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STS-77 SPACE SHUTTLE MISSION REPORT

June 1996

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

NOTE

The STS-77 Space Shuttle Mission Report was prepared from inputs received from the Space Shuttle Vehicle Engineering Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

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STS-77

SPACE SHUTTLE

MISSION REPORT

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INTRODUCTION

The STS-77 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-seventh flight of the Space Shuttle Program, the fifty-second flight since the return-to-flight, and the eleventh flight of the Orbiter Endeavour (OV-105). STS-77 was also the last flight of OV-105 prior to the vehicle being placed in the Orbiter Maintenance Down Period (OMDP). In addition to the Orbiter, the flight vehicle consisted of an ET that was designated ET-78; three SSMEs that were designated as serial numbers 2037, 2040, and 2038 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-080. The RSRMs, designated RSRM-47, were installed in each SRB and the individual RSRMs were designated as 360T047A for the left SRB, and 360T047B for the right SRB.

The STS-77 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 successfully perform the operations necessary to fulfill the requirements of Spacehab-4, the SPARTAN 207/Inflatable Antenna Experiment (IAE), and the Technology Experiments Advancing Missions in Space (TEAMS) payload. Secondary objectives of this flight were to perform the experiments of the Aquatic Research Facility (ARF), Brilliant Eyes Ten-Kelvin Sorption Cryocooler Experiment (BETSCE), Biological Research in Canisters (BRIC), Get-Away-Special (GAS), and GAS Bridge Assembly (GBA).

The STS-77 mission was planned as a 9-day flight plus 1 day, plus 2 contingency days, which were available for weather avoidance or Orbiter contingency operations. The sequence of events for the STS-77 mission is shown in Table I, and the Space Shuttle Vehicle Management 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 six-person crew for STS-77 consisted of John H. Casper, Col., U. S. Air Force, Commander; Curtis L. Brown, Jr., Lt. Col., U. S. Air Force, Pilot; Andrew S. W. Thomas, Civilian, Ph.D., Mission Specialist 1; Daniel W. Bursch, CDR., U. S. Navy, Mission Specialist 2; Mario Runco, Jr., Civilian, Mission Specialist 3;

and Marc Garneau, Civilian, Ph.D., Mission Specialist 4. STS-77 was the fourth flight for the Commander; the third space flight for the Pilot, Mission Specialist 2 and Mission Specialist 3; the second space flight for Mission Specialist 4; and the first space flight for the Mission Specialist 1.

MISSION SUMMARY

The STS-77 countdown proceeded nominally with no unplanned holds, and the vehicle was launched on-time at 140:10:30:00.009 G.m.t. (5:30 a.m. c.d.t.) on May 19, 1996. No Orbiter problems were noted during the countdown. The ascent phase was nominal, and the vehicle was inserted into the planned circular orbit of 153 nautical miles on an inclination of 39 degrees.

During ascent, water spray boiler (WSB) 2 experienced an under-cooling condition on controller A. When the auxiliary power unit (APU) 2 lubrication oil temperature rose past the nominal 250 °F for start of spray cooling and reached 306 °F, the backup controller was selected at 140:10:43:54 G.m.t. (00:00:13:54 MET). Spray cooling was observed approximately 2 minutes 47 seconds after switching to the backup controller, and that was approximately one minute after APU 2 shutdown. The lubrication oil temperature at the time of the start of spraying was 331 °F.

An analysis of the vehicle performance 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 3g throttling was 453.8 seconds compared to a Space Shuttle main engine (SSME) tag value of 452.88 seconds.

The orbital maneuvering subsystem (OMS) 1 maneuver was not required as the direct ascent trajectory was flown as planned. The OMS 2 maneuver was performed at 140:11:11:47.2 G.m.t. (00:00:41:17.2 MET). The maneuver was 126.4 seconds in duration, and the differential velocity (ΔV) was 198.6 ft/sec. The resulting orbit was 152.8 by 153.3 nmi.

The payload bay doors were opened satisfactorily at 140:12:12:28 G.m.t. (00:01:42:28 MET).

The flash evaporator system (FES) experienced a shut down at 140:12:27:09 G.m.t. (00:01:57:09 MET) before the high-load evaporator had transitioned to standby. The FES was restarted and performed nominally.

After the remote manipulator system (RMS) checkout was successfully completed at 140:18:19 G.m.t. (00:07:49 MET), the RMS was used to perform a payload bay survey. The RMS deployed the SPARTAN satellite with the successful release taking place at 141:11:29:12 G.m.t. (01:00:59:12 MET). Following Inflatable Antenna Experiment (IAE) operations, the RMS was cradled at 141:15:59 G.m.t. (01:05:29 MET).

The Ku-Band radar successfully acquired and tracked the SPARTAN satellite following its deployment. The SPARTAN was acquired at a range of 136 ft and tracked through the V Bar and R Bar stationkeeping activities. The payload was again acquired after the jettison of the IAE while at a range of about 6000 feet.

The post-SPARTAN deployment reaction control subsystem (RCS) -X/multi-axis separation maneuver (SEP S-1) was performed at 141:11:31:16 G.m.t. (01:01:01:16 MET). At 141:11:32:46 G.m.t. (01:01:02:46 MET), the RCS redundancy management (RM) software annunciated a Fail-Leak message and deselected thruster F2F (Flight Problem STS-77-V-01). The crew closed the forward RCS manifold 2 (both fuel and oxidizer) at 141:12:06:49 G.m.t. (01:01:36:49 MET), and this action also isolated thrusters F2R, F2U and F2D. Thruster F2F was confirmed to have an oxidizer leak.

During SPARTAN rendezvous operations, the Ku-Band radar successfully acquired the SPARTAN satellite at 142:09:48 G.m.t. (01:23:18 MET) at a range of 118,000 feet. Radar-lock on the satellite was intermittent until the range was less than 78,000 feet because of the small radar cross-section of the SPARTAN. The satellite was tracked satisfactorily until a range of 80 feet was attained when the radar system broke lock and was configured back to the communications mode.

The RMS retrieved the SPARTAN satellite with a successful capture taking place at 142:14:52:47 G.m.t. (02:04:22:47 MET). Prior to retrieving the SPARTAN satellite, an RMS wrist-pitch direct-drive test was performed to verify the slightly lower-than-normal wrist-pitch direct-drive response that was obtained during the RMS checkout at the start of the mission. The repeat test showed nominal wrist-pitch direct-drive rate responses in both the positive and negative directions. The SPARTAN satellite was successfully berthed at 142:15:55:41 G.m.t. (02:05:25:41 MET). The RMS was subsequently cradled.

At approximately 142:20:00 G.m.t. (02:09:30 MET), downlink video revealed that a portion of the payload bay liner had become detached. This condition had no impact on the mission.

The primary RCS thruster R3A heater failed off at approximately 142:23:30 G.m.t. (02:13:00 MET). The primary R3A thruster was hot-fired to maintain the valve temperature above the 40 °F lower limit because of the heater failure. The first of these firings was performed at approximately 143:06:20 G.m.t. (02:19:50 MET), and the temperatures responded as expected.

The Ku-Band radar performance was nominal during the Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test Unit (PAMS/STU) operations.

During the first STU stationkeeping operation, RCS thrusters L3A and R3A were fired with injector temperatures exceeding the Shuttle Operational Data Book (SODB) limit of 157 °F. To avoid similar temperature excesses on upcoming stationkeeping operations, a procedure was developed to switch to thrusters L1A and R1A (reprioritization) when L3A and R3A approached 157 °F.

Fuel cell 3 reached its 2400-hour life limit on its stack at 143:16:57 G.m.t. (03:06:27 MET). For this mission, an exception had been written to extend the life to 2800 hours. Fuel cell 3 performance remained nominal throughout the mission.

The Mission Management Team (MMT) approved an extension of one day to the mission, making it a 10-day mission.

In fulfilling the requirements of the RCS passive hot-fire, all RCS thrusters were fired during the mission except F2U.

A supply water dump through the FES was initiated at 145:05:32 G.m.t. (04:19:02 MET). Just prior to the scheduled supply water dump, the FES did not come out of the standby mode as expected for nominal on-orbit cooling operations while operating on the A controller. FES operation was recovered after the controller power was cycled, and the supply water dump was performed without incident. The supply water dump was terminated at 145:08:00 G.m.t. (04:21:30 MET).

Aft primary RCS thruster fuel injector temperatures were managed during the second PAMS/STU rendezvous operations by thruster reprioritization. Thruster pairs R3A/L3A or R1A/L1A were used to prevent the upper fuel injector temperature limit of 157 °F from being exceeded. One minor exceedance occurred on thruster R3A during which the fuel injector temperature reached 158 °F before thruster pair R1A/L1A was selected.

When the pressure control system (PCS) was reconfigured to system 1 at 147:03:12 G.m.t. (06:16:42 MET), the system 1 oxygen pressure supply transducer failed off-scale low. This transducer had been tracking with the other transducers in the systems until the time of failure. Approximately 14 hours later at 147:17:11:02 G.m.t. (07:06:41:02 MET), the measurement returned in one step to the normal indication. The transducer performed nominally for the remainder of the mission.

During the third PAMS/STU rendezvous, RCS thruster temperatures were managed adequately with repriortization. After completion of the final rendezvous of the mission, the separation maneuver was performed at 148:15:45 G.m.t. (08:05:15 MET) and imparted a ΔV of 5.9 ft/sec.

The flight control systems (FCS) checkout was successfully performed, beginning at 149:05:28 G.m.t. (08:18:58 MET) and ending at 149:06:22 G.m.t. (08:19:52 MET). As planned, APU-2 ran for an extended time during FCS checkout to verify the proper functioning of WSB 2 on both the A and B controllers. The APU was started at 149:05:40:02.234 G.m.t. (08:19:10:02.234 MET), ran for 11 minutes and 14 seconds, and consumed 25 lb of fuel. All performance parameters of the APU were nominal. The WSB-2 performance and steam-vent-heater operation were nominal. Spray cooling using the 'A' controller was observed for 2 minutes, 58 seconds, followed by nominal cooling using the 'B' controller. Approximately 1.4 lb of water was used for cooling. Nominal performance of all subsystems exercised during the FCS checkout was observed.

