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STS-72
SPACE SHUTTLE
MISSION REPORT

April 1996

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

NOTE

The STS-72 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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MISSION REPORT

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INTRODUCTION

The STS-72 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-fourth flight of the Space Shuttle Program, the forty-ninth flight since the return-to-flight, and the tenth flight of the Orbiter Endeavour (OV-105). In addition to the Orbiter, the flight vehicle consisted of an ET that was designated ET-75; three Block I SSMEs that were designated as serial numbers 2028, 2039, and 2036 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-077. The RSRMs, designated RSRM-52, were installed in each SRB and the individual RSRMs were designated as 360W052A for the left SRB, and 360W052B for the right SRB.

The STS-72 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 objectives of this flight were to retrieve the Japanese Space Flyer Unit (SFU) and deploy and retrieve the Office of Aeronautics and Space Technology-Flyer (OAST-Flyer). Secondary objectives of this flight were to perform the operations of the Shuttle Solar Backscatter Ultraviolet/A (SSBUV/A) experiment, Shuttle Laser Altimeter (SLA)/Get-Away Special (GAS) payload, Physiological and Anatomical Rodent Experiment/National Institutes of Health-Rodents (PARE/NIH-R-03) experiment, Space Tissue Loss/National Institutes of Health-Cells (STL/NIH-C) experiment, Protein Crystal Growth-Single Locker Thermal Enclosure System (PCG-STES) experiment, Commercial Protein Crystal Growth (CPCG) payload and perform two extravehicular activities (EVAs) to demonstrate International Space Station Alpha (ISSA) assembly techniques.

The STS-72 mission was planned as an 8-day flight plus 2 contingency days, which were available for weather avoidance or Orbiter contingency operations. The sequence of events for the STS-72 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 five-person crew for STS-72 consisted of Brian Duffy, Col., U. S. Air Force, Commander; Brent W. Jett, Jr., Lt. Cdr., U. S. Navy, Pilot; Leroy Chiao, Civilian Ph.D., Mission Specialist 1; Winston E. Scott, Capt., U. S. Navy, Mission Specialist 2; Koichi Wakata, Civilian, National Space Development Agency of Japan, Mission Specialist 3; and Daniel T. Barry, Civilian, M. D., and Ph.D., Mission Specialist 4. STS-72 was the third space flight for the Commander, the second space flight for the Mission Specialist 1, and the first space flight for Pilot, Mission Specialist 2, Mission Specialist 3, and Mission Specialist 4.

MISSION SUMMARY

The STS-72 mission was completed with satisfactory results in all areas. The Japanese spacecraft, (Space Flyer Unit) was retrieved, the OAST-Flyer was deployed and retrieved, and two EVAs were completed.

The launch of the STS-72 mission occurred at 011:09:41:00.015 G.m.t., (January 11, 1996) from launch complex 39B on a launch azimuth of 28.45 degrees, and the ascent phase was satisfactory in all respects. The launch countdown was held at T-9 minutes for a problem with the front end processor at the Mission Control Center-Houston (MCC-H). The countdown was subsequently held at T-5 minutes due to a ground configuration problem between the MCC-H and the White Sands Complex on the S-band forward link. After this problem was corrected, the hold was extended to avoid a possible collision with space debris. The total launch delay was 23 minutes.

All SSME and RSRM start sequences occurred as expected, and the launch phase performance was satisfactory in all respects. First stage ascent performance was nominal. SRB separation, entry, deceleration and water impact were as expected, and both SRBs were recovered and returned to Kennedy Space Center (KSC) for disassembly and refurbishment. Performance of the SSMEs, ET, and the main propulsion system (MPS) was also nominal. Analysis of the propulsive vehicle performance during ascent was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine specific impulse (Isp) determined for the time period between SRB separation and start of 3-g throttling was 453.14 seconds as compared to the MPS tag value of 452.87 seconds.

At 011:10:24:30 G.m.t. (00:00:43:30 MET), a dual-engine, straight-feed orbital maneuvering subsystem (OMS) 2 orbit-circularization maneuver was initiated. The maneuver lasted approximately 71 seconds, and imparted a differential velocity (ΔV) of 116 ft/sec.

At 011:11:07 G.m.t. (00:01:26 MET), while on the primary A controller, the flash evaporator system (FES) shut down as the high-load evaporator transitioned to standby. The high-load transition to standby occurred as the heat load to the FES decreased because of radiator flow initiation just prior to payload bay door opening.

The FES subsequently failed to come out of standby twice during the first day of flight. The FES was successfully restarted on the primary A controller in both cases. On flight day 4, the FES experienced four shutdowns. At approximately 015:03:03 G.m.t. (03:17:22 MET), while still operating on the primary A controller, the FES shut down (Flight Problem STS-72-V-01). At the time of the shutdown, the cabin pressure was at 10.2 psia in preparation for EVA 1 and a FES water dump was being performed. The FES was successfully restarted on the A controller about 10 minutes after the shutdown. Twenty minutes later, the FES shut down again. Twenty-four minutes later, the FES was started on the primary B controller. Prior to the FES outlet temperature reaching the control temperature, the FES once again shut down. FES operation on the primary B controller was attempted again approximately 4 hours later. The FES outlet temperature came into range, but the FES shut down again after approximately 11 minutes. It was suspected that ice had formed in the FES topper core, and the FES core-flush procedure was performed; however, the FES core-flush was terminated prematurely because of low duct temperatures (0 °F). A second FES core-flush procedure was initiated at 017:13:07 G.m.t. (06:03:26 MET), and no evidence of ice was noted during this procedure. Nominal FES operation with radiators at the high set point was demonstrated using the primary B controller for 20 minutes following the flush procedure. The FES primary B controller was deactivated at 017:13:52 G.m.t. (06:04:11 MET) and remained off with the radiators configured to the normal set point throughout the subsequent crew sleep period. After crew awakening, the FES was enabled on the primary B controller and it performed nominally in both the topping and water-dump modes for the remainder of the mission.

Review of the data from the remote manipulator system (RMS) checkout identified a lower-than-expected drive rate for the wrist-roll joint in the direct-drive mode (Flight Problem STS-72-F-04). The typical joint-motor drive rate for this RMS (S/N 303) is 24 rad/second; the actual rate obtained was 20 radians/second. A repeat of the direct-drive test showed normal wrist-roll rates of 24 rad/second on flight days 2 through 5. On flight day 6, the result of the joint drive test was approximately +21.5 radians/second and -22.5 rad/second, and similar results were obtained on flight day 7. Also, a slight degradation of the shoulder joint pitch rate was noted. The RMS was removed and replaced during the postflight turnaround activities.

A series of precise reaction control subsystem (RCS) and OMS maneuvers culminated in a successful rendezvous with the Space Flyer Unit (SFU). During preparations for retrieval, several attempts were made to obtain the ready-to-latch indication from the retracted solar arrays on the SFU. All attempts failed and the panels were jettisoned one at a time in a retrograde direction. The SFU was then grappled and moved to the payload bay for berthing and latching into the payload bay. Berthing and latching of the SFU was successfully completed at approximately 013:11:39 G.m.t. (02:01:58 MET). Activation of the SFU heaters was completed during a loss of signal (LOS) period, indicating successful mating of the remotely operated electrical umbilical (ROEU).

Extravehicular mobility unit (EMU) checkout for the three EMUs began at approximately 012:09:53 G.m.t. (01:00:12 MET). All three EMUs were verified to be ready for use for the planned STS-72 EVAs.

A cabin depressurization to 10.2 psia in preparation for the EVA on flight day 5 was initiated at 013:13:03 G.m.t. (02:03:22 MET) and completed at 013:13:29 G.m.t. (02:03:48 MET).

Two OMS maneuvers were performed to lower the orbit in preparation for the OAST-Flyer deployment. Both maneuvers were dual engine and straight feed. The first maneuver (OMS-5) occurred at 013:14:37:13 G.m.t. (02:04:56:13 MET) and the second (OMS-6) maneuver occurred at 013:15:24:29 G.m.t. (02:05:43:29 MET). Each maneuver lasted 93 seconds and imparted a ΔV of 155 ft/sec to the vehicle.

The OAST-Flyer was satisfactorily deployed at approximately 014:10:32 G.m.t. (03:01:51 MET). The first OAST-Flyer separation maneuver was performed at 014:11:38 G.m.t. (03:01:57 MET) using RCS thrusters R1U, L1U, and F3U. Each thruster fired 10 times, and the total ΔV imparted to the vehicle was 0.7 ft/sec. The second OAST-Flyer separation maneuver occurred at 014:12:08 G.m.t. (03:02:27 MET). This maneuver involved firing RCS thrusters L3A and R3A 10 times each and imparted a ΔV of 1.2 ft/sec to the vehicle.

EVA 1 preparations, including Orbiter configuration and suit donning, began at 015:02:44 G.m.t. (03:17:03 MET). The EVA began with EMU battery power on at 015:05:34 G.m.t. (03:19:53 MET). EVA activities included a demonstration of a rigid umbilical tray deployment and stowage. The crewmembers were favorably impressed with the new EMU lights and the body restraint tether. Other tasks included evaluating the portable workstation platform, the articulating portable foot restraint, a utility box, and a label. The only problem noted was that the EV2 crewmember had some difficulty ingressing the articulating portable foot restraint (APFR).

The EMUs performed flawlessly. The crewmembers reported that the active heated gloves were not used. One crewmember reported slightly cold feet, but engagement of the cooling water bypass rectified the situation and restored thermal comfort. The EVA ended at the start of airlock repressurization at 015:11:43 G.m.t. (04:02:02 MET).

The completion of a series of RCS maneuvers resulted in a successful rendezvous with the OAST-Flyer. All Orbiter systems performed nominally in support of the OAST-Flyer rendezvous. The OAST-Flyer was grappled at 016:09:47 G.m.t. (05:00:06 MET) and berthed and latched at 016:10:15 G.m.t. (05:00:34 MET).

The second EVA began at 017:05:40 G.m.t. (05:19:59 MET) and proceeded nominally. The two crewmembers ingressed the airlock at 017:12:25 G.m.t. (06:02:44 MET). The EVA was 6 hours 53 minutes in duration. During EVA 2, the EV 1 crewmember reported that communications were not being received through the left portion of the communication cap (Flight Problem STS-72-F-03). This condition persisted for approximately 30 minutes, then recovered. The problem recurred during airlock ingress. The hardware was not used for the remainder of the mission.

The flight control system (FCS) checkout was performed with nominal results. In support of the FCS checkout, auxiliary power unit (APU) 3 was started at 19:02:47:46 G.m.t. (07:17:06:46 MET), and the APU ran for 4 minutes and 2 seconds, during which time 9 lb of fuel were used. Its performance was nominal. Hydraulic cooling was not required because of the short run time of the APU.

The RCS hot-fire was begun at 19:03:33 G.m.t. (07:17:52 MET). Primary thruster L1A failed off because of low chamber pressure (Pc) on its first pulse (also its first pulse of this mission). The thruster reached a maximum Pc of approximately 16 psia with both injector temperatures dropping, indicating at least partial flow through both valves. Additionally, primary thruster R2U began leaking oxidizer following its first pulse (also its first pulse of this mission) as indicated by the injector temperatures. The redundancy management (RM) software deselected the thruster after the second pulse. Both pulses indicated nominal Pc. All other thrusters fired nominally.

