

# **STS-87 SPACE SHUTTLE MISSION REPORT**

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February 1998



**National Aeronautics and  
Space Administration**

**Lyndon B. Johnson Space Center  
Houston, Texas**

NOTE

The STS-87 Space Shuttle Mission Report was prepared from inputs received from the Flight Projects Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

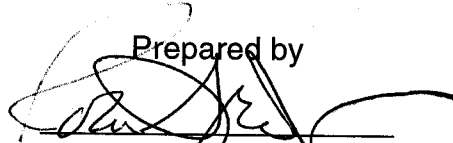
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STS-87

SPACE SHUTTLE

MISSION REPORT

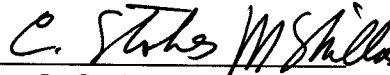
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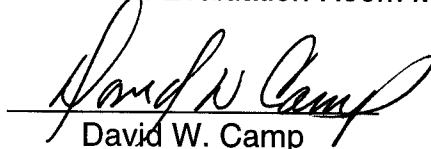
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## INTRODUCTION

This Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified. The report also summarizes the activities of the STS-87 mission and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this eighty-eighth mission of the Space Shuttle Program. STS-87 was the sixty-second flight since the return to flight, and the twenty-fourth flight of the OV-102 (Columbia) Orbiter vehicle.

The flight vehicle consisted of the OV-102 Orbiter; an ET that was designated ET-89; three SSMEs that were designated as serial numbers (S/N) 2031 (Phase II), 2039 (Block IA), and 2037 (Block IA) in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-092. The two RSRMs were designated RSRM 63 with one installed in each SRB. The individual RSRMs were designated 360T063A for the left SRB, and 360T063B for the right SRB.

The STS-87 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirements as documented in NSTS 07700, Volume VII, Appendix E. The requirement 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 the STS-87 flight were to successfully perform the operations necessary to fulfill the requirements of the United States Microgravity Payload -4 (USMP-4) and SPARTAN-201. The secondary objectives of this flight were to perform the operations of the Collaborative Ukraine Experiment (CUE), EVA Demonstration Flight Test (EDFT) -05, Shuttle Ozone Limb Sounding Experiment (SOLSE), Loop Heat Pipe (LHP), Sodium Sulfur Battery Experiment (NaSBE), Get-Away Special (GAS) G-744, Turbulent Gas-Jet Diffusion (TGDF), and Autonomous EVA Robotic (AER) Camera/Sprint.

The STS-87 mission was a planned 16-day plus 2-contingency-day mission during which experiments were to be conducted as well as an extravehicular activity. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. The STS-87 sequence of events is shown in Table I, the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List in Table II, and the Marshall Space Flight Center In-Flight Anomaly List in Table III. Appendix A lists the sources of data, both informal and formal, that were used in the preparation of this report. Appendix B provides the definitions of all acronyms and abbreviations using in this report. All times are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The six-person crew of the STS-87 mission consisted of Kevin R. Kregel, Civilian, Commander; Steven W. Lindsey, Major, U. S. Air Force, Pilot; Kalpana Chawla, Ph. D., Civilian, Mission Specialist 1; Winston E. Scott, Captain, U. S. Navy, Mission Specialist 2; Takao Doi, Ph. D., Civilian, National Space Development Agency (NASDA) of Japan, Mission Specialist 3; Leonid K. Kadenyuk, Colonel, Russian Air Force, Payload Specialist 1. STS-87 was the third space flight for the Commander; the second space

flight for Mission Specialist 2; and the first space flight for the Pilot, Mission Specialist 1, Mission Specialist 3 and Payload Specialist 1.



## MISSION SUMMARY

The launch of the STS-87 vehicle occurred at 323:19:45:59.993 G.m.t. (2:46 p.m. e.s.t. on November 19, 1997) following a countdown with no significant problems and no unexpected holds. All SSME and RSRM start sequences occurred as expected, and launch phase performance was satisfactory in all respects. First stage ascent performance was as expected. SRB separation, entry, deceleration, and water impact occurred as anticipated. Both SRBs were successfully recovered and returned to Kennedy Space Center (KSC) for disassembly and refurbishment. Performance of the SSMEs and main propulsion system (MPS) was normal. Six minutes into the ascent, the vehicle was maneuvered to a "heads-up" attitude to provide communications through the Tracking and Data Relay Satellite System (TDRSS), which will be required when the Bermuda Tracking Station closes.

Analysis of the vehicle performance during ascent was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine specific impulse ( $I_{sp}$ ) determined for the time period between SRB separation and the start of 3g throttling was 453.58 seconds as compared to a MPS tag value of 452.93 seconds. Post-separation photography of the ET revealed a significant loss of thermal protection system (TPS) material from both thrust panels (Flight Problem STS-87-T-01). Also, the photography showed a relatively minor TPS loss from a few stinger tops in the -Z axis area and in one location in the +Z axis area.

During the prelaunch cabin leak checks, a seal on the port used to pressurize the cabin came off (Flight Problem STS-87-V-01). The seal was replaced and the cabin leak check was completed satisfactorily. The problem delayed the cabin leak check, thus causing a concern over the residual oxygen ( $O_2$ ) concentration in the aft compartment exceeding the limits required to begin the countdown again after the planned hold. However, the aft compartment  $O_2$  readings did drop below the 500-ppm level just prior to the end of the planned hold period, and the countdown was resumed at the planned time.

