:02.25 G.m.t. (11:19:49:39.25 MET) using auxiliary power unit (APU) 3. APU 3 ran for 7 minutes 9 seconds and all subsystems performed satisfactorily.

The RCS hot-fire test was conducted at 190:07:50 G.m.t. (12:15:38 MET). During the hot fire test, thruster F2F failed off because of low chamber pressure. The failure occurred on the first pulse of the thruster at 190:07:50:42.38 G.m.t. (012:15:38:19.39 MET). Chamber pressure reached only 5 psi during the firing, and injector temperatures indicated that propellant initially flowed through both valves to the combustion chamber.

Because of the unsatisfactory weather conditions at Edwards Air Force Base, the preflight-planned landing opportunity and the next revolution landing opportunity were not acceptable. The landing was postponed approximately 24 hours and planned for Edwards Air Force Base or Kennedy Space Center on July 9, 1992. The weather remained unsatisfactory at Edwards Air Force Base and the decision was made to land at Kennedy Space Center on the first daylight opportunity.

After the decision was made to delay the landing for 24 hours, an OMS-3 orbit-adjust maneuver was performed at 190:15:09:22 G.m.t. (12:22:56:59 MET) to better align the orbit for the planned landing opportunities on the following days. The dual engine maneuver was 30.8 seconds in duration and the ΔV was 49.6 ft/sec.

Both payload bay (PLB) doors were closed by 191:08:04:29 G.m.t. (13:15:52:06 MET). At 191:07:52 G.m.t. (13:15:40 MET) during the PLB door closure operations, the starboard forward payload bay door floodlight failed. The loss of the floodlight did not affect mission operations.

The deorbit maneuver was performed at 191:10:41:38.0 G.m.t. (13:18:29:48 MET). The maneuver was approximately 203.9 seconds in duration and the ΔV was 341.9 ft/sec. Entry interface occurred at 191:11:10:46 G.m.t. (13:18:58:23 MET).

During entry while performing the programmed test inputs (PTI's) for development test objective 251 - Entry Aerodynamic Control Surfaces Test, the aileron roll trim began to diverge, eventually reaching 1.7 degrees with spikes as high as 2.2 degrees at Mach 8. The flight rule trim limit is 1.5 degrees, consequently, the PTI's were terminated. No vehicle control or stability problems were encountered as a result of this divergence.

Main landing gear touchdown occurred at Kennedy Space Center, FL, on concrete runway 33 at 191:11:42:27 G.m.t. (13:19:30:04 MET) on July 9, 1992. Nose landing gear touchdown occurred 18 seconds later with wheels stop at 191:11:43:25 G.m.t. (13:19:31:02 MET). The rollout was normal in all respects. The drag chute was deployed immediately following nose gear touchdown and was jettisoned at 191:11:43:10.7 G.m.t. (13:19:30:47.1 MET). The flight duration was 13 days 19 hours 30 minutes 04 seconds. Because of an abnormal repressurization of the APU 1 gearbox, the APU was shut down about 4 minutes after landing. The Orbiter weight at landing was 225,615 lb.

A hydraulic load test was performed on APU's 2 and 3 after which the two APU's were shut down by 191:12:01:03 G.m.t. The crew completed the required postflight reconfigurations and departed the Orbiter landing area at 191:13:08:30 G.m.t. (09:08:30 a.m. e.d.t. on July 9, 1992).

Fourteen of the 16 planned development test objectives (DTO's) were completed, and all 17 detailed supplementary objectives (DSO's) were accomplished.

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTER/REDESIGNED SOLID ROCKET MOTOR

All SRB systems performed as expected. The SRB prelaunch countdown was normal, and no SRB in-flight anomalies were identified. No SRB or RSRM LCC or OMRSD violations occurred.

Power-up and operation of all case, igniter, and field joint heaters were accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. For this flight, the heated ground purge in the SRB aft skirt was powered up and maintained the case/nozzle joint and flexible bearing temperatures within the required LCC ranges.

The RSRM propulsion performance was well within the specification limits, and the propellant burn rate for each RSRM was normal. RSRM thrust differentials during the buildup, steady-state, and tailoff phases were well within specification, and were typical of the performance observed on previous flights. Key RSRM propulsion performance parameters are presented in the table on the following page.

The SRB flight structural temperature response was as expected. Postflight inspection of the recovered hardware indicated that the SRB thermal protection system (TPS) performed properly during ascent with very little TPS acreage ablation; however, one RSRM in-flight anomaly was identified during postflight inspection of the TPS on the left RSRM forward-center segment. Three areas of cork were missing on the aft ground environment instrumentation (GEI) cork run (station 1099) at the 180-, 186-, and 192-degree locations (Flight Problem STS-50-M-1). The investigation has determined that the missing cork was associated with a processing problem that occurred only on this segment when a vacuum bag leak caused a delay in the installation of the cork beyond the pot life of the adhesive, resulting in several small unbonded areas. This condition did not present a safety-of-flight issue for STS-50 because the areas of concern were on the side of the RSRM away from the Orbiter.

Both SRB's were successfully separated from the ET at 126.3 seconds after lift-off. Separation subsystem performance was normal with all booster separation motors (BSM's) expended and all separation bolts severed. Nose cap jettison, frustum separation, and nozzle jettison occurred normally on each SRB. The entry and deceleration sequence was properly performed on both SRB's. RSRM nozzle jettison occurred after frustum separation, and subsequent parachute deployments were successfully performed. Both SRB's were recovered and returned to Cape Canaveral by the retrieval ships. The SRB's have been disassembled and are being refurbished for future use.

EXTERNAL TANK

All objectives and requirements associated with the ET propellant loading and flight operations were met. All ET electrical equipment and instrumentation performed satisfactorily throughout the countdown and flight. ET purge and heater operations were monitored and all performed properly. Propellant loading was completed as scheduled and all prelaunch thermal requirements were met. No LCC or OMRSD violations were identified. ET flight performance was excellent.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 78° F		Right motor, 78° F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	65.27	64.67	64.95	64.88
I-60, 10^6 lbf-sec	174.15	173.36	173.38	173.73
I-AT, 10^6 lbf-sec	296.79	296.63	296.67	296.60
Vacuum Isp, lbf-sec/lbm	268.6	268.5	268.6	268.5
Burn rate, in/sec @ 60 °F at 625 psia	0.3655	0.3638	0.3645	0.3649
Event times, seconds				
Ignition interval	0.232	N/A	0.232	N/A
Web time	110.3	110.8	110.8	110.8
Action time	120.1	121.2	120.7	120.4
Separation cue, 50 psia	122.2	123.7	122.8	122.8
PMBT, °F	78.0	78.0	78.0	78.0
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	3.4	2.8	3.1
Tailoff imbalance Impulse differential, klbf-sec	Predicted N/A		Actual 888.4	

As expected, only the normal ice/frost formations for the June atmospheric environment were observed during the countdown. There was no frost or 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. A small amount of frost was also present along the edge of the LH_2 protuberance air load (PAL) ramps. All of the observations were acceptable and in accordance with NASA documentation. The Ice/Frost "Red Team" reported that there were no anomalous TPS conditions; however, a crack in the TPS foam at the junction of the vertical strut cable tray and fairing at the base of the strut was identified and determined to be acceptable. No ice or frost line was present at the crack.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the period of the ullage pressure slump was 14.6 psid.

ET separation was confirmed to have occurred properly, and the ET entry and breakup were determined to have occurred within the predicted footprint.

The ET tumble system was deactivated for this flight, and radar reports from Bermuda confirmed that the ET did not tumble. There were no significant ET problems identified; however, one ET in-flight anomaly was identified during postflight activities. Review of the ET umbilical film and photographs taken by the crew showed two areas of TPS damage on the forward bipod (Flight Problem STS-50-T-1). Approximately one-half of the insulation that was formed around the bipod ramp was missing, and the jackpad closeout located immediately below the right bipod strut was also missing.

SPACE SHUTTLE MAIN ENGINE

All SSME parameters appeared to be normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. The engine "ready" condition was achieved at the proper time, all LCC were met, and engine start and thrust buildup were normal.

Flight data indicate that SSME performance during mainstage, throttling, shutdown, and propellant-dump operations were normal. High pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures appeared to be well within specification throughout engine operation.

The SSME controllers provided the proper control of the engines throughout powered flight. Engine dynamic data generally compared well with previous flight and test data. All SSME on-orbit activities were accomplished successfully. No significant SSME problems were identified; however, an in-flight anomaly was identified during the postflight data review. SSME 3 (serial no. 2011) data showed a HPFTP pressure spike (-10,600 psia) at engine start +219.46 seconds and immediately recovered at engine start +219.54 seconds. (Flight Problem STS-50-E-1). Although this particular sensor was used for "maintenance only" indication, concern exists because this same type sensor is also used as an input to the engine controller in other applications. The sensor was returned to the vendor and dissected, and a small metallic sliver and a solder bead were found. These contaminants most likely caused the anomalous indication.

An evaluation of SRB/SSME ascent performance was made using vehicle acceleration and preflight propulsion data. From these data, the average flight-derived SSME specific impulse (Isp) determined for the time period between SRB separation and start of 3g throttling was 452.4 seconds as compared to a fleet average tag value of 452.42 seconds.

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 performance was as expected throughout the launch phase.

Prior to SRB separation, the SRB S&A devices were safed, and SRB system power was turned off, as planned. The ET system remained active until ET separation from the Orbiter. The SRSS on the ET was modified for this flight and subsequent flights by removing the linear-shaped charge from the liquid hydrogen tank. The system signal strength remained well within system requirements throughout the ascent phase.

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion System

The overall performance of the MPS was excellent. The pressurization systems performed as predicted. Evaluation of flow control valve data revealed nominal operation of these valves.

All pretanking purges were properly performed, and liquid oxygen and liquid hydrogen loading was completed as planned with no stop-flows or reverts. Calculated propellant loads were very close to the inventory loads. The MPS helium system performed satisfactorily with a total of 55.9 lbm of helium used during the mission. No OMRSD or LCC violations were identified.