All entry stowage and deorbit preparations were completed in preparation for entry on the nominal end-of-mission landing day. The payload bay doors were successfully closed and latched at 020:04:03 G.m.t. (08:18:22 MET). RCS thruster R2U stopped leaking, and no action had been taken to stop the leak. The thruster was reselected at 020:04:37 G.m.t. (08:18:56 MET) and left in last priority for entry. The deorbit maneuver for the first landing opportunity at the SLF was performed on orbit 141 at 020:06:41:22.98 G.m.t. (08:21:00:22.98 MET), and the maneuver was 156 seconds in duration with a ΔV of 272 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on Shuttle Landing Facility (SLF) concrete runway 15 at 020:07:41:45 G.m.t. (08:22:00:45 MET) on January 20, 1996. The Orbiter drag chute was deployed at 020:07:41:43 G.m.t. and the nose gear touchdown occurred 8 seconds later. The drag chute was jettisoned at 020:07:42:17 G.m.t. with wheels stop occurring at 020:07:42:46 G.m.t. The rollout was normal in all respects. The flight duration was 8 days 22 hours 0 minutes and 45 seconds. The APUs were shut down 14 minutes 4 seconds after landing.

EXTRAVEHICULAR ACTIVITY

The EVA Development Flight Test-03 (EDFT-03) experiment was the third in a series of EVA flight tests of Space Station EVA tasks. This was defined as Development Test Objective (DTO) 671, and its objective was to complete the procedures documented in the EVA Checklist (JSC-48024-72, dated December 15, 1995) through performance of the two scheduled EVAs. Crewmembers Leroy Chiao (EV1) and Dan Barry (EV2) completed EVA 1, and crewmembers Leroy Chiao (EV1) and Winston Scott (EV3) completed EVA 2.

DTO 672 was also completed with the evaluation of the Electronic Cuff Checklist. In addition, DTO 833 was completed with a subjective evaluation of thermal effects of various suit and EMU enhancements.

EVA 1 preparations, including Orbiter configuration and suit donning, began at 015:02:44 G.m.t. (03:17:03 MET). The EVA began with EMU battery power on at 015:05:34 G.m.t. (03:19:53 MET). EVA activities included a demonstration of a rigid umbilical tray deployment and stowage. The crewmembers were favorably impressed with the new EMU lights and the body restraint tether. Other tasks included evaluating the portable workstation platform, the articulating portable foot restraint, a utility box, and a label.

The EMUs performed flawlessly with no EMU anomalies recorded. The crewmembers reported that the active heated gloves were not used. One crewmember reported slightly cold feet and engaged the cooling water bypass for approximately 2 hours. Engagement of the bypass rectified the situation and restored thermal comfort. All planned activities were completed and the EVA ended at the start of airlock repressurization at 015:11:43 G.m.t. (04:02:02 MET). The first extravehicular activity had an official duration of 6 hours and 9 minutes.

During EVA 1, all planned tasks were completed plus some additional tasks classified as EZ on the checklist. Tasks completed during the EVA included portable work platform (PWP) assembly, rigid umbilical deployment and connector installation, free umbilical installation, and rigid umbilical restowage. The crew gave the PWP an "A" rating with recommendations for minor adjustments to the actuator height on the portable foot restraint work station stanchion (PFRWS).

The truss-to-truss utility box avionics line tasks were performed, and it was noted that the TEFZEL cable was considerably stiffer than the Superflex cables. Stiffness was also noted in the cable tray slider mechanism. Cargo bay temperature sensors read from -17 to -9 °F during EVA 1. Both crewmembers used the body restraint tether (BRT) in numerous locations with good results. The crew ingressed the airlock approximately 15 minutes ahead of schedule.

The second EVA began at 017:05:40 G.m.t. (05:19:59 MET) and ended with airlock repressurization at 017:12:33 G.m.t. (06:02:52 MET) for an official duration of 6 hours 53 minutes. The EVA was satisfactory, and the crew completed 94 percent of the planned tasks with the PWP mass handling task the only item not completed. The portable data acquisition package (PDAP) was installed, and a nominal crew loads evaluation was completed. Video of the EVA showed visible movement of the APFR load limiter as planned preflight. Both crewmembers completed the pre-integrated truss (PIT) box evaluation, which was rated as a "B" (can accomplish task with some compensation) and again showed that the TEFZEL cable was stiffer than similar diameter Superflex cable. The crew also had difficulty installing the large fluid line. Both crewmembers also completed installation and removal of the EVA-installed slide-wire with little difficulty.

The Electronic Cuff Checklist (ECC) was evaluated by both crewmembers and some difficulty was noted in reading the smaller fonts in the sunlight. Also, large fonts were recommended for the malfunction procedures, and the crew noted that the ECC interfered with reaching the EMU purge valve.

Six in-flight anomalies were noted during the EVAs, and these are discussed in the following paragraphs.

During EVA 2, the EV 1 crewmember reported that communications were not being received through the left portion of the communication cap (Flight Problem STS-72-F-03). This condition persisted for approximately 30 minutes, then recovered. The problem recurred during airlock ingress. The hardware was not used for the remainder of the mission.

As a result of a late engineering change, the temporary equipment restraint aid (TERA) grapple fixture was rotated 60 degrees from the orientation in which the crew trained in the Weightless Environment Test Facility (WET-F) (Flight Problem STS-72-F-05).

The PWP work-site interface fixture (WIF) on the APFR was installed 180 degrees from the correct orientation and that caused the alignment marks to read improperly (Flight Problem STS-72-F-06).

The flight support equipment (FSE) latch for the APFR plate was very difficult to operate (Flight Problem STS-72-F-07). During removal of the APFR from the latch, the APFR was stuck in the latch. The crew was required to exert a large force to remove the APFR from the latch. During stowage of the APFR, the crew noted a small cloud of black dust released from the plate latch when the latch bolt was driven closed by the power tool. The cloud substance may have been dry-film lubricant from the FSE latch.

The EDFT-03 utility box evaluation resulted in a Velcro patch on the connector cover becoming loose (Flight Problem STS-72-F-08). The Velcro patch was brought into the cabin at the end of the EVA.

After the second EVA as the crew was midway through the file transfer procedure (step 11), the "can't find file" message appeared, and the display of ECC 1 was permanently disrupted despite cycling the power (Flight Problem STS-72-F-09). After renaming the input file, the ECC update procedure was re-attempted using ECC 2 with the same result. Later, the crew reported that ECC 2 still operated normally despite the failed attempt, but the ECC 1 display remained disrupted.

During the postflight inspection of the EVA equipment, cuts were found on each of the glove thermal micrometeorite garments (TMG) of all three extravehicular (EV) crewmembers. Most of the cuts were in the room temperature vulcanizing (RTV) coating on the palm side of the fingers and the finger caps. An investigation board was established, and this board identified several sharp edges on the EDFT-05 hardware. The board concluded that the most likely cause of the damage was the sharp edges on the connector/receptacles in the utility box, the back-side of rivets in the utility box, the exposed screw threads, and the lock-wire.

SPACE STATION IMPLICATIONS, LESSONS LEARNED AND RECOMMENDATIONS RESULTING FROM EXTRAVEHICULAR ACTIVITY

The results of the EVA provided valuable data that are applicable to the International Space Station Alpha (ISSA) program. The following paragraphs delineate recommendations applicable to the ISSA program.

The BRT should be baselined as an ISSA tool. The BRT was extremely useful as a stabilization aid and showed promise as an ORU translation aid. However, handrail placement for the BRT interface is critical and should be verified through WETF evaluations prior to flight use.

Evaluations should be conducted into reducing the height of the temporary equipment restraint aid (TERA) on the portable work platform (PWP) as well as raising the portable foot restraint work station stanchion (PFRWS). In addition, use of the EDFT-03 PWP flight support equipment (FSE) should be considered for the ISSA launch, and all training hardware should be modified to match the flight configuration.

Superflex cables should be substituted for all TEFZEL cables that require crew manipulation and have a diameter in excess of 0.75 inch. In addition, the minimum avionics-connector spacing of 1.6 inches should be maintained. Furthermore, the crew favorably commented on all three types of cable clamps flown. Finally, installation of the large fluid line may be beyond the nominal crew installation capability.

Use of the self-aligning two-step installation process for the umbilical trays (probe into cone at one end, rotate down for final latch) is recommended for use in the ISSA program. Additionally, the ISSA Program should evaluate the rigid umbilical (RU) FSE design for potential use.

The two EVAs demonstrated the capability of an Orbiter-based EVA to support ISSA assembly tasks. Although the SFU thermal constraints led to a real-time rearrangement of EVA 2 tasks, the crew completed 94 percent of the stated objectives. Further data analysis of recorded crew comments is required before conclusive results will be available on crew loads.

As a result of the cuts found in each EV crewmembers' gloves, a formal review of the Space Station sharp-edge criteria was held, and the design of the zero-g connectors as well as any effects after repeated use of the connectors were evaluated.

PAYLOADS

Nine payloads were manifested on the STS-72 mission. Five of the payloads were located in the payload bay and four were located in the cabin.

PAYLOAD BAY PAYLOADS

Space Flyer Unit

The major objective of the STS-72 mission was to retrieve the Japanese-launched and owned Space Flyer Unit (SFU) satellite, which had been in orbit for 47 weeks. This objective was completed on flight day 3 following a flawless rendezvous. During the retrieval operations, several attempts were made to obtain the ready-to-latch indication from the retracted solar array panels. When all attempts had failed, the solar array panels were jettisoned one at a time, retrograde, in accordance with the flight rules and after concurrence from the Japanese and the local SFU management. The satellite was successfully grappled, berthed and latched as planned using the RMS. The problem with the solar array panels delayed the berthing of the SFU for 93 minutes. Following the berthing, one of the six temperature monitors apparently failed and the remaining one heater string proved to be insufficient to maintain thermal stability of the SFU. Real-time SFU heater management was employed for the remainder of the mission, and the SFU temperatures were maintained using various techniques of heater, radiator flow and thermal-attitude management.

Office of Aeronautics and Space Technology-Flyer

The Office of Aeronautics and Space Technology (OAST)-Flyer, a Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN) -carrier spacecraft, was the seventh SPARTAN to fly during the Space Shuttle Program.

Four experiments were mounted on the SPARTAN and these were:

1. Return Flux Experiment - The Return Flux (REFLEX) experiment was to provide data for the determination of the accuracy of computer-generated models on contamination of equipment while on-orbit. The main objective of REFLEX was to investigate molecular backscattering (return flux) on orbiting spacecraft lenses, sensors, and instruments. The return flux phenomenon occurs when spacecraft give off the tiny particles of dirt, which then collide with other particles and bounce back to the spacecraft.

2. Global Positioning System Attitude Determination and Control Experiment - The primary objective of the Global Positioning System (GPS) Attitude Determination and Control Experiment (GADACS) was to demonstrate the use of the GPS technology in space. The GADACS experiment will use GPS

to determine the attitude of the SPARTAN, the location and velocity of the spacecraft, and provide accurate timing for one portion of the SPARTAN mission. GADACS will also use the GPS data to calculate the SPARTAN orientation and fire thrusters to point the spacecraft in different directions. This experiment will provide the first on-orbit GPS experience of controlling a spacecraft.

3. Solar Exposure to Laser Ordnance Device - The Solar Exposure to Laser Ordnance Device (SELODE) was developed to test the safety and reliability of a family of five different types of laser-triggered pyrotechnic devices. The primary investigation centered on the effects of direct and concentrated sunlight in the space environment on different explosives and design methods. Flight testing will evaluate accidental firing levels, and postflight testing will examine the effects of exposure on the chemical stability of the explosives.

4. Spartan Packet Radio Experiment - The Spartan Packet Radio Experiment (SPRE) is an amateur radio (HAM radio) communications experiment. The primary objective of this experiment was to test satellite tracking using amateur packet radio and a GPS. The primary mission of SPRE was to relay ground station positions and transmit telemetry containing the GPS location of the spacecraft plus housekeeping data.