The OMS 1 maneuver was not required because of the satisfactory direct-ascent trajectory that was flown. The OMS 2 maneuver was performed at 323:20:27:08.9 G.m.t. [00:41:08.9 mission elapsed time (MET)]. The maneuver was 126.2 seconds in duration, and a differential velocity ( $\Delta V$ ) of 193.8 ft/sec was imparted to the vehicle.

The payload-bay-door opening sequence was completed at 323:21:17:02 G.m.t. (00:01:31:02 MET). Nominal dual motor times were recorded for the door-opening operations.

Recent medical findings that link iodine consumption to thyroid problems resulted in the preflight development of a method for removing iodine from the drinking water and that equipment was stowed for this flight. The crew installed the Iodine Removal Mineral Injection System (IRMIS) cartridges to remove iodine and iodide from the drinking water. The IRMIS cartridges are the same cartridges used to remove iodine and iodide from the water that is transferred to the Mir Space Station. The postflight water samples revealed a very small amount of iodine in the water. Further examination and testing of the microbial check valve (MCV) revealed that no iodinated resin was in the valve, and that no resin had been packed in the valve prior to flight. Action has been taken to ensure that this anomaly does not recur.

The remote manipulator system (RMS) was activated at 324:00:50 G.m.t. (00:05:04 MET). The on-orbit checkout commenced at 324:02:05 G.m.t. (00:06:19 MET), and was completed at 324:04:46 G.m.t. (00:09:00 MET). Data indicated that all operations were nominal.

At approximately 324:02:25:26 G.m.t. (00:06:39:26 MET), after supply-water tank A reached full quantity, the supply-water storage inlet-pressure increased from 33.21 psia to 39.58 psia over a 5-minute period before the tank A/B check/relief valve cracked open (Flight Problem STS-87-V-04). The pressure rise required to crack (open) the check valve was approximately 6 psia, whereas past flights have shown a range between 0.4 and 0.8 psia for the crack pressure. The specification value for relief valve cracking is between 0.8 psid and 2.5 psid. The valve reseats at 0.8 psid. The check/relief valve stayed open until the level in tank A dropped below full near the end of the mission. At 339:07:07:29 G.m.t. (015:11:21:29 MET), the A/B check/relief valve cracked open after a 1.35 psia pressure rise.

The Ku-band radio frequency (RF) power output telemetry measurement had erratic indications from 324:14:51 G.m.t. (00:19:05 MET) to 324:15:38 G.m.t. (00:19:52 MET), and from 324:16:50 G.m.t. (00:21:04 MET) to 324:17:13 G.m.t. (00:21:27 MET) (Flight Problem STS-87-V-02). However, during these time periods, the White Sands Ground Station reported a good Ku-band downlink signal. This measurement is normally relatively stable at about 4.5 Vdc; however, during the cited times the uncalibrated signal varied from 0 to 4.3 Vdc. No other indications of a power-output problem or measurement problem occurred during the remainder of the mission.

The first samples of on-orbit fuel cell monitoring system (FCMS) data were gathered between 325:03:40:46 G.m.t. (01:07:54:46 MET) and 325:03:52:46 G.m.t. (01:08:06:46 MET) with a sampling rate of one sample per second. The second batch of on-orbit data from the FCMS began being recorded at 325:04:01:49 G.m.t. (01:08:15:49 MET), which was during the crew-sleep period. This 10-hour sample was taken at the rate of 1 sample every 5 minutes. The initial evaluation of the FCMS data indicated 288 healthy individual cells. The data were satisfactory for performing the primary function of providing individual cell voltages over time.

The RMS arm was powered up and uncradled at 325:19:19 G.m.t. (01:23:33 MET). The arm was then maneuvered to the SPARTAN pre-grapple position at 325:19:29 G.m.t. (01:23:43 MET), and SPARTAN capture occurred at 325:19:32 G.m.t. (01:23:46 MET). The payload was unberthed and maneuvered to the Video Guidance System (VGS) acquire/verification position at 325:20:18 G.m.t. (02:00:32 MET), and was then moved to the SPARTAN release position at 325:20:25 G.m.t. (02:00:39 MET). The derigidize/rigidize command sequence to initialize the SPARTAN was issued at 325:21:04 G.m.t. (02:01:18 MET), and the end effector immediately derigidized and released the SPARTAN. When the SPARTAN failed to perform its pirouette attitude maneuver (Flight Problem STS-87-P-09), an attempt to re-grapple the SPARTAN was made at 325:21:10 G.m.t. (02:01:24 MET). The re-grapple maneuver was not successful and a tip-off rate of approximately 2 deg/sec was imparted to the SPARTAN. The subsequent attempt by the Orbiter to reduce the relative rates to allow re-capture had to be terminated because of propellant limitations. The arm was returned to the precradle position at 325:22:28 G.m.t. (02:02:42 MET), and cradled and powered down 4 minutes later.

After the SPARTAN operations problem, the RMS was selected at 326:01:42:31 G.m.t. (02:05:56:31 MET) to perform a test of the end effector. The end effector checkout was completed successfully. A visual inspection using closed circuit television (CCTV) camera B confirmed that the snare wires operated properly and were not damaged. The RMS was deselected at 326:01:58:35 G.m.t. (02:06:12:35 MET). The RMS arm was cradled in the manipulator positioning mechanisms (MPMs), and the arm was placed in the temperature-monitoring mode.

