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STS-73 SPACE SHUTTLE MISSION REPORT

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National Aeronautics and
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Lyndon B. Johnson Space Center
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SPACE SHUTTLE

MISSION REPORT

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NOTE

The STS-73 Space Shuttle Mission Report was prepared from inputs received from the Orbiter Project Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

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STS-73 Table of Contents

STS-73 Table of Contents

List of Tables

Appendixes

INTRODUCTION

The STS-73 Space Shuttle Program Mission Report summarizes the Payload activities as well as the Orbiter, External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and the Space Shuttle main engine (SSME) systems performance during the seventy-second flight of the Space Shuttle Program, the forty-seventh flight since the return-to-flight, and the eighteenth flight of the Orbiter Columbia (OV-102). STS-73 was also the first flight of OV-102 following the vehicle's return from the Orbiter Maintenance Down Period (OMDP). In addition to the Orbiter, the flight vehicle consisted of an ET that was designated ET-73; three SSMEs that were designated as serial numbers 2037 (Block I), 2031 (PH-1), and 2038 (Block 1) in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-075. The RSRMs, designated RSRM-50, were installed in each SRB and the individual RSRMs were designated as 360L050A for the left SRB, and 360W050B for the right SRB.

The STS-73 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement as documented in NSTS 07700, Volume VII, Appendix E. The requirement stated in that document is that each organizational element supporting the Program will report the results of their hardware (and software) evaluation and mission performance plus identify all related in-flight anomalies.

The primary objective of this flight was to successfully perform the planned operations of the United States Microgravity Laboratory (USML) -2 payload. The USML-2 consisted of the following major experiments payloads:

a. Three-Dimensional Microgravity Accelerometer (3-DMA);
b. Astroculture (ASC);
c. Commercial Generic Bioprocessing Apparatus (CGBA);
d. Commercial Protein Crystal Growth (CPCG);
e. Crystal Growth Furnace (CGF);
f. Drop Physics Module (DPM);
g. Geophysical Fluid Flow Cell (GFFC);
h. Glovebox Experiments (GBX);
I. Single-Locker Protein Crystal Growth (SPCG);
j. Space Acceleration Measurement System (SAMS);
k. Surface Tension Driven Convection Experiment (STDCE);
l. Zeolite Crystal Growth (ZCG);
m. Advanced Protein Crystallization Facility (APCF); and
n. High-Packed Digital Television (HIPAC).

The secondary objective of this flight was to complete the operations of the Orbital Acceleration Research Experiment (OARE).

The STS-73 mission was planned as a 16-day flight plus 2 contingency days, which were available for weather avoidance or Orbiter contingency operations. The sequence of events for the STS-73 mission is shown in Table I, and the Orbiter Project Office Problem Tracking List is shown in Table II. The Government Furnished Equipment/Flight Crew Equipment (GFE/FCE) Problem Tracking List is shown in Table III. Appendix A lists the sources of data, both formal and informal, that were used to prepare this report. Appendix B provides the definition of acronyms and abbreviations used throughout the report. All times during the flight are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The seven-person crew for STS-73 consisted of Kenneth D. Bowersox, CDR., U. S. Navy, Commander; Kent V. Rominger, CDR., U. S. Navy, Pilot; Kathryn C. Thornton, Civilian, PhD., Payload Commander and Mission Specialist 3; Catherine G. Coleman, Capt., U. S. Air Force, Ph.D, Mission Specialist 1; Michael E. Lopez-Alegria, Lt. Cdr., U. S. Navy, Mission Specialist 2; Fred W. Leslie, Ph.D., Civilian, Payload Specialist 1; and Albert Sacco, Jr., Ph.D., Civilian, Payload Specialist 2. STS-73 was the fourth flight for the Payload Commander/Mission Specialist 3; the third space flight for the Commander; and the first space flight for the Pilot, Mission Specialist 1, Mission Specialist 2, and Payload Specialists 1 and 2.

MISSION SUMMARY

The first attempt to launch the STS-73 mission occurred on September 28, 1995; however, shortly after propellant loading of the External Tank (ET) began, a hydrogen leak through the Space Shuttle main engine (SSME) 1 main fuel valve was noted. As a result, the launch was scrubbed so that the main fuel valve could be replaced. The launch was rescheduled for October 5, 1995, but the weather effects from Hurricane Opal resulted in a decision at the L-1 briefing to delay the launch until Friday, October 6. The October 6 launch attempt was scrubbed prior to ET loading when it was determined that hydraulic fluid had been inadvertently drained from hydraulic system 1 following the SSME 1 main fuel valve replacement. A compressibility test of the system was performed and it showed that the system was satisfactory for launch, and the launch was rescheduled for October 7. The launch on October 7 was scrubbed when master events controller 1 (MEC 1) built-in test equipment (BITE) indicated that the MEC 1 core B critical drivers were not enabled. MEC 1 was replaced and satisfactorily retested, and the launch was rescheduled for October 14, 1995. The launch on October 14 was rescheduled to October 15 to allow additional time to inspect the main engine oxidizer ducts as a result of finding a crack in a test engine oxidizer duct. No anomalous conditions were found. Also during this delay, multiplexer/demultiplexer (MDM) flight aft (FA) 1 was bypassed. Data were reviewed, troubleshooting of the data bus was performed, and general purpose computer (GPC) 1 was replaced and successfully retested.

Early on the morning of October 15, the time of launch was delayed one hour to 10:46 a.m. e.d.t. (9:46 a.m. c.d.t.) because weather conditions were predicted to be unacceptable at the planned time; however, the conditions did not improve and the launch was tentatively rescheduled to Thursday, October 19, 1995, based on the launch of an Atlas on Tuesday, October 18. The Atlas launch was delayed and the STS-73 launch was rescheduled to Friday, October 20, 1995. The STS-73 vehicle was successfully launched on October 20, 1995, at 293:13:53:00.013 G.m.t. The Orbiter was inserted into a nominal 150-nmi. circular orbit on an inclination of 39 degrees after a satisfactory launch phase. Total vehicle weight at liftoff was 4,521,539 lb of which the Orbiter constituted 257,327 lb.

During ascent, water spray boiler (WSB) 3 experienced a freeze-up as evidenced by the auxiliary power unit (APU) 3 lubrication oil return temperature increasing above the normal spray-start temperature of 250 °F. When the temperature reached 290 °F, the crew was requested to switch from controller A to controller B on system 3. However, the boiler was apparently shut off instead, and when the temperature reached 310 °F, the crew was requested to turn the WSB power back on and switch to controller B. After switching controllers, the temperature rise rate did not change, indicating a spray bar freeze-up. When the temperature reached 326 °F, the crew was directed to shut down APU 3 earlier than planned. Approximately one minute later, WSB 3 (on controller B) began spraying, indicating that the spray bar had thawed. All three WSBs have the heater modification that was implemented to preclude WSB freeze-ups. This heater modification was also flown on STS-69/OV-105 on WSB 3.

All SSME and RSRM start sequences occurred as expected and launch phase performance was satisfactory in all respects. First stage ascent performance was as expected. SRB separation, entry, deceleration, and water impact occurred as anticipated. Both SRBs were successfully recovered and returned to Kennedy Space Center (KSC) for disassembly and refurbishment. Performance of the SSMEs, ET and main propulsion system (MPS) was normal.

When closing the Orbiter/ET doors following ET separation, AC 1 phase B current did not power the four motors normally supported by this circuit. Further data review showed that the left vent doors 8/9 motor 1 had also lost AC 1 phase B current when the doors were opened prior to launch. This loss caused these motors to operate on two phases, a condition for which the motors are certified. AC1 phase B current was not present during any of the vent door 8/9 repositioning during the remainder of the mission or during the ET door opening postlanding. Data evaluation indicates that the most probable cause of the failure was an open circuit of phase B between circuit breaker (CB) 4 on panel MA73C and aft motor controller assembly (AMCA) 1. Believing that oxidation of the circuit breaker contact was a likely cause of the problem, CB 4 on panel MA73C was cycled during postlanding operations, and the AC1 phase B current returned.

The orbital maneuvering subsystem (OMS) 2 maneuver was performed at 293:14:34:28.7 G.m.t. (000:00:41:28.7 MET). The two-engine firing was 118.9 seconds in duration and imparted a ΔV of 186 ft/sec. The OMS performed satisfactorily throughout the firing.

Opening of the payload bay doors was completed at 293:15:28:36 G.m.t. (00:01:35:36 MET). The port payload bay door was positioned to the 62-degree open position instead of fully open. This position was used to minimize the chance of micrometeorite/orbital debris (M/OD) impacts on the port radiator, since the predominant attitude flown during the mission would have exposed the port radiator to a higher-than-normal M/OD flux.

The first reaction control subsystem (RCS) trim firing was initiated at 293:16:54:40 G.m.t. (000:03:01:40 MET). It was a 30-second -X maneuver which imparted a ΔV of 6.9 ft/sec. Thruster F1F failed off 320 ms after initiation of the firing because the chamber pressure (Pc) reached only 17 psia. All other thruster firings during the trim maneuver were nominal. The F1F thruster temperature decrease indicated that both propellant valves achieved at least pilot-valve flow. The Pc subsequently required about 15 minutes to return to zero psia. The fact that the Pc decreased so slowly indicates that the thruster fail-off condition was caused by a blockage of the Pc-tube orifice. This Pc tube was last flushed during the STS-73 processing flow. The Pc tube was inspected on the vehicle for blockage and none was found. However, the problem does appear to be within the F1F pressure-sensing system. The thruster was removed and replaced.

The flash evaporator system (FES) feedline A mid 2 temperature measurement slowly decreased beginning at approximately 293:19:53 G.m.t. (00:05:30 MET), and the heater did not cycle. Based on previous flight data, a heater cycle would have been expected at approximately 70 °F. When the temperature reached 54.7 °F at approximately 296:17:16 G.m.t. (003:03:23 MET), the FES feedline A mid 2 heater system 1 was declared failed off. The FES feedline A mid 2 heater system 2 was activated and cycled nominally for the remainder of the mission. Postflight troubleshooting isolated the problem to a broken wire at a ground lug. A repair was made.

Occurrences of S-band forward-link dropouts were observed while transmitting on the lower right antenna. An examination of data from 20 orbits indicated that there were no noticeable differences between transmissions on the high and low frequencies, and that the dropouts were on both Tracking and Data Relay Satellites (TDRSs). Troubleshooting and testing were performed later in the mission to further define the S-band lower-right-antenna degraded performance problem. The troubleshooting and testing activity appear to have isolated the problem to the path between the lower-right antenna and the antenna switch. The problem was repeated intermittently during ground testing. The lower right-hand antenna was removed and replaced; however, dropouts were still received during transmit/receive tests.

At approximately 298:13:43 G.m.t. (004:23:50 MET), the port payload bay door was taken to the full-open position in support of the mission's only Spacelab condensate dump. The door was moved to the 52-degree open position following the dump at approximately 298:14:20 G.m.t. (005:00:27 MET). Door operation was nominal. Video of the door centerline was taken before and after repositioning. The video was reviewed, and no anomalous conditions were found.

Vernier RCS thrusters R5R and R5D failed to fire when commanded at 300:18:04 G.m.t. (007:04:11 MET). Data show that the fire command B was issued for one sample to both thrusters, but no driver output or Pc was indicated for either thruster. Since Pc was not present, the redundancy management (RM) software deselected both thrusters. Because no indication of a thruster failure was present, both the R5D and R5R thrusters were hot-fired and each provided a good one-second pulse. The two vernier thrusters were then reselected for flight use. During the course of the mission, the same two vemier thrusters failed off seven additional times and two primary thrusters (L3D and R3D) failed off once. The failure signature was similar in all of the occurrences. A similar failure of thruster R5D occurred during the previous flight of this vehicle (STS-65), and troubleshooting failed to indicate the cause. This appears to be a problem in the command path. The MDM (S/N 121) and the reaction jet driver (RJD) (S/N 20) in the command path to the R5D and R5R vemier thrusters as well as the aft manifold 3 primary thrusters are the same units flown on STS-65. Extensive troubleshooting has failed to recreate the anomaly. The MDM and the RJD in the command path have been removed and replaced.