Throughout preflight operations, no significant hazardous gas concentrations were detected, and the maximum corrected hydrogen level in the Orbiter aft compartment was 125 ppm. The level is well within the historical limits of this vehicle. The aft compartment helium concentration peaked at 9600 ppm, and the maximum aft compartment oxygen concentration was 60 ppm.

The gaseous oxygen pressurization system performed normally throughout the flight. The gaseous oxygen flow control valves were shimmed to a target position corresponding to a 80.6-percent flow area. The minimum liquid oxygen ullage pressure experienced during the period of ullage pressure slump was 14.6 psid. The liquid oxygen ullage pressure transducers did not remain within an OMRSD File IX-required 0.9-psi band between cryo loading and MECO. While liquid oxygen ullage pressure 2 and 3 tracked each other closely, liquid oxygen ullage pressure 1 read lower than the others, reaching a maximum differential of 0.95 psia about two minutes after lift-off. Feed system performance was normal, and liquid oxygen and liquid hydrogen propellant conditions were within specified limits during all phases of operation. All net positive suction pressure (NPSP) requirements were met. Propellant dump and vacuum inerting were accomplished satisfactorily.

Reaction Control Subsystem

The performance of the RCS was acceptable; however, two anomalies were identified. Propellant consumption during the mission was 5297.4 lb which includes the forward RCS propellant dump before landing. The RCS was used to support DTO 251 - Entry Aerodynamic Control Surfaces Test; however, not all the planned programmed test inputs (PTI's) were completed because of an aileron trim problem near Mach 10. These totals do not include the OMS propellant consumed during RCS/OMS interconnect operations.

The RCS thruster L1U heater was declared failed on at 177:23:42 G.m.t. (00:07:30 MET) (Flight Problem STS-50-V-01). This is the first flight of this thruster, and the maximum temperature reached was 159° F. The crew turned off the heater when it was declared failed. Five other thrusters were also affected by turning off heater power (R1U, R1R, R1A, L1L, and L1A). The crew managed the thruster heaters to maintain temperatures within the 60° F to 160° F range for all thrusters. This was the same plan that was used on STS-49 to manage a similar failure. Early in the mission (approximately flight day 2), a subsequent failure within the heater controller limited the power to the L1U heater. As a result of this second failure, the temperature of the thruster was maintained at approximately 135° F for the remainder of the mission with no further manual cycles required.

During the RCS hot-fire test, conducted at 190:07:50 G.m.t. (012:15:38 MET), thruster F2F was deselected as "failed off" because of low chamber pressure on the first pulse of the thruster (Flight Problem STS-50-V-18). The maximum chamber pressure reached was 5.5 psia. Injector temperature traces indicated some oxidizer and fuel flowed through both valves to the combustion chamber. The most likely failure mode was full fuel flow and oxidizer pilot-valve-only operation. Vehicle rates indicated that the thruster did not fire. Failure of the oxidizer valve main stage to open is most likely due to an accumulation of iron nitrates.

Vernier RCS thruster F5L was deselected as "failed leak" when the injector temperatures dropped below the leak detect limit of 130° F. It was determined that the leak indication was false and the thruster was reselected and fired. The vernier thruster heaters are undersized and in the cold attitude coupled with a low duty cycle, the temperatures can drop below the leak detect limits. Vernier thruster temperatures were managed by employing a tighter deadband to ensure a higher duty cycle.

Data showed that thruster R1R experienced a fuel injector temperature drop after the orbit adjust (OMS-3) maneuver, indicating some fuel flow had occurred. It is believed that the temperature drop was caused by a valve bounce resulting from the pressure transients caused by the shutdown of thruster R1U. The RCS thruster valve is a pressure-assisted valve and pressure surges through the system (i.e., thruster shutdowns and start ups could cause a large pressure differential between the valve inlet and the valve upper cavity). Should the pressure differential be high enough, the sealing capability of the valve can be degraded and allow a small amount of propellant to pass. This phenomenon is understood and has been seen on previous flights.

Orbital Maneuvering Subsystem

The OMS performance during the mission was satisfactory with three dual-engine firings completed normally:

a. OMS-2 - a 141.6-second maneuver with a ΔV of 222.0 ft/sec.

b. OMS-3 - a 30.8-second maneuver with a ΔV of 49.6 ft/sec.

c. Deorbit - a 203.9-second maneuver with a ΔV of 341.9 ft/sec.

Propellant usage during the three maneuvers plus during RCS interconnect operations was 10,352.1 lb of oxidizer and 6112.0 lb of fuel. Propellant usage was 2.17 percent during the right-OMS-to-right-RCS interconnect and 2.38 percent during left-OMS-to-left-RCS interconnect operations.

The right OMS yaw actuator moved approximately 0.24 degree during ascent. The movement began at lift-off and ended shortly after the period of max Q was completed (Flight Problem STS-50-V-06). On-orbit OMS firing and entry aerodynamic data indicated the no-back device operated properly. A more detailed discussion of this anomaly is provided in the Avionics and Software Subsystem section of this report.

Both the left and right oxidizer gaging systems as well as the left-hand forward fuel gaging system performed satisfactorily. Approximately 14 seconds into the OMS-3 maneuver, the right-hand fuel total quantity measurement shifted from 42.8 percent to 50.8 percent (Flight Problem STS-50-V-19). This anomaly resulted in high readings on the total quantity gaging system following the deorbit maneuver. The offset associated with the forward probe has occurred on other pods, but this is the first anomaly on a redesigned probe.

The OMS fuel high-point bleed heater system A control thermostat that is located on the aft bulkhead high point bleed line failed off (Flight Problem STS-50-V-14). The loss of this heater did not impact the mission as the overtemperature thermostat for the A heater was functioning normally as well as the B-heater thermostats.

Power Reactant Storage and Distribution Subsystem

STS-50 was the first flight of the EDO pallet which carried four cryogenic tank sets in addition to the normal four tank sets carried on the Orbiter. The PRSD subsystem including the EDO pallet performed satisfactorily in meeting all mission requirements. The EDO pallet tanks began supplying hydrogen and oxygen about 24 hours into the flight and operated satisfactorily throughout the mission. A total of 549.7 lb of hydrogen was consumed from the eight-tank-set configuration, and 4735 lb of oxygen was consumed of which 209.8 lb was consumed by the crew and 160 lb leaked overboard from oxygen tank 2. After landing, the calculated mission extension capability based on oxygen remaining was 56 hours.

The PRSD subsystem oxygen tank 2 pressure indicated a decrease at the rate equivalent to a leak of approximately 0.9 lb/hr throughout the flight (Flight Problem STS-50-V-08). Leakage from this tank did not impact mission duration or entry as the tank 2 management plan called for 125 lb of oxygen to be used from this tank early in the mission to ensure that the 13-day plus 2-day contingency capability was preserved in the remaining PRSD tanks.

Prior to the mission, a known leak in the airborne half of the fill quick disconnect (QD) poppet existed. Since the leak was within specification and since a flight cap was to be installed, the known leak was acceptable for flight. During postflight leak testing, it was discovered that the flight cap had not been properly torqued. This lack of proper torque damaged the cap seal and allowed the QD leak to resume and at a higher rate than seen before the flight.

At 186:02:00 G.m.t. (08:09:48 MET), data showed that the PRSD oxygen tank 7 pressure was tracking the manifold pressure that feeds the fuel cells. Tank 7 heaters were not powered; therefore, the tank should not have been feeding the manifold/fuel cells at that time. The tank 7 pressure behavior was an indication of a stuck-open check valve in tank 7 (Flight Problem STS-50-V-12).

Configuring to tank-7-operation-only to increase the flow through the check valve did not correct the problem. The check valve reseated and began functioning nominally at 190:14:10 G.m.t. (12:21:58 MET), but stuck open again during entry. This anomaly did not impact the successful completion of the planned mission. The valve will be replaced during postflight turnaround activities.

At 189:17:35 G.m.t. (12:01:23 MET), the PRSD oxygen tank 3 quantity measurement began shifting erratically from 80 percent to off-scale-high (Flight Problem STS-50-V-20). The measurement later stabilized at the nominal quantity. The erratic behavior did not impact the successful completion of the mission.

The oxygen tank 2 heater A2 "on" indication was intermittent (Flight Problem STS-50-V-05). Pressure and amperage data indicated that the heater was operating intermittently as well. The data indicate that the problem existed in the heater control box and not in the heater element itself. This conclusion was supported by the fact that the indication was downstream of the control box and upstream of the heater.

Fuel Cell Powerplant Subsystem

Performance of the fuel cell powerplant subsystem was nominal during the mission except for the fuel cell 3 purge valve failure discussed in the following paragraph. During the 331.5-hour mission, the fuel cells produced 6204.7 kWh of electrical energy and 4914.6 lb of potable water from 4364.9 lb of oxygen and 549.7 lb of hydrogen. The average total Orbiter electrical power/load was 18.7 kW/625 amperes. The fuel cells were shut down at 192:08:34 G.m.t. Fuel cell 1, 2, and 3 operating times for the mission were 364.8, 364.0, and 363.3 hours, respectively.

At 181:11:41 G.m.t., (03:19:29 MET) the fuel cell 3 oxygen purge valve failed to close completely after the completion of the eighth fuel cell purge (Flight Problem STS-50-V-07). The oxygen flow rate remained high at 70 percent of the purge flow rate, indicating a partially open oxygen purge valve. Ten minutes later, the valve was manually opened to the full purge flow rate for 10 seconds; the valve was then manually closed and the valve reseated completely. The probable cause of the anomaly was the presence of fuel cell corrosion products under the valve seat that cleared during the manual purge. Because of the possibility of the valve sticking open again during subsequent purges, a decision was made to refrain from purging fuel cell 3 for the rest of the mission unless performance degraded to near the end of the life curve. The performance degraded only 0.4 volt for the last 240 hours of the mission, and no purge was required. The valve operated nominally during the postlanding purge operations.

Auxiliary Power Unit Subsystem

Improved auxiliary power unit (IAPU) were flown in all three APU slots. This was the first flight of OV-102 with the IAPU's. Two anomalies were noted, neither of which impacted the successful completion of the mission. Run-times for the IAPU's as well as propellant consumption are shown in the table on the following page.