The OAST-Flyer was deployed and successfully retrieved after 46 hours of free-flight time. This was the first flight where experiment status data were available from the SPARTAN carrier in real-time, and the evaluation of that data showed nominal SPARTAN-carrier mission performance. However, data from the onboard recorder will provide the final verification of SPARTAN performance.

During the retrieval of the OAST-Flyer, the spacecraft's retrieval position was noted to be 54.5 nmi. from the predicted position. The preliminary evaluation showed that the translation may have been caused by the REFLEX gas release impinging on the spacecraft. This impingement resulted in the OAST-Flyer attitude control system (ACS) firing excessively to maintain attitude.

About 17 hours after SPARTAN release, the SPRE could no longer be contacted by the ground team. This condition may have been caused by a failure of the SPRE onboard equipment or by the OAST-Flyer shutting off the experiment. A complete assessment of these two in-flight anomalies will be made using the recorded data that were retrieved postflight.

Shuttle Solar Backscatter Ultraviolet Experiment

After an accumulation of approximately 1600 hours of Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment on-orbit operating time during eight previous flights, STS-72 was the last flight of this payload. The SSBUV instrument, which was rigorously calibrated, measured ozone concentrations by comparing solar ultraviolet radiation with radiation scattered back from the Earth's atmosphere. Data from the SSBUV are compared with observations from several ozone-measuring instruments that have flown since 1989.

During STS-72, 65 orbits of Earth-view data, 4 orbits of solar-view data, and two orbits of lunar-view data were collected. STS-72 was the first flight where observations of Moon views and Earth lightning strikes were also performed and collected. The payload's major objective of providing highly accurate Ozone measurements to verify the accuracy of satellite data was accomplished

Shuttle Laser Altimeter Payload

STS-72 was the first of four planned Shuttle Laser Altimeter-01 (SLA-01) remote-sensing flights to precisely measure the distance between the Earth's surface and the Space Shuttle. Ten laser pulses were transmitted each second toward the Earth, and the subsequent reception of weak echoes from the Earth's surface were used to accurately measure the orbital altitude. The primary objectives were to acquire samples of land topography and vegetation data, and provide an in-space engineering test-bed for future space-flight laser sensors.

STS-72 was a very successful flight for the SLA-01 payload with full system performance noted. Approximately 83 hours of Earth observations were made, and approximately three million laser pulses were fired. The signals returned to the SLA-01 were two to five times better than expected, and a part of this can be attributed to less atmospheric attenuation and less misalignment than expected. Postflight processing of the topology height measurement is expected to exceed the 1-meter precision and will include measurements over the Dead Sea. Fifty percent of the readings were made over clouds and many cloud heights were measured. During the operational period, the Hitchhiker carrier experienced one problem with the loss of the payload data interleaver (PDI) link for the laser housekeeping and the safety inhibit data. Flexibility in the flight rules allowed for safety-critical monitoring via science data and allowed science data collection on an alternate Ku-band channel.

Thermal Energy Storage-2 Experiment

The Thermal Energy Storage -2 (TES-2) experiment was mounted on the Getaway Special (GAS) Bridge. The TES-2 provided data for understanding the long-duration behavior of thermal energy storage fluoride salts, which underwent repeated melting and freezing in microgravity. These salts are used in advanced solar dynamic power systems that use heat to produce electricity.

Get Away Specials

a. G-342 - Flexible Beam Experiment 2 - The Flexible Beam Experiment 2 (FLEXBEAM 2) (G-342) GAS experiment measured the duration of vibrations. These data will be used to analyze and predict other vibration responses. The results of this experiment may be obtained from the U. S. Air Force Academy, Colorado Springs, CO, or the Technical Manager for this payload at Goddard Space Flight Center, MD.

b. G-459 - Protein Crystal Growth - The Protein Crystal Growth (PCG) GAS payload will provide data from 16 independent crystallization units on crystal formation. These data will be used in the re-examination of the effects of the microgravity environment on protein-crystal nucleation. Crystal form and size were recorded on photographic film for postflight examination and evaluation.

IN-CABIN PAYLOADS

Physiological and Anatomical Rodent Experiment/National Institutes of Health-Rodents Experiment

The Physiological and Anatomical Rodent Experiment/National Institutes of Health-Rodents (PARE/NIH-R-03) experiment was nominally completed and its primary objective was met. A postflight assessment was conducted to more clearly observe and understand the results of the experiment. This twenty-sixth flight of the animal enclosure module (AEM) was also the third flight of a collaborative project by the National Aeronautics and Space Administration (NASA) and the National Institutes of Health (NIH). The goal of this experiment was to study the neurological and physiological effects of microgravity on different age groups of rodents.

The experiment is a research tool which will provide data on the early development of neonate rats with adult female rats. The first three weeks of life are a period of very rapid development for newborn rats. The animals are transformed from small newborns focused on obtaining nourishment from their mother into young independent rats. The nervous system undergoes dramatic development during this period. The rats were housed in an AEM that was modified to be a nursing facility. The facility contained six adult rats and approximately 60 neonate rats, and the facility was stowed in a middeck locker.

Results of this experiment may be obtained from the National Institutes of Health-Rodents, as no results will be available for publication in this document.

Space Tissue Loss/National Institutes of Health-Cells Experiment

The Space Tissue Loss/National Institutes of Health-Cells (STL/NIH-C) experiment was also a collaboration between NASA and the NIH. The scientific objectives of this collaboration of two biomedical studies were to investigate fundamental biological processes governing cell action, independent of the effects of gravity, and to study the effects of microgravity on the cellular functions of both muscle and bone cells.

The two biomedical studies will use muscle and bone cells from chicken embryos, which will be mounted in a STL Culture Module that was developed by the Walter Reed Army Institute of Research, Washington, D.C.

The experiment did not function during the mission.

Protein Crystal Growth-Single Locker Thermal Enclosure System

The STS-72 mission introduced the enhanced version of the Protein Crystal Growth Vapor Diffusion Apparatus. The original apparatus had been used for 23 Shuttle experiments and produced highly ordered crystals of selected proteins for analysis on Earth. Four apparatus trays were housed in a single middeck locker, and each tray had 20 experiment chambers. All planned temperature checks were performed, and no anomalies were reported.

Crystals produced in the gravity environment of Earth are often too small and may have internal defects that make crystallographic analysis difficult or impossible. As has been demonstrated on Space Shuttle missions since 1985, some protein crystals grown in space are not only larger, but also have fewer defects than the Earth-grown counterparts. This experiment will continue to provide data to promote a better understanding of the fundamentals of crystal-growth phenomena.

Results of this experiment may be obtained from the Principal Investigator at the University of Alabama at Birmingham, as the results were not available for publication in this document.

Commercial Protein Crystal Growth-8 Experiment

The Commercial Protein Crystal Growth-8 (CPCG-8) experiment used the batch temperature-induction crystallization methodology to produce crystals of a new form of recombinant human insulin whose parent molecule, insulin, is used for treatment of type I diabetes (juvenile-onset). This twenty-sixth flight of this experiment was performed nominally and no anomalies were reported.

One objective of this flight was to use protein sample containers of different volumes and geometry's to investigate the effect of various temperature gradients on protein crystal growth in microgravity. These smaller volumes, less than 50 milliliters, allowed a greater number of samples than the four sample containers previously flown in a middeck locker. Also, the new containers provided greater flexibility in temperature gradients and sample sizes.

Results of this experiment are not available for publication in this report.

VEHICLE PERFORMANCE

The overall performance of all vehicle elements was very satisfactory with no anomalies defined from the Marshall Space Flight Center (MSFC) elements and only four anomalies defined from the Orbiter subsystem data. The following subsections discuss each element's performance with particular emphasis on the Orbiter.

SOLID ROCKET BOOSTERS

All Solid Rocket Booster (SRB) systems performed as expected with no in-flight anomalies defined. The SRB prelaunch countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operational Maintenance Requirements and Specification Document (OMRSD) violations were noted.

Analysis of the flight data and assessment of the postflight condition of the recovered hardware indicates nominal performance of the SRB subsystems with a new experience base established.

The right-hand tilt hydraulic system pressure moved outside the experience base on the lower side for approximately 0.85 second during the prelaunch timeframe with a system pressure of 497 psia. This occurred just before system pressurization when no systems pressure requirements exist; consequently, no minimum standards were exceeded. However, the right-hand tilt hydraulic system did exhibit a lower pressure than the other three systems throughout ascent, but the pressure always remained within specification. The cause of this condition was a higher level of internal leakage, but within specification, of the right-hand tilt position hydraulic pump.

Both SRBs were successfully separated from the External Tank (ET) at T +124.36 seconds, and radar data plus visual reports from the landing area indicate that all SRB deceleration subsystems performed as designed. Both SRBs were observed during descent, and were retrieved by the deployed retrieval ships. The SRBs were returned to Kennedy Space Center for disassembly and refurbishment.

REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motors (RSRMs) performed satisfactorily with no LCC or OMRSD violations.

All 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.

Data indicate that the flight performance of both RSRMs was well within the allowable performance envelopes and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was 56 °F at liftoff. The maximum trace shape variation of pressure vs. time was calculated to be 0.6 percent at 79.5 seconds (left motor) and 80.0 seconds (right motor). These values were within the 3.2 percent allowable limits. Propulsion performance parameters are shown in the following table.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 56 °F		Right motor, 56 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	65.50	65.48	65.32	64.82
I-60, 10^6 lbf-sec	174.72	174.94	174.31	174.20
I-AT, 10^6 lbf-sec	297.45	296.98	297.18	296.41
Vacuum Isp, lbf-sec/lbm	268.4	268.0	268.4	268.7
Burn rate, in/sec @ 60 °F at 625 psia	0.3709	0.3724	0.3706	0.3719
Burn rate, in/sec @ 56 °F at 625 psia	0.3698	0.3713	0.3695	0.3708
Event times, seconds[a]				
Ignition interval	0.232	N/A	0.232	N/A
Web time[b]	110.1	109.6	110.3	109.7
50 psia cue time	119.9	119.5	120.1	119.5
Action time[b]	122.0	121.4	122.2	121.8
Separation command	125.0	124.4	125.0	124.4
PMBT, °F	56	56	56	56
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	3.0
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		447.1	

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).

STS-72 had the lowest PMBT flown in the RSRM program at 56 °F. Both the left-hand and right-hand motors experienced out-of-family burn rate of

0.3724 and 0.3719 ips, respectively. The new family maximum was documented, even though no limits were violated. Because of the high burn rate of the left-hand motor, new minimums for web and action time were set, as well as new maximums for burn rate, web time average pressure, maximum sea-level thrust, and web time average thrust.

Field joint heaters operated for 12 hours 44 minutes during the launch countdown. Power was applied to the heating element 45 percent of the time during the LCC time frame to maintain field joint temperatures in the normal operating range. Igniter joint heaters operated for 17 hours 56 minutes during the launch countdown. Power was applied to the igniter heating elements 86 percent (average) of the time to maintain the igniter joints in the normal operating range.

EXTERNAL TANK

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

Typical ice/frost formations were observed on the ET during the countdown. There was no observed ice on the acreage areas of the ET. Normal quantities of ice or frost were present on the LO_2 and LH_2 feedlines and on the pressurization line brackets, and some frost or ice was present along the LH_2 protuberance air load (PAL) ramps. These observations were all acceptable based on NSTS 08303. The ice/frost "Red Team" noted no anomalous thermal protection system (TPS) conditions. Some frost was visible; however, no acreage ice was noted.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the ullage pressure slump was 13.3 psid.

ET separation was satisfactory, and ET entry and breakup occurred 158 nmi. uprange of the nominal preflight-predicted impact point.

SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) parameters appeared to be normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. However, the cold ambient temperatures caused the high-pressure turbine discharge temperatures (H_2 and O_2) to read significantly lower than normal. At one time during the countdown, the temperatures read within 7 °F of disqualification; however, reinstatement of the heated GN_2 purge alleviated the problem. Data showed that the conditions were not associated with any SSME technical problem. Engine Ready was achieved at the proper time, all LCC were met, engine start and thrust buildup were normal, and no OMRSD violations were noted.

Flight data indicate that SSME performance during mainstage, throttling, shutdown and propellant dump 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 506.654 seconds after liftoff. No in-flight anomalies or significant SSME problems were identified during the data review.

SHUTTLE RANGE SAFETY SYSTEM

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

A new experience-base value was established when the ET range safety system (RSS) battery A voltage read 36.48 Vdc at the start of the countdown. The previous low experience value was 36.64 Vdc on STS-64. Since the OMRSD value is 35.1 Vdc, this new experience base posed no problem for this mission and was not indicative of a problem.

ORBITER SUBSYSTEM PERFORMANCE

Main Propulsion System

The overall performance of the main propulsion system (MPS) was satisfactory with no OMRSD or LCC violations. The LO_2 and LH_2 loading was performed as planned with no stop-flows or reverts. No significant hazardous gas concentrations were detected during the preflight-operations period. The maximum hydrogen concentration level in the Orbiter aft compartment was 135 ppm (this occurred shortly after start of fast-fill), which compares favorably with previous flight data for this vehicle.

A comparison of the calculated propellant loads at the end of replenish and the inventory (planned) loads results in a loading accuracy of 0.019 percent for the LH_2, and 0.033 percent for the LO_2.

Ascent MPS performance was nominal in all areas. Data indicate that the LO_2 and LH_2 pressurization and feed systems performed as planned, and that all net positive suction pressure (NPSP) requirements were met throughout the flight. and no in-flight anomalies were noted.

Data review revealed all valve timings were within specification as well as within the historical data base. The gaseous oxygen (GO_2) fixed-orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely matched the actual ET ullage-pressure measurements, and no sluggishness was noted in the valve operation during flight. The gaseous hydrogen (GH_2) flow control valves (FCVs) performed nominally, and this was the second flight since the FCVs had been cleaned.

Propellant dump operations were performed as planned, and postflight analysis indicates nominal performance. The MPS helium system performed as expected and met all requirements during powered flight operations as well as propellant dumping and vacuum inerting operations. The helium consumption during entry was 60.813 lbm, which is nominal and within the historical data base.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed satisfactorily throughout the mission. In addition to the normal attitude control, the RCS was used to perform 20 rendezvous maneuvers, and one collision avoidance maneuver. The RCS consumed 5242.2 lbm of propellants from the RCS tanks, plus 593.1 lbm and 234.4 lbm of propellants from the left and right OMS, respectively, during interconnect operations. During entry, the forward RCS propellant dump was performed, and 3.1 percent and 0.8 percent of the oxidizer and fuel, respectively, remained following the dump.

The RCS hot-fire was begun at 19:03:33 G.m.t. (07:17:52 MET). Primary thruster L1A failed off because of low chamber pressure (Pc) on its first pulse (also its first pulse of this mission). The thruster reached a maximum Pc of approximately 16 psia with both injector temperatures dropping, indicating at least partial flow through both valves (Flight Problem STS-72-V-02). Additionally, primary thruster R2U began leaking oxidizer following its first pulse (also its first pulse of this mission) as indicated by the injector temperatures (Flight Problem STS-72-V-03). The redundancy management (RM) software deselected the thruster after the second pulse. Both pulses indicated nominal Pc. Later in the mission, the R2U thruster stopped leaking and the thruster was reselected; however, it was not fired again during the mission. All other thrusters fired nominally.

In preparation for entry when the crew was configuring the crossfeed valves, the aft left RCS crossfeed 3/4/5 valve-position indication talkback displayed an intermittent incorrect indication (barberpole instead of closed). Following the postlanding tests, the switch was exercised and it operated correctly. This condition is a known phenomenon with OV-105 and did not affect the flight.

Orbital Maneuvering Subsystem

The orbital maneuvering subsystem (OMS) performed satisfactorily throughout the flight during which 6 OMS maneuvers were performed. The following table presents pertinent data concerning the OMS maneuvers.

OMS FIRINGS

OMS firing	Engine	Ignition time, G.m.t./MET	Firing duration, seconds	ΔV, ft/sec
OMS-2	Both	011:10:24:30 G.m.t. 00:00:43:30 MET	71	116
OMS-3	Both	012:13:40:02 G.m.t. 01:03:59:02 MET	156	256
OMS-4	Right	013:02:49:45 G.m.t. (01:17:08:45 MET)	12	10
OMS-5	Both	013:14:37:13 G.m.t. 02:04:56:13 MET	93	155
OMS-6	Both	013:15:24:29 G.m.t. 02:05:43:29 MET	93	155
Deorbit	Both	020:06:41:23 G.m.t. 08:21:00:23 MET	156	272

The OMS propellant consumption was 22,975 lbm of which 827.5 lbm was used by the RCS during interconnect operations.

The right OMS pod low-pressure gaseous nitrogen (GN_2) system exhibited external leakage of approximately 40 scch after the OMS 2 maneuver. The accumulator bottle was repressurized four times prior to the deorbit maneuver. After the fourth repressurization, the leak rate decreased to 30 scch. This behavior was exhibited on four previous flights, and extensive troubleshooting during previous turnaround operations did not isolate the leak. The condition was waived for each flight after the leakage was noted, as it neither affected flight safety nor impacted mission operations.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performance was nominal throughout the mission. The PRSD subsystem supplied the fuel cells 2048 lbm of oxygen and 258 lbm of hydrogen for the production of electrical energy. The environmental control and life support system was also supplied 127 lbm of oxygen.

The Orbiter landed with 1756 lbm of oxygen and 199 lbm of hydrogen remaining. Based on the average flight power level of 13.8 kW, a 148-hour mission extension existed at landing. There were no in-flight anomalies noted.

Two oxygen manifold pressure spikes were noted during the mission. The first occurred at 011:17:00 G.m.t. (00:07:29 MET) when high oxygen flow to the cabin was terminated. This termination increased the manifold 1 pressure to 989 psia, causing the manifold relief valve, which has a minimum cracking pressure of 975 psia, to relieve into oxygen tank 1. Proper resetting of the relief valve was verified by observing the pressure cycles in the other oxygen tanks with no corresponding pressure increase in oxygen tank 1. The second pressure spike occurred when the cabin was repressurized after completion of the EVAs; however, the pressure did not reach the manifold relief valve cracking pressure. These pressure spikes have been seen on previous flights and do not impact normal flight operations.

Fuel Cell Powerplant Subsystem

The performance of the fuel cell powerplant (FCP) subsystem was nominal during the STS-72 mission, and no in-flight anomalies were identified from the fuel cell data. The Orbiter electrical power level averaged 13.8 kW, and the total Orbiter load averaged 454 amperes. For the 214-hour mission, the fuel cells produced 2964 kWh of electrical energy and 2305 lbm of potable water. The fuel cells consumed 2048 lbm of oxygen and 258 lbm of hydrogen. Three purges of the fuel cells were performed with the time period between the second and third purge being 117 hours. The actual fuel cell voltages at the end of the mission were 0.30 Vdc above predicted for fuel cell 1, 0.25 Vdc above predicted for fuel cell 2, and 0.1 Vdc above predicted for fuel cell 3. The overall thermal performance of the fuel cell water relief, water line and reactant purge systems was nominal.

The purge interval between the second and third fuel cell purges was the longest nominal purge interval experienced during the Space Shuttle Program. The voltage decay was about 0.2 Vdc. (On STS-50, fuel cell 2 did operate 240 hours without purging after a purge valve failure, and the decay for this period was 0.4 Vdc.)

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performance was nominal throughout the STS-72 mission, and no in-flight anomalies were recorded against the APU subsystem during the flight. The run times and fuel consumption for the APUs are summarized in the following table.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 203)		APU 2 (S/N 308)		APU 3 (S/N 304)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	20:08	47	20:15	50	20:20	46
FCS checkout					04:02	9
Entry[a]	62:43	117	83:27	175	62:52	120
Total	82:51	164	103:42	225	87:14	175

[2]The APUs ran 14 minutes and 4 seconds after touchdown.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/water spray boiler (WSB) subsystem performed nominally throughout the mission except for the two over-cooling conditions noted during entry. STS-72 was the first flight where all three APUs had the WSB water feed-line electric heaters installed and operational. STS-69 had the three heaters installed; however, only the system 3 heater was powered.

WSB 3 experienced two over-cooling conditions during entry after spray start. System 3 lubrication oil return temperature dropped from 251 °F to 227 °F and then returned to 251 °F before dropping again to 235 °F. The temperature increased to 249 °F and remained steady through landing. These conditions did not affect the APU operation or the mission.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed nominally throughout the mission. The data review revealed no in-flight anomalies.

Pyrotechnics Subsystem

The ET/Orbiter pyrotechnic separation devices EO-1, EO-2, and EO-3 functioned normally. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly. Three clips were missing from both the EO-2 and EO-3 fitting "salad bowls". Virtually no umbilical closeout foam or white room temperature vulcanizing (RTV) dam material adhered to the umbilical plate near the LH_2 recirculation line disconnect. The only debris found on the runway under the umbilical cavities consisted of a bolt that was 1.25 inches in length by 0.1875 inch in diameter.

During the postflight inspection of the ET/Orbiter umbilical attachment hardware, one of the two detonators in the frangible nut for the LO_2 umbilical inboard attachment stud (disconnect 2) had not fired (Flight Problem STS-75-V-04). During troubleshooting, a short was found in a connector at the debris containment canister. The harness was removed and replaced and sent to the laboratory for analysis. Damage was found in a wire at the connector.

Environmental Control and Life Support System

The environmental control and life support system (ECLSS) performed satisfactorily throughout the mission. One in-flight anomaly was identified concerning the operation of the flash evaporator system.

The active thermal control subsystem (ATCS) operation was satisfactory throughout the mission with the exception of the flash evaporator system. There were no active payload cooling requirements; consequently, both Freon cooling loops remained in the interchanger position throughout the flight.

At 011:11:07 G.m.t. (00:01:26 MET), while on the primary A controller, the flash evaporator system (FES) shut down as the high-load evaporator transitioned to standby. The high-load transition to standby occurred as the heat load to the FES decreased because of radiator flow initiation just prior to payload bay door opening. The transient temperature response resulting from this transition apparently caused the shutdown. This phenomenon was also observed on STS-69, the previous flight of this vehicle.

The FES subsequently failed to come out of standby at approximately 012:01:36 G.m.t. (00:15:55 MET). Operating on the primary A controller, it had gone in to standby at 011:22:54 G.m.t. (00:13:13 MET). The FES was successfully restarted on the primary A controller. This phenomenon recurred at 013:12:42 G.m.t. (02:03:01 MET), and the FES was successfully restarted 10 minutes later. Similar shutdowns have been seen with this FES on STS-61 and STS-67.