At approximately 300:07:18 G.m.t. (06:17:25 MET), the crew reported a small impact crater on window W2. The crew estimated the size of the crater to be approximately 1 mm in diameter. The crater was located near the edge of the window closest the vehicle centerline. Camcorder video and electronic still camera images of the impact site were analyzed, and the assessment of the damage indicated that the crater was not a concern for the mission.

At 302:04:27 G.m.t. (008:14:34 MET), the Orbiter was maneuvered to a bottom-Sun attitude for thermal conditioning of the left main landing gear (MLG) tire. As expected, the port MLG tires were cooling off, and therefore, their pressure was dropping as a result of the vehicle attitude and the port payload door position. Prior to the maneuver, the port payload bay door was fully opened to maximize the warming effect of the bottom-Sun attitude. This attitude was maintained until 302:12:27 G.m.t. (008:22:34 MET). During the maneuver back to the biased -XLV -YVV attitude, the port payload bay door was moved back to the 52-degree open position. The data from this period of thermal conditioning were used to update tire-temperature predictions for the remainder of the mission and to determine end-of-mission conditioning requirements.

At 304:05:11:00 G.m.t. (010:15:18 MET), the Orbiter was maneuvered to a bottom-Sun attitude for the second thermal conditioning period of the port MLG tires. Prior to the maneuver, the port payload bay door was again fully opened to maximize the warming effect of the bottom-Sun attitude. The vehicle remained in the bottom-Sun attitude until 304:19:01:33 G.m.t. (011:05:08:33 MET), and was then maneuvered back to a biased -XLV -YVV attitude. The port payload bay door was returned to the 52-degree open position.

At 304:21:48 G.m.t. (011:07:55 MET), the FES experienced an under-temperature shutdown. The shutdown was caused by operating the topping evaporator at a heat load that was higher than its design-specified capability (reference Shuttle Operational Data Book). Contributing factors to this heat load included Beta angle, vehicle attitude, and lower port-radiator efficiency due to the 52-degree-open port-door position. The primary controller A was reset, and FES operation was restored. Nine additional FES shutdowns occurred during the next 24 hours. As a result, the decision was made to leave the port payload bay door fully open following the third thermal conditioning period for the port MLG tires that was initiated at 306:08:23 G.m.t. (012:18:30 MET). With the door fully open, no additional FES under-temperature shut downs occurred during the mission, and there were no further thermal issues with the attitude timeline for the remainder of the mission.

At 308:08:55 G.m.t. (014:19:02 MET), the crew reported that cathode ray tube (CRT) 2 was flashing on and off and that the symbols on the screen were garbled. These symptoms were intermittent, and the data indicated a problem with the CRT. As a result, an in-flight maintenance (IFM) procedure to switch positions of CRT 2 and CRT 4 was performed, and the CRT in position 2 performed satisfactorily for the remainder of the mission. The failed CRT was not repowered for the remainder of the mission.

At 308:09:16 G.m.t. (014:19:23 MET), an RCS vernier thruster plume impingement test was performed. The purpose of the test was to obtain acceleration data to better understand the plume impingement effects of the aft vernier down-firing thrusters on the wings and body flap as first noted during STS-71 operations while docked with the Mir. The 20-second pitch-pulse test of vernier thrusters L5D and R5D was performed satisfactorily, followed by a 20-second single-thruster firing of L5D, which was also satisfactory.

The flight control system (FCS) checkout began with APU 3 being started at 308:09:35:29.878 G.m.t. (014:19:42:29.885 MET), and APU 3 ran for 12 minutes and 18.372 seconds. A total of 27 lbm of APU fuel was used during the FCS checkout. Data review indicates that the FCS, APU, and hydraulic subsystems performed nominally. The APU run-time was lengthened to check out the WSB 3 controllers as a result of the ascent cooling anomaly. The maximum lubrication oil return temperature reached with WSB 3 controller A was 273 °F. This is within the specification of no greater than 275 °F for start-of-spray cooling. An over-cooling condition to 236 °F followed before the steady-state temperature of 252 °F was reached. Spray cooling was observed for about 2.5 minutes before switching to the WSB 3 controller B as planned. Nominal steady-state cooling was observed on the WSB 3 controller B.

At 308:10:38 G.m.t. (014:20:45 MET), the RCS primary thruster hot-fire test was initiated. The procedure was performed twice, and no thruster failures were noted.

The hydrogen and oxygen manifold isolation valves were being cycled for the in-flight checkout, and the hydrogen manifold 1 isolation valve, which had been open, failed to close when commanded at 308:13:42 G.m.t. (014:23:49 MET). Four minutes later, the switch was held in the CLOSE position for 10 seconds, but the valve position again did not change. Manifold pressure data confirmed that the valve was still open. This failure did not impact the mission.

All entry stowage and deorbit preparations were completed in preparation for the nominal end-of-mission landing day. The Ku-band antenna was stowed at 308:23:05 G.m.t. (015:09:12 MET). The payload bay doors were successfully closed and latched at 309:08:15 G.m.t. (015:18:22 MET). The deorbit maneuver was performed on orbit 255 at 309:10:46:40 G.m.t. (015:20:53:40 MET) for a KSC Shuttle Landing Facility (SLF) landing, and the maneuver was 162.5 seconds in duration with a ΔV of 270 ft/sec. Entry interface (400,000 ft) occurred at 309:11:13:19 G.m.t. (015:21:20:19 MET).

Entry was completed satisfactorily, and main landing gear touchdown occurred on SLF concrete runway 33 at 309:11:45:21.4 G.m.t. (015:21:52:21.4 MET) on November 5, 1995. The Orbiter drag chute was deployed at 309:11:45:29 G.m.t. and the nose gear touchdown occurred 6.4 seconds later. The drag chute was jettisoned at 309:11:45:58 G.m.t. with wheels stop occurring at 309:11:46:16 G.m.t. The rollout was normal in all respects. The flight duration was 15 days 21 hours 52 minutes and 21 seconds. The vehicle weight at landing was 230,416 lb. The APUs were shut down 18 minutes 46.5 seconds after landing.

Postlanding, a decay was noted in the APU 1 fuel pump inlet pressure. The pressure dropped from 150 psia to 35 psia during a 20-minute period (Flight Problem STS-73-V-09). The fuel pump seal cavity drain line pressure rose from 20.5 to 22.0 psia during the same period. Data review revealed that a slower decay was experienced after the prelaunch hot-fire of the APU and following the on-orbit APU shutdown. The signature indicates possible leakage of fuel past the fuel pump seal into the seal cavity. Postflight inspection and testing found approximately 108 cc of fuel in the APU 1 catch bottle. The decision was made to remove and replace the APU.

PAYLOADS

STS-73 was the second United States Microgravity Laboratory (USML-2) Spacelab mission, and it scientific success was building on the foundation of the first USML (-1) mission, which flew in 1992 (STS-50). USML data were gathered in five major scientific areas during the STS-73 mission. These areas were:

a. Fluid physics;
b. Materials science;
c. Biotechnology;
d. Combustion science; and
e. Commercial space processing technologies.

The experiments were housed in a 23-foot Spacelab module inside the payload bay as well as in the middeck of the Orbiter.

This mission was the longest microgravity Spacelab mission. The payload was comprised of 14 experiments, seven investigations, one demonstration, and one evaluation. Over 60 Tera (60 X 10^{12}) bits of real-time scientific data were processed during the mission, and this is three times more than any previous mission. More than 750 video tapes were recorded and over 300 electronic still camera high-resolution images were processed. Over 1500 protein samples were processed in three Protein Crystal Growth experiments.

ASTROCULTURE

The Astroculture (ASC) experiment met its objectives by demonstrating the capability of the ASC plant growth facility to provide the conditions required to conduct plant science research in the space environment. The viability of the facility was satisfactorily demonstrated by the growing of five small potatoes from tubers. This experiment contributed to the study of growing edible foods in space. Near the end of the mission, the leaves began to yellow and deteriorate, an expected event that led investigators to believe the tiny potatoes were drawing photosynthetic energy from the leaves. The potato tubers continued to grow through the end of the mission until they were preserved postflight.

SURFACE TENSION DRIVEN CONVECTION EXPERIMENT

The Surface Tension Driven Convection Experiment (STDCE) enabled researchers to view in great detail the basic fluid mechanics and heat transfer of thermocapillary flows. The STDCE measured the transition from steady, two-dimensional flows to oscillatory, or three-dimensional, flows using silicone oil.

The STDCE gathered extensive data on the instability of fluid flows caused by variations in surface temperatures. A total of 49 tests were conducted and that was six more than planned. Except in very tiny containers such as capillary tubes, such oscillations have not been observed on Earth. Varied conditions such as chamber size and proportions, surface shape (cannot be varied on Earth) and heat location and intensity were applied to the silicone fluid surface. Using the downlink video enabled the scientists to clearly pinpoint when the fluid flows transition from stable to oscillatory (unstable) flows. Also, the scientists found that when the temperature was increased past the point where oscillations began, the flows became erratic. These data will be used to form a fluid physics data base for improved materials processing.

DROP PHYSICS MODULE

The Drop Physics Module (DPM) manipulated free-floating liquid drops in microgravity to expand the current fluid physics models and theories and to measure the properties of liquid surfaces. The rectangular experiment chamber where liquid samples were deployed had four loudspeaker drivers which were used to position the water drops in the chamber.

The experiment successfully achieved major steps toward drop encapsulation in the DPM, a facility that used sound waves to levitate and manipulate liquid drops for close study. Several more firsts were achieved and one of these was the forming of compound drops. The injecting of one drop into another led to successful coalescence--two drops being deployed separately and coming together to become one. Another first was the formation of a chemical membrane that was formed when two drops were deployed and coalesced and formed one drop. Drop fissioning, where one drop was spun until it broke into two drops, also was achieved. Another study that evaluated the surface-altering chemical influences was successful, providing scientists with a wealth of data on different surface behaviors when water drops with subfactants were oscillated using the sound waves.

Drop Dynamics Experiment

The Drop Dynamics Experiment (DDE) gathered high quality data on the dynamics of liquid drops in low gravity for comparison with theoretical predictions and ground-based studies. The experiment investigated fluid physics and chemical interactions involved with centering one liquid drop inside another, and the results will apply to cell encapsulation research.

Science and Technology of Surface-Controlled Phenomena

The Science and Technology of Surface-Controlled Phenomena examined the influence of surfactants on the behavior of drops, and the manner in which the surfactants altered the surface properties of a liquid.

GEOPHYSICAL FLUID FLOW CELL EXPERIMENT

The Geophysical Fluid Flow Cell (GFFC) Experiment gathered data on the movement of fluids in a microgravity. Results of this experiment from the STS-51B Spacelab 3 mission revealed new types of convection. This STS-73 experiment expanded on that knowledge.

The experiment ran for 150 hours, modeling 29 different scenarios of fluid flows in oceans, atmospheres, planets, and stars. The simulations studied how fluids move in microgravity. Several of the scenarios simulated the atmosphere of the planet Jupiter. Some experiment runs seemed to validate predictions in a mathematical model of planetary and solar fluid flows. One simulation showed an atmospheric flow predicted by a computer model that previously had not been validated.

CRYSTAL GROWTH FURNACE

The Crystal Growth Furnace (CGF) was a reusable Spacelab facility that was used for growing crystals of semiconducting materials, metals and alloys. This furnace, which had it debut on USML-1, is the first space furnace developed by the United States for processing multiple large samples at very high temperatures (above 1,832 °F). On this mission, four primary crystal growth experiments were flown as a continuation of the experiments from USML-1.