At 325:23:10:30 G.m.t. (02:03:25:30 MET), a 3.5-second multi-axis RCS posigrade maneuver was performed to move the Orbiter a safe distance from the SPARTAN.

The extravehicular mobility unit (EMU) checkout was completed satisfactorily. Both units were found ready to support the scheduled extravehicular activity (EVA). The crew reported that the EMU helmet floodlight, one of four lights on the helmet that was used by the EV2 crewmember, was flickering during the EMU checkout (Flight Problem STS-87-X-01). Later, the crew removed and replaced the bulb, but the light continued to flicker. The EV2 crewmember used an EMU helmet spot light during the EVA to replace the failed floodlight.

At approximately 327:09:15:28 G.m.t. (03:13:29:28 MET), it was determined that the primary RCS thruster R2D heater had failed off (Flight Problem STS-87-V-03). RCS injector temperatures are desired to be maintained above 40 °F to prevent leakage from the thruster valves. As of 328:00:00 G.m.t. (04:04:14 MET), the R2D temperature had dropped into the 45 to 50 °F range and was being maintained in that range by the external environment and the RCS stinger heater.

The NC-4 multi-axis rendezvous maneuver was completed at 328:08:33:17 G.m.t. (04:12:47:17 MET), imparting a 1.4 ft/sec  $\Delta V$  to the vehicle. During this six-second maneuver, the RCS R2D primary thruster was fired, resulting in warming it to a level in excess of 80° F.

The decision was made to rendezvous with SPARTAN and have the two EVA crewmembers manually capture and berth the spacecraft.

At 328:22:20 G.m.t. (05:02:34 MET), the Ku-Band system was placed in the radar mode. The SPARTAN spacecraft was acquired at 328:23:14 G.m.t. (05:03:28 MET) at an approximate range of greater than 40,000 feet. The radar tracked SPARTAN until 329:00:53 G.m.t. (05:05:07 MET) when the range was approximately 85 feet.

The RMS arm was powered up at 328:22:52 G.m.t. (05:03:06 MET). The three manipulator retention latches (MRL's) were released nominally in dual-motor time at 328:22:56:39 G.m.t. (05:03:10:39 MET). In preparation for the SPARTAN rendezvous, the RMS was maneuvered to the modified Poise-for-Capture position at 328:23:07 G.m.t. (05:03:21 MET).

The RCRS was deactivated at 328:23:33 G.m.t. (05:03:47 MET), followed by airlock depressurization starting at 328:23:40 G.m.t. (05:03:54 MET). The depressurization was temporarily stopped at 328:23:42 G.m.t. (05:03:56 MET) for the 5.5-psia hold. Airlock depressurization was completed satisfactorily. The cabin repressurization to 14.7 psia was initiated at 329:00:02 G.m.t. (05:04:16 MET) and was completed at 329:00:15 G.m.t. (05:04:29 MET).

The EVA started when the crew members placed their power switches to the battery position at 329:00:01 G.m.t. (05:04:15 MET). The airlock B hatch was opened nominally for the EVA egress at 329:00:02 G.m.t. (05:04:16 MET). The RMS was moved to an observation position for the manual SPARTAN retrieval at 329:01:04:00 G.m.t (05:05:18:00 MET). When the SPARTAN proved to be difficult to manually berth, the arm was maneuvered to grapple SPARTAN at 329:02:39:04 G.m.t. (05:06:53:04 MET). SPARTAN was berthed with the RMS at 329:03:23:22 G.m.t. (05:07:37:22 MET) and un-grappled at 329:03:26:36 G.m.t. (05:07:40:36 MET).

Following SPARTAN berthing, astronauts Winston Scott and Takao Doi performed several tasks in the EVA Demonstration Flight Test (EDFT-05) development test objective (DTO) 671. The EVA was completed in 7 hours and 43 minutes. The EVA was successful in the capture and stowage of SPARTAN and the evaluation of equipment to be used on the Space Station. The crew entered the airlock at 329:07:35 G.m.t. (05:11:49 MET) and the airlock B hatch was closed and locked nominally. Airlock repressurization began at 329:07:45 G.m.t. (05:11:59 MET) and was completed at 329:07:58 G.m.t (05:12:12 MET).

The decision was made to complete SPARTAN/VGS operations. An unscheduled second EVA was also planned to complete those objectives not accomplished during the first EVA.

The RMS was powered up at 337:03:29 G.m.t. (013:07:43 MET) in support of the SPARTAN/VGS operations. The Spartan grapple occurred at 337:04:52 G.m.t. (013:09:06 MET), and the SPARTAN was unberthed at 337:05:52 G.m.t. (013:10:06 MET). The SPARTAN was berthed at 337:09:11 G.m.t. (013:13:25 MET) and latched at 337:09:12 G.m.t. (013:13:26 MET) after a successful completion of VGS operations. The RMS was parked in the EVA hatch-viewing position for monitoring EVA egress and ingress.