All entry stowage and deorbit preparations were completed in preparation for entry on the one-day-extension (approved by MMT on flight day 5) landing day. The Ku-Band antenna was stowed at 149:13:35 G.m.t. (09:03:05 MET). The payload bay doors were successfully closed and latched at 150:07:30:09 G.m.t. (09:21:00:09 MET).

The deorbit maneuver was performed at 150:10:09:30.2 G.m.t. (09:23:39:30.2 MET) on orbit 160 for a landing at the Shuttle Landing Facility (SLF) at Kennedy Space Center, Florida. The firing duration was 208.8 seconds and the ΔV was 353.7 ft/sec. Entry interface (400,000 ft) occurred at 150:10:37 G.m.t. (10:00:37 MET).

The hydraulic system 2 priority valve lagged when the main pump was placed to normal pressure after APU 2 start for entry. The lag was 1.4 seconds in duration, and the specification value is no greater than 1 second.

WSB 3 experienced two over-cooling conditions during entry. In both cases, the lubrication oil temperature dropped to approximately 200 °F and then returned to the nominal value of 250 °F. WSB 3 over-cooling was observed on the previous two flights of this vehicle.

Entry was completed satisfactorily, and main landing gear touchdown (weight on wheels) occurred on SLF concrete runway 33 at 150:11:09:24 G.m.t. (10:00:39:24 MET) on May 29, 1996. The Orbiter drag chute was deployed at 150:11:09:26.9 G.m.t., and the nose gear touchdown occurred 7.1 seconds later. The drag chute was jettisoned at 150:11:09:56.0 G.m.t., with wheels-stop occurring at 150:11:10:11 G.m.t. The rollout was normal in all respects. The flight duration was 10 days 0 hours 39 minutes and 24 seconds. The APUs were shut down approximately 16 minutes 02 seconds after landing.

PAYLOADS

The STS-77 mission was extremely successful from the science standpoint with all minimum mission objectives exceeded. The SPARTAN 207/Inflatable Antenna Experiment (IAE) was deployed, the SPARTAN 207 carrier and IAE data were retrieved, the Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test Unit (PAMS/STU) was deployed and the four rendezvous operations were conducted with the PAMS/STU very successfully. In addition, excellent scientific data were provided to the Spacehab-04 scientists, as well as the Technology Experiments Advancing Missions in Space (TEAMS) and the Brilliant Eyes Ten-Kelvin Sorption Cryocooler Experiment (BETSCE) scientists.

SPACEHAB-4

All experiment operations were successfully completed and excellent results were achieved for the Spacehab-4 (fourth flight) payload over the 10-day flight. The module subsystems performed in a near-flawless manner. The video control switch and serial (data) converter unit provided ground commanding and switching onboard, permitting teleoperations for four experiments. The scientists were happy with the results of the12 experiments that were accommodated in 55 locker-volume equivalents, including two rack facilities.

The Spacehab module was located in the forward part of the payload bay and connected to the middeck with a short tunnel. The module carried nearly 3,000 lb of experiments and support equipment, which was packed in 28 lockers, 4 soft stowage bags, and 2 single racks. The experiments carried in the Spacehab module were:

a. Advanced Separation Process for Organic Materials (ADSEP);
b. Commercial Generic Bioprocessing Apparatus (CGBA);
c. Plant Generic Bioprocessing Apparatus (PGBA);
d. Fluids Generic Bioprocessing Apparatus-2 (FGBA-2);
e. Gas Permeable Polymer Membrane (GPPM);
f. Hand-held Diffusion Test Cell (HHDTC);
g. Commercial Float Zone Furnace (CFZF); and
h. Space Experiment Facility (SEF).

Advanced Separation Process for Organic Materials

During activation of the ADSEP, it was noted that the onboard command capability for the ADSEP was not operational. Troubleshooting revealed that the problem was between the ADSEP computer and the Spacehab Interface Processor. The command capability was restored by reconfiguring and using the SEF cable.

Commercial Generic Bioprocessing Apparatus

The CGBA housed several test-tube sized fluid-mixing syringes that were controlled at different temperatures. Because of the versatility of this apparatus, 272 individual investigations were conducted in four temperature-controlled compartments. The experiment performed nominally throughout the flight.

Plant Generic Bioprocessing Apparatus

The PGBA onboard-screen displayed an incorrect mission elapsed time, and procedures to correct this condition were unsuccessful. The data received on the ground were good and this indicates that the PGBA is operating correctly.

Fluids Generic Bioprocessing Apparatus

This apparatus for dispensing two-phase fluids (carbonated beverages) performed successfully. However, an in-flight maintenance (IFM) procedure was performed to correct the temperature control for the beverage fluids. Approximately 40 drinks were dispensed (including ad-lib drinks), and the desired technology was satisfactorily demonstrated

The onboard water quantity in the common water supply was reduced during preflight operations to eliminate an overweight condition. As a result, the FGBA could support the option for ad-lib drinks to only a limited extent.

Gas Permeable Polymer Membrane

The GPPM was flown for the third time and it was sponsored by Langley Research Center and Paragon Vision Sciences. The purpose of the experiment was the development of enhanced polymers under microgravity conditions for use in contact lenses. Results of the experiment were not available at the time of publication and may be obtained from the sponsors.

Hand-Held Diffusion Test Cell

The HHDTC experiment units each contained eight test cells for crystal growth. Postflight assessment was required and the results may be obtained from the experiment sponsor.

Commercial Float Zone Furnace

The CFZF was the highest priority experiment on STS-77 and it was a joint endeavor with a U. S/Canadian developed furnace facility (using a German furnace). The experiment performed above expectations throughout the mission with 14 material samples processed (12 planned). The 12 planned runs were operated via telescience with over 700 commands uplinked with visual feed-back by real-time video. first run was completed two hours early and with 25 percent less power than ground-based processing. Power consumption was less than that observed in ground-based processing. Three materials were processed for the first time in microgravity.

Space Experiment Facility

The SEF was activated at 144:04:30 G.m.t. (03:18:00 MET), and initially the crew experienced trouble loading the run profile using the hard-drive and floppy disk that were onboard. The Principal Investigator (PI) successfully commanded the profile from the ground. Both the A and B furnaces were powered and nucleation was established on both furnaces after reworking a spurious nucleation on side B.

The SEF shut down at 146:05:51 G.m.t. (05:19:21 MET) while performing the transparent run after 49 hours 21 minutes of operation. The cause of the shut down was not determined; however, the shut down did not impact the performance of the transparent run. Evaluation determined that the transparent run was successful as two crystals were formed and saved. This was the first success with this run after three previous flights. The opaque furnace successfully completed the planned materials processing with help from the crew.

SPARTAN 207/INFLATABLE ANTENNA EXPERIMENT

The successful SPARTAN 207/IAE was one of the primary payloads for the STS-77 mission, which was the most ambitious SPARTAN mission of the Space Shuttle Program. The spacecraft had a unique configuration for this mission as the IAE was a separate additional unit that was ejected at the completion of the experiment.

The IAE was a 14-meter diameter inflatable antenna reflector structure, and it was mounted on three 92-foot (28 meter) struts. The RMS deployed the SPARTAN satellite with the successful release taking place at 141:11:29:12 G.m.t. (01:00:59:12 MET). After the SPARTAN was released from the Orbiter, the IAE inflation process was begun, resulting in an antenna that was approximately the size of a tennis court.

The antenna structure, despite some unexpected deployment dynamics, inflated to the proper shape and maintained the rigid shape for a complete orbit while rotating at approximately 180 degrees per minute, successfully demonstrating the fundamental performance of this new technology. Final assessment of the canopy inflation performance will be determined from the data recorded onboard the SPARTAN 207 spacecraft.

The SPARTAN 207 spacecraft, after IAE jettison, was able to return to the pre-mission attitude and maintain a stable configuration until the RMS grappled the SPARTAN and returned it to the payload bay. The only malfunction was the failure of the extravehicular mobility unit (EMU) radio frequency (RF) system to radiate the video signal from the camera on the SPARTAN to the Orbiter closed-circuit television (CCTV) for recording (backup to IAE experiment video). The analysis of the IAE video will enable a determination of the reasons for the rotation of the IAE and the shape of the antenna lens (if off-nominal). All objectives of the experiment were met.

The RMS retrieval of the SPARTAN satellite, with the IAE data, was completed with the successful capture taking place at 142:14:52:47 G.m.t. (02:04:22:47 MET). The SPARTAN satellite was successfully berthed in the Orbiter payload bay at 142:15:55:41 G.m.t. (02:05:25:41 MET), after which the RMS was cradled.

An extravehicular mobility unit (EMU) television camera and an frequency modulated (FM) transmitter were mounted on the SPARTAN to provide video to the Orbiter. During preparations for the SPARTAN deployment, the crew noted that the EMU video signal could not be acquired. In addition, several ground stations also attempted to acquire the video transmission from the EMU camera, but it was reported that no carrier signal was present.

Brilliant Eyes Ten Kelvin Sorption Cryocooler Experiment

The Brilliant Eyes Ten Kelvin Sorption Cryocooler Experiment (BETSCE) carried an instrument that was capable of quickly cooling infrared and other sensors to near absolute zero (10 °K or -441.6 °F).

The BETSCE heaters were turned on during flight day 2, and the unit was activated at 143:07:30 G.m.t. (02:21:00 MET). A computer software problem interrupted the data collection; however, a new set of command tables were developed by the ground team and transmitted to the experiment, which was again operational in less than 4 hours from the original shutdown.

During the first operational cool-down period, the temperature of the hydrogen bed was slightly warmer than expected, and the hold-time at the cold temperature was reduced when compared to expectations. An investigation revealed that a small leak existed across valve V2 in the hydrogen system. Attempts to seal the leak were unsuccessful; however, the experiment continued to operate for the remainder of the mission. Approximately one day of useful data was lost as future cool-downs were limited to 19° Kelvin. Flight data were obtained on a total of 18 compressor cycles, 8 liquid hydrogen cool-down cycles, and one 10° Kelvin solid-hydrogen cycle. Solid hydrogen was produced on the first attempt (flight day 4) at 10° Kelvin. These data fulfill approximately 80 percent of the planned data requirements. An interesting sidelight was that over 20,000 people accessed, via Internet, live BETSCE data downlinked from the Orbiter.