This experiment grew crystals as a liquid bridge for the first time, thus minimizing contact with the container wall and decreasing the number of defects in the crystal. A total of eight semiconductor crystals were successfully grown in the crystal growth furnace. The furnace was also used to grow gallium arsenide crystals, which are faster and require less power than traditional silicon crystals, that will be used for study of how tiny traces of intentionally added impurities enhanced electrical properties.

Orbital Processing of High Quality Cadmium Zinc Telluride Compound Semiconductors

This experiment provided data as well as a crystal from which the effects of gravity on the growth and quality of the alloyed compound semiconductor were evaluated. Evaluation of the crystal showed the effects of gravity in causing structural defects in the crystal.

Study of Dopant Segregation Behavior During the Crystal Growth of Gallium Arsenide in Microgravity

This experiment provided data on techniques of uniformly distributing a small amount of selenium, a dopant, within a gallium arsenide crystal to improve and precisely control the electronic characteristics of the crystal. Growing the crystals is space greatly reduces the gravitational influences that cause an uneven distribution of the dopants in crystals grown on Earth, as well as allowing the identification of more subtle influences on the distribution.

The furnace was also used to grow gallium arsenide crystals, which are faster and require less power than traditional silicon crystals, that will be used for study of how tiny traces of intentionally added impurities enhanced electrical properties.

Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification

This experiment provided data for the confirmation of how gravity influences the introduction and distribution of structural defects in alloy semiconductors during crystal growth. One crystal of mercury zinc telluride, about 3/4 inch in length, was grown, and it will be analyzed postflight to determine its chemical and physical properties.

Vapor Transport Crystal Growth of Mercury Cadmium Telluride in Microgravity

This experiment built on the success of the USML-1 mission and focused on the initial phase of vapor crystal growth in a complex alloy semiconductor. One crystal was grown that consisted of a layer of mercury cadmium telluride on a cadmium telluride substrate (base). This crystal was analyzed to determine the effects of microgravity on the growth rate, chemical composition, structural characteristics and other properties of the initial crystalline layer that formed on the substrate.

Mercury Cadmium Tellluride, an infrared detecting material, was used to study the initial crystal layer formation. On the first USML mission, the first layer had significantly fewer defects (1000 times more defect free) than ground-based crystals.

ZEOLITE CRYSTAL GROWTH FURNACE

The Zeolite Crystal Growth (ZCG) Furnace was used to process 38 Zeolite samples during the course of the mission. The scientists believe that analyzing the crystals will provide a better understanding of the three-dimensional structure of the crystals, as well as techniques for creating large, near-perfect Zeolite crystals in microgravity. This experiment was also flown on USML-1.

Data were obtained from the downlink video which indicated a uniform population of suspended particles throughout the samples in which growth was expected. Ground-control samples were unlike the space-grown samples in that the particles had settled.

GLOVEBOX FACILITY

The Spacelab Glovebox Facility, developed by the European Space Agency, provided a versatile, transparent enclosure for testing and developing procedures and technologies in microgravity. The Glovebox Facility was flown on USML-1, but it was improved by increasing the working area and the lighting. Seven experiments made use of the facility during the STS-73 mission.

Interface Configuration Experiment

This experiment provided data on the shapes of fluid surfaces when contained in specific containers in microgravity. The behavior of free liquid-vapor interfaces cannot be predicted satisfactorily at this time, and the scientists believe that this experiment will resolve some the questions that exist on the subject. This experiment was flown on USML-1.

Scientists were able to see definite differences in the way fluids adhered to chamber walls in the experiment's various containers, and some of the behavior was different from that predicted by classic mathematics models. The new insights will aid in the design of fluid systems for space such as those for fuels.

Oscillatory Thermocapillary Flow Experiment

This experiment complements the Surface Tension Driven Convection Experiment. Data were taken at the onset of oscillations, or periodic variations, in surface-temperature-induced fluid flows.

Fiber Supported Droplet Combustion

This experiment provided data on combustion of droplets of fuel in microgravity. Drops normally burn unevenly in 1-g, but in microgravity it was expected that the drops would assume a symmetric sphere shape, and thus burn more evenly, thereby easing the process of validating combustion theories.

More than 25 droplets of a variety of fuels were ignited while suspended on a ceramic wire tether in the fiber-supported droplet combustion (FSDC) experiment. This experiment, which was flown for the first time, confirmed theories about how fuels burn in microgravity. The individual experiments resulted in larger droplet extension diameters (size of drop as it burns out) than any initial droplet size capable of being studied on Earth. The burning time was 10 times longer than any other experiment runs. The data from this mission has confirmed scientific predictions about burn rate and the amount of fuel remaining after the fire goes out. These data will allow scientists to refine theories, and possibly develop new ones about combustion by-products such as soot and smog.

Protein Crystal Growth - Glovebox

The Protein Crystal Growth - Glovebox is a repeat of the highly successful USML-1 experiment. Data from this experiment will be used to confirm the advantages of crew interaction in the process of growing crystals in microgravity. During the USML-1 mission, the crew interaction enabled the growth of much higher quality crystals than ever grown previously.

Zeolite Crystal Growth - Glovebox

This investigation extended the USML-1 experiment where on-orbit mixing procedures for Zeolite crystal growth experiments were demonstrated. The Zeolite crystals are used as catalysts and filters in the chemical processing industry. The USML-1 mixing process resulted in more uniform mixing and helped minimize bubble formation.

Colloidal Disorder - Order Transitions

This investigation obtained additional data on how the density of a substance finely and uniformly dispersed within another substance of a different phase - a mixture called a colloid - affected its transition from a liquid to an ordered solid phase. A number of containers that were holding different concentrations of microscopic solid spheres suspended in liquid were placed in the furnace, and during the postflight investigation, the scientist determined which concentration had a high enough density to arrange the spheres in an ordered state.

The scientific team observed a stable disc-shaped crystal with dendrites (branches) projecting outward from its edges, a phenomenon that had not been seen on Earth. The crystals were described as being a snowflake in a glass of water that was not melting or dissolving. Photographic data and downlink data revealed growing crystals throughout a sample that was thought to be too densely packed to grow crystals. On Earth, this dense concentration causes the sphere to move so slowly that the crystals only form on a geological time scale (millions of years).

Particle Dispersion Experiment

This investigation studied the microgravity environment influence on fine natural particles such as dust, and how the dust particles are dispersed and reassembled into larger clusters. This investigation is a continuation of the experiment that was begun on USML-1.

The Particle Dispersion Experiment confirmed the theory concerning the behavior of dust and particle clouds in that aggregation occurs in all dust clouds, drawn together by static electrical charges. The testing included variations in particle size, density of the cloud, and type of material (volcanic material, rounded quartz, angular quartz, or copper). All of the materials tested showed a similar propensity to aggregate due to electrostatic attraction.

PROTEIN CRYSTAL GROWTH EXPERIMENTS

A record number of protein crystal growth experiments were being flown on the STS-73 mission. The crystal growth experiments from USML-1 were most successful with almost half of the 30 protein crystals grown being large enough for X-ray diffraction analysis. The crystals being grown were from proteins that are very instrumental in fighting diseases. Postflight evaluation will be required to determine the success of the Protein Crystal Growth experiments.

Single-Locker Protein Crystal Growth - Two Methods

This experiment processed more than 800 protein samples in a facility designed for the production of crystals with enhanced internal order. The protein crystallization apparatus for microgravity (PCAM) holds more than six times as many samples as are normally accommodated in the same amount of space.

Crystal Growth by Liquid-Liquid Diffusion

This experiment used four hand-held diffusion test cells to grow protein crystals by diffusing one liquid slowly into another. The units were activated after launch and deactivated prior to entry.

Commercial Protein Crystal Growth

This experiment grew large quantities of crystals of various proteins using the batch-process method. A protein crystallization facility was housed in a commercial refrigeration/incubation module (CRIM) in the Orbiter middeck. The facility contained four cylindrical crystallization chambers which were activated when the Shuttle reached orbit. The units were shut down after 100 hours of operation.

Advanced Protein Crystallization Facility

This facility, developed by the European Space Agency, is the first ever designed to provide three methods of protein crystal growth; liquid-liquid diffusion, dialysis, and vapor diffusion. Video images were made of the crystals as they formed, and were used by the scientists to study crystal development in microgravity. Fifteen individual experiments were flown in the facility.

COMMERCIAL GENERIC BIOPROCESSING APPARATUS

The Commercial Generic Bioprocessing Apparatus allowed in excess of 200 sophisticated bioprocessing experiments to be performed in one piece of hardware. Each experiment was housed in a fluid processing apparatus (FPA), and groups of eight FPA's were activated at one time. Processing was terminated automatically, after which the samples were removed and stored for return to Earth. This unique facility enabled a large, diverse range of commercial investigators, such as pharmaceutical companies, to fly an experiment in the Spacelab.

The facility for the Experiment provided an environment for growing plants, brine shrimp, protein crystals as well as other investigations in microgravity. The two objectives for this mission were to test the three main subsystems to verify that the apparatus was an effective on-orbit plant growth system, and secondly, to investigate the nature of starch accumulation in microgravity.

SPACE ACCELERATION MEASUREMENT SYSTEM

The Space Acceleration Measurement System (SAMS) measured the acceleration environment of the Spacelab module over a specific range of frequencies. Sensors were located on the Surface Tension Driven Convection Experiment, the Crystal Growth Furnace, and the Glovebox. Data from this system will be used to determine the effect of crew movement, equipment operations, and Shuttle maneuvers on experiment operations.

THREE-DIMENSIONAL MICROGRAVITY ACCELEROMETER

The Three-Dimensional Microgravity Accelerometer (3-DMA) measured the absolute level of microgravity accelerations, and microvibrations that could affect the onboard investigations. The scientists made ongoing adjustments to their experiments based on readings from the 3-DMA. Loss of some real-time data from 3DMA was of minimal impact since all data were recorded onboard.

SUPPRESSION OF TRANSIENT ACCELERATIONS BY LEVITATION EVALUATION

The Suppression of Transient Accelerations by Levitation Evaluation (STABLE) was developed in five months, and was the first facility of its kind. The facility enabled testing of a small science experiment to determine how well it can be isolated from high-frequency accelerations, including Shuttle operations and crew activity. The isolation was accomplished using electromagnetic levitation.

HIGH-PACKED DIGITAL TELEVISION TECHNICAL DEMONSTRATION

The High-Packed Digital Television (HI-PAC) was flown as a flight demonstration of the new digital television system that operates from the Spacelab. It provided researchers on the ground with up to six channels of TV when desired. The HI-PAC demonstration provided four times the normal amount of video data for scientist feedback during the mission. The system collected more than 41,000 gigabits of digital data during the demonstration of video communication techniques that will help pave the way for Space Station experiment operations.

ORBITAL ACCELERATION RESEARCH EXPERIMENT

The Orbital Acceleration Research Experiment (OARE) measured microgravity levels caused by the atmospheric drag of the Shuttle, changes in Orbiter velocity and vibrations of onboard equipment, as well as Shuttle and crew operations. Data from the OARE gave the scientists the opportunity to make on-the-spot adjustments to their experiments to account for the on-orbit disturbances.

The OARE data on the payload recorder was reported by Marshall Space Flight Center (MSFC) as being poor quality. The data were transmitted on Ku-band channel 2 (payload recorder playback). The second TDRS ground terminal (STGT) reported that the integrated receiver (IR) was not able to maintain lock when configured to receive the 640 Kbps Bi-phase-L data from the payload recorder. Troubleshooting at the STGT and at Johnson Space Center (JSC) revealed that changing the configuration of the IR to 1.28 Mbps NRZ-L resulted in good lock and better quality data at MSFC. Additional troubleshooting at STGT also revealed that setting the IR loop bandwidth at 4 percent (instead of the nominal 0.1 percent) enabled the IR to maintain lock at the 640 Kbps Bi-phase-L configuration. The resolution for the STS-75 mission when continuous payload recorder playback via Ku-band channel 2 is required is being evaluated.