Flight Phase	IAPU 1 (S/N 204K)		IAPU 2 (S/N 403)		IAPU 3 (S/N 402)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	19:37	48	19:37	53	19:37	54
FCS checkout					07:09	19
Entry[a]	48:10	84	63:03	152	84:19	177
Total[a]	67:47	132	82:40	205	111:05	250

[a]APU 1 was operated for 4 minutes 5 seconds after landing; APU 2 was operated for 18 minutes 59 seconds after landing; and APU 3 was operated for 19 minutes 3 seconds after landing.

After ascent and following the APU tank/fuel line B heater system activation, the APU 3 test line heater cycled low and the test line temperature sensor 1 indicated a temperature that was near the lower fault detection and annunciation (FDA) limit of 48° F (Flight Problem STS-50-V-09). When the heaters were reconfigured to the A system, the test line heater initially cycled at a higher than normal range. The test line temperature 2 measurement sensor exceeded the FDA upper limit of 95° F. Table maintenance block updates (TMBU's) were sent to change the limit to 110° F. Shortly after the TMBU, the temperature measurement exceeded the 110° F limit and a new TMBU was sent to change the upper limit to 120° F. Following these changes, the heater cycled nominally but had unusually low and high peaks.

About 22 minutes after APU 1 was started for entry, the gearbox pressure measurement became erratic (Flight Problem STS-50-V-22). This erratic behavior caused the measurement to intermittently fail off-scale low (0 psia), which caused the APU controller to activate the gearbox repressurization circuit. The measurement failed to zero six times and this resulted in the complete dumping of the gaseous nitrogen from the repressurization bottle into the gearbox. During the repressurization, the gearbox pressure increased from about 8 psia to 28 psia. This increase in pressure was within the operational range of the APU. Because of this anomaly, the crew was instructed to shut down APU 1 about 4 minutes after landing.

The APU 1, 2, and 3 seal cavity drain line relief valves appeared to be leaking during the on-orbit portion of the flight. APU 1 pressure decreased from 15 psia to 11 psia while the APU 2 and 3 relief valves leaked from 15 psia to about 5 psia.

A hydraulic loads test was performed after landing to determine the roughness of the gas generators after their first flight. Due to the APU 1 being shut down about 4 minutes after landing, the load test was only performed on APU's 2 and 3. Both of these systems had acceptable roughness measurements below 50 psi. A hydraulic loads test will be performed on APU 1 after its next flight.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/water spray boiler subsystem operated satisfactorily throughout the mission. Three anomalous conditions were noted, none of which impacted the successful completion of the planned mission.

At approximately 179:21:59:50 G.m.t. (02:05:47 MET), the hydraulic circulation pump 2 pressure transducer indication went to 0 psia (Flight Problem STS-50-V-10). The main pump filter module transducer continued to read approximately 200 psia, indicating nominal circulation pump performance. While this condition was occurring, the vehicle entered loss-of-signal (LOS). During LOS, the crew received an FDA alarm indicating a loss of circulation pump pressure and the pump was deactivated. About 10 minutes after the initial indication, the circulation pump 2 pressure transducer returned to the normal reading of 50 psia while in the off position. The temporary loss of the measurement was evaluated. A backup pressure measurement was available and was used during subsequent circulation pump operations. A TMBU was transmitted to disable the FDA alarms for the primary pressure transducer to preclude nuisance alarms during pump operations. The circulation pumps remained in the automatic mode for thermal control of the hydraulic subsystem.

Data from a series of six recharges of the hydraulic system 2 accumulator indicate a leak of GN2 from the system 2 bootstrap accumulator (Flight Problem STS-50-V-15). The first four recharges showed nominal GN_2 pressures of approximately 2500 psi. However, the fifth recharge at approximately 188:15:44 G.m.t. (10:23:32 MET) and the sixth recharge 7 hours 15 minutes later showed pressures of 2356 and 2127 psi, respectively. Continuous manual operation of the circulation pump began at 189:06:03 G.m.t. (11:13:51 MET) after the recharge began under GPC mode with a set pressure point of 1960 psi. The concern was that loss of GN_2 pressure could result in loss of head pressure to the main hydraulic pump. Main pump start with loss of reservoir/bootstrap pressure is uncertified. Head pressure was maintained with manual circulation pump 2 operation.

During a long operational run of circulation pump 2 to recharge the accumulator, the data indicate an excessive temperature rise and leakage from hydraulic system 2 to system 1 and system 3 (Flight Problem STS-50-V-25). Leakage from hydraulic system 2 into system 1 was approximately 10 percent and into system 3 was approximately 28 percent. Later in the flight, circulation pump 3 was operated to return some of the hydraulic fluid to system 1 and 2.

Following the Orbiter landing, a hydraulic load test was performed on APU's 2 and 3, after which the two APU's were shut down by 191:12:01:03 G.m.t.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPD&C) subsystem performed satisfactorily throughout the mission. All electrical functions associated with the EDO pallet and drag chute (both flown on this vehicle for the first time) were performed nominally.

Pyrotechnics Subsystem

The pyrotechnics subsystem performed all required functions in a satisfactory manner. The nose gear extension thruster operated correctly. All drag chute pyrotechnics operated as planned culminating the second use of the drag chute on a Space Shuttle vehicle.

During the postflight inspection, two expended umbilical attachment pyrotechnic connectors were found on the runway under the right Orbiter/ET umbilical door. This Orbiter did not have the umbilical attachment debris containment modification; consequently, this condition was not unexpected.

Environmental Control and Life Support Subsystem

Atmospheric Revitalization System.- The atmospheric revitalization system (ARS) performed nominally except for the RCRS.

The ARS air and water coolant loops performance was nominal, and the CO_2 partial pressure was maintained below 7.25 mm Hg. The cabin air temperature and relative humidity peaked at 80.5° F and 57.0 percent, respectively. The avionics bay 1, 2, and 3 air outlet temperatures peaked at 104.5° F, 107.5° F, and 90.25° F, respectively, and the avionics bay 1, 2, and 3 water coldplate temperatures peaked at 90.5° F, 93.0° F, and 88.0° F, respectively.

STS-50 was the first flight of the RCRS. The RCRS was activated shortly after orbital insertion and operated satisfactorily for the first 25 hours of the mission. The RCRS uses regenerable solid amine to adsorb CO2 and water from the Orbiter cabin environment instead of non-regenerable LiOH.

Beginning at 178:13:38 G.m.t. (00:21:26 MET), the RCRS experienced a total of six shutdowns (Flight Problem STS-50-V-02). Both controllers were affected by the shutdowns. The cause of the shutdowns was determined to be shorting of the shaft position sensor circuits in a vacuum cycle valve actuator near an actuator shaft bearing. The RCRS was deactivated at 01:06:06 MET and fresh LiOH canisters were installed in the Spacelab and in the Orbiter.

An IFM procedure was developed for regaining single-string operation of the RCRS. Development included duplicating the failure condition in the ground test facility, performing the IFM procedure, and verifying the RCRS operation by a two-hour verification run. The procedure was initiated onboard the Orbiter at approximately 182:12:12 G.m.t. (04:20:00 MET). The procedure, which required about 4 hours and 45 minutes to complete, began with the removal of four stowage lockers and the volume D floor panel to gain access to the RCRS controller wiring. The crew then removed the controller 2 J8 connector backshell, after which the wire pairs for the actuators clockwise position indicator were identified. The wire pairs were cut and spliced together to bypass the indicators, and the RCRS was powered up.

Following the IFM, the RCRS began single-string operation at 182:16:57 G.m.t. (05:00:45 MET), and operated satisfactorily for the remainder of the mission. The RCRS maintained the Orbiter cabin atmosphere CO_2 level between 4.0 and 4.5 mmHg, and the Spacelab CO_2 level tracked about 1 to 1.25 mmHg higher than the Orbiter, as expected, once the tunnel duct cap was removed.

Pressure Control System.- The cabin and PPO_2 pressure control system performance was normal throughout the mission. The Spacelab pressure control system was used for the first five days of the flight and the Orbiter pressure control system was used for the remainder of the flight.

Active Thermal Control System.- The active thermal control system operated nominally throughout the mission. Satisfactory cooling was provided to the Spacelab at the payload heat exchanger. The radiator cold soak provided vehicle cooling from flash evaporator system (FES) deactivation through landing plus 10 minutes. The ammonia boiler system B, operating on the primary controller, provided cooling for 39 minutes until the ammonia supply was depleted and ground support equipment (GSE) cooling was initiated.

Supply and Waste Water Systems.- The supply and waste water management systems performed adequately throughout the mission. By the completion of the mission, all of the associated supply water in-flight checkout requirements and all but one of the waste water requirements had been satisfied.

Supply water was managed through the use of the FES. No supply water dumps through the dump nozzle were performed because of the vehicle cooling requirements. The supply water dump line temperature was maintained between 72 and 110 °F throughout the mission with the operation of the line heater.

Waste water was gathered at approximately the predicted flow rate. Four waste water dumps were performed. The first three dumps had an average dump rate of 1.94 percent/minute (3.21 lb/min), while the last segment of dump three and all of dump four were degraded in flow (Flight Problem STS-50-V-16). Dump four averaged 0.9 percent/minute (1.49 lb/min), and slowed to less than 0.5 percent/minute before being terminated. At the time of termination, adequate ullage was available to support the end-of-mission timelines. The waste water dump line temperature was maintained between 53 and 75° F throughout the mission while the vacuum vent line temperature was between 59 and 75° F.

Waste Collection System.- The waste collection system (WCS) performed adequately throughout the mission. The crew reported a whining noise being produced from the coffee can when a bag was not installed.

Smoke Detection and Fire Suppression Subsystem

There were no smoke detector alarms and the fire extinguishers were not required or used.