TECHNOLOGY EXPERIMENTS FOR ADVANCING MISSIONS IN SPACE

The Shuttle Hitchhiker (HH) payload experiment carrier housed four experiments in addition to the PAMS experiment discussed previously, and these were called Technology Experiments for Advancing Missions in Space (TEAMS). The three experiments were:

a. Global Positioning System (GPS) Attitude and Navigation Experiment (GANE);
b. Vented Tank Resupply Experiment (VTRE);
c. Liquid Metal Thermal Experiment (LMTE); and
d. Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test Unit.

Global Positioning System Attitude and Navigation Experiment

The GANE collected data for GPS position as well as attitude. These data will be evaluated for system (hardware and software) applicability of the GPS to the International Space Station Alpha (ISSA). The ISSA will use the GPS for position, velocity, and time information as well as attitude and navigation determination.

The initial power-up of the GANE inertial reference unit (IRU) and the GPS was successful. The IRU performance was excellent early in the mission. The GPS data collection was upset three times because of abnormal payload general support computer (PGSC) software exits; however, no significant data loss occurred and a power-cycle of the PGSC corrected the upset. Subsequently, the PGSC software was modified to reduce the possibility of abnormal upsets.

All primary data-take periods were accomplished, and all star line maneuver data takes were successful. The GANE/GPS hardware performed well. All mission objectives were met as well as the secondary science objectives.

Vented Tank Resupply Experiment

The VTRE was flown to test improved methods for in-space refueling, and all mission objectives were met. The key component in this experiment was the capillary acquisition vane (CAV), which is a set of flat panels inside the tank that keep the liquid away from the tank vent tap.

The experiment was activated and all eight test sequences were completed successfully, and no anomalies were noted. These sequences represent the first successful venting in the history of space flight.

Liquid Metal Thermal Experiment

The LMTE was developed to evaluate the performance of liquid metal heat pipes in microgravity conditions. The three potassium heat pipes initial characterizations were successful.

All mission success criteria were fulfilled prior to the end of the mission with the maximum mission profile of 24 tests being completed. Three liquid potassium heat pipes were the hottest (>500° Celsius) to ever operate in space. This experiment successfully demonstrated heat pipe performance over a range of temperatures and powers, duplicated 1-g ground tests, and evaluated start-up and cool-down phenomena. No in-flight anomalies were reported.

Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test Unit

The objective of the PAMS/STU was to provide data on the stabilization of satellites.

The PAMS/STU successfully performed its functional tests, and was deployed at 143:09:19 G.m.t. (02:22:49 MET). The first rendezvous (proxevous), which was followed by proximity operations at approximately 2000 ft, was completed at 143:14:00 G.m.t. (03:03:30 MET). In addition to the initial proxevous, two individual rendezvouses with the PAM/STU were also completed.

The attitude measurement system (AMS) tracking during the first rendezvous could not be confirmed, but over 1000 images of the satellite were collected. During the second rendezvous, AMS tracking was confirmed and minimum mission objectives were completed. Overall science objectives and demonstrations of aerodynamic satellite stabilization were achieved. The PAMS PGSC had data over-flows which were corrected by an uplinked software fix.

Aquatic Research Facility

The Aquatic Research Facility (ARF) was the first flight of a joint experiment of the Canadian Space Agency (CSA) and NASA with CSA providing the flight hardware and the United States providing flight opportunities and both agencies sharing in the scientific investigations. The three experiments housed within the ARF enables scientists to investigate the process of fertilization, embryo formation and differentiation; development of calcified tissue; and feeding behaviors of small aquatic organisms. The crew reported two anomalies with the ARF equipment, and these are discussed in the following paragraphs.

At 140:16:34 G.m.t. (00:06:04 MET), the crew reported that the needle in the zero-g fertilization syringe unit was bent. The needle was bagged and taped for crew safety reasons, and the one-g needle was used for the remainder of the mission. The use of this needle did not seriously impact the science return from the standard container units.

While performing fertilization on US1 unit 3, resistance was met when inserting the needle. Because of the possibility of misalignment, this unit was left unfertilized, but a backup sample was processed. Very little science was last as a result as the remaining 11 samples were fertilized. The ARF performed nominally throughout the remainder of the mission.

Biological Research in a Canister

The Biological Research in a Canister (BRIC) experiment provided research data that will aid in the discovery of the mechanism(s) behind one endocrine system in insects that may aid in research on endocrine systems in general, including human systems. The experiment consisted of tobacco horn worms larvae flown in containers, the experiment performed nominally with no known anomalies during the mission.

Get Away Specials

The STS-77 mission carried 10 Get Away Special (GAS) experiments. These are described in the following paragraphs; however, no results are presented. The data concerning results must be obtained from the primary investigator.

G-056 - Gamma-ray Astrophysics Mission - The Gamma-ray Astrophysics Mission (GAMCIT) payload was built by the California Tech chapter of the Students for the Exploration and Development of Space (SEDS). This experiment studied the enigmatic source of cosmic radiation known as gamma-ray bursts. These intense bursts of high-energy radiation were first discovered in the late 1960s, and there nature and origin still remain an astrophysical mystery.

G-142 and G-144 - Autonomous Material Science Experiments under Microgravity - The two GAS experiments were sponsored by the German Space Agency (DARA), and were developed by scientists at the Technical University in Munich and the Technical University of Clausthal.

G-163 - Diffusion Coefficient Measurement Facility - This experiment measured the speed at which Mercuric Iodide (solid) was evaporated and then transported as a vapor under microgravity conditions.

G-200 - Utah State University - Three experiments were flown in this canister. In addition, an elementary school flew a payload of popcorn kernels in zip lock bags while maintaining an identical sample on the ground. Postmission the popcorn will be popped and a comparison of the two samples will be made.

G-490 - British Sugar plc. - Two main experiments were carried in this canister, both of which were designed and constructed by the School of Electronics and Electrical Engineering in the Robert Gordon University, Aberdeen, Scotland.

The first investigation provided data in an attempt to verify that low-level gravitational fields can be measured by observing their effect on the convection currents present in heated liquid. The second investigation, devised by pupils of Elrick Primary School, studies microgravity growth patterns of selected samples of seeds, oats, wheat, barley and nape-oil.

G-564 and G-565 - Canadian Space Agency - Two GAS canisters were used to perform the Nanocrystal Get Away Special (NANO-GAS) and the Atlantic Canadian Thin Organic Semiconductors (ACTORS). The data from these experiments were used in an attempt to develop new materials with applications in high-performance lasers and in electronic equipment and components.

G-703 - Microgravity Smoldering Combustion - The smolder characteristics of porous materials in a microgravity environment were studied to obtain more data on the propagation of the smolder reaction. This experiment was sponsored by the NASA Lewis Research Center.

G-741 - Nucleate Pool Boiling Heat Transfer - This experiment studied Nucleate Pool Boiling Heat Transfer under microgravity conditions. This experiment has broadened its range of parameters in this reflight. The experiment was sponsored by the NASA Lewis Research Center.

Tank Pressure Control Experiment/Reduced Fill Level

The Tank Pressure Control Experiment/Reduced Fill Level (TPCE/RFL) experiment provided data on pressure control of cryogenic tankage. The experiment investigated pressure rise rates and pressure control for tanks that were approximately 40-percent full of oxygen. The flight hardware for this experiment was on loan from the NASA Lewis Research Center.

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTERS

Analysis of the flight data and assessment of the postflight condition of the recovered hardware indicates nominal performance of all Solid Rocket Booster (SRB) systems. No SRB in-flight anomalies were identified from the review and analysis of the data.

The SRB prelaunch countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements and Specification (OMRSD) violations occurred. For this flight, the high-pressure heated ground purge in the SRB aft skirt was used to maintain the case/nozzle joint temperatures within the required LCC ranges throughout the countdown.

Both SRBs were successfully separated from the External Tank (ET) at T+ 124.24 seconds. The SRBs were recovered and returned to Kennedy Space Center (KSC) for inspection, disassembly and refurbishment.

REUSABLE SOLID ROCKET MOTORS

Data analysis showed that the Reusable Solid Rocket Motors (RSRMs) performance was nominal and within the contract end item (CEI) specification with no LCC or OMRSD violations during the countdown. The performance was typical of that observed on previous flights and the table on the following page summarizes that performance. The RSRM propellant mean bulk temperature (PMBT) was 79 °F at liftoff. No in-flight anomalies were identified from the review and analysis of the data. The maximum trace shape variation of pressure versus time was less than 0.46 percent for both motors throughout the operational time frame. The allowable limit for the trace shape variation is 3.2 percent.

Power-up and operation of all igniter and field-joint heaters was accomplished routinely. The field joint heaters operated for 11 hours 21 minutes during the countdown, and all field joint temperatures were maintained within the normal operating range. The igniter joint heaters operated for 11 hours 12 minutes during the countdown, and all igniter joint temperatures were maintained within the normal operating range. The aft skirt purge operated for 12 hours 51 minutes during the countdown and maintained the nozzle/case joint temperatures in the normal operating range.

EXTERNAL TANK

All prelaunch and flight objectives and requirements associated with the ET loading and flight operations were met, and flight performance was excellent. All

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 79 °F		Right motor, 79 °F	
	Predict	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	64.93	65.41	65.32	65.33
I-60, 10^6 lbf-sec	173.43	175.01	174.29	175.02
I-AT, 10^6 lbf-sec	297.11	296.29	297.15	295.80
Vacuum Isp, lbf-sec/lbm	268.5	267.8	268.5	267.3
Burn rate, in/sec @ 60 °F at 625 psia	0.3654	0.3689	0.3667	0.3693
Burn rate, in/sec @ 79 °F at 625 psia	0.3685	0.3721	0.3699	0.3725
Event times, seconds[a]				
Ignition interval	0.232	N/A	0.232	N/A
Web time[b]	111.0	109.4	110.3	109.5
50 psia cue time	120.8	119.5	120.1	118.9
Action time[b]	122.9	121.7	122.2	121.0
Separation command	125.7	124.2	125.7	124.2
PMBT, °F	72	72	72	72
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	3.0	2.8	2.8
Tailoff Imbalance Impulse	Predicted		Actual	
differential, Klbf-sec	N/A		247.5	

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).

ET electrical equipment and instrumentation performed satisfactorily. The ET purge and heater operations were monitored, and all performed properly. No ET LCC or OMRSD violations were identified, and no in-flight anomalies were noted during the data review and analysis.