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTERS

Analysis of the flight data and assessment of the postflight condition of the recovered hardware indicates nominal performance of the Solid Rocket Booster (SRB) systems. The SRB countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred.

No SRB in-flight anomalies were noted; however, data and film analysis show hold-down post 2 stud hang-up and subsequent broaching of the hold-down post bore at liftoff. This condition did not affect the launch or ascent phase.

Both SRBs successfully separated from the ET 123.6 seconds after liftoff, and reports from visual sightings indicate that the deceleration subsystems performed as designed. The SRBs were retrieved and returned to KSC for disassembly and refurbishment.

REUSABLE SOLID ROCKET MOTORS

The fiftieth Reusable Solid Rocket Motor (RSRM) set performed nominally with all parameters within the Contract End Item (CEI) specification limits. There were no LCC violations, and no RSRM in-flight anomalies identified.

Power up and operation of all igniter and field joint heaters was accomplished routinely. All Reusable Solid Rocket Motor (RSRM) temperatures were maintained within acceptable limits throughout the countdown. For this flight, the low-pressure heated ground purge in the SRB aft skirt was used to maintain the case/nozzle joint temperatures within the required LCC ranges. At T-15 minutes, the purge was changed to high pressure to inert the SRB aft skirt.

Field joint heaters operated 52 hours 36 minutes total, including activations for the scrubbed launch attempts, and 11 hours 28 minutes for the successful launch countdown. Power was applied for an average of 18 percent of the time during the LCC time frame to maintain temperatures in the normal operating range.

Igniter joint heaters operated for 52 hours 25 minutes total, including activations for the scrubbed launch attempts, and 11 hours 28 minutes for the successful launch countdown. Power was applied to the igniter joints an average of 34 percent of the time to maintain temperatures in the normal operating range.

The aft skirt purge operated for 7 hours 13 minutes total, including activations for the scrubbed launch attempts. During two countdowns, the purge was activated to maintain the nozzle/case temperatures above the minimum LCC requirement. During the same two countdowns, the high-flow rate purge was activated at T-15 minutes to ensure that all hazardous gasses were removed from the aft skirt compartments at launch.

The RSRM propellant mean bulk temperature (PMBT) was 80°F at liftoff. The maximum trace-shape variation of pressure vs. time was 2.4 percent at 73.5 seconds for the left motor and 0.7 percent at 80.0 seconds (right motor). The following table presents a comparison of the actual and predicted propulsion system performance data.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 80 °F		Right motor, 80 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	65.80	66.17	65.73	65.96
I-60, 10^6 lbf-sec	175.35	176.09	175.22	176.33
I-AT, 10^6 lbf-sec	297.16	296.83	297.30	296.83
Vacuum Isp, lbf-sec/lbm	268.6	268.3	268.6	268.2
Burn rate, in/sec @ 60 °F at 625 psia	0.3664	0.3684	0.3660	0.3685
Burn rate, in/sec @ 80 °F at 625 psia	0.3717	0.3734	0.3713	0.3736
Event times, seconds[a]				
Ignition interval	0.232	N/A	0.232	N/A
Web time[b]	109.6	108.7	109.7	108.7
50 psia cue time	119.3	118.7	119.5	118.2
Action time[b]	121.4	120.7	121.5	120.6
Separation command	124.4	123.6	124.4	123.6
PMBT, °F	80	80	80	80
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	2.7	2.8	3.3
Tailoff Imbalance Impulse	Predicted		Actual	
differential, Klbf-sec	N/A		280.2	

Impulse Imbalance = Integral of the absolute value of the left motor thrust minus right motor thrust from web time to action time.

[a] All times are referenced to ignition command time except where noted by a [b].

[b] Referenced to liftoff time (ignition interval).

Postflight inspections of the STS-70 and STS-71 nozzle joints 3 and 4 revealed gas paths in the joint room temperature vulcanizing (RTV) and resultant minor heat damage to the primary O-ring. The ensuing investigation showed that gas paths occurred in RTV voids, and these were caused by the back-fill closeout methods. An understanding of the phenomenon led to the development of a technique to repair or rework all nozzle joints 3 and 4 in the flight inventory. Postflight inspections and disassembly of STS-73 RSRM's showed that the repaired J-joints (igniter and field) performed as designed, and no gas paths were noted. However, a gas path was observed through the STS-73 left-hand nozzle-to-case joint polysulfide. Soot was observed up to but not past the wiper O-ring. The wiper O-ring was heat affected and eroded with a maximum erosion depth of 0.027 inch.

EXTERNAL TANK

The ET loading and flight performance was excellent. All flight objectives were satisfied. All ET electrical equipment and instrumentation operated nominally, All ET purges and heaters operated properly, and there was no unacceptable ice/frost formation. No ET LCC or OMRSD violations were identified, nor were there any in-flight anomalies identified.

Typical ice/frost formations were observed on the ET during the countdown. No ice or frost was observed 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) feed-lines and on the pressurization line brackets, and some frost or ice was present along the LH_2 protuberance air load (PAL) ramps. These observations were acceptable per NSTS 08303. The Ice/Frost team reported that no anomalous thermal protection system (TPS) conditions were found.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the ullage pressure slump was 14.4 psid.

ET separation was confirmed, and ET entry and breakup occurred within the expected footprint, with the impact point 44 nmi. uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

All tanking and prelaunch preparations were met. All LCC, ignition confirm limits, and mainstage redline margins were satisfactory. All Interface Control Document (ICD) start and shutdown transient requirements were met. All engines were below the thrust-load-indicator recommended limit during start.

Engine performance during start, mainstage, and shutdown was nominal and as predicted.

The specific impulse (Isp) was rated at 452.87 seconds based on trajectory data. Controller and software performance was good. One SSME in-flight anomaly was identified. The main fuel valve leak of SSME 1 leaked and caused a scrub of the first launch attempt on September 28, 1995. The valve was replaced and failure analysis was conducted (Flight Problem STS-73-E-01). No anomalous conditions were detected on the valve. The leak was attributed to transient contamination or nitrogen ice formation on the ball.

Flight data indicate that the SSME performance during main-stage, throttling, shutdown, and propellant dumping operations was normal. High pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures were well within specification throughout engine operation. Main engine cutoff (MECO) occurred at T+509.35 seconds. There were no in-flight failures identified nor significant problems noted.

SHUTTLE RANGE SAFETY SYSTEM

All Shuttle range safety system (SRSS) measurements indicated that the system performed nominally. The 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.

A new high-experience base value (28.48 Vdc under load) was set for the ET range safety system (RSS) battery B voltage, which has an upper LCC limit of 28.8 Vdc. The previous high value was 28.18 Vdc and it was established on STS-26. Bench test data shows that the voltage regulator in the range safety distributor (RSD) was set to 28.74 Vdc which corresponds directly to a 28.48 Vdc reading from the onboard instrumentation system.

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

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion System

The overall performance of the MPS was as expected with no in-flight anomalies identified on this first flight with two Block 1 SSMEs installed. The vehicle was loaded four times in support of STS-73. Loading for the first launch attempt was aborted after transition to reduced fast-fill because of internal leakage of the

SSME 1 main fuel valve. The valve was replaced prior to the next loading attempt.

For launch day, LO_2 and LH_2 loading were performed as planned with no stop-flows or reverts. The ET LO_2 100-percent sensor 2 toggled between wet and dry during the preloading sensor checkout. As a result, the sensor was bypassed for the 3-hour checkout and for LCC verifications. This sensor is used only for ground operations. No OMRSD or LCC violations were identified.

Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment (occurred shortly after the start of fast-fill) was approximately 98 ppm, which compares favorably with previous data for this vehicle.

The LH_2 loading operations were normal through chilldown, slow fill, fast fill, topping, and replenish. Based on the analysis of loading system data, the LH_2 load at the end of replenish was 231,892 lbm, which when compared with the predicted (inventory) load yields a satisfactory difference of +0.03 percent.

The LO_2 loading operations were normal during all phases of the loading. Based on an analysis of loading system data, the LO_2 load at the end of replenish was 1,388,730 lbm, which when compared to the predicted load yields a satisfactory difference of +0.06 percent.

Ascent MPS performance was completely normal. Data indicate that the LO_2 and LH_2 pressurization systems performed as planned, and all net positive suction pressure (NPSP) requirements were met throughout the flight. The minimum LO_2 ullage pressure experienced during the period of ullage-pressure slump was 14.1 psid.

This was the first flight of the GH_2 pressurization system modifications with all modifications incorporated on the vehicle (rotated flow control valve housings in the flow control valve manifold, rerouted lines from engine interfaces to flow control valve manifold, and the pre-pressurization line filter housing). Filters were only installed in SSME 1 and the pre-pressurization line to verify filter sizing for design assessment.

The filter installation was transparent to hydrogen tank pre-pressurization operations. The ET LH_2 tank reached flight pressure within the expected time frame and maintained tank ullage pressure within the required band.

The GH_2 pressurization system functioned nominally during ascent. Review of the data showed satisfactory functioning of all flow control valves (FCVs) with no evidence of sluggish performance (newly refurbished FCVs were installed due to the modification activity). Engine outlet pressure differentials were within the expected range as predicted by the new analytical model using the new system configuration and engine specific impulse tag values for the SSMEs installed.

Propellant dumping operations and vacuum inerting were performed satisfactorily with nominal results.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed acceptably with two in-flight anomalies identified. Total propellant usage by the RCS during the mission was 4,083.4 lbm.

The first RCS trim firing was initiated at 293:16:54:40 G.m.t. (000:03:01:40 MET)., and it was a 30-second -X maneuver which imparted a ΔV of 6.9 ft/sec. Thruster F1F failed off 320 ms after initiation of the firing because the chamber pressure (Pc) reached only 17 psia (Flight Problem STS-73-V-03). All other thruster firings during the trim maneuver were nominal. The F1F thruster temperature decrease indicated that both propellant valves achieved at least pilot-valve flow. The Pc subsequently required about 15 minutes to return to zero psia. The fact that the Pc decreased so slowly indicates that the thruster fail-off condition was caused by a blockage of the Pc tube orifice. This Pc tube was last flushed during the STS-73 processing flow. The Pc tube was inspected on the vehicle for blockage and none was found. However, the problem does appear to be within the F1F pressure-sensing system. The thruster was replaced.

At approximately 300:18:04 G.m.t. (007:04:11 MET), RCS vernier thrusters R5R and R5D failed off. The R5D and R5R vernier thrusters failed to fire seven more times when commanded, and the L3D and R3D primary RCS thrusters failed off once. The failure signature was essentially the same for each occurrence. As a result, the aft manifold 3 primary thrusters were placed in last priority for entry. The fail-offs were caused by a command path problem that is discussed in the Avionics section of this report.

Orbital Maneuvering Subsystem

The orbital maneuvering subsystem (OMS) performed satisfactorily for the two firings made by the system (OMS 2 and deorbit firing). The OMS fired for a total of 281.3 seconds with no in-flight anomalies noted, and a total of 10,864.5 lbm of propellants were used during the two firings. There was no RCS interconnect usage during this mission.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed nominally throughout the mission. A total of 5383 lbm of oxygen and 652 lbm of hydrogen were consumed during the mission. Consumables remaining would support a mission extension of 70 hours at an average power level of 19.5 kW. The PRSD supplied 204 lbm of oxygen to the environmental control and life support system for crew breathing.

At 308:13:42 G.m.t. (014:23:49 MET), when the hydrogen and oxygen manifold isolation valves were being cycled for the in-flight checkout, the hydrogen manifold 1 isolation valve failed to close when commanded (Flight Problem STS-73-V-08). Four minutes later, the switch was held in the CLOSE position for 10 seconds, but the valve position again did not change. Heater cycles confirmed that the valve was still open. No further attempts were made to operate this valve during the mission. This failure did not impact the mission. The valve was cycled postlanding and operated properly. This valve also failed to close on STS-43 (OV-104), after it had cycled satisfactorily five times on that flight. The valve remained on the vehicle and cycled nominally for three additional flights. The valve was removed during the OMDP for cryogenic screening, which it passed satisfactorily, and then installed on OV-102 during this vehicle's OMDP. The valve was removed and replaced during turnaround activities following this mission (STS-73).