Airlock Support System and Tunnel Adapter

The airlock was not used for extravehicular activity, but along with the tunnel adapter provided intravehicular access to the Spacelab. The tunnel duct cap, which is redundant to the manual payload isolation valve in the event of a Spacelab module air leak, was not removed during Spacelab activation. The cap was not removed because the crew was not aware that the cap must be removed and no written procedures existed that required the cap removal. As a result, there was no forced air transfer between the Spacelab and the Orbiter cabins across hatch D. However, the Spacelab CO_2 system controlled the Orbiter CO_2 level for two days and the Orbiter system controlled the Spacelab CO_2 level for three days with only a 2-mmHg differential between the two cabins. The cap was removed on flight day 8, and within three hours the CO_2 difference between the two cabins was decreased to a nominal level of 1.0 to 1.25 mmHg.

Avionics and Software Subsystem

The integrated guidance, navigation and control subsystem performed nominally throughout the mission. The flight control system performed satisfactorily with the exception of the OMS no-back operation. The right OMS yaw actuator moved approximately 0.24 degree during ascent (Flight Problem STS-50-V-06). The movement began at lift-off and ended shortly after the period of max Q was completed. The 0.24-degree movement indicated slippage of the actuator "no-back" device. The OMRSD File IX limit is 0.20 degree; however, 0.24-degree movement was determined not to be a concern for entry. Redundancy management monitors actuator movement and drives the engine back to the stowed position if the movement exceeds 0.7 degree. This precludes the engine nozzle from entering the air stream where engine/nozzle damage could result. Entry aerodynamic data indicated the no-back device operated properly.

The IMU performance was satisfactory during the mission; however, a problem was noted during the prelaunch countdown. During the T-9 minute hold, the IMU 3 gyro drift rate exceeded the specification of 0.09 deg/hr by 0.0011 deg/hr during an IRAMS filter pass. After the next filter pass, the drift rate was within specification. Since the data were acceptable during the subsequent filter passes, no LCC were violated, and the countdown was not held for this problem.

The star tracker performance, as well as the data processing system and flight software, was satisfactorily.

The displays and controls subsystem performed satisfactorily except for the forward starboard payload bay floodlight. At 191:08:25 G.m.t. (13:16:13 MET) during the payload bay (PLB) door closure operations, the starboard forward PLB door floodlight failed (Flight Problem STS-50-V-21). The loss of the floodlight did not affect the remaining PLB operations.

The operational instrumentation (OI) performance was acceptable with three anomalies. Neither of these anomalies compromised the successful completion of the mission.

At approximately 179:21:59:50 G.m.t. (02:05:47:27 MET), the hydraulic circulation pump 2 pressure transducer indication went to 0 psia. The main pump filter module transducer continued to read approximately 200 psia, indicating nominal circulation pump performance. The anomaly is discussed in more detail in the Hydraulics/Water Spray Boiler section of this report.

At 186:11:05 G.m.t. (08:18:53 MET), the Orbiter experiments (OEX) recorder was commanded to mark 5, but the recorder skipped the mark and continued to the end of the tape (Flight Problem STS-50-V-24). The recorder was commanded back to mark 5 and the recorder stopped at the mark. A label command was then sent and the recorder did not function as commanded. After an all-stop command and a label command were sent, the recorder operated properly for the remainder of the mission.

At 191:10:41 G.m.t. (13:18:29 MET), the beginning of the OMS deorbit maneuver, the modular auxiliary data system (MADS) frequency data multiplexer (FDM) 1, multiplexer 4 built-in test equipment (BITE) indicated an intermittent failure (Flight Problem STS-50-V-23). This anomaly did not impact the successful completion of the mission.

Communications and Tracking Subsystem

Performance of the communications and tracking subsystem was acceptable with five anomalies identified. None of the anomalies impacted the successful completion of the mission.

An unscheduled UHF-communications-only DTO (not planned for STS-50) was performed at lift-off plus 107 seconds when an incorrect air-to-ground 1 only transmission was performed instead of a UHF-only transmission. The UHF-only check was performed at lift-off plus 2 minutes, but this time was too late to provide conclusive data.

Closed circuit television (CCTV) camera A video downlink contained numerous lines of noise (Flight Problem STS-50-V-03). The problem was intermittent in nature and did not impact video operations.

An IFM procedure was performed on the text and graphics system (TAGS), which had malfunctioned during an uplink at approximately 179:21:44 G.m.t. (02:05:32 MET) (Flight Problem STS-50-V-04). The crew reported that the upper booster roller turned and then stopped, indicating that the developer motor had failed. The TAGS was powered off and was not used for the remainder of the mission. As a result, the portable audio data modem (PADM) was used with the payload and general support computer (PGSC) for graphics uplink.

The CCTV camera D heater failed off at 181:14:00 G.m.t. (03:21:48 MET) (Flight Problem STS-50-V-11). Camera temperatures as low as -13° C were noted. Camera temperatures below -29° C could have resulted in the operational loss of camera D. Acceptable camera temperatures were maintained for the remainder of the mission by powering the camera heater on whenever temperatures were low.

The crew stated that the MKII camcorder (flight deck unit) would no longer image a video picture at 187:22:00 G.m.t. (10:05:48 MET), and a blank screen would appear each time the camcorder was used as a video unit (Flight Problem STS-50-V-13). However, the camera still operated satisfactorily in the playback mode. The crew tried to troubleshoot the failed camera by selecting the auto mode; however, the screen was still blank when the unit was used as a camera.

It was noted in a video playback at 189:22:37 G.m.t. (12:06:25 MET) that CCTV camera C provided no video image (Flight Problem STS-50-V-17). Camera operation could not be regained. No significant data were lost because of this camera failure.

At 186:14:28 G.m.t. (08:22:16 MET), the camcorder dump video exhibited poor quality color (rainbowing, and no color lock). NASA Ground Terminal (NGT), which is located at White Sands, attempted a failover to backup color processing equipment with no success. NGT reported an IRE value that was less than 25 percent of the nominal color burst value. A subsequent dump, however, exhibited good color lock but marginal color saturation. The color quality was deemed acceptable, and the camera was used for the remainder of the mission.

The performance of the S-band lower right antenna degraded during the mission. The S-band system occasionally dropped the forward link on the lower right antenna. The reflected power from this antenna was not constant and some of the dropouts occurred when switching between the antennas. Investigation is continuing in an effort to isolate the problem.

CCTV camera B had a spot burned on the image tube and this resulted in degraded video transmissions. The camera, however, remained usable for the duration of the mission.

Structures and Mechanical Subsystem

All mechanically actuated systems performed nominally including the vent doors, ET/Orbiter umbilical doors, payload bay doors, star tracker doors, Ku-Band antenna deployment actuator, and air data probe deployment system. The landing and braking data are shown in the table on the following page.

All landing and braking parameters were nominal with the exception of one of the four pressures (right-hand outboard 4), which was biased low by about 400 psi (Flight Problem STS-50-V-26). The main landing gear tires were in good condition with less-than-expected wear for the heavy Orbiter weight and a KSC runway landing.

STS-50 was the second flight of the drag chute and the first on this vehicle, and the drag chute performed as expected with no problems noted. The sequence of drag chute events began with deployment at nose wheel touchdown. The drag chute door landed approximately 8700 ft down the runway, bounced three times and then slid for 30 ft before stopping. The sabot landed at approximately 8800 ft down the runway. The mortar cover was found off the edge of the runway and approximately 8800 ft from the threshold. The pilot chute was found at the 8950-foot point on the runway, and the reefing line was found at the 11,300-foot point on the runway. The main chute was found at the 12,500-foot point, and the Orbiter wheels-stop occurred at the 13,000 ft point.

During the postlanding inspection, the port payload bay door "dogbone seal" between panels one and two was protruding (Flight Problem STS-50-V-27).

Aerodynamics, Heating, and Thermal Interfaces

The ascent aerodynamics were nominal with no problems reported or observed in the data. The entry aerodynamics were satisfactory, although some problems were noted. The control surfaces for the most part responded at the forward c.g. as expected; however, during the performance of DTO 251 - Entry Aerodynamic Control Surfaces Test, the aileron trim appeared divergent near Mach 10, eventually

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2428	205.2	~2.0	n/a
Nose gear touchdown	7849	144.9	n/a	4.4

Drag chute deploy	137.6 knots (keas)
Braking initiation speed	112.9 knots
Drag chute jettison	51.2 knots
Brake-on time	28.4 seconds
Rollout distance	10,674 feet
Rollout time	58.5 seconds
Orbiter weight at landing	225,615.2 lb

Brake sensor location	Pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	1080	Left-hand outboard	25.67
Left-hand inboard 3	1212	Left-hand inboard	27.50
Left-hand outboard 2	1164	Right-hand inboard	19.43
Left-hand outboard 4	996	Right-hand outboard	12.76
Right-hand inboard 1	936		
Right-hand inboard 3	984		
Right-hand outboard 2	1008		
Right-hand outboard 4	588		

reaching 1.7 degrees with spikes as high as 2.2 degrees at Mach 8. At this point, the PTI's were terminated because a flight-rule trim limit of 1.5 degrees is specified. The aerodynamic model had predicted that no more than 0.5 degree of roll trim would be required. No vehicle control or stability problems were encountered and the anomaly is being investigated (Flight Problem STS-50-V-28).

Only two of the six PTI's to be performed in conjunction with DTO 0251 - Part 1 were completed. PTI one was not performed because of the proximity to the bank reversal maneuver. Also, PTI's four through six were inhibited because of the aileron trim problem discussed in the preceding paragraph.

All thermal interface temperatures were maintained within limits and no violations of the LCC were observed. The integrated heating also was nominal in all areas.

Thermal Control Subsystem

The performance of the Orbiter thermal control system was nominal during all phases of the flight with the exception of two in-flight anomalies. All Orbiter subsystem temperatures were maintained within acceptable limits.

The RCS thruster L1U heater was declared failed on at 177:23:42 G.m.t. (00:07:30 MET) (Flight Problem STS-50-V-01). This anomaly is discussed in detail in the Reaction Control Subsystem section of this report.

The hydraulic brake line heaters were activated at 190:13:00 G.m.t. (12:20:48 MET) for the first entry attempt, and one of the left MLG brake line temperatures increased to 267° F prior to deactivation of the heaters about four hours later. Temperatures between 100° F and 160° F were expected. It is believed that the heater element is wrapped on or near the temperature transducer and that the actual line temperature was much less than the indicated temperature. The heaters were selectively activated to maintain the desired temperatures during entry.