Typical ice/frost formations were observed on the ET during the countdown. There was no observed ice or frost on the acreage areas on the ET. Normal quantities of ice or frost were present on the LO_2 and LH_2 feed-lines and on the pressurization line brackets, and some frost or ice was present along the LH_2 protuberance air load (PAL) ramps. All observations were acceptable based on the NSTS 08303 documentation. The Ice/Frost Red Team reported that there were no anomalous thermal protection system (TPS) conditions.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the ullage pressure slump was 13.6 psid.

ET separation occurred as planned, and the postflight predicted intact impact point of the ET was approximately 7 nmi. Uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

STS-77 was the first flight of a cluster of three Block 1 Space Shuttle main engines (SSMEs). All SSME parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine-ready was achieved at the specified time; all LCC were met; and engine start and thrust buildup were normal.

Flight data indicate that the SSME performance during main-stage, throttling, shutdown, and propellant dump operations was normal. The high pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures were well within specification throughout engine operation. Several minor problems were noted, but all were within the experience base. SSME cutoff (MECO) occurred at 514.06, 514.20, and 514.33 seconds for SSMEs 1, 2, and 3, respectively after engine start, which was approximately 6 seconds prior to liftoff. The specific impulse (Isp) was rated as 453.8 seconds based on trajectory data. No in-flight anomalies were identified during the data evaluation.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as planned 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 satisfactorily throughout the countdown and flight.

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

ORBITER SUBSYSTEM PERFORMANCE

Main Propulsion System

The overall performance of the main propulsion system (MPS) was nominal with no failures or in-flight anomalies identified. There were no OMRSD or LCC violations during the countdown. LO_2 and LH_2 loading were performed as planned with one LO_2 stop flow and revert of 26 minutes duration. The flow stoppage did not impact launch preparations or cause any delay in the launch.

Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment (shortly after start of fast-fill) was approximately 183 ppm (corrected), which compares favorably with previous data for this vehicle.

The LH_2 loading operations were normal, and the LH_2 load at the end of replenish was 231,819 lbm. When this loading values is compared with the inventory (planned) loading of 231,832 lbm, a difference of -0.006 percent is yielded and this is well within the required loading accuracy of ± 0.37 percent.

The LO_2 loading operations were normal, and the LO_2 load at the end of replenish was 1,387,684 lbm. When this loading values is compared with the inventory (planned) loading of 1,388,277 lbm, a difference of -0.04 percent is yielded and this is well within the required loading accuracy of ± 0.43 percent.

Ascent MPS performance appeared to be completely normal. 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. Performance analyses of the propulsion systems during start, main-stage, and shutdown operations indicated that performance was nominal and all requirements were met.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed nominally throughout the STS-77 mission. Two in-flight anomalies were identified. The RCS consumed 4570.5 lbm of propellants from the RCS tanks during the mission. In addition, the RCS consumed 4875.4 lbm (37.64 percent) of OMS propellants during interconnect operations. In addition to attitude control, the RCS was used to perform 31 maneuvers in support of the four rendezvous operations.

The post-SPARTAN deployment RCS -X/multi-axis separation maneuver (SEP S-1) was performed at 141:11:31:16 G.m.t. (01:01:01:16 MET). At 141:11:32:46 G.m.t. (01:01:02:46 MET), the RCS redundancy management (RM) software annunciated a Fail-Leak message and deselected thruster F2F (Flight Problem STS-77-V-01). The leak rate was calculated to be 1000 cc/hr. The crew closed the forward RCS manifold 2 (both fuel and oxidizer) at 141:12:06:49 G.m.t. (01:01:36:49 MET), and this action also isolated thrusters F2R, F2U and F2D. Thruster F2F was confirmed to have an oxidizer leak. Later in the flight, the manifold 2 valves were reopened utilizing a 3-stage repressurization procedure in an attempt to recover thruster F2F; however, the oxidizer valve continued to leak, and manifold 2 was closed for entry. The leak rate of F2F was calculated to be 400 cc/hr after manifold 2 was closed the second time.

The primary RCS thruster R3A heater failed off at approximately 142:15:00 G.m.t. (02:04:30 MET) (Flight Problem STS-77-V-02). The primary R3A thruster was hot-fired to maintain the valve temperature above the 50 °F lower limit because of the heater failure. The first of these firings was performed at approximately 143:06:20 G.m.t. (02:19:50 MET), and the temperatures responded as expected.

During the first STU stationkeeping operation, RCS thrusters L3A and R3A were fired with injector temperatures exceeding the SODB limit of 157 °F. To avoid similar temperature excesses on following stationkeeping operations, a procedure was developed to switch via reprioritization to thrusters L1A and R1A when L3A and R3A approached 157 °F.

In fulfilling the requirements of the RCS passive hot-fire, all RCS thrusters were fired except F2U. That thruster was not fired during the remainder of the mission, and the need for the RCS hot-fire that is normally conducted late in the mission was negated.

Aft primary RCS thruster fuel injector temperatures were managed during the second PAMS/STU rendezvous operations by thruster reprioritization. One minor exceedance occurred on thruster R3A during which the fuel injector temperature reached 158 °F before thruster pair R1A/L1A was selected.

Primary RCS thruster L3A approached the 157°F upper temperature limit after heavy usage during the third PAMS/STU rendezvous operation. Because of this, thruster prioritization was changed to place the manifold 1 aft firing thrusters R1A and L1A in first priority, allowing the manifold 3 thrusters to cool down.

After completion of the final rendezvous of the mission, the separation maneuver was performed at 148:15:45 G.m.t. (08:05:15 MET) and imparted a ΔV of 5.9 ft/sec.

Orbital Maneuvering Subsystem

The orbital maneuvering subsystem (OMS) performed satisfactorily throughout the mission. Data review and analysis did not identify any in-flight anomalies. A total of 13,026.5 lbm of propellants were consumed during the two OMS firings, and an additional 4875.4 lbm (37.64 percent) was consumed by the RCS during interconnect operations. The following table provides pertinent data about OMS operation during the two maneuvers.

OMS FIRINGS

OMS firing	Engine	Ignition time, G.m.t./MET	Firing duration, seconds	ΔV, ft/sec
OMS-2	Both	140:11:11:47.2 G.m.t. 00:00:41:47.2 MET	126.08	198.6
Deorbit	Both	150:10:09:30 G.m.t. 09:23:39:30 MET	208.8	353.7

The OMS 1 maneuver was not required as the direct ascent trajectory was flown as planned. The performance of the OMS during the OMS 2 maneuver was satisfactory and the resulting orbit was 152.8 by 153.3 nmi.

The OMS performance during the deorbit maneuver was also satisfactory. The maneuver was completed on orbit 160 for a landing at the SLF at Kennedy Space Center, Florida.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed nominally throughout the STS-77 mission, and no in-flight anomalies were identified from the data analysis. The PRSD supplied 2745 lbm of oxygen and 346 lbm of hydrogen to the fuel cells for the production of electricity. In addition, 111 lbm of oxygen was supplied to the environmental control and life support system for crew breathing and cabin pressurization. Reactants remaining at landing (1058 lbm of oxygen and 110 lbm of hydrogen) were adequate to perform a 67-hour mission extension at average mission power levels, and a 98-hour mission extension was available at the extension-day power level of 11.1 kW.

Fuel Cell Powerplant Subsystem

The fuel cell powerplant subsystem performed satisfactorily throughout the mission. The average electrical power level and load was 16.3 kW and 541 amperes. The fuel cells produced 3091 lb of potable water and 3924 kWh of electrical energy from the 2745 lbm of oxygen and 346 lbm of hydrogen, and five purges of the fuel cells were performed.

The actual fuel cell voltages at the end of the mission were 0.10 Vdc above the level predicted for fuel cell 1, and 0.15 Vdc above the predicted level for fuel cell 2. Fuel cell 3 exceeded the certified operating life of 2400 hours, and the fuel cell was performing 0.25 Vdc above the predicted level and 0.4 Vdc above the end-of-life curve at landing (2652 hours) and had 2574 hours on its stack at fuel-cell shutdown. A waiver allowed fuel cell 3 to be used for this mission, and the fuel cell will be sent to the vendor for tear-down and evaluation in accordance with the fuel cell life extension program.

No in-flight anomalies were identified; however, three conditions were noted. During the first 10 hours of the mission, the fuel cell 2 hydrogen flow meter operation was erratic with flow indications between 0.4 and 2.1 lbm/hr when the actual flow was between 0.5 and 0.6 lbm/hr. This was the first mission that this condition was noted on this fuel cell. This condition did not impact the flight, and the flow meter will not be replaced until the fuel cell is required to be sent to the vendor for a more significant anomaly.

The fuel cell 2 alternate water-line temperature was erratic for the entire mission, indicating some leakage of warm water past the alternate water-line check valve. The water-line temperature ranged from 87 °F to a maximum of 138 °F, compared to a product water line temperature of 144 °F. This condition has been present on this fuel cell since STS-47, the second flight of this vehicle. The check valve will receive a checkout for proper crack and reseat pressure during the upcoming Orbiter Maintenance Down Period (OMDP).

The fuel cell 3 alternate water-line temperature was erratic for the entire mission, indicating some leakage of warm water past the alternate water-line check valve. On-orbit, the water-line temperature ranged from 78 °F to a maximum of 124 °F, compared to a product water line temperature of 144 °F. This condition has been present on this fuel cell since STS-67, the eighth flight of this vehicle. The check valve will receive a checkout for proper crack and reseat pressure during the upcoming OMDP.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission. No in-flight anomalies were identified in the data evaluation. The run times and fuel consumption for each APU are summarized in the table on the following page.

The APU 2 seal cavity drain line relief valve indicated a slight leak at an initial decay rate of approximately 1.34 psi/day (18.8 psia to 7.0 psia). This exceeded the File IX OMRSD limit of 0.5 psi/day. This condition did not impact the mission. Tests were performed on the APU prior to removing the APU from the vehicle.

The FCS checkout was successfully performed, beginning at 149:05:28 G.m.t. (08:18:58 MET) and ending at 149:06:22 G.m.t. (08:19:52 MET). As planned, APU-2 ran for an extended time during FCS checkout to verify the proper functioning of WSB 2 on both the A and B controllers. The APU was started at 149:05:40 G.m.t. (08:19:10 MET), ran for 11 minutes and 14 seconds, and consumed 23 lb of fuel. All performance parameters of the APU were nominal.