Oxygen tank 3 experienced a pressure collapse to 544 psia at 73 percent quantity due to destratification. The quantity dropped to 65 percent before recovering. The pressure remained above the two-phase region throughout the flight; consequently, the destratification was not a constraint to the use of this tank.

Fuel Cell Powerplant Subsystem

The fuel cell powerplant (FCP) subsystem performed nominally throughout the mission and generated 7446 kWh of electrical energy for subsystem and payload usage. The average power level during the mission was 19.5 kW and 644 amperes. The fuel cells used 5179 lbm of oxygen and 652 lbm of hydrogen and produced 5831 lbm of water as a by-product of the electrical energy production. Six purges were made of the fuel cells during the mission. The actual fuel cell voltages at the end of the mission were 0.10 Vdc above that predicted for fuel cells 1 and 2 and 0.15 Vdc above that predicted for fuel cell 3. The overall performance degradation during the mission was 0.10 Vdc for fuel cell 1 and 0.15 Vdc for fuel cells 2 and 3.

A problem that was noted during prelaunch operations persisted throughout the mission. The fuel cell 3 substack 1 cell performance monitor (CPM) differential voltage measurement was latched at the full-scale high value of 500 mVdc. This condition existed because of an out-of-limit self-test input. Loss of this measurement was a constraint to launch; consequently, a waiver was approved for flight. The CPM was replaced during the turnaround activities following this mission.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission. As a result of water spray boiler 3 spray-bar freeze-up during ascent that caused the APU 3 lubrication oil return temperature to increase to 326 °F, the decision was made to shut down APU 3 earlier than planned. The temperature reached 332 °F before cooling began; however, this over-heating of the lubrication oil return did not impact mission operations. The following table presents the APU serial numbers that were flown, and the fuel consumption and run times for the APUs.

APU RUN-TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 402)		APU 2 (S/N 303)		APU 3 (S/N 403)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	21:53	47	22:09	58	18:55	43
FCS checkout					12:19	27
Entry[a]	63:34	117	82:09	187	63:35	120
Total	85:27	164	104:18	245	94:49	190

[a] The APUs were shut down approximately 18 minutes 45 seconds after main gear touchdown, following a hydraulic load test.

Approximately 45 minutes after the postlanding shut down of the APUs, the pump inlet pressure of APU 1 had decayed from 150 psia to 35 psia during the previous 20-minute period. The drain-line pressure rose from 20.5 psia to 22.0 psia during the same period, indicating leakage across the fuel pump seal (Flight Problem STS-73-V-09). During postflight operations, 108 cc of liquid was drained from the APU 1 catch bottle. The APU was replaced.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/WSB subsystem performed nominally during the mission, and one in-flight anomaly was noted during ascent.

The October 6 launch attempt was scrubbed prior to ET loading when the data showed a 16-percent drop in reservoir quantity, and it was determined that hydraulic fluid had been inadvertently drained from hydraulic system 1 following the SSME 1 main fuel valve replacement. A compressibility test of the system was performed, and it showed that the air content was 1.24 percent and should have been no greater than 1.0 percent. This level was determined to be satisfactory for launch, and a waiver was generated to document the higher-than-normal air content and its acceptability for launch.

During ascent, WSB 3 experienced a freeze-up as evidenced by the APU 3 lubrication oil return temperature increasing above the normal spray start temperature of 250 °F (Flight Problem STS-73-V-02). When the temperature reached 297 °F, the crew was requested to switch from controller A to controller B on system 3. However, the boiler was apparently shut off instead, and when the temperature reached 316 °F the crew was requested to turn the boiler power back on and switch to controller B. After switching controllers, the temperature rise rate did not change, indicating a spray bar freeze-up. When the temperature reached 326 °F, the crew was directed to shut down APU 3 earlier than planned. Approximately one minute later, WSB 3 (on controller B) began spraying, indicating that the spray bar had thawed. All three WSBs had the water feed-line heater modification that was implemented to preclude WSB freeze-ups. This heater modification was also flown on STS-69/OV-105 on WSB 3.

APU 3 and WSB 3 were used for the FCS checkout, and both controller A and B were also exercised during this checkout. Although under-cooling to a temperature of 273 °F and a subsequent over-cooling to 236 °F were experienced, lubrication oil cooling on the WSB 3 controller A was satisfactory. In addition, WSB 3 performance with controller B was satisfactory during entry. Postflight troubleshooting verified that the water feed-line heater is functioning normally. Controller A was removed and sent to the vendor for troubleshooting. With a replacement controller A installed, further testing of the WSB found no anomalies.

The APUs were shut down in the 3, 1, and 2 order with APU 3 being shut down about 3 minutes prior to APU 1 and 2. No anomalous pressure hang-ups or power drive unit (PDU) motor back-driving was noted on any system during the APU shut-down sequence.

During on-orbit operations, brake isolation valve 3 was opened for a short period of time to maintain the hydraulic fluid temperature for the brake modules above -4 °F. Total circulation pump runs were 51 on system 1, 36 on system 2, and 44 on system 3, and circulation pump operation was nominal throughout the mission.

Hydraulic system performance during entry was satisfactory with hydraulic heat exchanger mode being achieved for all three systems. A hydraulic load test was performed postlanding during which systems 1 and 3 were alternately taken to low pressure and the aerosurfaces exercised. All operations were nominal during the load test.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed satisfactorily with the exceptions discussed in the following subparagraphs.

During prelaunch operations, no drive current was observed on AC 1 phase B when the left vent door 8/9 was driven. After main engine cutoff, when closing the Orbiter/ET doors following ET separation, AC 1 phase B current did not power the four motors normally supported by this circuit. This loss caused these motors to operate on two phases. Data evaluation indicated that the most probable cause of the failure was an open circuit of phase B between CB 4 on panel MA73C and aft motor controller assembly (AMCA) 1. AC1 phase B current was not present during any of the vent door 8/9 repositioning during the remainder of the mission or during the ET door opening postlanding. Believing that oxidation of the circuit breaker contact was a likely cause of the problem, CB 4 on panel MA73C was cycled during postlanding operations, and the AC1 phase B current returned. No further action is required.

During postlanding activities at KSC, when the midbody motor control assembly (MMCA) 3 logic power main bus B switch was placed in the off position, the associated operational status (OP STAT) indications for OP STAT 8, OP STAT 11, and OP STAT 12 failed to power down. The events eventually cycled to the nominal off condition approximately 4 hours after the logic power switch was placed in the off position. This same condition occurred following the last flight of this vehicle (STS-65), and at that time required 6.5 hours to reach the nominal off condition. The problem is suspected to be a leaky remote power controller in the midpower controller assembly (MPCA) -2. There is no mission impact associated with this condition.

Environmental Control and Life Support System

The environmental control and life support system (ECLSS) performed satisfactorily throughout the mission.

The active thermal control system (ATCS) operation was satisfactory throughout the mission. The ATCS successfully supported payload cooling requirements by placing both of the Freon coolant loops' (FCLs) flow proportioning valves in the payload position prior to Spacelab activation. The loop was returned to the interchanger position for entry as part of the Spacelab deactivation procedure.

The flash evaporator system (FES) feedline A mid 2 temperature measurement slowly decreased beginning at approximately 293:19:53 G.m.t. (00:05:30 MET), and the heater did not cycle. Based on previous flight data, a heater cycle would have been expected at approximately 70 °F. When the temperature reached 54.7 °F at approximately 296:17:16 G.m.t. (003:03:23 MET), the FES feedline A mid 2 heater system 1 was declared failed off (Flight Problem STS-73-V-04). The FES feedline A mid 2 heater system 2 was activated and cycled nominally for the remainder of the mission. Troubleshooting isolated the problem to a broken wire at a ground lug. The wire was repaired.

At 304:21:48 G.m.t. (011:07:55 MET), the topping FES experienced an under-temperature shutdown. The shutdown was caused by operating the topping evaporator at a heat load between 35,000 and 38,000 Btu, which exceeded the design-specified capability (30,000 Btu) stated in the Shuttle Operational Data Book. Contributing factors to this heat load included Beta angle, vehicle attitude, and lower port radiator efficiency due to the 52-degree-open port-door position, which resulted in panel temperatures in excess of 75 °F. The primary controller A was reset, and FES operation was restored. Nine additional FES shutdowns occurred during the next 24 hours. As a result, the decision was made to leave the port payload bay door fully open following the third thermal conditioning period for the port MLG tires that was initiated at 306:08:23 G.m.t. (012:18:30 MET). With the door fully open, no additional FES under-temperature shut downs occurred during the mission, and there were no further thermal issues with the attitude timeline for the remainder of the mission. No postflight action was required.

Freon coolant loop (FCL) 1 experienced erratic flow in the interchanger and payload legs. The flow oscillations returned to normal for two short periods of time and the flow-rates remained steady throughout most of the mission. This condition is believed to be associated with the documented overall flow degradation, and the erratic-flow condition did not impact the mission. The filtered components (flow proportioning valve, radiator flow controller assembly, and pump inlet filter) in FCL 1 were replaced.

The radiator cold-soak provided cooling during entry through touchdown plus 5 minutes when ammonia boiler system (ABS) A was activated using the primary/GPC controller. To minimize thermal stress on the crew after a long-duration flight, ammonia cooling was activated early by selecting the high outlet temperature set point (57 °F) on both FCL radiator flow controllers when the radiator controller outlet temperatures exceeded 40 °F. This provided the necessary heat load for the ABS and avoided the increased cabin temperature and humidity transient which occurs during nominal postlanding operations between cold-soak depletion and ammonia activation. System A operated for 37 minutes before ground cooling was connected and operational.

The atmospheric revitalization system (ARS) performance was nominal. The ARS air and water coolant loops performed normally. Cabin temperature and relative humidity peaked at 82.2 °F and 50.8 percent, respectively. Avionics bays 1, 2, and 3 air outlet temperatures peaked at acceptable levels of 102.9 °F, 104.9 °F, and 89.7 °F, respectively. Avionics bays 1, 2, and 3 water cold-plate temperatures peaked at acceptable levels of 88.2 °F, 91.1 °F, and 81 °F, respectively.

The regenerative CO_2 removal system (RCRS) was activated after MECO, and the RCRS operated nominally throughout the mission. The cabin CO_2 partial pressure was maintained below a level of 4.59 mmHg, which was satisfactory.

The atmospheric revitalization pressure control system performed nominally. During the redundant component check, the pressure control configuration was switched to the alternate system. Both systems exhibited normal operation.

The supply water and waste management system performed nominally throughout the mission. Supply water was managed through the use of the FES and overboard dump systems. A total of 18 supply water dumps (three of which were simultaneous with waste water dumps) were performed at an average dump rate of 1.56 percent/minute (2.58 lb/minute). The supply water dump line temperature was maintained between 76 °F and 107 °F throughout the mission with the operation of the line heater.

Waste water was gathered at approximately the predicted rate. Three waste water dumps were performed at an average rate of 2.08 percent/minute (3.44 lb/minute). The waste water dump line temperature was maintained between 53 °F and 79 °F throughout the mission. The vacuum vent line temperature was maintained between 59 °F and 73 °F, and the nozzle temperature remained in a range between 100 °F and 157 °F.

The waste collection system performed nominally throughout the mission.

Smoke Detection and Fire Suppression Subsystem

The performance of the smoke detection subsystem was nominal and showed no indication of smoke generation during the flight. Use of the fire suppression subsystem was not required.

Airlock Support System

The performance of the airlock support system and tunnel adapter was nominal throughout the mission. Use of the airlock support components was not required because there was no extravehicular activity.