Aerothermodynamics

The aerothermodynamics performance during entry was nominal. The slumped tiles aft of the ET umbilical door is the only concern in this area. All structural temperatures were maintained within limits and the structural temperature rise noted was within the experience base.

Thermal Protection Subsystem

The TPS performance was nominal based on structural temperature response data and some tile surface temperature measurement data. The overall boundary layer transition from laminar to turbulent flow was non-symmetric. Transition occurred 1200 seconds after entry interface on the aft portion of the vehicle, and at 1300 seconds after entry interface on the forward side of the vehicle. This is the latest transition time recorded for the forward section of the vehicle.

The Orbiter thermal surfaces were inspected and 184 debris impact damage sites were noted, of which 45 had a major dimension of 1 inch or greater. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from previous missions of similar configuration indicates that the total number of hits 1 inch or larger is much higher than average.

The Orbiter lower surface sustained 141 hits, of which 28 had a major dimension of 1 inch or greater. The distribution of hits on the lower surface does not point to a single source of ascent debris, but does indicate a shedding of ice and TPS debris from random sources. The most significant damage site measured 9 inches by 4.5 inches by 0.5 inch, spanned three tiles, and was located approximately 3 ft outboard of the ET/Orbiter liquid hydrogen umbilical. The distribution and size of debris impact on the lower surface does not point to a single source, and is indicative of random shedding of ice and low-density TPS material.

No TPS damage was attributed to material from the wheels, tires, or brakes.

There was no visible damage to the reusable-carbon-carbon (RCC) nosecap or wing leading edge panels. However, white streaks were present on the right-hand wing leading edge panels 2, 6, 17, and 18.

Damage to the base heat shield tiles was less than average. No tiles around the drag chute opening were damaged. The main engine closeout blanket on SSME 3 was badly torn and frayed in one location. Two of the sacrificial patches from this area were missing. The blanket on SSME 2 was in good condition. The sacrificial patch on the SSME 1 blanket at the 4:00 to 6:30 o'clock position exhibited significant fraying.

All Orbiter windows exhibited lighter-than-usual hazing. Window 4 exhibited a few light streaks. The Orbiter window perimeter damage was less than usually observed.

The postflight inspection of the thermal panes of the flight deck windows revealed six impact damage sites. The six damage sites were found on windows 2, 3, 4, 6, and 8, with window 4 (starboard forward) having the largest impact site (0.0605 inch diameter and 0.00447 inch depth) of any observed in the Space Shuttle Program. As a result, window 4 was removed and sent to JSC for scanning electron microscope analysis of the damage site, as this is the only type of analysis that can determine the projectile material.

The remaining windows had impact pits that were comparable to those observed previously during the program. Windows 6 and 8 were also removed after analysis showed inadequate strength remaining for another flight. Overhead window 8 was damaged by an orbital impact. STS-50 involved pointing the overhead windows into the velocity vector for approximately 12 days, which was much longer than any previous flight. This attitude is the worst for orbital impacts on the overhead windows, and as a result, an orbital impact on window 8 was not surprising.

A portable Shuttle thermal imager (STI) was used to measure the surface temperatures of several areas on the vehicle. Nine minutes after landing, the Orbiter nose cap RCC was 202° F; the right-hand wing leading edge RCC panel 9 was 118° F, and panel 17 was 115° F 22 minutes after landing.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The flight crew equipment performed satisfactorily throughout the mission. A 35-mm Nikon F4 camera failed. The crew reported that a shutter leaf was visible floating loose inside the camera. This failure did not impact photography operations as one additional Nikon F4 camera was available.

The crew reported that the 16-mm Arriflex camera operated intermittently throughout the mission. This same intermittent operation has been noted on previous flights. Postflight testing, both at JSC and the vendor, has failed to duplicate the problem.

CARGO INTEGRATION

All cargo integration hardware operated satisfactorily during the STS-50 mission.

PAYLOADS

The United States Microgravity Laboratory -1 (USML-1) was the first in a series that will build a vital microgravity program linking NASA, academia, and private industry in investigations of fundamental microgravity sciences.

NASA has established a long-term space laboratory program that is designed to build the United States leadership in microgravity science and technology. The program pioneers investigations into the role of gravity in five basic areas: fluid dynamics; crystal growth; combustion science; biological science; and technology demonstration; and introduced several large experiment facilities that were designed for multiple users and multiple flights. Spacelab activities ended on July 8 with the deactivation of the Spacelab module. The mission was extended one day because of inclement weather at the primary landing site; however, no science activities were planned or executed during the extension day.

CRYSTAL GROWTH FACILITY

The crystal growth facility contains the first space furnace capable of automatically processing multiple large samples at temperatures up to 2900° F (1600° C). The furnace was operated for 286 hours and processed seven electronic crystal samples. Several significant achievements were made during the mission:

a. Investigators uplinked commands in response to downlinked data to remotely control the furnace;

b. Samples were automatically positioned for processing by the sample exchange mechanism; and

c. The crew proved the feasibility and safety of manually exchanging furnace samples in a habitable (flexible glovebox) environment.

Preflight planning scheduled four samples for processing during the mission. However, on flight day 4 one of the furnace circuit breakers was inadvertently opened, cutting the second sample growth short of the planned time. As a result, backup samples were loaded into the furnace and the timeline permitted crystal growth on a total of seven samples.

DROP PHYSICS MODULE

The drop physics module (DPM) hardware worked perfectly throughout the mission. The DPM permitted study of the dynamics of fluids freed from both the influences of gravity and the influences of the walls of the container. Some first-time experiences on this mission include the following:

a. The first compound drop (one fluid within another, much like a yolk in an egg) was observed;

b. The first drop coalescence (individual drops merging to form a single drop);

c. The smallest and largest drops ever deployed in space; and

d. The first retrieval of a drop by the module injectors.

SURFACE TENSION DRIVEN CONVECTION EXPERIMENT APPARATUS

The surface-tension-driven convection experiment successfully demonstrated that surface tension coupled with thermal gradients is a powerful driving force for fluid motion, and investigators received excellent data on the response of fluids to various thermal geometries. The experiment provided the first observations of thermocapillary flows in a curved-surface fluid. All of the surface-tension-driven convection experiment hardware, including the sophisticated infrared imager and flow visualization systems, operated as designed and planned.

GLOVEBOX FACILITY

Operations were faultless on the first flight of this glovebox facility. All 16 technology demonstrations scheduled for the enclosed mini-laboratory were successfully performed. The versatility of the glovebox was proven repeatedly in scheduled experiments. The glovebox hosted several experiments that complemented investigations in other USML-1 facilities, and intriguing results were observed in simple demonstrations ranging from fluid physics and crystal growth to combustion science.

ASTROCULTURE

Two planned experiment runs and several additional treatments in the astroculture plant nutrient delivery system successfully supplied water to simulated plant roots. Flow rates for fluid transfer in microgravity were correlated with previous ground runs using the Astroculture hardware. Results indicate that the unit functions as well in microgravity as it does on Earth.

EXTENDED DURATION ORBITER MEDICAL PROJECT

The USML-1 was used to conduct the first operations of the EDO Medical Project's (EDOMP) lower body negative pressure device in the Spacelab, and all 10 runs performed by the crew were successful. Cardiovascular measurements were made on two crew members at the beginning, middle, and end of the flight, and periodic air samples were taken to track bacteria or fungal growth.

On flight day 10, the American Echocardiograph for Research in Space (AERIS) was powered down when a flickering on the video screen occurred. The flickering was followed by an odor from the vent. As a result, final echocardiograph readings were not taken, and the AERIS was not powered for the remainder of the flight. However, EDOMP objectives were not significantly impacted by this loss.

Data collection for this 13-day flight may allow refinement of countermeasures that have been developed to protect crew health and well-being during future extended duration flights.

GENERIC BIOPROCESSING APPARATUS

The maiden flight of the generic bioprocessing apparatus (GBA) with 132 sample containers was successful, although some leakage was experienced with a few of the sample containers. Video data of alfalfa and clover, brine shrimp, and bacteria indicated that the samples thrived over the 13-day period. Optical density data, downlinked and analyzed, show that processing of other samples was as expected. Ground analysis of retrieved samples will allow investigators to assess the impact of the microgravity environment on these biomedical specimens.

PROTEIN CRYSTAL GROWTH

Even though USML-1 was the fourteenth flight of the protein crystal growth experiment, the STS-50 mission represents the first time that growth conditions could be optimized in space. Samples of the middeck experiment benefited from the longest period of crystal growth in the history of the Space Shuttle Program, allowing several slow-growing crystals to be included in the experiment for the first time. In a related glovebox demonstration, the crew set up protein crystal growth experiments, then observed them and adjusted conditions based on these observations. About 300 samples were processed with an optical microscope from a total of 24 protein types, and some of the completed crystals could be the largest and/or highest crystalline quality of their type ever grown in space.

SOLID SURFACE COMBUSTION EXPERIMENT

During the solid surface combustion experiment, filter paper was ignited in a sealed container to study the way flames spread over solid fuels in the absence of gravity-driven or externally imposed air flows. The experiment video was downlinked to the ground and sent to a combustion conference in Australia. It was presented in the first published paper of the flight. STS-50 is the experiment's fourth flight in an eight-step program, designed to test combustion in microgravity.

SPACE ACCELERATION MEASUREMENT SYSTEM

The space acceleration measurement system investigators gathered a wealth of information to add to their data base on low-frequency accelerations. The system collected approximately 1.2 gigabytes of data, roughly equivalent to 1000 personal computer disks. The triaxial accelerometers were distributed throughout the Spacelab module with one specifically attached to the crystal growth furnace.

ZEOLITE CRYSTAL GROWTH

The zeolite crystal growth furnace operated as planned on its first Spacelab flight, growing crystals in 38 individual autoclaves. Zeolite crystals are used as catalysts and adsorbents/filters in industrial chemical processes. Solutions that were used to grow zeolite crystals were mixed by the flight crew in the glovebox facility in transparent autoclaves to determine optimum mixing conditions. After determining optimum mixing conditions, the opaque autoclaves were activated on the middeck and inserted into the furnace.