The topping FES experienced four shutdowns on flight day 4. At approximately 015:03:05 G.m.t. (03:17:25 MET), while operating on the primary A controller, the FES shut down (Flight Problem STS-72-V-01). At the time of the shutdown, the cabin pressure was at 10.2 psia in preparation for EVA 1, and a FES water dump was being performed (radiator controller in high set point). Operating the FES while the cabin is depressed to 10.2 psia results in a slightly lower feed-water pressure at the FES. The FES was successfully restarted on the A controller about 10 minutes after the shutdown. Twenty minutes later, at

015:03:33 G.m.t (03:17:52 MET) the FES shut down again. At 015:03:57 G.m.t. (03:18:16 MET), the FES was started on the primary B controller. Prior to the FES outlet temperature reaching the control temperature, the FES once again shut down. FES operation on the primary B controller was attempted again at 015:07:42 G.m.t. (03:22:01 MET) with the radiators controlling to the high set point. The FES outlet temperature came into range, but the FES shut down again after approximately 11 minutes. It was suspected that ice had formed in the FES topper core, and the crew performed the FES core-flush procedure. The FES core-flush procedure was terminated when the duct temperatures decreased to 0 °F.

A second FES core-flush procedure was initiated at 017:13:07 G.m.t. (06:03:26 MET) following the second EVA, and no evidence of ice was noted during this procedure. The secondary controller successfully controlled the FES outlet temperature to approximately 61 °F during the 7-minute period following the flush cycles. Nominal FES operation with radiators at the high set point was demonstrated using the primary B controller for 20 minutes following the flush procedure. The FES primary B controller was deactivated at 017:13:52 G.m.t. (06:04:11 MET) and remained off with the radiators configured to the normal set point throughout the subsequent crew sleep period. After crew awakening, the FES was enabled on the primary B controller and it performed nominally for the remainder of the mission during which time two FES water dumps were performed. The FES was used for entry in the full-up mode (topper and high-load) as planned with the primary B controller and its performance was nominal. Following the flight, no cause for the problem could be isolated. The A controller and A spray valves were replaced as a precautionary measure.

The crew reported being warm (cabin temperature was 84.2 °F) and at 019:03:41 G.m.t. (07:18:00 MET), the cabin temperature valve actuator linkage was found unpinned. The crew had reported having difficulty pinning the valve linkage to the secondary actuator when the reconfiguration was performed earlier in the mission. The crew was requested to pin the temperature control valve in the 1/3-cool position at 019:03:51 G.m.t. (07:18:10 MET). This action stabilized the cabin temperature. At 019:04:18 G.m.t. (07:18:37 MET), the crew was asked to pin the valve in the 2/3-cool position to further cool the cabin, and the cabin temperature decreased to below 78 °F.

At 019:06:13 G.m.t. (07:20:32 MET), the crew was asked to check the humidity separator for water as it was suspected that manually moving the temperature control valve might have "slugged" the humidity separator with water. The crew reported a golf-ball size accumulation of water attached to a test port. The water was removed using a dry wipe.

The atmospheric revitalization pressure control system (ARPCS) performed nominally throughout the mission. During the redundant component check, the pressure control configuration was switched to the alternate system, and both systems exhibited normal operations. The system was also exercised in depressing the cabin to 10.2 psia at 013:13:03 G.m.t. (02:03:22 MET) for the scheduled EVAs, and repressurizing the cabin to 14.7 psia at 017:06:18 G.m.t. (05:20:37 MET) following the second EVA.

The radiator cold-soak provided cooling during entry through landing plus 12 minutes when ammonia boiler system (ABS) A was activated using the secondary controller at 020:07:53 G.m.t. (08:22:12 MET). ABS system A operated for 41 minutes until deactivated for ground cooling connection.

The supply and waste water management systems performed normally throughout the mission.

Supply water was managed through the use of the overboard dump system and the FES. Five overboard dumps were performed at an average rate of 1.44 percent/minute (2.38 lb/min). Four of the dumps were performed at 10.2-psia cabin pressure, and three were simultaneous with waste water dumps. These conditions explain the lower flow rate. The supply water dump line temperature was maintained between 73 and 97 °F throughout the mission with the operation of the line heater.

Waste water was collected at the expected rate. Three waste water dumps were completed at an average dump rate of 1.88 percent/minute (3.09 lb/min). The waste-water dump-line temperature was maintained between 54 and 79 °F throughout the mission. The vacuum vent line temperature was maintained between 58 and 80 °F, while the nozzle was between 116 and 154 °F.

The waste collection system (WCS) performed adequately throughout the mission. The urine monitoring system was supported on this mission without incident.

Smoke Detection and Fire Suppression Subsystem

The smoke detection subsystem showed no indications of smoke generation during the entire mission. Use of the fire suppression subsystem was not required.

Airlock Support System

The airlock support system was used to support two periods of EVA. The airlock was depressurized at 015:05:16 G.m.t. (03:19:35 MET) for the first EVA and repressurized at 015:11:43 G.m.t. (04:02:02 MET) when the first EVA was completed. The airlock was depressurized at 017:05:22 G.m.t. (05:19:41 MET) for the second EVA and repressurized at 017:12:34 G.m.t. (06:02:53 MET). The active system monitors indicated normal operation throughout the flight.

Avionics and Software Support Subsystems

The avionics and software support subsystems performed nominally with no in-flight anomalies noted. An in-depth discussion of the avionics subsystems performance during both rendezvous operations is provided in a separate section entitled "Rendezvous Operations."

Communications and Tracking Subsystem

All communications and tracking subsystems performed nominally, and were satisfactory in all respects. The S-band system operated flawlessly, and Ku-band operation was normal in both the communications and the radar mode. The UHF communications during the EVAs were nominal except for the intermittent ear phone and the camcorder tape jams, which are discussed in the Government Furnished Equipment section of this report.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation (OI) and modular auxiliary data system (MADS) performed very satisfactorily with no in-flight anomalies or problems identified.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission with no in-flight anomalies identified after review of the data. The landing and braking parameters are shown in the table on the following page.

The tires and brakes were reported to be in good condition for a landing on the KSC concrete runway.

The drag chute functioned normally. No significant damage was observed on any of the drag chute components. All drag chute hardware was recovered in the expected places on the runway. The postlanding walk-down of the runway revealed some flight hardware debris in the general vicinity of the pilot chute at the 4800-foot marker. The debris consisted of a 1.25-inch long by 0.75-inch wide piece of metal similar in appearance to speed brake spring clips on the trailing edge of the rudder.

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	3617	191.0	~ 1.4	N/A
Nose gear touchdown	6559	145.5	N/A	~5.8

Brake initiation speed	86.3 knots
Brake-on time	36.3 seconds
Rollout distance	8,770 feet
Rollout time	65.3 seconds
Runway	15 (Concrete) KSC SLF
Orbiter weight at landing	218,062 lb

Brake sensor location	Peak pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	864	Left-hand outboard	15.06
Left-hand inboard 3	828	Left-hand inboard	16.51
Left-hand outboard 2	828	Right-hand inboard	12.33
Left-hand outboard 4	864	Right-hand outboard	9.31
Right-hand inboard 1	792		
Right-hand inboard 3	672		
Right-hand outboard 2	624		
Right-hand outboard 4	636		

Integrated Aerodynamics, Heating and Thermal Interfaces

The integrated aerodynamics, heating and thermal interfaces were nominal during the mission.

The prelaunch thermal interface purges were nominal, as was ascent aerodynamic and plume heating. The entry aerodynamic heating to the SSME nozzles was also nominal.

Thermal Control Subsystem

The thermal control subsystem performance was nominal during all phases of the mission. During the on-orbit period of the mission, thermal analyses were performed on 12 proposed revisions to the attitude timeline. The beta angle ranged from approximately -9 degrees at orbital insertion to +8 degrees at entry interface. No heater failures or instrumentation anomalies occurred during the mission, and all temperatures were maintained within limits.

Aerothermodynamics

The Orbiter aerothermodynamics were nominal. Acreage heating as well as local heating was nominal. The boundary layer transition was early and asymmetric with the lower left surface forward of the inboard elevon transitioning first. No thermal protection subsystem (TPS) or structural over-temperature conditions were noted nor were there any surface protuberances to cause the early and asymmetric boundary-layer transition.

Thermal Protection Subsystem and Windows

The TPS performed satisfactorily. Based on structural temperature response data (temperature rise), the entry heating was nominal. Boundary layer transition from laminar flow to turbulent flow was symmetrical and occurred at 1280 seconds after entry interface on both the forward and aft centerline of the vehicle.

The postflight inspection of the TPS identified 55 damage sites (hits) of which seven had a major dimension of 1 inch or greater. This total does not reflect the numerous hits on the base heat shield attributed to the flame arrestment sparkler system. A comparison of these numbers to statistics from 57 previous missions of similar configuration indicates that the total number of hits as well as the number of hits 1-inch or larger was exceptionally low and well below average. The distribution of the hits on the Orbiter is shown in the following table.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	3	23[a]
Upper Surface	1	22
Right Side	0	1
Left Side	0	2
Right OMS Pod	1	4
Left OMS Pod	2	3
Total	7	55

Note a: Lowest total number of lower-surface hits recorded during Space Shuttle flights.

The postflight inspection revealed two tiles were missing from the upper body flap at the leading edge center hinge area. One of the two was also lost on a previous flight (flight 7 of OV-104). The most likely cause of the loss was ground handling damage. The tiles were replaced with stronger fibrous refractory composite insulation (FRCI) -12 tiles.

The largest lower surface tile damage site occurred approximately 15 feet forward of the right-hand main landing gear (MLG) wheel well and measured 6.0 inches in length by 0.375 inch in width by 0.25 inch maximum depth. Hits on the right side along a line from nose to tail are generally attributed to ice impacts from the ET LO_2 feedline bellows and support brackets.

Virtually no tile damage sites were recorded aft of the ET/Orbiter LH_2 and LO_2 umbilicals. Damage sites in this area are typically caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the air-stream. A possible reason for this unusual finding was the absence of ice on the umbilicals after being shaken loose during SSME ignition prior to liftoff.

No tile damage from micrometeorites or on-orbit debris was identified during the inspection.

All three dome mounted heat shield (DMHS) closeout blankets were in excellent condition with no missing material. The SSME 1 DMHS blanket was damaged at the six o'clock position. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged.

No ice adhered to the payload bay door. A white residue was observed around the waste water dump nozzles. Some, but no unusual, tile damage sites were found on the leading edges of the OMS pods and the vertical stabilizer.
Less than the usual amount of hazing was visible on the Orbiter windows. A total of 18 damage sites on the window perimeter tiles was most likely caused by impacts from forward RCS thruster paper covers and RTV adhesive.

RENDEZVOUS OPERATIONS

This section provides an in-depth discussion of the rendezvous operations with the Space Flyer Unit (SFU) and the OAST Flyer.

SPACE FLYER UNIT RENDEZVOUS

The SFU rendezvous phase of the flight was initiated at 013:03:18:00 G.m.t. (01:17:18:00 MET), with the height adjustment (NH-S) maneuver. The maneuver raised the Orbiter's apogee to within 10 nmi. of the SFU's orbit. The firing was posigrade with respect to the vehicle's X axis and had a magnitude of 10.5 ft/sec. The firing was executed with the right OMS engine, and no problems were noted.

The phasing maneuver, the second maneuver executed for the rendezvous, had a magnitude of 4.5 ft/sec and was posigrade in direction. The firing adjusted the catch-up rate between the two vehicles. The firing time was long enough to use the +X RCS firing attitude (>4.0 ft/sec); however, the multi-axis firing procedure, which was less fuel efficient, was used.

The first rendezvous sensor pass used the star tracker for state-vector updates. The pass lasted for approximately 22 minutes, during which time 170 marks were incorporated without any rejected marks. The navigation-computed horizontal angular residuals (errors) never exceeded 3.8 degrees, and the ratios of maximum error to maximum allowable error never exceeded 0.065. After approximately six marks, the horizontal residual had decreased to less than one degree. By the end of the star-tracker pass, the Orbiter filtered state had been updated 750 ft (RSS) and 1.0 ft/sec.