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	22:15	56	20:27	54	22:29	54
FCS checkout			11:14	23		
Entry[a]	59:37	112	80:12	165	60:25	117
Total	81:52	168	111:53	242	82:54	171

[a] The APUs were shut down 16 minutes 2 seconds after landing.

Hydraulics/Water Spray Boiler Subsystem

The hydraulic/water spray boiler (WSB) performance was nominal, except for the under-cooling condition observed on WSB system 2 during ascent and the two over-cooling conditions observed on WSB system 3 during entry. Neither the under-cooling nor the over-cooling conditions impacted the mission. No in-flight anomalies were identified for the hydraulic/WSB system.

During ascent, WSB 2 experienced an under-cooling condition on controller A. When the APU 2 lubrication oil temperature reached 302 °F, the backup controller was selected at 140:10:43:54 G.m.t. (00:00:13:54 MET). Spray cooling was observed approximately 2 minutes 47 seconds after switching to the backup controller, and that was approximately one minute after APU 2 shutdown. The lubrication oil temperature at the time of the start of spraying was 331 °F.

Development Test Objective (DTO) 416 - WSB Quick Restart was performed for the first time this flight to determine the WSB capability to support revolution 2 deorbit and modified abort-once-around (AOA) aborts. A discussion of the results of this first performance of the DTO is contained in the Development Test Objective section of this report.

As a result of the WSB 2 under-cooling condition during ascent that is discussed in a previous paragraph, the FCS checkout was successfully performed using APU 2 instead of APU 1 which is normally used. As planned, APU 2 ran for an extended time during FCS checkout to verify the proper functioning of WSB 2 on both the A and B controllers. The WSB-2 performance and steam-vent-heater operation were nominal. Spray cooling using the 'A' controller was observed for 2 minutes 58 seconds, followed by nominal cooling using the B controller. Approximately 1.4 lb of water was used for cooling. Nominal performance of all subsystems exercised during the FCS checkout was observed.

The hydraulic system 2 priority valve lagged when the main pump was placed to normal pressure after APU 2 start for entry. The lag was 1.4 seconds in duration, and the specification value is no greater than 1 second. The valve exhibited satisfactory performance during ascent and FCS checkout with cracking times of 0.222 second and 0.333 second, respectively. Contamination is believed to be the most likely cause of this lag in valve operation.

WSB 3 experienced two over-cooling conditions during entry. The first over-cooling condition occurred 12 minutes after achieving spray cooling when the lubrication oil temperature decreased from 251 °F to 195 °F and then recovered to a steady-state temperature of 249 °F. Seven minutes later, the lubrication oil temperature decreased again to 205 °F after which it returned to 249 °F. WSB 3 over-cooling was observed on the previous two flights of this vehicle.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed satisfactorily throughout the mission. No abnormal conditions or in-flight anomalies were identified.

Near the end of the mission, a large single-sample current transient of 52 amperes was detected on the main A and main B buses. The analysis of the data indicated that the most probable cause was a thermal impulse printer system (TIPS) power cycle that is powered from AC1 phase B. A review of laboratory tests confirmed that the TIPS could have produced such a transient. Discussion with flight controller personnel confirmed that TIPS power cycles occurred during the period of the current transient.

Environmental Control and Life Support System

The environmental control and life support system (ECLSS) performed satisfactorily throughout the mission. No in-flight anomalies were identified from the data analysis.

The atmospheric revitalization system (ARS) performed nominally. The maximum cabin environmental conditions encountered during the flight were a cabin air temperature of 81 °F, cabin humidity of 49.16 percent, and a peak partial pressure of carbon dioxide ($PPCO_2$) of 4.58 mm Hg of $PPCO_2$.

The avionics bay temperatures reached a maximum value of 97.41 °F in bay 1, 89.7 °F in bay 2, and 78.57 in bay 3. The avionics bay water coolant loop heat exchanger outlet maximum temperatures were 76.65 °F for bay 1, 89.7 °F for bay 2, and 79.86 for bay 3. The avionics bay water coolant loop cold plate outlet maximum temperatures were 80.97 °F for bay 1, 78.0 °F for bay 2, and 82.85 °F for bay 3.

The ac phase A current on the inertial measurement unit (IMU) fan B was lost at 144:04:47 G.m.t. (03:18:17 MET), and the fan continued to operate on two phases. IMU fan C was activated and operated satisfactorily for the remainder of the flight. The loss of IMU fan B did not impact the flight.

The supply water and waste management systems performed normally throughout the mission. Supply water was managed through the use of the flash evaporator system (FES) and the overboard dump system. Eight supply water dumps were performed at a rate of 1.51 percent/minute (2.49 lb/min), and three of these dumps were performed simultaneous with waste water dumps. The supply water dump line temperature was maintained between 71 and 97 °F throughout the mission with the operation of the line heater. Water tank D was again noted to have a lower quantity reading of -5 percent as had been seen on previous missions of this vehicle. This transducer will be inspected during the Orbiter Maintenance Down Period scheduled to follow this flight.

Waste water was gathered at the predicted rate. Three waste water dumps were performed at an average rate of 2.08 percent/minute (3.44 lb/min). The waste water dump line temperature was maintained between 53 and 85 °F, which is within the nominal range, throughout the mission. The vacuum vent line temperature was between the nominal values of 57 and 80 °F throughout the mission, and the vacuum vent nozzle temperature was maintained between the nominal values of 110 and 161 °F.

A simultaneous supply and waste water dump was initiated at 142:06:06 G.m.t. (01:19:36 MET). The supply and waste water dump quantities at the start of the dump were 551.2 lb and 67.6 lb, respectively. The waste tank was inadvertently dumped to an indicated tank quantity of 1.9 lb. This resulted in a waste liquid pressure of 0.0 psia on the water side of the bellows. The supply water dump was terminated at 142:07:28 G.m.t. (01:20:58 MET), with a total quantity of 339 lb remaining. This dump did not impact mission operations or the waste water hardware.

A supply water dump through the FES was initiated at 145:05:32 G.m.t. (04:19:02 MET). Just prior to the scheduled supply water dump, the FES did not come out of the standby mode as expected for nominal on-orbit cooling operations while operating on the A controller. FES operation was recovered after the controller power was cycled, and the supply water dump was performed without incident. The supply water dump was terminated at 145:08:00 G.m.t. (04:21:30 MET).

The waste collection system performed normally throughout the mission.

The flash evaporator system (FES) experienced a shut down at 140:12:27:09 G.m.t. (00:01:57:09 MET) before the high-load evaporator had transitioned to standby. The FES was restarted and performed nominally.

When the pressure control system (PCS) was reconfigured to system 1 at 147:03:12 G.m.t. (06:16:42 MET), the system 1 oxygen pressure supply transducer failed off-scale low. This transducer had been tracking with the other transducers in the systems until the time of failure. Approximately 14 hours later at 147:03:11:02 G.m.t. (06:16:41:09 MET) the measurement returned in one step to the normal indication. The transducer performed nominally for the remainder of the mission.

Smoke Detection and Fire Suppression Subsystem

No evidence of smoke within the cabin was noted during the mission. The fire suppression subsystem was not used.

Airlock Support System

There were no extravehicular activities during this mission, and thus, the airlock support system was not used.

Avionics and Software Support Subsystems

The guidance, navigation and control subsystem performed satisfactorily throughout the mission, which included four rendezvous operations. A more complete discussion of the rendezvous operations is contained in the Rendezvous section of this report.

The navigation equipment operation during entry was excellent. There were no hardware failures or deselections by redundancy management (RM). Data from the external sensors were incorporated into the onboard navigation states at the expected times. Drag measurement processing began at 234,000 ft and ended at 85,000 ft. Tactical Air Navigation (TACAN) station acquisition occurred at approximately 152,000 ft, and the TACAN bearing data were not used during the passage through the zone of confusion. The air data transducer assembly (ADTA) data incorporation began at approximately 81,900 ft and continued to 16,400 ft. The microwave scanning beam electronic system data processing was satisfactory. All external-sensor measurement residuals and residual ratios were nominal. The backup flight system (BFS) data were nominal and were similar to the primary flight system.

The flight control system performed satisfactorily throughout the mission. The flight control systems (FCS) checkout was successfully performed, beginning at 149:05:28 G.m.t. (08:18:58 MET) and ending at 149:06:22 G.m.t. (08:19:52 MET). The checkout demonstrated that the FCS was ready for entry.

The hangar calibration of the IMUs showed the units to be within the specification. One adjustment of the onboard IMU compensations was performed for each IMU early in the flight. IMU performance during the on-orbit and entry phases was satisfactory.

Displays and Controls Subsystem

Arcing was noted on the mid-starboard floodlight for approximately 30 minutes during the time-frame of payload bay door closure. The floodlight were removed prior to the vehicle being ferried to the OMDP site.

Communications and Tracking Subsystems

The communications and tracking equipment performed satisfactorily throughout the mission. No in-flight anomalies were identified from the mission data.

The Ku-Band system failed every self-test during the mission because of a known hot-receiver condition of this deployed assembly; however, the Ku-Band system operated nominally at all other times in the mission.

The Ku-Band radar successfully acquired and tracked the SPARTAN satellite following its deployment. The SPARTAN was acquired at a range of 136 ft and tracked through the V Bar and R Bar stationkeeping activities. The payload was again acquired after the jettison of the IAE while at a range of about 6000 feet. During SPARTAN rendezvous operations, the Ku-Band radar successfully acquired the SPARTAN satellite at 142:09:48 G.m.t. (001:23:18 MET) at a range of 118,000 feet. Radar-lock on the satellite was intermittent until the range was less than 78,000 feet because of the small radar cross-section of the SPARTAN. The satellite was tracked satisfactorily until a range of 80 feet was attained when the radar system broke lock and was configured back to the communications mode.

The Ku-Band radar performance was nominal during the PAMS/STU operations.

The crew experienced some difficulty with the wireless crew communications system (WCCS) during a 36-minute period of the Public Affairs event held at 144:12:22 G.m.t. (04:01:52 MET). Following the event, the crew rechecked the system and decided that the middeck coverage was being affected by the crew escape pole that was stored on the middeck ceiling. It was apparently partially obscuring the wall-mounted antenna; however, the condition could not be reproduced in postflight testing.