A 10.2-psia cabin depressurization was initiated at 336:14:54 G.m.t. (012:19:08 MET) and completed at 336:15:18 G.m.t. (012:19:32 MET). The deactivation of the RCRS occurred at 337:08:38 G.m.t. (013:12:52 MET) in support of the airlock depressurization. The airlock depressurization began at 337:08:47 G.m.t. (013:13:01 MET) and completed at approximately 337:09:05 G.m.t. (013:13:19 MET). The RCRS was reactivated at 337:09:18 G.m.t. (013:13:32 MET). The EVA began when the crew members placed their power switches to battery at 337:09:10 G.m.t. (013:13:24 MET). The cabin repressurization to 14.7 psia was completed at 337:11:03 G.m.t. (13:15:17 MET).

The second EVA was concluded with the start of airlock repressurization at 337:14:08 G.m.t. (013:18:22 MET) for a total time of 4 hours and 59 minutes. Airlock repressurization was completed at 337:14:17 G.m.t. (013:18:31 MET). Astronauts Winston Scott and Takao Doi completed the EDFT-05 tasks successfully and satisfactorily deployed and retrieved the Autonomous EVA Robotic (AER) Camera/Sprint during this second EVA. The total STS-87 EVA time was 12 hours and 42 minutes.

The flight control subsystem (FCS) checkout was performed using APU 3. APU 3 was started at 338:09:51:25 G.m.t. (014:14:05:25 MET) and ran for 11 minutes and 59 seconds with 21 lb of fuel consumed. While APU 3 was running, a slight over-cooling was observed immediately after spray cooling was achieved on the WSB 3B

controller. Spray cooling was observed for approximately 2 minutes and 24 seconds before switching to controller 3A. Steady-state cooling was nominal on controller 3A. Controller 3B was reselected immediately prior to APU shutdown. Water usage during FCS checkout was approximately 3.36 lb. Steam vent heater operation was nominal during FCS checkout.

During the FCS checkout, the positive stimulus test of speedbrake channel 3 caused the secondary differential pressure ( $\Delta P$ ) to exhibit a delayed response of 1.43 seconds before achieving the expected value. The results of the negative stimulus test were nominal. This condition had no effect on entry and landing operations.

The RCS hot-fire was performed immediately following FCS checkout. All primary thrusters fired nominally during the hot-fire.

The third sample of on-orbit FCMS data was gathered between 338:05:57 G.m.t. (014:10:11 MET) and 338:06:09 G.m.t. (014:10:21 MET) with a sampling frequency of one sample per second. Evaluation of the data showed that the fuel cells were operating nominally with little or no change from the previous samples of FCMS data taken on flight day 2. The data are also similar to the first two samples in terms of offset of the calculated FCMS differential voltage versus the cell performance monitor (CPM) differential voltage.

The payload bay doors were closed and latched for landing at 339:08:43:14 G.m.t. (015:12:57:14 MET). The dual-engine deorbit maneuver for the landing at the Shuttle Landing Facility (SLF) runway 33 was performed on orbit 251 at 339:11:21:27.9 G.m.t. (015:15:35:27.9 MET). The maneuver was 152.2 seconds in duration with a  $\Delta V$  of 250.5 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on KSC concrete runway 33 at 339:12:20:02 G.m.t. (015:16:34:02 MET) on December 5, 1997. The Orbiter drag parachute was deployed at 339:12:20:09 G.m.t. and the nose gear touchdown occurred 6 seconds later. The drag chute was jettisoned at 339:12:20:38 G.m.t. with wheels stop occurring at 339:12:21:02 G.m.t. The rollout was normal in all respects. The flight duration was 15 days 16 hours 34 minutes 02 seconds. The APUs were shut down 15 minutes 31 seconds after landing.

## **PAYLOADS AND EXPERIMENTS**

The STS-87 mission payloads included the United States Microgravity Payload-4 (USMP-4), the SPARTAN 201-94 payload, the extravehicular activity (EVA) payloads, the Hitchhiker payloads, the Get-Away Special (GAS) payload, and the Collaborative Ukrainian Experiment (CUE). All minimum payload mission requirements were met or exceeded with the exception of the SPARTAN operations, which are discussed in this section.

The USMP-4 experiments met or exceeded all of the pre-mission planned science objectives except for the processing of one of the three Advanced Automated Directional Solidification Furnace (AADSf) samples because of a failure which is discussed later in this section. Deployment of the SPARTAN 201-04 payload was delayed one day to flight day 3 and thereby provided time for the Solar Heliospheric Observatory (SOHO) to reconfigure from a safe-hold shutdown that occurred on November 19, 1997. The SOHO satellite is in orbit about the Sun and was to provide simultaneous solar observations with the SPARTAN. However, the SPARTAN attitude control system did not activate properly at payload release from the remote manipulator system (RMS) arm (Flight Problem STS-87-P-01), and all attempts to re-grapple the payload and return it to the payload bay were unsuccessful on that day. An EVA to manually capture the SPARTAN and re-berth it in the payload bay was accomplished on flight day 6 as part of the pre-mission planned EVA to accomplish Development Test Objective (DTO) 671 - EVA Hardware for Future Scheduled EVA Missions (EDFT-05). A second EVA was then planned to perform the operations deleted from the first EVA because of the SPARTAN recapture activities. A selection of the high-priority tasks for EDFT-05 and Risk Mitigation Experiment (RME) 1323 - Autonomous EVA Robotic Camera (AERCam)/Sprint were successfully performed on flight day 14. The activities on flight day 14 also included RMS-attached SPARTAN video guidance sensor (VGS) operations that were not accomplished during earlier SPARTAN operations. A discussion of the EVA operations and activities is contained in the Extravehicular Activity section of this report.