Avionics and Software Support Subsystems

The avionics and software support subsystem performed satisfactorily with the following exceptions.

The launch on October 7 was scrubbed when master events controller 1 (MEC 1) built-in test equipment (BITE) word 5, bit 9, indicated that the MEC 1 core B critical drivers were not enabled (Flight Problem STS-73-V-01). MEC 1 was replaced and satisfactorily retested.

Vernier RCS thrusters R5R and R5D failed to fire when commanded at 300:18:04 G.m.t. (007:04:11 MET) (Flight Problem STS-73-V-05). Data show that the fire command B was issued for one sample to both thrusters, but no driver output or Pc was indicated for either thruster. Since Pc was not present, the redundancy management (RM) software deselected both thrusters. Because no indication of a thruster failure was present, both the R5D and R5R thrusters were hot-fired and each provided a good one-second pulse. The two vernier thrusters were then reselected for flight use.

At approximately 306:14:38 G.m.t. (013:00:45 MET), RCS vernier thrusters R5R and R5D again failed off. The signature was similar to that of the previous failure of these thrusters. Since the crew was instructed to reselect the thrusters without performing the hot-fire procedure, the thrusters were reselected and fired nominally when required. At 306:20:52 G.m.t. (013:06:59: MET), the R5D and R5R vernier thrusters again failed to fire when commanded. The failure signature was verified as the same signature as the first occurrence. A few minutes after this occurrence, the crew reselected the thrusters, and the thrusters failed when commanded to fire. The thrusters were reselected about 30 minutes later, and the thrusters fired properly.

The R5R and R5D thrusters failed off a fourth, fifth and sixth time. Following the sixth occurrence, the primary RCS thrusters were selected. Primary RCS thrusters L3D and R3D subsequently annunciated fail-off at 307:19:44 G.m.t. (014:05:51 MET). Thruster data show a signature similar to the failure of vernier thrusters R5R and R5D in that the chamber pressure remained at 0 psia and the injector temperatures indicated no propellant flow. The jet-driver output indication and command B were not present during the fail-off. Commands for these two primary thrusters share MDM FA2 cards and channels with vernier thrusters R5R and R5D, as well as with primary thrusters L3A, R3A, L3L, and R3R. As a result, the aft manifold 3 primary thrusters were placed in last priority for entry. Following the fail-off of the two primary thrusters, the vernier thrusters were reselected and thrusters R5R and R5D were brought on line. Two additional occurrences (seventh and eighth) of the R5R and R5D vernier thrusters failing off occurred during the remainder of the mission.

Extensive postflight troubleshooting was performed and as of this writing, the problems was not repeated. The MDM (S/N 121) and RJD (S/N 20) were removed and replaced. Troubleshooting on the Orbiter failed to reproduce the anomaly. The MDM and the RJD were replaced, and failure analysis of the removed components also has not identified the problem.

A similar failure of thruster R5D occurred during the previous flight of this vehicle (STS-65), and troubleshooting failed to indicate the cause. The MDM (S/N 121) and the RJD (S/N 20) in the command path to the R5D and R5R vernier thrusters as well as the aft manifold 3 primary thrusters are the same units flown on STS-65.

A vernier RCS hot-fire test was performed on flight day 16, during which RCS thrusters L5D and R5D were fired for 20 seconds. Linear acceleration data was recorded by the OARE and SAMS accelerometers. These data will be used to improve the understanding of the effect of vernier thrust impingement on the Orbiter, and this should lead to a refinement of models and better on-orbit vehicle control.

At 308:08:55 G.m.t. (014:19:02 MET), the crew reported that cathode ray tube (CRT) 2 (S/N 24) was flashing on and off and that the symbols on the screen were garbled (Flight Problem STS-73-V-07). These symptoms were intermittent, and the data indicated a problem with the CRT. As a result, an IFM procedure was performed to switch the CRTs in position 2 and 4, and the CRT in position 2 performed satisfactorily for the remainder of the mission. The failed CRT in position 4 was not repowered for the remainder of the mission. Initial indications are that the failure was caused by the deflection amplifier or the high voltage power supply. Postflight, the CRT in position 4 was removed and replaced, and the installation of the CRT in position 2 was verified.

The displays and controls operated nominally with the exception of one minor problem. When closing the Orbiter/External Tank (ET) doors following ET separation, AC 1 phase B current did not power the four motors normally supported by this circuit. The current was present after the postflight cycling of the circuit breaker, and no postflight action was required. This problem is discussed in greater detail in the Electrical Power Distribution and Control section of this report.

Communications and Tracking Subsystems

The communications and tracking subsystem performance was acceptable during the ascent, on-orbit and entry phases of the mission. The following paragraphs discuss the anomalies and problems that were noted during the mission.

Performance of the S-band lower right antennas was degraded in both the high- and low-frequency modes with either power amplifier selected (Flight Problem STS-73-V-06). An examination of data from 20 orbits indicated that there were no noticeable differences between transmissions on the high and low frequencies, and that the dropouts were on both TDRSs. Troubleshooting and testing were performed later in the mission to further define the S-band lower-right-antenna degraded performance problem. The troubleshooting and testing activity indicated that the problem was most likely in the path between the lower-right antenna and the antenna switch. Apparently, the cables were heating up and an arcing effect was occurring that caused the degradation. Postflight troubleshooting repeated the problem on an intermittent basis. The lower right antenna was replaced; however, dropouts were still received during transmit/receive tests.

Color television camera (TVC) 1 in the Spacelab module had flickering horizontal color bands scrolling at a high rate through its downlinked image. This is the first flight of this particular camera. This video was being downlinked through the HI-PAC digital television demonstration equipment. The black and white video was acceptable for science documentation. Later, TVC-1 video was downlinked through the Ku-band system in analog form, and the color video was good. The crew swapped the TVC-1 and TVC-2 inputs to the HI-PAC, and the video quality improved on TVC-1 without any degradation to TVC-2. This configuration was used for the remainder of the mission, and the performance was nominal.

Structures and Mechanical Subsystems

When the payload bay doors were opened at the beginning of on-orbit operations, the port door was initially placed at the 52-degree open position to protect the radiators from micrometeorite or orbital debris impacts. At approximately 298:13:43 G.m.t. (004:23:50 MET), the port payload bay door was taken to the full-open position in support of the mission's only Spacelab condensate dump. The door was moved back to the 52-degree open position following the dump at approximately 298:14:20 G.m.t. (005:00:27 MET). Video of the door centerline was taken before and after repositioning. The video was reviewed, and no anomalous conditions were found. Also, the payload bay door was moved to the full-open position several times for thermal reasons following the condensate dump and all door-drive cycles were nominal.

The tires and brakes were in good condition for a landing on the KSC concrete runway. The table on the following page presents the landing and braking parameters for the STS-73 mission.

Landing and Braking Parameters

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2579	212.3	~ 2.2	N/A
Nose gear touchdown	7098	156.6	N/A	~4.9

Brake initiation speed	119.6 knots
Brake-on time	35.4 seconds
Rollout distance	9,038 feet
Rollout time	55.6 seconds
Runway	33 (Concrete) KSC SLF
Orbiter weight at landing	230,200 lb

Brake sensor location	Peak pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	1032	Left-hand inboard	21.17
Left-hand inboard 3	1008		
Left-hand outboard 2	960	Left-hand outboard	19.97
Left-hand outboard 4	984		
Right-hand inboard 1	1344	Right-hand inboard	23.98
Right-hand inboard 3	1272		
Right-hand outboard 2	1392	Right-hand outboard	25.23
Right-hand outboard 4	1320		

Integrated Aerodynamics, Heating and Thermal Interfaces

Ascent and entry aerodynamics were nominal.

Ascent heating was nominal; however, entry heating was greater than previously experienced. See the Thermal Protection Subsystem and Window subsection for entry heating effects on the TPS.

Thermal interfaces were nominal.

Thermal Control Subsystem

The thermal control subsystem performed satisfactorily except for the FES feedline A mid 2 heater system 1, which failed off (Flight Problem STS-73-V-04). The loss of this heater did not impact the mission or proper maintenance of FES feedline temperatures.

Aerothermodynamics

The entry performance of aerothermodynamics was satisfactorily; however, the lower midfuselage and lower aft fuselage heating was the highest experienced on any flight in these two areas. All temperatures were within the design capability of the vehicle. Early transition may have occurred as a gap filler was protruding approximately 1.5 inches and was folded over from the high heating. This protrusion may have caused an early transition, but it does not appear to have caused an assymetric transition. Data analysis is continuing.

Thermal Protection Subsystem and Windows

The thermal protection subsystem (TPS) performed satisfactorily in accomplishing the task of protecting the vehicle during all phases of the mission.

At approximately 300:07:18 G.m.t. (06:17:25 MET), the crew reported a small impact crater on window W2. The crew estimated the size of the crater to be approximately 1 mm in diameter. The crater was located near the edge of the window closest the vehicle centerline. Camcorder video and electronic still camera images of the impact site were analyzed, and the assessment of the damage indicated that the impact was not a concern for the mission.

Structural temperature measurements along the aft center-line of the lower fuselage recorded the highest peak and differential temperatures in the Space Shuttle Program, exceeding previous maximums by as much as 19 °F. Some lower surface TPS materials showed signs of excessive heating. In particular, the ET door thermal barriers (TBs), which were on their first flight, were thermally degraded and embrittled. Six of the seven ET TBs on each side will be replaced. A large area of tile damage on the lower surface had glazed substrate material and peeled coating. Slumped tiles were also found on the left-hand wing, the left-hand forward chine area, and aft of the right-hand main landing gear door (MLGD). Also, a higher-than-average number of charred filler bar locations were noted early in the flow. This may be an effect of the vehicle landing weight, which was the highest ever flown (230,200 lb), and the high inclination (39 degrees). However, structural temperature measurements on the forward fuselage and both wings were not exceedingly high, indicating a possible early boundary layer transition event on the lower aft fuselage centerline. This was confirmed by the modular auxiliary data system (MADS) surface thermocouple data, which indicates that transition occurred at 880 seconds on the lower aft centerline of the vehicle. At the forward centerline locations, (available on port side only) transition was recorded at various times between 1240 and 1305 seconds, which is well after the average transition time of 1200 seconds.

The Orbiter TPS sustained a total of 147 hits of which 26 had a major dimension of 1 inch or larger. The following table shows the distribution of hits by areas of the Orbiter. This total does not reflect the numerous hits on the base heat shield that are attributed to the flame arrestment sparkler system. A comparison with 56 previous missions of the same configuration indicates both the total number of hits as well as the number of hits 1 inch or larger were greater than average.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total hits
Lower Surface	17	102
Upper Surface	6	35
Right Side	0	2
Left Side	1	4
Right OMS Pod	1	1
Left OMS Pod	1	3
Total	26	147

The postlanding inspection revealed 102 hits (average is 92) of which 17 were greater than 1 inch (average is 14) on the lower surface. The largest lower surface tile damage site occurred approximately 10 feet forward of the right-hand MLG wheel well and measured 11 inches long by 3.8 inches wide by 0.8 inch deep. The site showed significant signs of entry heating including interior glazing, slumping at the tile edge, and melting of the surface coating material. Another damage site 2.3 inches long by 0.8 inch wide aft of the right-hand MLG wheel well exhibited a cavity angled from the tile surface to a depth of approximately 1.5 inches. This site was located aft of the right-hand MLG door.

Many tile damage sites were located right of the center-line on the lower surface. Hits in this area along a line from nose to tail are generally attributed to ice impacts from the ET liquid oxygen feed-line bellows and support brackets. Two gap fillers inboard of the right-hand MLG wheel well and one gap filler aft of the nose landing gear (NLG) wheel well protruded from lower surface tiles.

Tile damage sites aft of the liquid hydrogen ET/Orbiter umbilicals was typical of that observed on previous flights. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the air stream.