Cross-talk was experienced on the onboard audio channels throughout the duration of the flight. The problem has been observed on previous Spacehab and Spacelab flights. Low-level speech on the onboard intercommunications channels was detected bleeding into the air-to-ground down-link channels. The speech was barely intelligible, but it was noticeable on ground keysets. This condition did not impact flight operations.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation and modular auxiliary data system (MADS) performed very satisfactorily throughout the mission.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. All drag chute hardware was recovered and it operated properly.

At approximately 142:20:00 G.m.t. (002:09:30 MET), downlink video revealed that a portion of the payload bay liner had become detached. This condition had no impact on the mission.

Integrated Aerodynamics, Heating and Thermal Interfaces

The prelaunch thermal interface purges were nominal.

The ascent and entry aerodynamics were nominal. There were no programmed test inputs for this flight.

The ascent aerodynamic and plume heating was nominal. Likewise, the entry aerodynamic heating to the SSME nozzles was nominal.

Thermal Control Subsystem

The thermal control system (TCS) performance was nominal during all phases of the STS-77 mission, successfully maintaining temperatures within required limits. The beta angle ranged from approximately -5° at orbit insertion to +41.5° at entry interface (EI). The orbital inclination was 39° and the orbital altitude was approximately 153 nmi.

At approximately 142:20:00 G.m.t. (02:09:30 MET), downlink video revealed that a portion of the payload bay liner had become detached. This condition had no impact on the mission.

The one problem was the failure of the primary RCS thruster R3A injector heater, which occurred at approximately 142:23:30 G.m.t. (02:13:00 MET). The thruster leak-detection low limit of 30 °F was protected through a combination of hot-firing the thruster on a payload non-interference basis and modifying the Orbiter attitude. No TCS instrumentation anomalies occurred during the STS-77 mission.

During the on-orbit period of the mission, thermal analyses were performed to evaluate changes to the planned attitude timelines (ATLs). Thirteen revisions to the planned ATL, not including ATL cases examining a one-day mission extension and a two-orbit wave-off for landing, were analyzed and assessed. No thermal constraint violations were predicted for the proposed ATLs, although one bond-line sensor location indicated a potential marginal condition for a two-orbit wave-off case.

Aerothermodynamics

The Orbiter entry aerothermodynamics were as expected for the STS-77 mission. The acreage heating and local heating were nominal. The boundary layer transition was also nominal.

Thermal Protection Subsystem and Windows

The evaluation of the structural temperature response data (temperature rise) showed that entry heating was nominal. Boundary layer transition from laminar to turbulent flow was symmetric, occurring at approximately 1320 seconds after entry interface (EI) at the forward center-line of the vehicle and at 1325 seconds after EI at the aft center-line of the vehicle.

Based on data from the debris team inspection, overall debris damage was below average. A total of 81 debris impact damage sites, of which 15 had a major dimension of one-inch or larger and were on the lower surface. This number is just above the average of 14. This total did not include the numerous damage sites, although less than usual, on the base heat shield that were attributed to the flame arrestment sparkler system. A comparison of these numbers to statistics from 60 previous missions of similar configuration indicates both the total number of damage sites as well as the number of damage sites having a major dimension of one inch or larger was less than average. The distribution of the hits on the Orbiter is shown in the following table.

No tile damage sites were identified that were caused by micrometeorites or on-orbit debris striking the vehicle.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	15	48
Upper Surface	2	19
Right Side	0	4
Left Side	0	3
Right OMS Pod	0	5
Left OMS Pod	0	2
Total	17	81

The largest lower surface debris damage site involved three tiles on the right chine and measured 3.5 inches long by 2.25 inches wide by 0.375 inch maximum depth. Damage sites on the right side along a line from the nose to the tail are generally attributed to ice impacts from the ET LO_2 feed-line bellows and support brackets. Damage sites aft of the LH_2 and LO_2 ET/Orbiter umbilicals, usually caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the air-stream, were less than usual in number and size. Three nose landing gear door inner-mold line (IML) thermal barriers were frayed, but the overall condition was above average. Also a patch on the left-hand side thermal barrier was torn and missing for approximately one foot.

The SSME 1 and 2 dome-mounted heat shield (DMHS) closeout blankets were torn at the 6:00 o'clock and the 3:00 to 5:00 o'clock locations, respectively. The SSME 3 DMHS was in excellent condition with no missing material. Tiles on the vertical stabilizer stinger and around the drag chute door were intact and undamaged.

No ice adhered to the payload bay door. The reddish-brown discoloration on the leading edge of the left-hand payload bay door had not changed in appearance from conditions at launch. No unusual tile damage was observed on the leading edges of the vertical stabilizer.

Orbiter window hazing and streaking was typical. Impact damage sites on the window perimeter tiles was somewhat less than usual in number and size. Four gray toughened unified fibrous insulation (TUFI) had been installed in place of the black perimeter tiles above window 3 as a part of a test to use densified tiles in high-impact locations. These four TUFI tiles were undamaged.

REMOTE MANIPULATOR SYSTEM

The remote manipulator system (RMS) performed satisfactorily throughout the STS-77 mission. This was the forty-fifth flight of an RMS and the fourteenth flight of this particular RMS.

After the RMS checkout was successfully completed at 140:18:19 G.m.t. (00:07:49 MET), the RMS was used to perform a payload bay survey.

Data from the initial operations showed a slightly slower-than-normal wrist- pitch direct-drive-rate response. A decision was made to perform another direct-drive-rate response test later in the mission to confirm the initial results.

The RMS deployed the SPARTAN satellite with the successful release taking place at 141:11:29:12 G.m.t. (01:00:59:12 MET). Following Inflatable Antenna Experiment (IAE) operations, the RMS was cradled at 141:15:59 G.m.t. (01:05:29 MET).

The RMS retrieved the SPARTAN satellite with a successful capture taking place at 142:14:52:47 G.m.t. (02:04:22:47 MET). Prior to retrieving the SPARTAN satellite, an RMS wrist-pitch direct-drive-response test was performed to verify the slightly lower-than-normal wrist-pitch direct-drive response rate that was obtained during the RMS checkout at the start of the mission. The repeat test showed nominal wrist-pitch direct-drive rate responses in both the positive and negative directions. The SPARTAN satellite was successfully berthed at 142:15:55:41 G.m.t. (02:05:25:41 MET). The RMS was subsequently cradled, and on flight day 10 the arm was stowed for entry.

RENDEZVOUS AND SEPARATION OPERATIONS

The rendezvous operations with the SPARTAN and the PAMS/STU were performed in a very satisfactory manner.

SPARTAN SEPARATION

The SPARTAN-207 was deployed on May 20, 1996, by the RMS. The Orbiter was maneuvered away from the SPARTAN by a 0.7 ft/sec firing in the +X local vertical local horizontal (LVLH) direction using the RCS -Z thruster firings.

The rendezvous radar (RR) successfully acquired and tracked the SPARTAN at a range of 136 ft, and track was maintained throughout the station-keeping activities, which began at approximately 400 ft. After inflation of the IAE, the structure rotation rates were much higher than expected and the Orbiter was separated to 800 ft. After IAE jettison, target tracking using the RR was initiated. The SPARTAN was acquired at a range of 6500 ft and a range rate of +7.00 ft/sec (opening). A total of 120 RR navigation marks were incorporated with none rejected. The RR data-good flag was on for all parameters (range, range rate, and angles) throughout this period of tracking. The measurement residuals (error) and ratios (error divided by the maximum allowable error) were small, indicating solid navigation performance.

SPARTAN RENDEZVOUS

The SPARTAN rendezvous operations were initiated with the circularization maneuver. The LVLH components of the maneuver -2.2 ft/sec in the X axis, 0.0 ft/sec in the Y and Z axes. The maneuver was performed manually, and the multi-axis firing procedure was used. RR tracking of the SPARTAN was achieved at 118,000 ft, negating the need for the star tracker pass. The RR pass lasted 110 minutes and 724 marks were incorporated without any rejected marks.

Four dropouts of the RR track occurred during the pass; however, after the range was reduced to 78,000 ft, the data-good flag remained equal to one indicating continuous RR target lock-on. During the RR tracking, the onboard rendezvous guidance solution for the corrective combination (NCC) maneuver was computed three times. The final solution for the maneuver was -0.2 ft/sec in the X axis, 0.3 ft/sec in the Y axis, and 1.1 ft/sec in the Z axis, and this was very close to the expected solution. The maneuver was executed using the onboard solution with the multi-axis RCS firing procedure.

The terminal phase initiation (TI) maneuver solution was also developed onboard and was used for the maneuver. The firing was executed on time based on the onboard solution with the multi-axis RCS firing procedure, and the vehicle orbital altitude was raised to 153.7 by 150.2 nmi.

Four midcourse correction maneuvers were performed at the expected times and values, culminating in a successful rendezvous and capture of the SPARTAN. During the approach, over 1480 navigation marks were incorporated into the trajectory data with none rejected. The hand-held laser (HHL) was used to obtain the range and range rate updates during the rendezvous.

PAMS/STU DEPLOYMENT OPERATIONS

The PAMS/STU was deployed by a spring-loaded device that imparted a 1.25 ft/sec separation velocity to the unit. The Orbiter was tracking the center of the Earth at the time of deployment; therefore, the initial velocity to the PAMS/STU was negative radial.

Target tracking of the satellite was initiated with the RR at a range of 500 ft and a range rate of +1.2 ft/sec (opening). The Orbiter was separated from the PAMS/STU 20 minutes later via a manually performed 1.5 ft/sec RCS firing in the +X LVLH direction. The magnitude of the firing was to separate the Orbiter from the satellite by 8 nautical miles in two orbits.

During a 1 hour and 50 minute period, 750 range and range-rate marks and 675 angle marks were incorporated, and this resulted in updating the relative state vector by approximately 3500 ft and 3.5 ft/sec. However, the unexpected angular rates of the satellite induced during its deployment resulted in the RR data-good flag dropping out 12 times. As the range to the satellite increased, the RR data-good flag drop-outs became increasingly more frequent. The maximum range to the target was approximately 52,500 ft.

FIRST PAMS/STU RENDEZVOUS

The rendezvous phase was initiated with the corrective combination (NCC) maneuver, which had a ΔV of 2.52 ft/sec and used the multi-axis firing technique. The LVLH components of the final NCC maneuver solution were -0.5 ft/sec, -0.2 ft/sec, and 2.3 ft/sec in the X, Y, and Z axes, respectively. The deployment phase transitioned directly into the rendezvous phase, thus the newly coined phrase for this mission was proxezvous. The normal rendezvous trajectory with an approach from the down-range direction was altered to satisfy the PAMS/STU mission requirements. The approach was from the uprange direction was not nominal; however, the rendezvous guidance computed accurate maneuver solutions.