### **UNITED STATES MICROGRAVITY PAYLOAD-4**

The fourth USMP-4 mission was described as a grand success with two immediate products - the first being improved mathematical models and theories, and the second being the graduate-student science-team members who will take this knowledge into the United States industrial complex. Highlights and most notable accomplishments of the mission were: the fastest dendritic growth ever measured and highest level of undercooling ever obtained for pivalic acid; the most precise temperature measurement ever taken in space; the first time observation of two separate processes of solidification and the first measurement of the speed of smooth crystal growth; and the first observation of the engulfment and pushing of large particle clusters, which is a materials crystallization study that is important to cryobiotechnology, composites, and possibly to highway construction materials. The series of USMP flights has also lead to pursuing numerous concepts for International Space Station (ISS) experiments.

The USMP-4 experiments carrier was located in the payload bay and consisted of two support structures and contained microgravity experiments in the areas of materials

science, combustion science and fundamental physics. The individual experiments comprising this payload were as follows:

- a. Advanced Automated Directional Solidification Furnace (AADSf);
- b. Confined Helium Experiment (CHeX);
- c. Isothermal Dendritic Growth Experiment (IDGE);
- d. Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit (MEPHISTO);
- e. Microgravity Glovebox Facility (three experiments);
  1. Enclosed Laminar Flames Experiment (ELF).
  2. Wetting Characteristics of Immiscibles (WCI) Experiment.
  3. Particle Engulfment and Pushing by a Solid/Liquid Interface (PEP) Experiment.
- f. Space Acceleration Measurement System (SAMS); and
- g. Orbital Acceleration Research Experiment (OARE).

The carrier performed as planned throughout the mission. One thermal sensor failed, and another sensor in the system was substituted satisfactorily. One minor problem occurred when attempting to acquire guidance, navigation and control data from the Orbiter for correlation with data from one experiment, but the process created some command interruptions that were expected. The acquisition of Orbiter data was halted, and the carrier system resumed normal command performance. These data were available on the Orbiter downlist; consequently, this interruption had no effect on the mission.

### **ADVANCED AUTOMATED DIRECTIONAL SOLIDIFICATION FURNACE**

The AADSf was used to conduct two experiments in materials science - one consisting of two ampoules containing lead-tin-telluride samples and another single ampoule containing a mercury-cadmium-telluride sample. Extensive research plus many millions of dollars are being spent each year on semiconductors to improve the speed and amount of information that can be stored and sent by computers and other high-tech electronics. The AADSf experiment continued efforts on this its third mission to develop better material processes, improve material performance and reduce production costs.

Approximately 145 hours of flawless performance of the AADSf enabled the science teams to complete one experiment ampoule each; however, an internal, over-current circuit problem in the drive motor controller and a failed temperature sensor in the furnace prevented processing the second ampoule of lead-tin-telluride. In spite of numerous attempts to process this last ampoule, the AADSf had to be powered down.

The first experiment ampoule of lead-tin-telluride was processed without any problems. The science team will conduct analyses of the three solidified crystals looking for the effects of low-temperature gradient growth, high growth rate, and elimination of the heat dispersion time on the integrity of the crystals. One interesting observation during sample processing was the recalescence signal when cells one and two nucleated. The temperature versus time plots showed a characteristic closer to that seen in Earth-based experiments rather than that seen on the USMP-3 experiment.

The second experiment ampoule, containing a single sample of mercury cadmium telluride was melted and solidified over a period of approximately 51 hours, which will

yield 36 mm of homogeneous material. The rapid removal of the sample at the end of the experiment should demonstrate the interface position and shape and will also "quench in" the diffusion barrier layer, which is expected to yield a structure from which the real diffusion coefficient for this material can be determined.

### **CONFINED HELIUM EXPERIMENT**

The CHeX facility was comprised of a refrigerated bottle (dewar) that contained 392 crystal silicon disks in a vacuum. These crystals were arranged to take maximum advantage of liquid helium's ability to conduct heat 1000 times more effectively than any other material. Thermal controls and heater feed-back systems regulate the temperature of the experiment sample to better than a billionth of a degree over several days. Using ultra-precise instruments, measurement techniques provided data from which an analysis of the behavior and properties of various materials will be made.

This CHeX performed very well throughout the mission and provided data that will aid in better understanding the effects of miniaturization on material properties in the development of smaller and more efficient electronic devices along with reduced costs. The primary mission objective was accomplished. During the fundamental physics experiment, which was the main part of the facility, the helium cryostat performed much better than on an experiment on the USMP-1 mission and achieved a lifetime in space of 12 days and 3 hours. The high resolution thermometers performed better than expected.

The primary minimum science objective was achieved. A total of 40 high-resolution sweeps through the transition region were collected and this met all science requirements. In addition, data were collected on 19 sweeps of lesser quality which also count toward the total desired sweeps of 80 for the mission. Data were also collected from five high-temperature sweeps, giving a total of 2450 heat-capacity measurements made during the mission.