SHUTTLE AMATEUR RADIO EXPERIMENT

The Shuttle amateur radio experiment had a very successful mission in which almost all mission objectives of configuration E were accomplished. All planned communications with students in the United States, Canada, Australia, and South Africa were accomplished. In addition to asking questions by voice, a number of groups including family members also exchanged slow-scan TV with the crew. Six fast-scan TV sessions were supported, but only one of the sessions was successful. Modifications to the antenna may be considered to improve the experimental mode of fast-scan TV.

A special contact was accomplished between Columbia and Hokule, a twin-hulled Polynesian sailing canoe currently navigating the Pacific in ancient fashion.

The Russian spacecraft MIR crew responded to a call from Columbia during a contact that was arranged during the flight. Unfortunately, ground interference prevented Columbia from receiving the Mir signal.

An evaluation of a future mode for educational purposes using slow-scan TV in auto-frame-grab mode was accomplished on flight day 13 with the camera zoomed in close and aimed at the ground track.

A number of volunteers manned ground stations in Honolulu, Hawaii; Adelaide, Australia; Corpus Christi, Texas; Houston, Texas; Johannesburg, South Africa; Sao Paulo, Brazil; and Northampton, Australia in support of the many phone-bridge contacts that were made during the flight.

INVESTIGATION INTO POLYMER MEMBRANE PROCESSING

The investigation into polymer membrane processing (IPMP) units A and B were successfully activated at 179:17:35 G.m.t. (02:01:23 MET) and restowed 1 hour 22 minutes later. Postmission evaluation will determine the success of this experiment.

ULTRAVIOLET PLUME INSTRUMENT

A state vector was supplied to support investigations with the ultraviolet plume instrument (UPI); however, the vernier RCS thruster firings during the mission were not suitable for observation.

DEVELOPMENT TEST OBJECTIVES AND DETAILED SUPPLEMENTARY OBJECTIVES

DEVELOPMENT TEST OBJECTIVES

Fifteen of the 17 assigned DTO's were completed. DTO 251 was not completed because of aileron trim problems which prevented the performance of all of the PTI's, and DTO 805 was not completed as landing crosswinds were below the required level for this DTO. The following paragraphs describe the accomplishments concerning each DTO.

DTO 236 - Ascent Aerodynamic Distributed Loads Verification on OV-102 - Preliminary data indicate that the biased alpha was achieved.

DTO 251 - Entry Aerodynamic Control Surfaces Test - Only two of the six planned PTI's were performed. The first PTI was not performed because of the proximity to the entry bank reversal maneuver. The second and third planned PTI were performed. The aileron trim appeared divergent near the Mach 10 region where the indication was rising through 1.5 degrees. As a result, PTI's four through six also were not performed.

DTO 301D - Ascent Structural Capability Evaluation - Data were collected for this DTO, and the data are being evaluated by the sponsor. The results will be published by the sponsor in a separate report.

DTO 307D - Entry Structural Capability Evaluation - Data were collected for this DTO, and the data are being evaluated by the sponsor. The results will be published by the sponsor in a separate report.

DTO 312 - ET TPS Performance (Method 1 and 2) - The three cameras located in the ET/Orbiter umbilical recess (one 35-mm and two 16-mm) provided photographic data on left SRB separation; however, direct sunlight saturated the field of view, obscuring a major portion of all three films. Analysis of the film did provide a view of a rectangular shaped divot, measuring 26.5 inches in length and 9.3 (at it largest) to 4.9 inches in width, and located on the LH_2/intertank flange at the PAL ramp at the base of the left leg of the forward ET/Orbiter attach bipod.

Eighty-nine hand-held 70-mm Hasselblad frames, taken from the Orbiter flight deck after ET separation, were reviewed. The first 65 frames were acquired while the window 8 ultraviolet filter was still mounted in the overhead window. The frames were underexposed. None of the 70 mm photography showed divots in the ET insulation area or in the LH_2 or LO_2 intertank interfaces.

DTO 319D - Shuttle/Payload Low Frequency Environment - Data were collected for this DTO, and the data are being evaluated by the sponsor. The results of the evaluation will be published by the sponsor in a separate report.

DTO 413 - On-Orbit PRSD Cryogenic Hydrogen Boiloff - Data were collected for this DTO, and the data are being evaluated by the sponsor. The results of the evaluation will be published by the sponsor in a separate report.

DTO 519 - Carbon Brake System Test (Test Condition 5) - Data were collected for this DTO, and the data are being evaluated by the sponsor. In addition, brakes were removed from one wheel for an in-depth evaluation of the hardware. The results of this evaluation will be published by the sponsor in a separate report.

DTO 521 - Orbiter Drag Chute System (Test 0) - The drag chute was deployed and evaluation of the photographic data as well as Orbiter data show that the drag chute performed satisfactorily. The sponsor will publish the results of the evaluation after all tests of this DTO on future flights are completed.

DTO 623 - Cabin Air Monitoring - Data were collected for this DTO. These data have been given to the sponsor for evaluation. The results of the evaluation will be published in a separate report.

DTO 655 - Foot Restraint Evaluation - The activities required in support of this DTO were completed on flight day 12. The data have been given to the sponsor for evaluation. The results of the evaluation will be published in a separate report by the sponsor.

DTO 658 - Ergometer Vibration Isolation System Evaluation - The ergometer vibration isolation system (EVIS) was used until flight day 6. In-flight video and data from the space acceleration measurement system (SAMS), high resolution accelerometer package (HiRAP), and the Orbiter experiments (OEX) orbital acceleration research experiment (OARE) are being evaluated by the sponsor to determine if the EVIS is effective as an isolation device for exercise during microgravity missions. The results of this evaluation will be published in a separate report by the sponsor.

DTO 663 - Acoustical Noise Dosimeter Data - This DTO was completed and the data have been given to the sponsor for evaluation. The results of this DTO will be published in a separate report.

DTO 665 - Acoustical Noise Sound Level Data - Data were collected for this DTO and have been given to the sponsor for evaluation. The results will be published in a separate report.

DTO 666 - Modify ECLSS Supply Air Ducting to Provide Chilled Air to Suited Crew Members - This modification was made. The crew commented that the cooling was ineffective because an outlet for the air from the suit was not available; consequently, there was no air flow through the suit. The crew has recommended that the modification not be flown until adequate outlet for airflow through the suit can be provided.

DTO 805 - Crosswind Landing Performance - Adequate crosswinds were not present at the landing site and data were not collected for this DTO.

DTO 910 - OEX Orbital Acceleration Research Experiment - The OEX Orbital Acceleration Research Experiment (OARE) was operated throughout the on-orbit phase of the mission and during entry. OARE data were recorded on the payload recorder and sent to the ground and, in addition, data pre-processed by the OARE's computer were stored in the OARE's internal memory for postflight transfer to GSE. Preliminary evaluation of data acquired during the mission indicated very satisfactory instrument performance. Special Orbiter maneuvers required by this DTO were accomplished on flight day 14. The OARE data were not recorded on the payload recorder during the extension day. The data are being evaluated by the sponsor and will be published in a separate report.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 314 - Acceleration Data Collection - Acquisition of High Resolution Accelerometer Package (HiRAP) data in support of this DSO were highly successful. Data were collected during the 1-degree deadband period (approximately 1 hour), during a quiet period mid-mission, during the FCS checkout and alternate digital autopilot (ALT DAP) operations, and during crew exercise periods. Data collected during crew exercise included periods with the ergometer mounted to the ergometer vibration isolation system (EVIS), hard-mounted to the floor, and supported by a "bungee cord" harness. Data were recorded on the OPS-1 recorder during 15 of the exercise periods and then dumped to the ground. Quick-look assessments of these data indicated that the HiRAP was performing normally, and that the bungee configuration was not as effective as the EVIS in isolating the ergometer from the vehicle in the X-axis. As expected, the hard-mounted configuration was noticeably worse in its reflection in the data of the vibration. Definitive comparisons are being made during the extensive postflight data evaluation. The results will be published in a separate report.

DSO 472 - Intraocular Pressure - This DSO was completed on Payload Specialist 2, and the data have been given to the sponsor for evaluation. The results of this DSO will be published in a separate report.

DSO 474 - Retinal Photography - The video portion of the DSO was completed with the data downlinked in real time. The still photography portion of this DSO was not completed because of the loss of the power supply to the Fundus camera.

DSO 603 - Orthostatic Function During Entry, Landing, and Egress - The DSO was completed and the data have been given to the sponsor for evaluation. The results of the evaluation will be published in a separate report.

DSO 617 - Evaluation of Functional Skeletal Muscle Performance Following Space Flight - Exercise as required by this DSO was performed during the flight and a log was maintained. The data are being evaluated by the sponsor, and the results will be published in a separate report.

DSO 618 - Effects of Intense Exercise During Space Flight on Aerobic Capacity and Orthostatic Function - This DSO was flown with two subjects; one active and one control. The DSO documentation required that the active subject was to perform a maximum-level cycle ergometer exercise 18 to 24 hours prior to landing. Previous ground-based studies have shown a positive protection of aerobic capacity and orthostatic tolerance following this protocol. Interpretation of results for the active subject on STS-50 was confounded by the 24-hour waveoff. The Investigator requested a repeat of the intense exercise, but the flight plan could not accommodate the requirement. Therefore, the active subject's data could not be interpreted in accordance with the experimental design. The control subject's data were valid and unaffected by the waveoff. The results of this DSO will be published in a separate report.

DSO 620 - Physiological Evaluation of Astronaut Seat Egress Ability at Wheels Stop - Data for this DSO were collected, and the data are being evaluated by the sponsor. The results of this experiment will be published in a separate report.

DSO 621 - In-Flight Use of Florinef to Improve Orthostatic Intolerance - Data for this DSO were collected and have been given to the sponsor. The results of the evaluation will be published in a separate report.

DSO 802 - Educational Activities (Objective 1) - The activities required in support of this DSO were completed on flight day 12. The results are being evaluated by the sponsor.

DSO 901 - Documentary Television - The activities in support of the DSO were recorded throughout the flight. The video is being evaluated by the sponsor and the results will be published in a separate report.