The RR sensor operations continued uninterrupted with 788 range, 835 range rate, and 736 angle marks incorporated with no rejections by the time the NCC maneuver was executed. However, the frequency of the data-good flag drop-outs had increased to a continuous level and were inhibited.

In computing the TI maneuver, it is normally targeted for a direct interception, however, for the PAMS/STU the target was 2150 ft behind and 190 ft above the target. This separation was to facilitate data takes on the satellite and to ensure minimum RCS thruster plume impingement on the satellite. The TI maneuver solution was computed three times, and the final LVLH solution was -4.3 ft/sec in the X axis, -0.2 ft/sec in the Y axis, and 1.6 ft/sec in the Z axis. The firing was performed on time in the +X RCS thruster configuration, and the range to the satellite was 50,000 ft. The resultant orbital altitude was 153.5 by 152.1 nmi.

The midcourse correction (MCC) 1 maneuver was executed on time approximately 20 minutes after the TI maneuver. The total maneuver velocity was 0.61 ft/sec. The RR tracking was reinitiated. A total of 55 navigation marks were incorporated prior to the MCC 2 maneuver, which has a total velocity of 0.9 ft/sec. The last two midcourse corrections were performed as planned 10 and 20 minutes after the MCC 2 TIG.

The last maneuver of the rendezvous was the Vbar null maneuver, which was performed to null the relative velocity at the target point (2000 ft behind the target). The total ΔV for this maneuver was 5.9 ft/sec.

The rendezvous was successfully completed with -Vbar arrival and stable station-keeping at approximately 143:13:54:05 G.m.t. (03:03:24:05 MET).

SECOND PAMS/STU RENDEZVOUS

The second PAMS/STU rendezvous was initiated with a 2.2 ft/sec circularization maneuver in the -X axis AT 146:05:12:00 G.m.t. (05:18:42 MET). Following the circularization maneuver, a star tracker pass was initiated. The 15-minute pass provided 120 star tracker angle marks, and the Orbiter state vector was updated approximately 5000 ft and 5.0 ft/sec by the marks.

The final corrective combination maneuver solution was computed after the star tracker pass was terminated. The LVLH components of the maneuver were -0.1, -0.5, and -0.5 ft/sec in the X, Y, and Z axes, respectively. The maneuver was executed manually as computed.

The RR locked on the PAMS/STU at a range of 80,000 ft with a closing rate of 50 ft/sec. The lock on was intermittent until the range to the target was less than 40,000 ft at which time the lock became continuous. The intermittent lock on to the target resulted from the target not yet being stabilized. The TI maneuver solution was computed three times and showed good reasonableness when compared with the ground-computed solution. The final solution was -4.5, 0.2, and -1.0 ft/sec in the X, Y, and Z axes, respectively. The maneuver was executed on time using the +X RCS configuration. The range to the target was a nominal 50,000 ft prior to the TI maneuver. The maneuver raised the orbital altitude parameters to 154.0 by 148.4 nmi.

The MCC 1 maneuver was executed as planned with a ΔV of -0.5, 0.2, and 1.0 ft/sec in the X, Y, and Z axes. The firing was executed on-time using onboard manual procedures. The MCC 2 maneuver was executed on time with 0.2, -0.2, and 2.4 ft/sec in the X, Y, and Z axes, respectively. The MCC 3 and 4 maneuvers were nominal short RCS firings that were performed 10 and 20 minutes after the MCC 2 TIG.

The last maneuver of the second rendezvous was the Vbar null firing. The components of the maneuver were 1.5, -0.2, and 7.5 ft/sec in the X, Y, and Z axes, respectively. The rendezvous was successfully completed with Vbar arrival and stable station-keeping at 146:08:00 G.m.t. (05:21:30 MET).

THIRD PAMS/STU RENDEZVOUS

The third PAMS/STU rendezvous was initiated with a circularization maneuver at 148:05:18 G.m.t. (07:18:48 MET). The components of the maneuver were -1.8, 0, and 0 in the X, Y, and Z axes, respectively. Following the circularization maneuver, the 15-minute star tracker pass was initiated, and during the pass, 96 angle marks were taken. The Orbiter state vector was updated approximately 10,000 ft and 12.5 ft/sec by the marks.

The final corrective combination maneuver solution was computed after the star tracker pass was terminated, and the components of the maneuver were 0.3, 0.2, and 0 ft/sec in the X, Y, and Z components. The maneuver was performed using the final solution. The effect of the star tracker pass on the corrective combination maneuver solution was dramatic in that the preliminary solution was 0.9, -0.5, and -2.1 ft/sec in the X, Y, and Z axes, respectively.

The RR locked on the PAMS/STU at a range of 115,000 ft with a range rate of 0 ft/sec. The lock was solid for 20 minutes, and the RR target track performance during the third rendezvous was much improved during the third rendezvous. The TI maneuver solution was computed three times and compared with the ground-computed solution for reasonability. The final solution, computed after 200 RR marks, was 1.5, 0.7, and 2.9 ft/sec in the X, Y, and Z axes, respectively. The maneuver was executed on time using the +X RCS thruster configuration, and the range to the target was a nominal 50,000 ft.

The four midcourse correction maneuvers were nominal, performed at the planned times, and achieved the desired results. The last maneuver of the third rendezvous sequence, Vbar null maneuver, brought the vehicle to the desired rendezvous position 2000 ft behind the PAMS/STU and stable station-keeping at 148:08:02:33 G.m.t. (07:21:32:33 MET).

FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

The Government furnished equipment/flight crew equipment (GFE/FCE) performed nominally throughout the mission. One minor problem was noted when the crew was initially unable to assemble the Spacehab overhead window bracket for use with the Arriflex camera. A back-up method using a multi-use bracket provided the necessary mounting provision. However, later in the flight, the crew was able to assemble the bracket although it required reducing the temperature of one part and then forcing them together. The lack of this bracket did not prevent obtaining the desired photography.

CARGO INTEGRATION

The cargo integration hardware performance was nominal throughout the mission. No anomalies or significant issues were noted.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

DEVELOPMENT TEST OBJECTIVES

DTO 301D - Ascent Structural Capability Evaluation - This DTO is data-only, with the data being recorded on the modular auxiliary data system (MADS) recorder. The data were dumped from the MADS recorder postflight and were given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DTO 305D - Ascent Compartment Venting Evaluation - This DTO is data-only, with the data being recorded on the MADS recorder. The data were dumped from the MADS recorder postflight and were given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DTO 306D - This DTO is data-only, with the data being recorded on the MADS recorder. The data were dumped from the MADS recorder postflight and were given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DTO 307D - This DTO is data-only, with the data being recorded on the MADS recorder. The data were dumped from the MADS recorder postflight and were given to the sponsor for evaluation. The results of the evaluation will be reported in separate documentation.

DTO 312 - External Tank Thermal Protection System Performance (Method 1 Only) - Photography of the ET after separation was acquired with a 35 mm camera having a 300 mm lens and a 2X extender. Five views of the ET were received. Exposure was good on all frames; however, focus was good on only four frames. Timing data were present on the roll of film. The first picture was taken approximately 16.5 minutes after liftoff, and the last picture was taken approximately 5 minutes 23 seconds later. An early OMS-2 pitch maneuver was planned and performed and the photography session was shortened as a result.

The -Y axis, -Z axis and the aft dome of the ET were imaged. Two possible divots are visible on the intertank foam near the left SRB forward-attach point. Several pieces of unidentified debris were imaged.

Three rolls of umbilical well camera film (16 mm with 5mm lens and 10 mm lens and 35 mm film) were screened. Good coverage of the left SRB separation and ET separation was obtained. The 16 mm and 35 mm film exposure ranged from good to dark with both having good focus. Normal light- and dark-colored debris was observed throughout the SRB film sequence, and no anomalous conditions were noted. Numerous light-colored pieces of debris (probably insulation and frozen hydrogen) were seen throughout the ET separation sequence. All observations were typical of those seen on films from previous missions.

DTO 415 - Water Spray Boiler Electrical Heater Capability - Data were collected for this DTO. These data have been given to the DTO sponsor for evaluation. The results of that analysis will be reported in separate documentation.

DTO 416 - Water Spray Boiler Quick Restart Capability - This DTO was successfully performed for the first time on this flight and will continue to be performed until 21 data points have been collected.

All three WSB heaters were turned on following ascent when the APU lubrication oil temperature had decreased to 230 °F. The system 1 vent heater was activated approximately 18 minutes after APU 1 shut down, and 58 minutes were required for the temperature to rise above 122 °F. The system 2 vent heater was activated approximately 47 minutes after APU 2 shut down (longer delay due to WSB under-cooling condition) and required 20 minutes to raise the temperature above 122 °F. System 3 was activated 18 minutes after APU 3 shut down and 23 minutes were required to raise the temperature above 122 °F. The significance of the data is being evaluated to determine its application to the DTO.

DTO 700-8 - Global Positioning System Development Flight Test - This DTO was performed with nominal results throughout the STS-77 mission. Data from the flight are being evaluated by the sponsor, and the results of the analysis will be reported in separate documentation.

DTO 805 - Crosswind Landing Performance - This DTO was not performed as the wind condition at the landing site did not meet the minimum requirements of the DTO.

DETAILED SUPPLEMENTARY OBJECTIVES

Data were collected on each of the Detailed Supplementary Objectives (DSOs). These data have been given to the Primary Investigator for evaluation. The results of the evaluation of the following DSOs will be reported in separate documentation.

a. DSO 331 - The Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress and Locomotion;

b. DSO 487 - Immunological Assessment of Crew Members;

c. DSO 491 - Characterization of Microbial Transfer among Crewmembers during Spaceflight;

d. DSO 493 - Monitoring Latent Virus Reaction and Shedding in Astronauts;

e. DSO 802 - Educational Activities;

f. DSO 901 - Documentary Television;

g. DSO 902 - Documentary Motion Picture Photography; and

h. DSO 903 - Documentary Still Photography.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO ANALYSIS

The launch film screening was completed, and no in-flight anomalies were identified from the various sources. A total of twenty-five 16 mm films, eighteen 35 mm films and twenty-four videos were used in the screening.