The main science goals were to map the detailed heat capacity curve near the finite size peak, determine the shift of the peak from the bulk transition temperature, and measure the surface-specific heat behavior above and below transition. Good measurements were made in all areas. Overall, the curve appears approximately as expected and the signal-to-noise ratio is sufficiently good to allow detailed testing of the finite size effect by over an order of magnitude relative to ground-based measurements.

### **ISOTHERMAL DENDRITIC GROWTH EXPERIMENT**

The IDGE provided data from which a better understanding of the process of solidification of metals and improvement of metal manufacturing techniques. The experiment was attempting to create new alloys that are stronger and have better controlled and more reliable properties than are currently available here on Earth. Two television cameras allowed scientists on the ground to watch dendrites emerge in near real time. As the dendrites grew in high-purity pivalic acid (PVA), the experiment computer triggered two 35 mm cameras to photograph the samples. The PVA is an organic acid that crystallizes with a face-centered, cubic structure like that of aluminum and copper. The onboard-exposed photographic data are being used to evaluate growth rates and dendrite shapes of various samples.



The IDGE instrument performed flawlessly and beyond expectations in microgravity. Video downlink, a new feature for this mission, yielded excellent scientific results and enhanced the experiment team's ability to plan and control the experimental cycles. There were approximately 110 experiment cycles performed at supercooling temperatures ranging from 09.5 to 1.25 K. This span of supercooling temperature ranges represents a dynamic range of 25, which is more than twice that originally planned. With the video downlink, IDGE scientists were able to measure for the first time the full-time development of a dendritic crystal, including its initial transient response before steady-state conditions were reached.

The team observed the first clear evidence that suggests that PVA grows in a diffusion-limited mode and is not affected by molecular processes occurring at the solid-melt interface. Additionally, the photographic combination used during dendritic growths will result in measurements of extraordinary precision.

### **MATERIALS FOR THE STUDY OF INTERESTING PHENOMENA OF SOLIDIFICATION ON EARTH AND IN ORBIT**

The MEPHISTO investigation is an international cooperative program between the National Aeronautics and Space Administration (NASA), the French Space Agency, the French Atomic Energy Commission and the University of Florida. The goal of the experiment is to understand how gravity-driven convection produced in a furnace affects the production of metals, alloys and electronic materials. This fourth flight of the experiment continued the investigation into how materials solidify under microgravity conditions.

The flight hardware performed well beyond its specifications. The materials science experiment using MEPHISTO involved repeated melting and solidification of three identical samples to measure the solid/liquid interface, using three different measuring techniques. The performance of the hardware and samples and the quality of telemetric data received were superb throughout the mission.

MEPHISTO scientists completed 35 Seebeck solidification and melting cycles over a wide range of velocities. Only 13 of these 35 cycles were planned. Twenty-one Peltier pulses were successfully performed in five regions of the Peltier sample, and a resistance sample was quenched near the end of the mission.

Preliminary analyses indicate that Seebeck signals during growth cycles depend not only on the interface velocity and growth distance, but also on the structure of the solid forming behind the interface. Correlation of the microstructure features with the Seebeck signals will allow definitive tests of the diffusion-controlled growth theories. Seebeck data during melting cycles are very similar to the growth cycles, but the melting is generally at a higher interface temperature than solidification. The difference between the two could represent both compositional differences at the interface as well as kinetic differences during melting and freezing. Postflight analysis of all the data will be performed.

### **MICROGRAVITY GLOVEBOX FACILITY**

Two materials science investigations and one combustion science experiment were conducted in the Microgravity Glovebox Facility (MGBX). All of the other experiments in

the USMP-4 require little or no crew involvement in completing the objectives; however, the Glovebox investigations required a high degree of crew involvement. The MGBX performed well and supported all investigations through 58 hours of operations with no anomalies that resulted in science loss or damage to the facility. Three science investigations were conducted in the MGBX facility.

### **Enclosed Laminar Flames**

The ELF experiment examined the effect of different air flow velocities on the stability of laminar (non-turbulent) flames. The ELF combustion investigation into the effects of air flow on the flame stability of laminar jet-diffusion flames proved very successful. Approximately 50 test points (flames) were conducted and all six fuel bottles onboard were used. The majority of the tests were used to identify the velocities at the flame's stability limits, while five of the tests were conducted to measure the temperature field of attached (stable) flames. Preliminary analysis of the results was used to map the flame stability as a function of the fuel and air velocities. The map revealed that considerably higher velocities were required to destabilize the flame in microgravity. The temperature information as well as the stability limits will be compared with numerical predictions in an effort to validate the present understanding of this type of flame.

### **Wetting Characteristics of Immiscibles**

Special metal alloys, known as immiscibles, contain components that do not mix in the liquid melting process before solidification. Previous microgravity experiments with these alloys revealed unexpected separation of their components into layers, even though gravity effects were not present. This Wetting Characteristics of Immiscibles (WCI) experiment investigated one possible cause for this segregation - droplet wetting or coating along the container walls - along with ways to control this behavior to improve material processing on Earth. The findings of this experiment were recorded on video tape for postflight study and analysis.