DSO 902 - Documentary Motion Picture Photography - The activities required in support of this DSO were accomplished throughout the flight. The film is being evaluated by the sponsor.

DSO 903 - Documentary Still Photography - The activities required in support of this DSO were accomplished throughout the mission. The individual photographs are being evaluated by the sponsor.

DSO 904 - Assessment of Human Factors - Data were collected for this assessment and have been given to the sponsor for evaluation. The results of this evaluation will be published in a separate report.

PHOTOGRAPHIC AND TELEVISION ANALYSIS

LAUNCH DATA ANALYSIS

On launch day, all 23 of the expected videos of launch were evaluated and no anomalies were noted. On the days following launch and prior to landing, 59 of the 61 expected launch films were analyzed. No anomalies were noted in the films; however, one item of interest, which was a bolt hangup on the right SRB holddown post number M-4, was noted. The bolt hangup had no effect on the successful launch of the vehicle.

ON-ORBIT DATA ANALYSIS

The crew obtained 89 photographs of the ET in support of DTO 312. No anomalies were noted in the preliminary screening of these photographs.

LANDING DATA ANALYSIS

A total of eight landing videos plus NASA Select were received three hours after landing for review and analysis. No anomalous events were noted in the landing videos. The videos again provided good coverage of the drag chute deployment and jettison.

TABLE I.- STS-50 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU activation	APU-1 GG chamber pressure	177:16:07:33.98
	APU-2 GG chamber pressure	177:16:07:34.87
	APU-3 GG chamber pressure	177:16:07:35.84
SRB HPU activation	LH HPU system A start command	177:16:11:55.33
	LH HPU system B start command	177:16:11:56.33
	RH HPU system A start command	177:16:11:55.77
	RH HPU system B start command	177:16:11:55.77
Main propulsion System start	Engine 3 start command accepted	177:16:12:16.457
	Engine 2 start command accepted	177:16:12:16.556
	Engine 1 start command accepted	177:16:12:16.696
SRB ignition command (lift-off)	SRB ignition command to SRB	177:16:12:22.997
Throttle up to 104 percent thrust	Engine 2 command accepted	177:16:12:27.036
	Engine 1 command accepted	177:16:12:27.057
	Engine 3 command accepted	177:16:12:27.057
Throttle down to 74 percent thrust	Engine 2 command accepted	177:16:12:54.716
	Engine 1 command accepted	177:16:12:54.737
	Engine 3 command accepted	177:16:12:54.738
Maximum dynamic pressure (q)	Derived ascent dynamic pressure	177:16:13:13
Throttle up to 104 percent thrust	Engine 2 command accepted	177:16:13:22.237
	Engine 1 command accepted	177:16:13:22.258
	Engine 3 command accepted	177:16:13:22.258
Both SRM's chamber pressure at 50 psi	RH SRM chamber pressure mid-range select	177:16:14:23.52
	LH SRM chamber pressure mid-range select	177:16:14:24.20
End SRM action	RH SRM chamber pressure mid-range select	177:16:14:25.93
	LH SRM chamber pressure mid-range select	177:16:14:27.01
SRB separation command	SRB separation command flag	177:16:14:29
SRB physical separation	LH rate APU A turbine speed LOS	177:16:14:29.32
	RH rate APU A turbine speed LOS	177:16:14:29.32
Throttle down for 3g acceleration	Engine 3 command accepted	177:16:19:52.147
	Engine 2 command accepted	177:16:19:52.216
	Engine 1 command accepted	177:16:19:52.187
3g acceleration	Total load factor	177:16:19:53.0
MECO	Command flag	177:16:20:50
Engine Shutdown	Engine 3 command accept	177:16:20:50.225
	Engine 2 command accept	177:16:20:50.241
	Engine 1 command accept	177:16:20:50.268
MECO	Confirm flag	177:16:20:51
ET separation	ET separation command flag	177:16:21:08

TABLE I.- STS-50 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
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-1 GG chamber pressure	177:16:27:10.77
	APU-2 GG chamber pressure	177:16:27:12.32
	APU-3 GG chamber pressure	177:16:27:13.27
OMS-2 ignition	Left engine bi-prop valve position	177:16:52:13.7
	Right engine bi-prop valve position	177:16:52:13.8
OMS-2 cutoff	Left engine bi-prop valve position	177:16:54:35.3
	Right engine bi-prop valve position	177:16:54:35.6
Payload bay door open	PLBD right open 1	177:17:39:34
	PLBD left open 1	177:17:40:54
Flight control system checkout		
APU start	APU-3 GG chamber pressure	189:12:02:02.25
APU stop	APU-3 GG chamber pressure	189:12:09:11.58
First payload bay door close	PLBD right close 1	190:09:27:43
	PLBD left close 1	190:09:29:22
Second payload bay door open	Voice call	190:13:30:22
OMS-3 ignition	Left engine bi-prop valve position	190:15:09:22.0
	Right engine bi-prop valve position	190:15:09:22.0
OMS-3 cutoff	Left engine bi-prop valve position	190:15:09:52.8
	Right engine bi-prop valve position	190:15:09:52.8
Second payload bay door close	PLBD right close 1	191:08:02:46
	PLBD left close 1	191:08:04:29
APU activation for entry	APU-3 GG chamber pressure	191:10:36:44.20
	APU-1 GG chamber pressure	191:10:57:54.76
	APU-2 GG chamber pressure	191:10:57:56.42
Deorbit maneuver ignition	Left engine bi-prop valve position	191:10:41:38.0
	Right engine bi-prop valve position	191:10:41:38.1
Deorbit maneuver cutoff	Left engine bi-prop valve position	191:10:45:02.0
	Right engine bi-prop valve position	191:10:45:01.9

TABLE I.- STS-50 SEQUENCE OF EVENTS (Concluded)

Event	Description	Actual time, G.m.t.
Entry interface (400K)	Current orbital altitude above reference ellipsoid	191:11:10:46
Blackout ends	Data locked at high sample rate	No blackout
Terminal area energy management	Major mode change (305)	191:11:36:00
Main landing gear contact	LH MLG tire pressure	191:11:42:27
	RH MLG tire pressure	191:11:42:27
Main landing gear weight on wheels	LH MLG weight on wheels	191:11:42:27
	RH MLG weight on wheels	191:11:42:27
Nose landing gear contact	NLG tire pressure	191:11:42:45
Nose landing gear weight on wheels	NLG WT on Wheels -1	191:11:42:45
Drag chute deployment	Drag chute deploy -1 cp volts	191:11:42:47.1
	Drag chute deploy -2 cp volts	191:11:42:47.2
Drag chute jettison	Drag chute jettison -1 cp volts	191:11:43:10.7
	Drag chute jettison -2 cp volts	191:11:43:10.8
Wheels stop	Velocity with respect to runway	191:11:43:25
APU deactivation	APU-1 GG chamber pressure	191:11:46:04.88
	APU-2 GG chamber pressure	191:12:01:00.08
	APU-3 GG chamber pressure	191:12:01:02.91

TABLE II.- STS-50 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-50-V-01	RCS Thruster L1U Heater Failed On	177:21:32 G.m.t. 00:07:29 MET IM50RF01 PR-LP05-0056	The RCS F4R thruster heater failed to turn off during the first cycle. Manual control of the heater was performed until temperature leveled out due to heater degradation. KSC: Remove thruster L1U for repair. (No OMS pod removal required.) Install spare thruster.
STS-50-V-02	RCRS Shutdown	178:20:26 G.m.t. 01:04:14 MET IM50RF02 PR-ECL-2-13-0824	The RCRS failed off several times while operating on both controller 1 and controller 2. Repaired by an IFM. KSC: Change out both actuators.
STS-50-V-03	CCTV Camera A Erratic	178:04:03 G.m.t. 00:17:51 MET	CCTV camera A video downlink contained numerous lines of noise. The problem was intermittent. KSC: Removal and replacement of camera to be scheduled.
STS-50-V-04	TAGS Failure	179:21:44 G.m.t. 02:05:32 MET	The TAGS jammed during an uplink. Attempts to clear were unsuccessful. Suspect failed developer motor. KSC: Remove TAGS unit and ship to JSC for troubleshooting and repair.
STS-50-V-05	Oxygen Tank 2 Heater A2 Erratic	178:05:42 G.m.t. 00:13:30 MET IPR 52V-0005 IM50RF18	Oxygen tank 2 heater A2 indicator (V45X1211E) not on when heaters commanded on. Inconclusive if heater is working or not. Suspect problem in cryogenic control box. KSC: Perform checkout of control box.
STS-50-V-06	Right OMS TVC Yaw Movement During Ascent	177:16:20 G.m.t. 00:00:08 MET IM50RF03 PR-RP05-2-02-0047	Right yaw actuator drifted from -6.060 ° to -5.815 ° (-0.245 °) during ascent. File IX limit is ± 0.20 °. First flight of this actuator. No flight impact for nominal burns KSC: Remove and replace actuator.
STS-50-V-07	Fuel Cell 3 Oxygen Purge Valve Leakage	181:11:43 G.m.t. 03:19:31 MET IM50RF04 PR FCP-2-13-0249	When fuel cell 3 purge was terminated, the oxygen flow only dropped from 7.2 to 6.5 lb/hr. Purge valve was cycled manually and apparently sealed. Suspect contamination or corrosion on valve seat. KSC: Remove and replace fuel cell 3.
STS-50-V-08	Oxygen Tank 2 Leak	178:00:02 G.m.t. 00:07:50 MET IPR 52V-0006 IM50RF17 and 08 PR FCP-2-13-0249	The oxygen tank 2 pressure dropped at a rate of approximately 0.9 lb/hr throughout the mission. During KSC troubleshooting, a leak was found at the quick disconnect poppet and at the flight cap. KSC: Remove and replace the quick disconnect.
STS-50-V-09	APU 3 Test Line Temperatures Out of Tolerance.	178:13:57 G.m.t. 00:21:44 MET IM 50RF05 IPR 52V-0003	The T1 and T2 temperatures both went below the caution and the warning limit of 48 °F. The lower C&W limit was changed by uplink to 45 °F. T2 also goes above the upper limit of 100.0 °F. Uplinked change to 120 °F. KSC: Evaluate heater wrap and thermostat installation.