Prior to the second star tracker pass, the first onboard rendezvous guidance corrective combination (NCC) maneuver solution was computed. The maneuver solution was X local vertical local horizontal (lvlh) = 0.5 ft/sec, Y lvlh = 0.2 ft/sec, and Z lvlh = 1.2 ft/sec, which was very close to the expected solution. The maneuver was performed on-time at 013:05:56:07 G.m.t. (01:20:56:07 MET) using the multi-axis RCS firing procedure.

The second star tracker pass provided the navigation with another 210 marks over a period of 26 minutes. The maximum residuals were again horizontal and never exceeded 2.0 degrees with a maximum ratio of 0.01 (an indication of the best possible relative state given the star tracker updates). A total of 380 star tracker marks were incorporated into the Orbiter state vector with no rejections. The pass updated the relative state vector approximately 1000 ft and 1.00 ft/sec.

Prior to the NCC maneuver, the rendezvous navigation was also configured for the rendezvous radar (RR) pass. The Ku-band was configured for general purpose computer (GPC) -commanded passive target track of the SFU. Initial RR lock-on occurred at a range of 150,000 ft.

Once the RR was selected as the source for the navigation state updates, the initial horizontal residuals (error: expected minus measured) increased to 23 degrees from 0.0 degree, but the ratio (error/maximum error) was small (0.05). After 15 navigation marks were incorporated into the onboard state vector, the horizontal error was reduced to -1.5 degree.

During the RR pass, the terminal-phase initiation (TI) maneuver solution was computed three times and compared to the ground solution for reasonability. The final maneuver solution was X = 3.3 ft/sec, Y = 0.2 ft/sec, and Z = 1.3 ft/sec. The ground-determined maneuver solution was X = 3.4 ft/sec, Y = 0.4 ft/sec, and Z = 1.1 ft/sec. The maneuver was executed on time at 013:06:43:49 G.m.t. (01:21:02:49 MET) using the multi-axis RCS thruster configuration. The resultant orbit was raised to 256.5 by 251.0 nmi.

After the transition back to major mode (MM) 201, the RR pass was re-initiated. Following this change, a filter-to-propagated state-vector transfer was performed to ensure that the backup state vector was updated.

Between the TI maneuver and target intercept, the midcourse correction (MCC) maneuvers one through four were executed to correct for dispersions in the relative trajectory and to ensure target intercept in sunlight. All of the maneuvers are nominally zero, and if not, are usually less than 2.0 ft/sec. The first MCC maneuver solution was X = -0.1, Y = 0.1, and Z = 0.2 ft/sec, and the maneuver was performed manually using the RCS thrusters while maintaining target-track attitude.

The time of ignition (TIG) of the second MCC maneuver may vary depending on the elevation angle between the local horizontal of the Orbiter and the line-of-sight to the target. The desired elevation angle is used to ensure that the target is illuminated during proximity operations. The nominal amount of variation between the planned and the actual maneuver time is + 7 minutes and - 3 minutes. For this rendezvous, the MCC 2 TIG slip was + 1.20 minutes. The final maneuver solution was: X = -0.0 ft/sec, Y = -0.0 ft/sec, and Z = 1.2 ft/sec and the TIG was 013:07:34:44 G.m.t. (01:21:53:44 MET). The maneuver was performed in the target-track attitude using the RCS thrusters. The last two MCC maneuvers (MCC 3 and 4) solutions were nominal and were short RCS firings performed 10 and 20 minutes after the MCC 2 TIG.

Between the TI maneuver TIG and the time that the Orbiter range to the SFU was less than 100 ft, the RR took more than 1000 navigation marks, none of which were rejected. The hand-held laser (HHL) was being used to provide the crew with range and range-rate updates to the SFU. As the range to the SFU decreased, the RR residuals and ratios became noisier. The RCS thruster firings during proximity operations for establishing braking gates also contributed to the noisy RR data. The rendezvous with the SFU was successfully completed with the grappling, berthing, and latching of the SFU in the payload bay at 013:11:39 G.m. t. (02:01:58 MET).

OAST FLYER RENDEZVOUS

The rendezvous flight phase for the retrieval of the OAST-Flyer was initiated with a phasing maneuver (NC-0), which was used to adjust the catch-up rate between the two vehicles. The components of the maneuver, referenced to local vertical local horizontal, were X = 3.0 ft/sec, Y = 0.0 ft/sec and Z = 0.0 ft/sec. The RCS multi-axis maneuver procedure was used.

The first rendezvous sensor pass used the star tracker for state vector updates. The pass lasted approximately 21 minutes and 162 marks were acquired and incorporated with no rejections. The navigation-computed horizontal angular residuals (errors) never exceeded -0.02 degree and the ratios (maximum error/maximum allowable error) never exceeded 0.025. The pass updated the relative state vector approximately 1500 ft and 1.5 ft/sec.

Prior to the second star tracker pass, the first onboard rendezvous guidance NCC maneuver solution was computed. The final NCC maneuver solution (X = 0.0 ft/sec, Y = 0.3 ft/sec and Z = 1.1 ft/sec) was very close to the expected maneuver solution. The onboard maneuver solution was executed on-time at 016:06:31:18 G.m.t. (04:20:50:18 MET) using the multi-axis RCS firing procedure.

The second star tracker pass provided the navigation with another 213 marks over a period of 29 minutes. The maximum residuals never exceeded 0.1 degree with a maximum ratio of 0.01. A total of 375 star tracker marks were incorporated into the Orbiter state with no rejections. The pass updated the relative state approximately 2500 ft. and 2.9 ft/sec.

Prior to the NCC maneuver, the rendezvous navigation was configured for an RR pass. The Ku-band was configured for GPC-commanded passive-target track of the OAST-Flyer. Initial RR lock-on occurred at a range of approximately 140,000 ft. Once the RR was selected as the source of the navigation state updates, the initial horizontal residuals increased to 0.30 degree from 0.0 degree, but the ratio remained small (0.05). The initial range residual was 1200 ft and the range-rate residual was -1.2 ft/sec After 30 navigation marks were incorporated into the onboard state, all residuals had been reduced to ± 0.1 degree.

During the RR pass, the TI maneuver solution was computed three times and compared to the ground solution for reasonability. The final maneuver solution was X lvlh = 4.0 ft/sec, Y lvlh = -0.1 ft/sec and Z lvlh - 0.7 ft/sec. The ground solution was X = 4.2 ft/sec, Y = -0.9 ft/sec and Z = 1.8 ft/sec. The maneuver was executed on-time at 016:07:28:45 G.m.t. (04:21:47:45 MET) using the multi-axis RCS thruster configuration, and the orbital altitude was raised to 166.2 by 160.8 nmi.

After the transition back to MM 201, the RR pass was re-initiated. Following this change, a filter-to-propagated state-vector transfer was performed to ensure that the backup state vector was updated.

Between the TI maneuver and target intercept, the MCC maneuvers one through four were executed to correct for dispersions in the relative trajectory and to ensure target intercept in sunlight. All of the maneuvers are nominally zero, and if not, are usually less than 2.0 ft/sec. The first MCC maneuver solution was X = -0.1, Y = 0.1, and Z = 0.2 ft/sec, and the maneuver was performed manually using the RCS thrusters while maintaining target-track attitude.

The TIG of the second MCC maneuver may vary depending on the elevation angle between the local horizontal of the Orbiter and the line-of-sight to the target. The desired elevation angle is used to ensure that the target is illuminated during proximity operations. The nominal amount of variation between the planned and the actual maneuver time is + 7 minutes and - 3 minutes. For this rendezvous, the MCC 2 TIG slip was + 2.40 minutes. The final maneuver solution was: X = -0.1 ft/sec, Y = -0.2 ft/sec, and Z = 0.8 ft/sec and the TIG was 016:08:21:01 G.m.t. (04:22:40:01 MET). The maneuver was performed in the target-track attitude using the RCS thrusters. The last two MCC maneuvers (MCC 3 and 4) solutions were nominal and were short RCS firings performed 10 and 20 minutes after the MCC 2 TIG.

During the time between the TI maneuver TIG and the time that the Orbiter range to the OAST-Flyer was less than 100 ft, the RR took over 1000 navigation marks, none of which were rejected. The hand-held laser (HHL) was being used to provide the crew with range and range-rate updates to the OAST-Flyer. As the range to the OAST-Flyer decreased, the RR residuals and ratios became noisier. The RCS thruster firings for establishing braking gates during proximity operations also contributed to the noisy RR data. The rendezvous with the OAST-Flyer was successfully completed with radius vector axis (RBAR) arrival at 016:08:45:00 G.m.t. (04:21:04:00 MET).

FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

The flight crew equipment/Government furnished equipment (FCE/GFE) performed nominally throughout the mission. The crew reported problems with three of the four camcorders.

The camcorders with serial numbers (S/Ns) 1005 and 1006 had tape jams (Flight Problem STS-72-F-01). The crew attempted several times to eject the tapes but were unsuccessful. The crew tried power cycling the units, changing video switching units (VSUs) and using battery power in attempting to eject the tapes, but none of these were successful.

A third camcorder, S/N 1004, had a gray screen on the viewfinder and no longer had the capability to auto-focus or zoom (Flight Problem STS-72-F-02). The crew reported that the viewfinder was gray when internal camera video was selected and when external video input was selected, the viewfinder had good video.

The fourth camcorder began making crunching sounds when operating. The crewmember immediately stopped the camcorder operation and was able to eject the crunched tape. The camcorder was usable for the remainder of the mission.

REMOTE MANIPULATOR SYSTEM

The remote manipulator system (RMS) operated nominally throughout the mission and all RMS operations were completed satisfactorily. STS-72 was the forty-fourth flight of the RMS and the eleventh flight of the S/N 303 arm. Two in-flight anomalies were identified from the data.

The primary RMS activities during the flight were the retrieval of the SFU, the deployment and retrieval of the National Aeronautics and Space Administration's SPARTAN-based Office of Aeronautics and Space Technology (OAST) -Flyer, as well as the RMS support of the two EVAs. The 8,800-lb SFU is a Japanese science satellite, which was launched by a Japanese expendable rocket in March of 1995 and was designed to be retrieved by the RMS. The 2900-lb OAST-Flyer payload was deployed by the RMS on flight day 4 and retrieved on flight day 6.

During the initial checkout of the RMS, the wrist-roll direct-drive rate was noted to be lower than expected for this arm (S/N 303) (Flight Problem STS-72-F-04). The steady-state rate achieved during the test was approximately 20 rad/sec. The typical rate for this joint, as determined from previous flights, was 24 rad/sec. The rate variation was also noted to be larger than nominal with a peak-to-peak variation of approximately 2 rad/sec compared with a typical variation of approximately 1 rad/sec. The wrist-roll direct-drive test was repeated (with drive times of 30 seconds in each direction) prior to RMS operations on each subsequent flight day to monitor performance of the joint. The rates were nominal on the tests conducted on flight days 2 through 5, but on flight day 6 the rates were lower than those achieved on previous tests. The rates were even more degraded on flight days 6 and 7.

Also during RMS checkout, the steady-state shoulder pitch direct-drive rate was lower than expected (Flight Problem STS-72-F-10). The rate achieved was approximately 23 rad/sec versus the nominal rate of 25 rad/sec. Peak-to-peak tachometer noise was normal. The performance of this joint will continue to be monitored on future flights with no further investigation conducted as a result of this anomaly. Because of this problem and the previously mentioned wrist-roll rate degradation, RMS S/N 303 was replaced during turnaround operations.

The activities supported by the RMS were as follows:

a. Flight day 2 - Camera survey of payload bay;
b. Flight day 3 - Retrieve and berth SFU payload;
c. Flight day 4 - Deployment of the OAST-Flyer;
d. Flight day 5 - Support first EVA operation;
e. Flight day 6 - Retrieve and berth OAST-Flyer; and
f. Flight day 7 - Support second EVA operation.