The investigative study of the way immiscible liquids behave successfully completed all 12 samples of succinonitrile/glycerin, including being able to reprocess two of the samples. Sample compositions spanned the miscibility gap and ranged from 15 weight-percent to 70 weight-percent glycerin. One interesting result was observed in the very last sample processed. Small glycerin-rich droplets actually moved away from the gasket surface after nucleation, resulting in a sample consisting primarily of a dispersion of glycerine-rich droplets, but with the perimeter being droplet free. Many of the findings followed the preflight predictions; however, some of the results have indicated that wetting characteristics may be a more dominant factor in microgravity processing than even the WCI team had anticipated.

### **Particle Engulfment and Pushing by a Solid/Liquid Interface**

Composite materials - those in which a mixture of two or more materials form a new material with specific properties - are developed to take advantage of the properties of each of the component materials. During solidification of these materials, a solidification interface forms. This interface moves and as it does, particles are either pushed ahead of or engulfed into the solid material. This Particle Engulfment and Pushing by a Solid/Liquid Interface (PEP) experiment enabled investigators to study the behavior and

movement of particles as the sample solidified in a convection-free microgravity environment.

The experiment's science objective was to evaluate the critical PEP velocity for free-floating particles in a quiescent liquid. PEP achieved its science objective by successfully running eight samples - four SCN/Polystyrene and four Biphenyl/Glass. These runs provided data to validate theoretical models that assume no liquid convection and no contact between particles and container walls. The preliminary analysis of experiment results shows the critical velocity agrees with the PEP team's theoretical model. Additionally, an experimental method was developed during the flight and implemented through direct interaction with the crew that operated the experiment. It consisted of accelerated back-melting and rapid solidification. This was necessary to evaluate the size of pushed particles in biphenyl which was semi-opaque after solidification.

### **SPACE ACCELERATION MEASUREMENT SYSTEM**

The SAMS was used to record and downlink in near real-time, precise measurements of disturbances in the vehicle which affect the microgravity environment which in turn affects the USMP-4 experiments. These disturbances were caused by crew exercise or movement in the vehicle, onboard equipment operation, or thrusters being fired for control purposes. The researchers and scientists rely on the SAMS to provide these data on vehicle changes in-flight. This experiment has been flown on a number of flights and again performed flawlessly during this flight.

STS-87 was the first flight during which SAMS data were recorded data on removable 8.4 gigabyte hard drives. SAMS data were used to help attain the optimum configuration for the crew exercise ergometer. Acceleration data from three different configurations was analyzed to determine the ergometer set-up of least disturbance to the microgravity experiments. Approximately 100 requests from the science users were made for SAMS data analyses, the majority of which focused on activities surrounding the SPARTAN and EVA operations, RCS configurations, and several disturbances with unknown sources.

### **ORBITAL ACCELERATION RESEARCH ENVIRONMENT**

The OARE provided extremely accurate measurements of small accelerations - changes in velocity - as well as vibration variations and disturbances during orbital travel using an accelerometer. The instrument is capable of sensing and recording accelerations on the order of one-billionth the acceleration of Earth's gravity.

The OARE instrument has been flown on several Shuttle flights and again performed flawlessly for the USMP-4 mission. Data were recorded by OARE and periodically downlinked during the mission to the Principal Investigator Microgravity Services (PIMS) group for processing. The PIMS team reported to the Principal Investigators (PI's) about the microgravity environment relative to water dumps, attitude maneuvers, crew-sleep versus crew-awake periods, and cabin depressurization operations in preparation for the EVA. This was the first time that cabin depressurization was studied using accelerometer data.

## **SPARTAN 201-04**

The SPARTAN 201-04 was a primary Shuttle mission, and its objective was to investigate the physical conditions and processes of the hot outer layers of the Sun's atmosphere (solar corona). Two instruments were to investigate the heating of the solar corona and the acceleration of the solar wind that originates in the corona. These complementary instruments, the Smithsonian Astrophysical Observatory's Ultraviolet Coronal Spectrometer (UVCS) and the Goddard Space Flight Center (GSFC) High Altitude Observatory White Light Coronagraph (WLC), have both flown on previous SPARTAN missions.

The SPARTAN 201-04 mission did not obtain any solar science data because of the anomalies during deployment on flight day 3. The SPARTAN spacecraft was deployed as planned; however, all indications are that spacecraft was not properly initialized prior to deployment and thus failed to perform the planned pirouette maneuver. The attitude control system was not activated (Flight Problem STS-87-P-01). During the attempt to regrapple, rotational rates were imparted to the spacecraft, and the Orbiter had to separate from the SPARTAN because of propellant limitations. The satellite was successfully captured by the EVA crewmembers a day later and returned to the cargo bay using the RMS and without accomplishing its primary mission. It was determined that the spacecraft was healthy and capable of a second deployment and a shortened free-flying mission. However, a decision was made to not deploy the SPARTAN because the Orbiter had insufficient propellant to perform a second spacecraft deployment and retrieval. As a result of this mission failure, a formal investigation board was convened to determine the cause of the failure.

### **Automated Rendezvous and Capture Video Guidance Sensor Experiment**

The automated rendezvous and capture video guidance sensor (VGS) experiment was to be performed in conjunction with the SPARTAN during the rendezvous and capture of the SPARTAN. The system consisted of a video camera, dual-frequency lasers and a docking target on the SPARTAN. The laser-video system offers improved accuracy over the use of radio frequency (RF) control systems for docking maneuvers. The system has demonstrated pinpoint accuracy, down to one-tenth of an inch, in ground tests.