TABLE II.- STS-50 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-50-V-10	Circulation Pump 2 Sensor Dropout	179:21:59 G.m.t. 02:05:47 MET IPR 52V-0015 IM 50RF09	At approximately 179:21:59 G.m.t., the circulation pump 2 pressure transducer went to 0 psia indicated. The main pump filter module transducer continued to read approximately 200 psia indicating normal circulation pump performance. The vehicle went LOS during this operation. While LOS, the crew got an FDA alarm and turned off the circulation pump. At 179:22:09:55 G.m.t., the circulation pump 2 pressure transducer returned to a normal reading of 50 psia. Behavior repeated during other operations of the circulation pump. Suspect either transducer or instrumentation . KSC: Remove and replace sensor.
STS-50-V-11	CCTV Camera D Heater Failed Off	181:14:00 G.m.t. 03:21:48 MET IPR 52-0024	At 181:14:00 G.m.t., CCTV camera D showed a temperature of -9 °C. During subsequent operations, the temperature dropped to -13 °C. Heaters in the camera should maintain the temperature above 0 °C. The camera temperature was controlled by powering the camera on periodically. KSC: Troubleshooting completed and camera removal and replacement to be scheduled. Troubleshooting verified power to the connector.
STS-50-V-12	Oxygen Tank 7 Check Valve Stuck Open	186:02:00 G.m.t. 08:15:03 MET IM 50RF06 PR EDO-1-2-0003	Oxygen tank 7 heater control pressure began reflecting oxygen manifold pressures. The heaters on tank 7 were off, and oxygen was being supplied from tank 8 and 9. This situation is indicative of a stuck check valve in oxygen tank 7. The valve unstuck on flight day 14. KSC: Probable removal and replacement after EDO pallet removal.
STS-50-V-13	Camcorder Mark II Failed	187:22:00 G.m.t. 10:05:48 MET	The crew reported that one of the Mark II camcorders onboard failed. The camcorder would not image and a blank screen would appear; however, it would still function as a VCR.
STS-50-V-14	OMS Fuel High Point Bleed Temperature High On A Heaters (Bulkhead Fuel V43T6234A)	177:23:45 G.m.t. 00:07:30 MET IPR 52V-0009 IM 50RF07	The bulkhead fuel high point bleed line temperature (V43T6234A) operated outside of its setpoint range while on the A heater and was possibly being controlled by the overtemperature thermostat. Also, The aft fuel high point bleed line temperature (V43T6238A) was cycling high on A heater. The A heater upper limit is higher than normal. KSC: Troubleshooting heater wrap and thermostat installation.
STS-50-V-15	Hydraulic System 2 Accumulator Nitrogen Leak	189:15:44 G.m.t. IM 50RF10 IPR 52V-0012 PR-HYD-2-13-0543	During the fifth recharge of the bootstrap accumulator by circulation pump 2 at 188:15:44 G.m.t., it was noted that bootstrap accumulator pressure (V58P0267A) peaked at only 2356 psia , but reservoir pressure (V58P0231A) was 75 psia. The two signatures are indicative of an external accumulator gaseous nitrogen leak. KSC: Remove and replace accumulator.

TABLE II.- STS-50 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-50-V-16	Waste Water Dump Degraded	189:18:00 G.m.t. 12:01:30 MET PR-ECL-2-13-0825	At 189:17:51 G.m.t., a waste water dump was initiated. The dump rate started at 2.1 percent/minute and decreased to 0.7 percent/minute. The crew was told to terminate the dump when EECOM observed the decreased dump rate. The dump was terminated at 12:01:29 MET with the final dump rate of 0.42 percent/minute. A blockage of the waste water dump line is highly likely. Waste water liquid pressure readings after dump valve closure suggest that the blockage may be located in the dump line filter which is upstream of the contingency water crosstie. Therefore, an IFM that purges the line with air or water would not clear the blockage. KSC: Troubleshooting to be scheduled.
STS-50-V-17	CCTV Camera C Failed	189:22:37 G.m.t. 12:06:25 MET	During an attempt to use camera C for downlink video, no video was received. Possible cause was a stuck iris. KSC: No action required.
STS-50-V-18	RCS thruster F2F Failed Off	190:07:50 G.m.t. 12:15:38 MET PR-FRC2-13-0326 IM50RF11	During the nominal end-of-mission RCS thruster hot fire procedure, RM declared thruster F2F failed off, and the thruster was auto-deselected. Oxidizer and fuel injector temperatures appeared nominal. However, the analog chamber pressure never exceeded 6 psia, indicating either low performance or a sensor problem. KSC: FRCS removal for thruster removal and replacement to be scheduled.
STS-50-V-19	Right OMS Fuel Quantity Bias High	190:15:09 G.m.t. 12:22:57 MET	During the orbit adjust maneuver, the ROMS fuel total quantity gage (V43Q5331C) value increased approximately 6 percent. This gauge counted down properly for the first 14 seconds of the maneuver and then jumped to a reading of 50.4 percent. IFA/PR to be upgraded for deferral to OMDP/opportunity for adjustment/repair.
STS-50-V-20	Oxygen Tank 3 Quantity Transducer Erratic	189:17:35 G.m.t. 12:01:23 MET IPR 52V-0023 IM 50RF19	At 189:17:35 G.m.t., cryogenic oxygen tank 3 quantity measurement V45Q1305A started shifting erratically from 80 percent to off-scale high. The reading stabilized back to the normal quantity.
STS-50-V-21	Starboard Forward Payload Bay Door Light Failed Off	191:07:52 G.m.t. 13:15:40 MET IM50RF12 IPR 52-0036	After payload bay door (PLB) door closing, the crew reported that the forward starboard floodlight flickered, but did not come on. KSC: Troubleshooting to be scheduled.

TABLE II.- STS-50 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-50-V-22	APU 1 Gearbox Nitrogen Pressure Low During Entry	191:11:29 G.m.t. 13:19:29 MET IPR 52V-0010 IM 50RF13	APU 1 gearbox nitrogen pressure decreased to the repressure value. After the gearbox was repressurized to 20 psia, the gearbox nitrogen pressure transducer (V46P0151A) cycled erratically during entry and postlanding. During entry, the gearbox nitrogen pressure transducer cycled below the repressurization value at least six times, and the gearbox nitrogen tank pressure (V46P0152A) continued to decrease until APU shutdown. KSC: Troubleshooting in progress.
STS-50-V-23	MADS FDM 1 Mux Bite Status	191:10:41 G.m.t. IM50RF14 IPR 52V-0027	At OMS deorbit burn ignition, the MADS FDM 1 got a Mux bite status failed. KSC: Remove and replace FDM.
STS-50-V-24	OEX System Control Module Anomaly	186:11:05 G.m.t. IM 50RF15	When the OEX was commanded to a mark, it skipped the mark and continued to the end of the tape. When commanded back to the mark, the tape stopped at the mark. A label command was then sent with no result. After sending an all-stop command and another label, the recorder began working properly. KSC: Troubleshooting to be scheduled.
STS-50-V-25	Excessive temperature in System 2 and Hydraulic Intersystem Leakage	189:16:30 G.m.t. IM 40RF15	During a long run of circulation pump 2 to recharge the accumulator, intersystem leakage from system 2 into system 2 and 3 was observed. Circulation pump 3 was later run to return some of the fluid to system 1 and 2. KSC: No activity required.
STS-50-V-26	Right Outboard Brake Pressure Lag	Postlanding IPR 52V-0011	Brake pressure did not respond for 8 to 9 seconds following braking initiation, then lagged for remainder of the braking phase. KSC: Troubleshooting is in progress.
STS-50-V-27	Protruding PLBD Dogbone Seal	Postlanding PR-STRUC-2-13-3652 IM50RF16	The "dogbone" seal on the left PLBD near panel 1 was protruding.
STS-50-V-28	Excessive Aileron Trim During Entry	191:11:30 G.m.t.	At approximately Mach 15 during entry, the Orbiter aileron trim started a slow ramp from 0.0 percent deflection to a maximum of 2.2 percent deflection at Mach 10.1. This large trim value appeared to be a function of the "more up" aileron deflection associated with flying the fixed forward aileron schedule that was selected for aero programmed test input (PTI) purposes.

ACRONYMS AND ABBREVIATIONS

APU	auxiliary power unit
ARS	atmospheric revitalization subsystem
BFS	backup flight system
BITE	built-in test equipment
CCTV	closed-circuit television
CPCG	Commercial Protein Crystal Growth
C/W	caution and warning
ΔP	differential pressure
DSO	detailed supplementary objective
DTO	development test objective
e.d.t.	eastern daylight time
EMU	extravehicular mobility unit
ET	External Tank
EVA	extravehicular activity
FCS	flight control system
FDA	fault detection and annunciation
FES	flash evaporator system
G.m.t.	Greenwich mean time
GPC	general purpose computer
GSE	ground support equipment
HPOTP	high pressure oxidizer turbopump
HPFTP	high pressure fuel turbopump
IAPU	improved auxiliary power unit
IFM	in-flight maintenance
Isp	specific impulse
JSC	Lyndon B. Johnson Space Center
LCC	Launch Commit Criteria
MADS	modular auxiliary data system
MCC	Mission Control Center
MECO	main engine cutoff
MER	mission evaluation room
MET	mission elapsed time
MPS	main propulsion system
MSFC	George C. Marshall Space Flight Center
NPSP	net positive suction pressure

OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
PAL	protuberance air load
PCS	pressure control system
PRSD	power reactant storage and distribution subystem
RCC	reinforced carbon carbon
RCS	reaction control subsystem
RSRM	redesigned solid rocket motor
RTV	room temperature vulcanizing
S&A	safe and arm
SRB	Solid Rocket Booster
SRSS	Shuttle Range Safety System
SSME	Space Shuttle main engine
STS	Space Transportation System
TAGS	text and graphics system
TPS	thermal protection system/subsystem
UVPI	Ultraviolet Plume Instrument
WCS	waste collection system
WSB	water spray boiler

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