A tile damage site 1.0 inch long by 0.75 inch wide by 0.75 inch deep was located on the left side of the Orbiter nose at the forward RCS pod +X, -Y, -Z corner. The damage site did not exhibit the fore-to-aft impact for any sharp edges typical of contact with adjacent tiles. The possibility of a micrometeorite or on-orbit debris impact while the port side of the vehicle was facing the velocity vector is being investigated.

The ET/Orbiter separation devices functioned normally, although numerous pieces of damaged clips were noted. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly, and virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the liquid hydrogen recirculation line disconnect. Although no debris was found on the runway beneath the umbilical cavities after wheel stop, a 2-inch long by 1/4-inch wide by 1/8-inch thick piece of white RTV had fallen from the liquid hydrogen ET/Orbiter umbilical plate onto one of the left ET door hinges. A scorched piece of vinyl or mylar tape 1-inch square adhered to the umbilical well 16 mm camera window.

All three dome mounted heat shield (DMHS) closeout blankets were in excellent condition with no missing material. The DMHS blankets at the SSME 1 5:00 and 7:00 o'clock positions were torn and frayed. No body flap hinge stub (piano key) tiles were missing or damaged, and the tiles on the vertical stabilizer stinger and around the drag chute door were intact and undamaged. Two tiles on the left side of the rudder/speed brake were missing corner material 1.0-inch by 1.0-inch by 0.5 inch down to the strain isolation pad (SIP). These two damage sites were caused by vibration, not debris impacts.

A white residue was observed around the waste-water dump nozzles. No unusual amounts of tile damage occurred on the leading edges of the OMS pods. However, one small tile damage site was noted on the leading edge of the vertical stabilizer Shuttle Infrared Leeside Temperature Sensing (SILTS) pod, and it measured 0.75-inch long by 0.25-inch wide by 0.5-inch deep.

Orbiter windows 3 and 4 exhibited moderate hazing and streaking. A light haze was present on the other windows. Tile damage on the window perimeter tiles was concentrated around windows 2, 3, and 5. The tile damage sites were caused by impacts from forward RCS paper cover pieces and RTV. Some of the damage sites were previous tile repairs that had vibrated loose. Five damage sites in the tiled area between windows 3 and 4 were also noted.

FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

The crew reported that the Arriflex camera was inoperative after being used for more than a day. The battery pack on the camera was replaced with a second unit which lasted approximately two minutes before the camera again became inoperative (Flight Problem STS-73-F-01). The crew reported that no battery test light (green or red) appeared when the test button was depressed, and that the camera was making an abnormal noise during operation. The batteries were replaced in one of the battery packs, but the problem persisted. During troubleshooting of one of the battery packs, a 3-ampere fuse in the battery pack was found to be open. Flight rules prohibit connecting Orbiter power into a possible short. As a result, the IFM procedure that connects the camera to Orbiter power was not performed. The camera was stowed for the remainder of the mission.

Two unsuccessful attempts at uplinking a thermal impulse printer system (TIPS) message occurred at 295:17:00 G.m.t. (02:03:07 MET) and at 297:21:45 G.m.t. (04:07:52 MET). In each case, a power cycle recovered the TIPS. This problem recurred at 298:23:29 G.m.t. (005:09:36 MET), and the crew was instructed to install the spare TIPS (Flight Problem STS-73-F-02). The spare TIPS operated satisfactorily for the remainder of the mission. The first TIPS unit was tested postflight, and the results were not complete at the time of this writing.

Audio interface unit (AIU) B lost its receive capability on channel 1 (Flight Problem STS-73-F-03). Channel 2 performance was nominal. A failure of the synthesizer in the channel is the most likely cause of the failure. Postflight troubleshooting and repair will be performed.

The electronic still camera experienced low-battery failure. Battery cycling and recharge procedures were performed with no success. Workaround procedures, using Orbiter power or recharging the battery after every five pictures were taken, were used successfully. All required photography was performed, and downlink of the photographs was performed nominally.

CARGO INTEGRATION

Cargo integration hardware performance was satisfactory with no anomalies or problems noted.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

A total of 13 Development Test Objectives (DTOs) and 12 Detailed Supplementary Objectives (DSOs) were assigned to the STS-73 mission. Eleven of the 12 DTOs were performed, and all of the DSOs were performed. Preliminary results are presented, when available, in the following paragraphs.

DEVELOPMENT TEST OBJECTIVES

Three of the 13 DTOs were data-only, and the data were recorded on the modular auxiliary data system (MADS) recorder, which was dumped postflight. The data have been given to the sponsors for evaluation and the results will be presented in separate documentation.

1. DTO 301D - Ascent Structural Capability Evaluation;
2. DTO 307D - Entry Structural Capability Evaluation; and
3. DTO 319D - Shuttle/Payload Low Frequency Environment.

The remaining 10 DTOs are presented in the following subparagraphs.

DTO 312 - ET TPS Performance (Methods 1 and 3) - Umbilical Cameras and Hand-Held Camera) - No +X translation maneuver was performed. A total of 37 photographs were taken of the ET. Analysis of the film showed the ET to be 1.37 kilometers away when the first photograph was taken at 16 minutes after liftoff, and approximately 3.0 kilometers away when the final photograph was taken. The tank separation velocity was 4.42 meters/second. The ET roll rate was calculated to be 0.15 deg/sec, and the tumble rate was 1.91 deg/sec.

Three rolls of umbilical well camera film of the ET were acquired; one 35 mm film from the LO_2 umbilical and the two 16 mm films (5 mm lens and 10 mm lens) from the LH_2 umbilical. Analysis of the films revealed no significant areas of damage or erosion.

DTO 414 - APU Shutdown Test [Sequence B - (APU s 2, 1, 3)] -This DTO was performed; however, the sequence A order of APU shutdown (3, 1, 2) was used because APU 3 was shutdown early as a result of lubrication oil temperatures. Data review has shown that no back-driving of the PDU occurred. Data gathering for DTO 414 has been completed with this flight, and the DTO will not be performed on any future flight of any of the Orbiters.

DTO 623 - Cabin Air Monitoring - Cabin air samples were collected as prescribed. These samples have been given to the sponsor for evaluation, and the results of the evaluation will be reported in separate documentation.

DTO 655 - Foot Restraint (Hardware part of USML-2 Complement) - The foot restraint was evaluated, and the results were given to the sponsor. The results of the evaluation by the sponsor will be published in separate documentation.

DTO 667 - Portable In-Flight Landing Operations Trainer - The Portable In-Flight Landing Operations Trainer (PILOT) was exercised by the crew as planned. This simulation program serves as a valuable aid in maintaining proficiency during a long-duration mission.

DTO 679 - Ku-Band Communications Adapter Demonstration - The objectives of the Ku-band Communications Adapter (KCA) DTO were met. An interactive white-board was established to demonstrate an IFM procedure. Video tape recorder control from the ground was also demonstrated. An extensive number of science files were down-linked during the mission, and these proved to be a valuable asset to the scientific community working the STS-73 mission. The capability to uplink data was also demonstrated.

DTO 682 - Inertial Vibration Isolation System Evaluation - The evaluation of real-time accelerometer data indicated nominal operations of the Inertial Vibration Isolation System (IVIS). The high-gain setting could not be used; however, this condition was not a detriment to science or the exercise. Stow procedures required modification because of the inability to set the gain at high.

DTO 805 - Crosswind Landing Performance - This DTO was not performed as the minimum crosswind speed conditions were not present at the time of landing.

DTO 913 - Microgravity Measuring Device Evaluation - The Microgravity Measuring Device (MMD) provided acceleration data during various periods of the mission. These data were downlinked via the KCA, and the data were very helpful for the science community.

DTO 1121 - Ground-to-Air Television Demonstration - The quality of the Ground-to-Air Television (GATV) Demonstration, both video and audio uplink, was excellent. Excerpts from the fifth game of the Major League World Series were uplinked to the crew. Principal Investigators were able to hold science briefings with the crew. Also, a GATV highlight was performing the first two-way conference in the Shuttle.

DETAILED SUPPLEMENTARY OBJECTIVES

The results of the DSOs require a significant period of time to evaluate and present the results. Data were collected for all 12 DSOs, and these data have been given to the sponsor for evaluation. The release or publication of the results is the responsibility of the sponsor. The DSOs performed on the STS-73 mission were as follows:

1. DSO 487 - Immunological Assessment of Crewmembers (Preflight and Postflight only);
2. DSO 491 - Characterization of Microbial Transfer Among Crewmembers (Preflight and Postflight only);
3. DSO 603C - Orthostatic Function During Entry, Landing, and Egress;
4. DSO 604-OI1 - Visual Vestibular Integration as a Function of Adaptation;
5. DSO 604-OI3 - Visual Vestibular Integration as a Function of Adaptation;
6. DSO 611 - Air Monitoring Instrument Evaluation and Atmosphere Characterization;
7. DSO 621 - In-Flight Use of Florinef to Improve Orthostatic Intolerance Postflight;
8. DSO 802 - Educational Activities;
9. DSO 901 - Documentary Television;
10. DSO 902 - Documentary Motion Picture Photography;
11. DSO 903 - Documentary Still Photography; and
12. DSO 904 - Assessment of Human Factors (Configuration C).

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

A total of 24 videos of the launch were received and reviewed as planned. Also, thirty-three 16 mm films and nineteen 35 mm films were reviewed. No anomalous conditions were noted in the films or videos.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

No on-orbit photography was reviewed except in support of DTO 312, and that review is discussed in a previous section of this report.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

A total of 10 videos of the landing were reviewed, and all activities appeared to be nominal with no anomalies identified.

TABLE I.- STS-73 MISSION EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	293:13:48:11.561 293:13:48:12.598 293:13:48:13.567
SRB HPU Activation[a]	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	293:13:52:32.083 293:13:52:32.243 293:13:52.32.403 293:13:52:32.563
Main Propulsion System Start[a]	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	293:13:52:53.458 293:13:52:53.577 293:13:52:53.690
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	293:13:53:00.013
Throttle up to 104 Percent Thrust[a]	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	293:13:53:03.878 293:13:53:03.878 293:13:53:03.890
Throttle down to 67 Percent Thrust[a]	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	293:13:53:32.198 293:13:53:32.198 293:13:53:32.210
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	293:13:53:50
Throttle up to 104 Percent[a]	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	293:13:54:00:519 293:13:54:00.519 293:13:54:00.531
Both SRM's Chamber Pressure at 50 psi[a]	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	293:13:54:58.213 293:13:54:58.733
End SRM [a] Action[a]	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	293:13:55:00.893 293:13:55:00.943
SRB Physical Separation[a]	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	293:13:55:03.613 293:13:55:03.613
SRB Separation Command	SRB separation command flag	293:13:55:04
Throttle Down for 3g Acceleration[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	293:14:00:30.285 293:14:00:30.288 293:14:00:30.297
3g Acceleration	Total load factor	293:14:00:32.1
Throttle Down to 67 Percent Thrust[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	293:14:01:23.086 293:14:01:23.089 293:14:01:23.098
SSME Shutdown[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	293:14:01:29.366 293:14:01:29.369 293:14:01:29.378
MECO	MECO command flag MECO confirm flag	293:14:01:30 293:14:01:30
ET Separation	ET separation command flag	293:14:01:49

[a]MSFC supplied data

TABLE I.- STS-73 MISSION EVENTS (Continued)