CARGO INTEGRATION

The cargo integration hardware performed satisfactorily throughout the mission with no in-flight anomalies identified.

Shortly after SFU berthing and engagement of the ROEU, a low temperature excursion to 7 °C was observed from instrumentation on the SFU propellant system. Because of the concern for the propellant system, an evaluation of the data was performed and this showed that no anomalies existed in the system. Also, it was shown that continuous electrical power to the heaters would be adequate to avoid out-of-tolerance thermal changes under anticipated conditions. In addition, it was agreed with the flight controllers that any future excursions could be further remedied by maneuvering the Orbiter to a more favorable thermal attitude.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

DEVELOPMENT TEST OBJECTIVES

The STS-72 flight had 16 Development Test Objectives (DTOs) assigned and information about these DTOs are presented in the following paragraphs.

DTO 301D - Ascent Structural Capability Evaluation - Data were recorded on the Modular Auxiliary Data System (MADS) for this data-only DTO. The data were recovered postflight and have been given to the sponsor for evaluation. The results of this DTO will be reported in separate documentation.

DTO 305D - Ascent Compartment Venting Evaluation - Data were recorded on the MADS for this data-only DTO. The data were recovered postflight and have been given to the sponsor for evaluation. The results of this DTO will be reported in separate documentation.

DTO 307D - Data were recorded on the MADS for this data-only DTO. The data were recovered postflight and have been given to the sponsor for evaluation. The results of this DTO will be reported in separate documentation.

DTO 312 - External Tank Thermal Protection System Performance - No maneuvers were performed in support of this DTO. However, the assigned crewmember (Koichi Wakata) was able to obtain 11 photographs of the ET using the Nikon camera and 300 mm lens with a 2X extender. The exposure was good on eight frames, and the focus was good on seven frames. Timing data were present on all frames. The first frame was taken about 23 minutes after liftoff and the last frame was taken about 2 minutes later.

The +Y and -Z (far) sides of the ET were imaged. The ET appeared to be in good condition with no anomalous conditions noted. The aeroheating marks and the booster separation motor burn scars appeared to be typical of those observed during previous missions.

In addition, two rolls of 16-mm film from the umbilical well cameras were received and evaluated. The evaluation showed that no anomalous conditions were present. The 35-mm umbilical well camera malfunctioned and no usable photographs were received.

Also, video from a hand-held camcorder was received and reviewed. This video did not show any anomalous conditions.

DTO 415 - Water Spray Boiler Electrical Heater Capability - Data were collected for this DTO. The DTO sponsor is evaluating the data, and the results will be documented in a separate publication.

DTO 664 - Cabin Temperature Survey - Data were collected for this DTO. The DTO sponsor is evaluating the data, and the results were be documented in a separate publication.

DTO 668 - Advanced Lower Body Restraint Test - Data were collected for this DTO, and these data have been given to the DTO sponsor for evaluation. The results of the evaluation will be documented in a separate publication.

EDFT-03 - EVA Demonstration Flight Test-03 - This DTO actually consisted of four DTOs and these were:

a. DTO 671 - EVA Hardware for Future Scheduled EVA Missions;

b. DTO 672 - EMU Electronic Cuff Checklist;

c. DTO 833 - EMU Thermal Comfort and EVA Worksite Thermal Environment Evaluations; and

d. DTO 1210 - EVA Operations and Procedures/Training.

These four DTOs were very complex and were completed in a very satisfactory manner. The first EVA was 6 hours 9 minutes in duration, and the second EVA was 6 hours 53 minutes in duration. A total of 16 objectives were planned for the two EVAs, and all were accomplished except the installation and removal of the portable work platform worksite interface (WIF), and part of the crew loads evaluation. After completion of the second EVA, the electronic cuff checklist update terminated due to a computer error, and this error will be evaluated postflight. Additional data concerning the two EVAs is contained in the Extravehicular Activity section of this report.

DTO 684 - Radiation Measurements in Shuttle Crew Compartment - At 011:13:54 G.m.t. (00:04:14 MET), the crew reported that the Tissue Equivalent Proportional Counter (TEPC) screen went blank. An in-flight maintenance (IFM) procedure was performed, but normal operation was not restored. Later in the mission, further troubleshooting revealed an open 2-ampere fuse. At this point, the TEPC was stowed. No data were collected for this DTO.

DTO 700-8 - Global Positioning System Development Flight Test - Data were collected for this DTO, and these data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DTO 805 - Crosswind Landing Performance - This DTO was not performed as the landing weather conditions (winds) did not meet the minimum criteria for fulfillment of this DTO.

DTO 833 - EMU Thermal Comfort and EVA Worksite Thermal Environment Evaluations - This DTO is discussed in the Extravehicular Activity section of this report.

DTO 1210 - EVA Operations Procedures/Training - This DTO is discussed in the Extravehicular Activity section of this report.

DETAILED SUPPLEMENTARY OBJECTIVES

A total of 14 Detailed Supplementary Objectives (DSOs) were assigned to the STS-72 mission. The following subparagraphs summarize the status of the DSO.

DSO 206 - Effects of Space Flight on Bone and Muscle - This DSO was performed during the preflight and postflight activities. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 330 - In-Flight Evaluation of the Urine Monitoring System - Data were gathered for this DSO during the mission. These data have been given to the sponsor for the evaluation. The results of that evaluation will be published in separate documentation.

DSO 483 - Back Pain Pattern in Microgravity - Data were collected for this DSO during the flight. These data have been given to the sponsor for the evaluation. The results of that evaluation will be published in separate documentation.

DSO 487 - Immunological Assessment of Crewmembers - This DSO was performed during the preflight and postflight activities. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 489 - EVA Dosimetry Evaluation - Data were collected in accordance with the flight plan. These data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 491 - Characterization of Microbial Transfer Among Crewmembers During Space Flight - This DSO was performed during the preflight and postflight activities. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 492 - In-Flight Evaluation of a Portable Blood Analyzer (Configuration B) - This DSO was performed during the preflight and postflight activities. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 493 - Monitoring of Latent Virus Reaction and Shedding in Astronauts - Data were collected in accordance with the flight plan. These data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 494 - Influence of Microgravity and Extravehicular Activity on Pulmonary Oxygen Exchange - The activities that were to take place prior to the FES problem were completed as planned; however, the flight day 7 activities were conducted at 14.7 psia instead of the desired 10.2 psia. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 604 - Visual-Vestibular Integration as a Function of Adaptation - The sessions scheduled for the subjects OI-1 and OI-3 were completed as scheduled. These data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 802 - Educational Activities - These activities were performed as planned. The video have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 901 - Documentary Television - These activities were performed throughout the course of the flight. The data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 902 - Documentary Motion Picture Photography - All activities including use of the AATON super-16-mm camera were completed. The film has been returned to the sponsor for development and evaluation.

DSO 903 - Documentary Still Photography - The activities for this DSO were performed throughout the flight. The film has been returned to the sponsor for development and evaluation.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Photography and video, which consisted of thirty-two 16-mm films nineteen 35-mm films and 24 videos of the launch were screened for the planned events as well as any anomalous conditions. No anomalous conditions were noted in any of the material screened.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

No requests for screening on onboard photography or video were made of the JSC team.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Video, consisting of video from 12 cameras, was screened for nominal and non-nominal events. No significant findings were reported.

TABLE I.- STS-72 SEQUENCE OF 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	011:09:36:12.742 011:09:36:13.681 011:09:36:14.490
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	011:09:40:32.085 011:09:40:32.245 011:09:40.32.405 011:00:40:32.585
Main Propulsion System Start[a]	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	011:09:40:53.458 011:09:40:53.577 011:09:40:53.713
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	011:09:41:00.015
Throttle up to 104 Percent Thrust[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	011:09:41:03.978 011:09:41:04.023 011:09:41:04.034
Throttle down to 67 Percent Thrust[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	011:09:41:30.058 011:09:41:30:104 011:09:41:30.114
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	011:09:41:51
Throttle up to 104 Percent[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	011:09:41:57:419 011:09:41:57.464 011:09:41:57.474
Both SRM's Chamber Pressure at 50 psi[a]	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	011:09:42:59.215 011:09:42:59.415
End SRM [a] Action[a]	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	011:09:43:01.615 011:09:43:02.065
SRB Physical Separation[a]	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	011:09:43:04.375 011:09:43:04.375
SRB Separation Command	SRB separation command flag	011:09:43:05
3g Acceleration	Total load factor	011:09:48:27.0
Throttle Down for 3g Acceleration[a]	ME-2 command accepted ME-3 command accepted ME-1 command accepted	011:09:48:27.188 011:09:48:27.232 011:09:48:27.242
Throttle Down to 67 Percent Thrust[a]	ME-2 command accepted ME-3 command accepted ME-1 command accepted	011:09:49:20.309 011:09:49:20.354 011:09:49:20.363
SSME Shutdown[a]	ME-2 command accepted ME-3 command accepted ME-1 command accepted	011:09:49:26.669 011:09:49:26.714 011:09:49:26.723
MECO	MECO command flag MECO confirm flag	011:09:49:27 011:09:49:28
ET Separation	ET separation command flag	011:09:49:46

[a]MSFC supplied data

TABLE I.- STS-72 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	011:09:56:20.695 011:09:56:28.579 011:09:56:34.021
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	011:10:24:30.1 011:10:24:30.2
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	011:10:25:41.9 011:10:25:42.0
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	011:11:07:17 011:11:08:35
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	012:13:40:02.6 012:13:40:02.7
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	012:13:42:37.8 012:13:42:37.9
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 013:02:49:45.2
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 013:02:49:57.8
Space Flyer Unit Grapple	Payload captured	013:10:57:19
Space Flyer Unit Latch	Payload Select 3 latch 2B Latched	013:11:39:30
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	013:14:37:13.3 013:14:37:13.4
OMS-5 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	013:14:38:46.9 013:14 38:47.0
OMS-6 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	013:15:24:29.5 013:15:24:29.6
OMS-6 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	013:15:26:02.5 013:15:26:02.6
OAST Unberth	Payload select 1 latch 3A ready to latch	014:10:57:13
OAST Release	Payload captured	014:11:32:33
OAST Grapple	Payload captured	016:09:47:15
OAST Berth	Payload select 1 latch 4A ready to latch	016:10:14:02
OAST Latch	Payload select 1 latch 4A latched	016:10:15:40
Flight Control System Checkout APU Start APU Stop	 APU-3 GG chamber pressure APU-3 GG chamber pressure	 019:02:47:46.533 019:02:51.48.943
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	020:04:00:10 020:04:02:48
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	020:06:36:29.139 020:06:57:07.566 020:06:57:09.262

TABLE I.- STS-72 SEQUENCE OF EVENTS (Concluded)

Event	Description	Actual time, G.m.t.
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	020:06:41:23.0 020:06:41:23.1
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	020:06:43:59.5 020:06:43:59.7
Entry Interface (400K feet)	Current orbital altitude above	020:07:10:01
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	020:07:35:06
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	020:07:41:41 020:07:41:41
Drag Chute Deployment	Drag chute deploy 1 CP Volts	020:07:41:43.0
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels RH main landing gear weight on wheels	020:07:41:45 020:07:41:46
Nose Landing Gear Contact	NLG LH tire pressure 1	020:07:41:51
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	020:07:41:51
Drag Chute Jettison	Drag chute jettison 1 CP Volts	020:07:42:17.4
Wheel Stop	Velocity with respect to runway	020:07:42:46
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	020:07:59:50.504 020:07:59:55.789 020:08:00:00.492