ON-ORBIT PHOTOGRAPHY AND VIDEO ANALYSIS

No on-orbit photography was screened as no anomalous occurrences were noted that required screening.

LANDING PHOTOGRAPHY AND VIDEO ANALYSIS

Eleven videos of landing operations were received and evaluated. No anomalous conditions were noted.

TABLE I.- STS-77 MISSION EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	140:10:25:11.377 140:10:25:13.340 140:10:25:14.967
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	140:10:29:32.079 140:10:29:32.239 140:10:29.32.399 140:10:29:32.559
Main Propulsion System Start[a]	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	140:10:29:53.458 140:10:29:53.577 140:10:20:53.683
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	140:10:30:00.009
Throttle up to 104 Percent Thrust[a]	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	140:10:30:03.882 140:10:30:03.884 140:10:30:03.909
Throttle down to 67 Percent Thrust[a]	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	140:10:30:29.963 140:10:30:29.964 140:10:30:29.990
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	140:10:30:51
Throttle up to 104 Percent[a]	ME-2 Command accepted ME-1 Command accepted ME-3 Command accepted	140:10:30:56.363 140:10:30:56.365 140:10:30:56.390
Both SRM's Chamber Pressure at 50 psi[a]	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	140:10:31:58.929 140:10:31:59:369
End SRM [a] Action[a]	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	140:10:32:01.209 140:10:32:01.959
SRB Physical Separation[a]	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	140:10:32:04.249 140:10:32:04.249
SRB Separation Command	SRB separation command flag	140:10:32:05
Throttle Down for 3g Acceleration[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	140:10:37:29.001 140:10:37:29.011 140:10:37:29.011
3g Acceleration	Total load factor	140:10:37:30 9
Throttle Down to 67 Percent Thrust[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	140:10:38:21.483 140:10:38:21.492 140:10:38:21.492
SSME Shutdown[a]	ME-3 command accepted ME-2 command accepted ME-1 command accepted	140:10:38:27.763 140:10:38:27.772 140:10:38:27.772
MECO	MECO command flag MECO confirm flag	140:10:38:28 140:10:38:29
ET Separation	ET separation command flag	140:10:38:47
APU Deactivation	APU-2 GG chamber pressure APU 1 GG chamber pressure APU 3 GG chamber pressure	140:10:45:39.794 140:10:47:26.221 140:10:47:44.307

[a]MSFC supplied data

TABLE I.- STS-77 MISSION EVENTS
(Concluded)

Event	Description	Actual time, G.m.t.
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	140:11:11:47.2 140:11:11:47.2
OMS-2 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	140:11:13:53.6 140:11:13:53.6
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	140:12:11:08 140:12:12:28
SPARTAN Deployment	Payload Captured	141:11:29:12
SPARTAN Grapple	Payload Captured	142:14:52:34
PAMS/STU Deployment	Payload Captured	143:09:19
Flight Control System Checkout APU Start APU Stop	 APU-2 GG chamber pressure APU-2 GG chamber pressure	 149:05:40:02.234 149:05:51:16.105
Payload Bay Doors Close	PLBD left close PLBD right close	150:07:26:42 150:07:29:07
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	150:10:04:36.027 150:10:24:46.710 150:10:24:47.797
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	150:10:09:30.2 150:10:09:30.3
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	150:10:12:57.9 150:10:12:58.0
Entry Interface (400K feet)	Current orbital altitude above	150:10:37:39
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	150:11:02:59
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	150:11:09:20 150:11:09:20
Main Landing Gear Weight on Wheels	RH main landing gear weight on wheels LH main landing gear weight on wheels	150:11:09:24 150:11:09:26
Drag Chute Deployment	Drag chute deploy 1 CP Volts	150:11:09:26.9
Nose Landing Gear Contact	NLG 1 RH tire pressure 1	150:11:09:34
Nose Landing Gear Weight on Wheels	NLG no weight on wheels	150:11:09:35
Drag Chute Jettison	Drag chute jettison 1 CP Volts	150:11:09:56.0
Wheel Stop	Velocity with respect to runway	150:11:10:11
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	150:11:24:23.930 150:11:24:47.856 150:11:25:12.979

TABLE II.- ORBITER IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-77-V-01	RCS Thruster F2F Failed Leak	141:11:32:46 G.m.t. 01:01:02:46 MET CAR 77RF03 PR FRCS-5-A0010	During the post-SPARTAN deployment -X maneuver (SEP 1-S) at 141:11:31:21 G.m.t. (01:01:01:21 MET), thruster F2F completed its first firing. The thruster was deselected by the redundancy management (RM) software 1 minute 25 seconds later when the oxidizer temperature dropped below the 30 °F leak detection limit. About 15 minutes later, the crew reported that they thought the leaking thruster was causing perturbations to the station keeping and requested concurrence to close forward manifold 2. The manifold was closed at 141:12:06:49 G.m.t. (01:01:36:49 MET). Liquid leakage apparently stopped, as indicated by oxidizer=fuel temperature, at approximately 141:15:40 G.m.t. (01:05:10 MET). The manifold was subsequently reopened at 149:10:24 G.m.t. (08:23:54 MET), and the leaking condition resumed. The manifold was isolated prior to the crew sleep period at 149:17:54 G.m.t. (09:07:24 MET) for the remainder of the mission. KSC: The forward RCS module was removed for Orbiter Maintenance Down Period (OMDP) that began in August 1996. The F2F thruster was removed from the module at the Hypergolic Maintenance Facility (HMF) at KSC.
STS-77-V-02	RCS Primary Thruster R3A Heater Failed Off	142:23:30:00 G.m.t. 02:13:00:00 MET CAR 77RF04 IPR 88V-0001	The heater on primary thruster R3A failed off at approximately 142:23:30 G.m.t. (02:13:00 MET). Primary thruster R3A was hot-fired several times on a non-interference basis with payload activities to maintain the valve temperature above 40 °F due to the failure of the heater. The first of these firings was performed at approximately 143:06:20 G.m.t. (02:19:50 MET). The Orbiter attitude during crew sleep was modified to maintain the temperature above 40 °F. The right pod is next scheduled to be installed on OV-102. KSC: The pod will be removed for the OMDP and the heater failure will be investigation in the HMF.

TABLE III.- GOVERNMENT FURNISHED EQUIPMENT PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-77-F-01	Arriflex Camera Window Bracket	141:10:35:00 G.m.t. 01:00:05:00 MET	The crew reported that the camera bracket that attaches to the Arriflex camera would not mate to the Spacehab window bracket. The crew reported after thermal conditioning of the hardware that the bracket could be assembled, but the fit was very tight. The crew was able to use the bracket for the planned events.

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 Problem Tracking List
7. MER Event Times
8. Subsystem Manager Reports/Inputs
9. MOD Systems Anomaly List
10. MSFC Flash Report
11. MSFC Event Times
12. MSFC Interim Report
13. Crew Debriefing comments
14. 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.

ACTORS	Atlantic Canadian Thin Organic Semiconductors
ADSEP	Advanced Separation Process for Organic Materials
AMS	attitude measurement system
AOA	Abort Once Around
APU	auxiliary power unit
ARF	Aquatic Research Facility
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
BETSCE	Brilliant Eyes Ten-Kelvin Sorption Cryocooler Experiment
BFS	backup flight system
BRIC	Biological Research in Canisters
CAV	capillary acquisition vane
CCTV	closed circuit television
c.d.t.	central daylight time
CFZF	Commercial Float Zone Furnace
CGBA	Commercial Generic Bioprocessing Apparatus
CSA	Canadian Space Agency
DARA	German Space Agency
DMHS	dome-mounted heat shield
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔV	differential velocity
ECLSS	environmental control and life support system
EMU	extravehicular mobility unit
EPDC	electrical power distribution and control subsystem
ET	External Tank
FCE	flight crew equipment
FCS	flight control system
FES	flash evaporator system
FGBA	Fluids Generic Bioprocessing Apparatus
ft/sec	feet per second
g	gravity
GAMCIT	Gamma-ray Astrophysics Mission
GANE	GPS Attitude and Navigation Experiment
GAS	Get-Away Special
GBA	GAS Bridge Assembly
GFE	Government furnished equipment
G.m.t.	Greenwich mean time
GN_2	gaseous nitrogen
GNC	guidance, navigation and control
GPC	general purpose computer
GPPM	Gas Permeable Polymer Membrane
GPS	Global Positioning System

HAINS	high accuracy inertial navigation system
HH	Hitchhiker
HH-DTC	Hand-held Diffusion Test Cells
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
IAE	Inflatable Antenna Experiment
IFM	in-flight maintenance
IMU	inertial measurement unit
IRU	inertial reference unit
Isp	specific impulse
ISSA	International Space Station Alpha
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 Company
LMTE	Liquid Metal Thermal Experiment
LO_2	liquid oxygen
MADS	modular auxiliary data system
MECO	main engine cutoff
MET	mission elapsed time
MPS	main propulsion system
NANO-GAS	Nanocrystal Get-Away Special
nmi.	nautical miles
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OMDP	Orbiter Maintenance Down Period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
PAL	protuberance air load
PAMS/STU	Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test
PCS	pressure control system
PGBA	Plant Generic Bioprocessing Apparatus
PGSC	payload and ground support computer
PI	Principal Investigator
PMBT	propellant mean bulk temperature
proxevous	proximity rendezvous
PRSD	power reactant storage and distribution
Rbar	radius vector axis
RCS	reaction control subsystem
RF	radio frequency
RM	redundancy management
RMS	remote manipulator system
RSRM	Reusable Solid Rocket Motor
S&A	safe and arm
SEDS	Students for the Exploration and Development of Space

SEF	Space Experiment Facility
SEP S-1	first separation maneuver
SLF	Shuttle Landing Facility
SODB	Shuttle Operational Data Book
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
TCS	Trajectory Control Sensor/thermal control system
TEAMS	Technology Experiments Advancing Missions in Space
TIPS	Thermal Impulse Printer System
TPCE/RFL	Tank Pressure Control Experiment/Reduced Fill Level
TPS	thermal protection subsystem
TUFI	toughened unified fibrous insulation
Vdc	Volts direct current
VTRE	Vented Tank Resupply Experiment
WCCS	wireless crew communications system
WCS	Waste Collection System
WSB	water spray boiler