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-3 GG chamber pressure APU 1 GG chamber pressure APU 2 GG chamber pressure	293:14:07:08.688 293:14:10:04.772 293:14:10:21.785
OMS-1 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
OMS-1 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	
OMS-2 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	293:14:34:28.7 293:14:34:28.7
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	293:14:36:27.6 293:14:36:27.6
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	293:15:27:14 293:15:28:36
Flight Control System Checkout APU Start APU Stop	 APU-3 GG chamber pressure APU-3 GG chamber pressure	 308:09:35:29.898 308:09:47.48.270
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	309:08:11:19 309:08:13:59
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	309:10:41:57.690 309:11:00:31.206 309:11:00:33.169
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	309:10:46:40.1 309:10:46:40.1
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	309:10:49:22.5 309:10:49:22:6
Entry Interface (400K feet)	Current orbital altitude above	309:11:13:19
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	309:11:39:09
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	309:11:45:21 309:11:45:22
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels RH main landing gear weight on wheels	309:11:45:22 309:11:45:26
Drag Chute Deployment	Drag chute deploy 1 CP Volts	309:11:45:29.2
Nose Landing Gear Contact	NLG LH tire pressure 1	309:11:45:35
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	309:11:45:36
Drag Chute Jettison	Drag chute jettison 1 CP Volts	309:11:45:58.1
Wheel Stop	Velocity with respect to runway	309:11:46:17
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	309:12:04:05.174 309:12:04:07.017 309:12:04:07.928

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-73-V-01	MEC 1 Preflight BITE Word Indicated Failure	280:13:08 G.m.t. CAR 73RF01 IPR 73V-0236 PR-OEL-2-18-1761	During the launch attempt on October 7, 1995, the master events controller 1 (MEC 1) preflight BITE word 5, bit 9, indicated that the MEC 1 core B critical drivers were not enabled. As a result, the launch was scrubbed. The MEC was replaced and the retest of the replacement MEC was successfully completed. The core B failure on the removed unit was confirmed in testing.
STS-73-V-02	WSB 3 Failed to Cool	293:14:07 G.m.t. 00:00:14 MET CAR 73RF02 IPR 75V-0012	During ascent, water spray boiler (WSB) 3 failed to provide cooling to APU 3 as evidenced by the lubrication oil return temperature increasing above the normal spray temperature of 250 °F. When the temperature reached 290 °F, the crew was requested to switch from controller A to controller B on system 3. After switching controllers, the temperature continued to rise at the same rate. When the temperature reached 326 °F, the crew was directed to shut down APU 3 early. Approximately one minute later, WSB 3 (on controller B) began spraying. The data suggest a spray-bar freeze-up that subsequently thawed. All three WSBs have the heater modification that was implemented to preclude WSB freeze-ups. This heater modification was also flown on STS-69/OV-105 on WSB 3. APU 3 was run during FCS checkout and the WSB 3 controllers A and B were used. Although an under-cooling condition to 273 °F followed by an over-cooling condition to 236 °F was experienced, lubrication oil cooling on the WSB 3 controller A was satisfactory. WSB 3 performance on controller B was nominal during entry. KSC: The heater has been checked out and no anomalies were noted. Controller A was removed and replaced.
STS-73-V-03	Primary Thruster F1F Failed Off	293:16:54 G.m.t. 00:03:01 MET CAR 75RF03 IPR-75V-0006	Primary thruster F1F failed-off when fired during the RCS trim firing at approximately 00:03:01 G.m.t. The thruster chamber pressure reached only 17 psia prior to the thruster being deselected by RM. F1F injector temperature drops indicated that both propellant valves achieved at least pilot valve flow. The chamber pressure subsequently took about 15 minutes to return to zero psia. The fact that the chamber pressure decreased so slowly indicates the fail-off was caused by a blockage of the PC tube orifice, rather than the typical oxidizer valve failure. This chamber pressure tube was flushed during the STS-73 flow. KSC: The chamber pressure tube was inspected for blockage and none was found. The thruster was removed and sent to WSTF for failure analysis.
STS-73-V-04	Failure of FES Feedline A Mid 2 Heater System 1 Level III Closure	294:07:21 G.m.t. 00:17:21 MET CAR 73RF04 IPR 75V-0009	The FES feed-line A mid 2 temperature slowly decreased during the first several days of the mission. When the temperature reached 54.7 °F at approximately 296:17:16 G.m.t. (03:03:23 MET), the FES feed-line A heaters were reconfigured from system 1 to system 2 and heater cycling was observed. From previous flight data, a heater-on cycle would have been expected on system 1 at approximately 70 °F . The system 1 heater was considered failed. All FES feed-line A heaters is considered failed. All FES feed-line A heaters cycled nominally on system 2. KSC: Postflight troubleshooting isolated the problem to a broken wire at a ground lug. The wire was repaired.

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-73-V-05	Transient Thruster Command Path Failure	300:18:04 G.m.t. 07:04:11 MET CAR 73RF05 IPR 75V-0013	Vernier RCS thrusters R5R and R5D failed to fire when commanded at 300:18:04 G.m.t. (07:04:11 MET). Chamber pressure (Pc) remained zero and RM software deselected both thrusters. Data suggested a command path problem. Because no indication of a thruster failure was present, both thrusters were hot-fired and each provided a good one-second pulse. The two vernier thrusters were then reselected for flight use. Note that a similar failure of thruster R5D occurred during the previous flight of this vehicle (STS-65), and troubleshooting failed to indicate a cause. The MDM (S/N 121) and the RJD (S/N 20) in the command path to the R5D and R5R vernier thrusters are the same units flown on STS-65. Several additional fail-offs of vernier thrusters R5D and R5R occurred, as well as a fail-off of primary thrusters L3D and R3D. The commands for the aft manifold 3 thrusters share the same MDM cards and channels as vernier thrusters R5D and R5R. KSC: Postflight troubleshooting was performed and the failure was not reproduced. The removed MDM was tested at the NSLD, and the failure was not repeated nor was any problem found. The RJD was also replaced.
STS-73-V-06	S-band Lower Right Antenna Forward Link Dropouts	295:12:27 G.m.t. 01:22:34 MET IPR 75V-0011	S-band forward link dropouts occurred while operating on the lower right antenna. The dropouts have occurred when operating at the low and high frequencies and on both TDRS satellites. The lower right antenna path is suspect. On orbit troubleshooting was performed and it indicates a problem in the cabling to the lower right antenna. KSC: Postflight troubleshooting intermittently reproduced the problem. The antenna was replaced, but testing indicates dropouts still present.
STS-73-V-07	CRT 2 Fail Level III Closure	308:08:55 G.m.t. 14:19:02 MET CAR 73RF06 IPR 75V-0018	At 308:08:55 G.m.t. (14:19:02 MET), the crew reported that cathode ray tube (CRT) 2 was flashing on and off and that the symbols on the screen were garbled. These symptoms were intermittent, and the data indicated a problem with the CRT. As a result, an IFM procedure to swap CRT 2 and CRT 4 was performed, and the CRT in position 2 performed satisfactorily for the remainder of the mission. The failed CRT was not repowered for the remainder of the mission. KSC: The CRT in position 4 was replaced, and the installation of the CRT in position 2 was verified.
STS-73-V-08	H_2 Manifold 1 Isolation Valve Failed Open.	308:13:42 G.m.t. 14:23:49 MET CAR 73RF07	When the hydrogen and oxygen manifold isolation valves were being cycled for the in-flight checkout, the hydrogen manifold 1 isolation valve , which had been open, failed to close when commanded at 308:13:42 G.m.t. (14:23:49 MET). Four minutes later, the switch was held in the close position for 10 seconds, but the valve position again did not change. Heater cycles confirmed that the valve was still open. This failure did not impact the mission. Postlanding, the valve cycled properly. KSC: Postflight troubleshooting was performed and the valve did operate. The valve panel was replaced.

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-73-V-09	APU 1 Fuel Pump Inlet Pressure Decay	309:12:10 G.m.t. Postlanding	Postlanding, a decay was noted in the APU 1 fuel pump inlet pressure. The pressure dropped from 150 to 35 psia during a 20-minute period. The fuel pump seal cavity drain line pressure rose from 20.5 to 22.0 psia during the same period. Data review revealed that a slower decay was experienced during prelaunch operations, after the hot-fire of the APU, and following the on-orbit APU shut down. The signature may indicate leakage past the fuel pump seal in the seal cavity. KSC: A total of 108cc of liquid was present in the catch bottle. The APU was removed and replaced.

DOCUMENT SOURCES

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

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

ACRONYMS AND ABBREVIATIONS

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

ABS	ammonia boiler system
AC/ac	alternating current
AIU	audio interface unit
AMCA	aft motor control assembly
APCF	Advance Protein Crystallization Facility
APU	auxiliary power unit
ARS	atmospheric revitalization system
ASC	Astroculture
ATCS	active thermal control system
BITE	built-in test equipment
Btu	British thermal unit
CB	circuit breaker
CEI	contract end item
CGBA	Commercial Generic Bioprocessing Apparatus
CGF	Crystal Growth Furnace
CO_2	carbon dioxide
CPCG	Commercial Protein Crystal Growth
CPM	cell performance monitor
CRIM	commercial refrigeration/incubation module
CRT	cathode ray tube
DDE	Drop Dynamics Experiment
DMHS	dome-mounted heat shield
DPM	Drop Physics Module
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔV	differential velocity
EPDC	electrical power distribution and control subsystem
ET	External Tank
FA	flight aft
FCE	flight crew equipment
FCL	Freon coolant loop
FCP	fuel cell powerplant
FCS	flight control system
FCV	flow control valve
FES	flash evaporator system
FPA	fluid processing apparatus
FSDC	fiber supported droplet combustion
ft/sec	feet per second
GATV	Ground-to-Air Television
GBX	Glovebox
GFE	Government furnished equipment
GFFC	Geophysical Fluid Flow Cell
GH_2	gaseous hydrogen

G.m.t.	Greenwich mean time
GPC	general purpose computer
GSE	ground support equipment
HI-PAC	High-Packed Digital Television
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
ICD	Interface Control Document
IFM	in-flight maintenance (procedure)
IR	integrated receiver
Isp	specific impulse
IVIS	Inertial Vibration Isolation System
JSC	Johnson Space Center
KCA	Ku-band communications adapter
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm	pound mass
LCC	Launch Commit Criteria
LH_2	liquid hydrogen
LMES	Lockheed Martin Engineering and Science
LO_2	liquid oxygen
MADS	modular auxiliary data system
Mbps	Megabits per second
MDM	multiplexer/demultiplexer
MEC	master events controller
MECO	main engine cutoff
MET	mission elapsed time
MLG	main landing gear
MLGD	main landing gear door
MMCA	midbody motor controller assembly
MMD	Microgravity Measuring Device
mmHg	millimeters of Mercury
M/OD	micrometeorite/orbital debris
MPCA	midpower controller assembly
MPS	main propulsion system
MSFC	Marshall Space Flight Center
mVdc	millivolts direct current
NLG	nose landing gear
NASA	National Aeronautics and Space Administration
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OARE	Orbital Acceleration Research Experiment
OMDP	Orbiter maintenance down period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OP STAT	operational status
PAL	protuberance air load
Pc	chamber pressure

PCAM	Protein Crystallization Apparatus for Microgravity
PDU	power drive unit
PH-1	Phase 1
PILOT	Portable In-flight Landing Operations Trainer
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution
psi	pound per square inch
psia	pound per square inch absolute
psig	pound per square inch gravity
RCRS	Regenerative Carbon Dioxide Removal System
RCS	reaction control subsystem
RJD	reaction jet driver
RM	Redundancy Management
RSD	Range Safety distributor
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAMS	Space Acceleration Measurement System
SILTS	Shuttle Infrared Leeside Temperature Sensing
SIP	strain isolation pad
SLF	Shuttle Landing Facility
S/N	serial number
SPCG	Single-Locker Protein Crystal Growth
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
STABLE	Suppression of Transient Accelerations by Levitation Evaluation
STDCE	Surface Tension Driven Convection Experiment
STGT	Second TDRS Ground Terminal
TB	thermal barrier
TDRS	Tracking and Data Relay Satellite
TIPS	Thermal Impulse Printer System
TPS	thermal protection subsystem
TV	television
TVC	television camera (color)
USML-1	United States Microgravity Laboratory-1
USML-2	United States Microgravity Laboratory-2
Vdc	Volts direct current
WSB	water spray boiler
ZCG	Zeolite Crystal Growth
3-DMA	Three Dimensional Microgravity Accelerometer

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