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-72-V-01	Flash Evaporator System (FES) shutdowns	015:09:00 G.m.t. 03:21:19 MET CAR 72RF01 PR ECL-5-11-0454	During this time period, the topping FES shut down twice on the A controller and twice on the B controller during a FES water dump. A subsequent FES core flush was terminated when the duct temperatures went below 50 °F, indicating an unsuccessful attempt to deice the FES. A core flush was performed at 017:13:13 G.m.t. (06:03:32 MET) and successful operation of the topping FES was regained. FES operated on the B Controller for the rest of the mission. Previously, the hi-load FES had experienced an A controller shutdown [011:11:07 G.m.t. (00:01:26 MET)] that was regained with a switch cycle. Additionally, the topper FES failed to come out of standby twice [011:22:54 G.m.t. (00:13:13 MET) and 013:12:42 G.m.t. (02:03:01 MET)] while on the A controller. These were considered to be nuisance shut downs caused by control sensor lags. KSC: A boroscope inspection of the topping evaporator core and a leak test of topping evaporator A isolation and spray valves was performed. The condition of the core was visually unchanged from its preflight condition and the valves did not leak. System controller A and control sensors were tested and no anomalies were found. Also, the system A feed-line accumulator was tested and no anomalies were noted. The topping evaporator system A valves and the system A controller will be replaced.
STS-72-V-02	Primary RCS Thruster L1A Failed Off	019:03:33:39 G.m.t. 07:17:52:39 MET CAR 72RF02 PR LP04-18-0673	During the RCS hot-fire, primary thruster L1A (s/n 574) failed off due to low chamber pressure (Pc) on its first pulse and was deselected by redundancy management (RM). The 320-msec pulse started at a Pc of 11 psia and ramped to a peak of 16.5 psia prior to the deselection. Injector temperature cooling trends indicated the presence of both oxidizer and fuel flow. On soak back, the injector temperatures undershot the initial pre-firing temperature, indicating minimal heat input and confirming low thruster performance. Based on the failure signature, the most probable failure mode is nitrate contamination of the oxidizer valve resulting in impeded pilot stage flow and failure of the main stage to open. KSC: All three thrusters on the L1 manifold will be removed and replaced.

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-72-V-03	Primary RCS Thruster R2U Failed Leak	019:03:39:45 G.m.t. 07:17:58:45 MET CAR 72RF03 PR-RP05-09-0191	During the RCS hot-fire, the primary thruster R2U (s/n 620) oxidizer valve began leaking after its first pulse. The thruster fired a second time prior to being deselected by RM as fail-leak. The fail-leak limit is approximately 30 °F for oxidizer. The actual deselection came when the oxidizer temperature was 17.5 °F. This can be explained by the O.52 Hz rate of the "Jet-Leak Monitor" module and the filter that requires three consecutive out-of-limit values prior to fault annunciation. This effectively requires the oxidizer temperature to stay below 30 °F for six seconds prior to deselection. The most probable cause of leakage is contamination trapped on the valve sealing surface. This could be either nitrates/oxides or transient foreign contamination. The leak stopped approximately six hours prior to landing. The thruster was reselected for entry and kept in last priority. KSC: All three thrusters on manifold R2 will be removed and replaced.
STS-72-V-04	LO_2 ET/Umbilical Frangible Nut Detonator Did Not Fire	011:09:49:46 G.m.t. 00:00:08:46 MET CAR 72RF05 PR OEL-5-11-1121	During the postflight inspection of the ET/umbilical attachment hardware, it was found that 1 of 2 detonators in the frangible nut for the LO_2 umbilical inboard attachment stud (disconnect 2) did not fire. During troubleshooting, a short was found in a connector at the debris containment can. The harness was removed and replaced and sent to the laboratory for analysis. Damage was found in a wire at the connector. Engineering is evaluating a potential overstress of a transistor in the EMEC.

TABLE III.- GOVERNMENT FURNISHED EQUIPMENT PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-72-F-01	Camcorder Tape Jams on S/N 1005 and 1006	016:10:20 G.m.t. 05:00:39 MET	Crew reported that camcorders s/n 1005 and 1006 were jammed with tapes inside. The crew attempted several times to eject tapes without success. Crew reported that one camcorder made crunching sounds while tape ejection was attempted. The second camcorder sounded normal during tape ejection attempts. The crew tried power cycles and alternate VSU's and battery power to recover the camcorders.
STS-72-F-02	Camcorder Viewfinder Failure on S/N 1004	016:10:20 G.m.t. 05:00:39 MET	Crew reported the viewfinder on camcorder s/n 1004 had a gray screen. The camcorder did not respond to zoom commands and did not perform auto-focus operations. Crew reported the viewfinder image gray with internal camera selected, and with external video input selected the viewfinder had good video.
STS-72-F-03	Crewman EV1 Left Earphone Failed	017:11:46 G.m.t. 06:02:05 MET	During the second EVA, EV1 reported that his left earphone had failed. It's function was regained later, but subsequently failed again at airlock ingress. Right earphone functioned normally.
STS-72-F-04	Wrist Roll Joint Rate Degradation	011:19:00:00 G.m.t. 00:09:19:00 MET IPR 77V-0004	Review of the data from the RMS checkout has identified a lower-than-expected drive rate for the wrist roll joint in the direct-drive mode. Typical joint motor drive rate for this RMS (s/n 303) was 24 rad/sec; the actual rate obtained was 20 rad/sec. A repeat of the direct drive test has shown a normal wrist roll rate of 24 rad/sec on flight day 2 through 5. On flight day 6, the result of the joint drive was approximately +21.5 and -22.5 rad/sec. Similar result on flight day 7.
STS-72-F-05	Incorrect EDFT-03 TERA Grapple Fixture Orientation	015:06:24:00 G.m.t. 03:20:43:00 MET	The EDFT-03 temporary equipment restraint aid (TERA) grapple fixture was installed 60 degrees away from the correct orientation. The TERA is a component of the portable work platform (PWP).
STS-72-F-06	EDFT-03 APFR Worksite Interface Misalignment	015:06:41:00 G.m.t. 03:21:00:00 MET	The worksite interface (WIF) on the articulating portable foot restraint (APFR) was misaligned such that the marks did not meet black-to-black when installed as designed.

TABLE III.- GOVERNMENT FURNISHED EQUIPMENT PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-72-F-07	EDFT-03 Difficult APFR Plate FSE Latch Operation	015:06:34:00 G.m.t. 03:20:53:00 MET	The flight support equipment (FSE) latch for the APFR plate was very difficult to operate. During removal of the APFR from the latch, the APFR was stuck in the latch. The crew was required to exert a large force to remove the APFR from the latch. During stowage of the APFR, the crew noted a small cloud of black dust released from the plate latch when the latch bolt was driven closed with the power tool. The cloud substance may be dry-film lubricant from the FSE latch.
STS-72-F-08	EDFT-03 Utility Box Connector Cover Loose Velcro	015:10:36:00 G.m.t. 04:00:55:00 MET	During the utility box evaluation, the Velcro patch on the connector cover of the secondary box came loose. The Velcro patch was brought into the cabin.
STS-72-F-09	DTO 672-ECC Update Failed	018:09:41:00 G.m.t. 07:00:00:00 MET	Attempts to update the electronic cuff checklist (ECC) failed. Crew reported that midway through the procedure, the message "can't find files.hed" appeared at step 11 of the ECC update procedure. The display of ECC 1 was permanently disrupted despite power cycles. After renaming the input file from DELTA.BIN to ECC.001, the ECC update procedure was reattempted using ECC 2 with the same result. During all attempts, the file resided on the ECC Update software disk in a directory named UPLINK. The crew reported that ECC 2 still operated normally despite the failed update attempt, but ECC 1's display remained disrupted.
STS-72-F-10	Shoulder Pitch Joint Rate Degradation		Review of the data from the RMS has identified a lower-than-expected drive rate for the shoulder pitch joint in direct-drive mode. The typical joint motor drive rate for this RMS (s/n 303) is 25 rad/sec; the actual rate obtained was 23 rad/sec.

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 Science 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
ACS	attitude control system
AEM	animal enclosure module
APFR	articulating portable foot restraint
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ATCS	active thermal control system
BRT	body restraint tether
CPCG	Commercial Protein Crystal Growth
DMHS	dome-mounted heat shield
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔV	differential velocity
ECC	electronic cuff checklist
ECLSS	Environmental Control and Life Support System
EDFT-03	EVA Development Flight Test - 03
EMU	extravehicular mobility unit
EPDC	electrical power distribution and control subsystem
ET	External Tank
EV	extravehicular (crewmember)
EVA	extravehicular activity
FCE	flight crew equipment
FCP	fuel cell powerplant
FCS	flight control system
FCV	flow control valve
FES	flash evaporator system
FLEXBEAM 2	Flexible Beam Experiment-2
FRCI	fibrous refractorya composite insulation
FSE	flight support equipment
ft/sec	feet per second
GADACS	GPS Attitude Determination and Control Experiment
GAS	Get Away Special
GFE	Government furnished equipment
GH_2	gaseous hydrogen
G.m.t.	Greenwich mean time
GN_2	gaseous nitrogen
GO_2	gaseous oxygen
GPC	general purpose computer
GPS	Global Positioning System
H_2	hydrogen
HHL	hand-held laser
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump

IFM	in-flight maintenance
Isp	specific impulse
ISSA	International Space Station Alpha
JSC	Johnson Space Center
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
LOS	loss of signal
lvlh	local vertical local horizontal
MADS	modular auxiliary data system
MCC	midcourse correction maneuver
MCC-H	Mission Control Center-Houston
MECO	main engine cutoff
MET	mission elapsed time
MLG	main landing gear
MM	major mode
MPS	main propulsion system
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NCC	corrective combination maneuver
NC-O	phasing maneuver
NH-S	height adjustment maneuver
NIH	National Institutes of Health
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O_2	oxygen
OAST	Office of Aeronautics and Space Technology
OI	operational instrumentation
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
PAL	protuberance air load
PARE/NIH-R	Physiological and Anatomical Rodent Experiment/National Institutes of Health -Rodents
Pc	chamber pressure
PCG	Protein Crystal Growth
PCG-STES	Protein Crystal Growth-Single Locker Thermal Enclosure System
PDAP	portable data acquisistion package
PDI	payload data interleaver
PFRWS	portable foot restraint workstation stanchion
PIT	pre-integrated truss
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution

psia	pound per square inch absolute
PWP	portable work platform
RBAR	radius vector axis
RCS	reaction control subsystem
REFLEX	Return Flux Experiment
RM	Redundancy Management
RMS	Remote Manipulator System
ROEU	remotely operated electrical umbilical
RR	rendezvous radar
RSRM	Reusable Solid Rocket Motor
RSS	range safety system/root sum square
RTV	room temperature vulcanizing (material)
RU	rigid umbilical
S&A	safe and arm
SELODE	Solar Exposure to Laser Ordnance Device
SFU	Space Flyer Unit
SLA	Shuttle Laser Altimeter/Satellite Linear Acceleration
SLF	Shuttle Landing Facility
S/N	serial number
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SPRE	SPARTAN Packet Radio Experiment
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSBUV/A	Shuttle Solar Backscatter Ultraviolet Experiment/A
SSME	Space Shuttle main engine
STL/NIH-C	Space Tissue Loss/National Institutes of Health-Cells
TEPC	Tissue Equivalent Proportional Counter
TERA	temporary equipment restraint aid
TES-2	Thermal Energy Storage-2
TI	terminal phase initiation
TIG	time of ignition
TMG	thermal micrometeorite garment
TPS	thermal protection system
Vdc	Volts direct current
WCS	waste collection system
WETF	Weightless Environment Test Facility
WIF	work-site interface fixture
WSB	water spray boiler