On flight day 14, the RMS was used to unberth the SPARTAN from the payload bay and successfully perform the VGS RMS-attached operations. A minor anomaly was encountered in the interfacing of the VGS payload and ground support computer (PGSC) and a second PGSC, but this anomaly concerned only ancillary desired data and was not critical to the success of VGS tests. A summary of the science accomplished during VGS operations will be available once the downlinked data have been reviewed.

## **RISK MITIGATION EXPERIMENTS**

### **RME 1309 - In-Suit Doppler Ultrasound for Determining the Risk of Decompression Sickness During Extravehicular Activities**

The Risk Mitigation Experiment (RME) 1309 - In-Suit Doppler Ultrasound for Determining the Risk of Decompression Sickness During Extravehicular Activities - investigated the possibility of reducing the EVA prebreathe time required to prevent decompression sickness in EVA crewmembers. The Doppler hardware can detect and record nitrogen bubbles in the pulmonary artery. RME 1309 was conducted in the crew compartment environment only to evaluate crew comfort and on-orbit operation prior to use in the EMU on later flights. Eight hours of In-Suit Doppler data collection were accomplished on flight day 9 by the Mission Specialist 2 crewmember. There were no discussions with the crew regarding any problems with the hardware. The Doppler hardware as well as the data collected during the mission are being analyzed.

### **RME 1323 - Autonomous Extravehicular Activity Robotic Camera Sprint**

The RME 1323 - Autonomous Extravehicular Activity (EVA) Robotic Camera Sprint (AERCam Sprint) experiment demonstrated the use of a prototype free-flying television camera that will provide the capability for conducting remote inspections of the International Space Station (ISS). The free-flyer portion of the system consisted of a 14-inch diameter, 35-lb sphere that contained two television cameras, an avionics system and 12 small nitrogen-gas-powered thrusters. The sphere looks like an oversized soccer ball.

The AERCam Sprint free-flyer was successfully deployed on flight day 14 (December 3, 1997, at 6:16 a.m. c.s.t.) during the second EVA, with astronaut Winston Scott hand-launching the free-flyer in the payload bay of the Orbiter. During the next 1 hour and 12 minutes, the Sprint free-flyer conducted a series of maneuvers and observations designed to evaluate the utility of a remotely-controlled free-flying camera platform for remote viewing of spacecraft systems such as the ISS, Space Shuttle payloads, EVA operations, science spacecraft, etc.

The Sprint free-flyer was controlled from the aft flight deck by the Pilot. The Sprint free-flyer was maneuvered around the Orbiter payload bay following a pre-defined flight test scenario. It then was maneuvered to a position approximately 40 feet directly above the overhead windows of the crew cabin and returned back to the payload bay to complete the flight test. The distance above the overhead windows was limited by the amount of time remaining before the end of the day pass. Approximately 65-percent of the cold-gas nitrogen propellant and 8-percent of the battery charge were used during the entire flight. The Sprint free-flyer sent video images back to the Pilot's control position and to the ground during the flight test. The experiment successfully demonstrated the ability of Sprint to collect and transmit images of Shuttle operations that could not otherwise be provided, proving a new capability for on-orbit operations.

At the completion of the experiment, Sprint was flown back to the MS2 crewmember, who manually grasped the free-flyer, safed it and returned it to the airlock.

Following recovery, the Pilot reported that the system "flew better than expected" and deserved a Cooper-Harper rating of Level 1, which is the highest possible evaluation of command and control of a vehicle.

All of the objectives of the experiment were completed, and no Sprint system anomalies were experienced during the flight test. The Pilot initially did not have a video image displayed on the Sprint Control video monitor, but this was caused by the Orbiter video system not being configured properly. The Pilot began the free-flight without the video image and was able to successfully perform the initial portion of the flight test scenario until the video image was available on the video monitor several minutes later. Video and data were provided to the ground during all times when the Orbiter Ku-band downlink was available. Overall, the flight test of the Sprint system was considered to be an unqualified success.

### **RME 1332 - Space Station - Test of Portable Computer System Hardware**

The RME 1332 - Space Station - Test of Portable Computer System Hardware - single event upset (SEU) software was initiated on flight day 7 and ran for approximately 140 hours. The software functioned nominally. The SEU counts for the mission, as called down during the status checks, were within the range of the predicted pre-flight data. The initial data show that accurate models can be created for these data. All indications are that the hardware should function in a predictable manner on the Space Station.

### **HITCHHIKER PAYLOADS**

The Hitchhiker payloads that were flown on the STS-87 mission are discussed in the following subparagraphs.

#### **Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment**

The Shuttle Ozone Limb Sounding Experiment (SOLSE) provided a capability to measure the vertical profiles of ozone with high resolution to determine the altitude distribution of ozone using the solar ultraviolet (UV) scattering from the Earth's atmospheric limb. The SOLSE was designed to record continuous UV wavelengths in the 290 to 340 nanometer range to measure the ozone profile between 15 miles (25 kilometers) and 34 miles (55 kilometers). The Limb Ozone Retrieval Experiment (LORE) was a complementary instrument to the SOLSE, and it also provided the capability of measuring vertical profiles of the ozone. The instrument obtained ozone data below the 15-mile lower limit of the SOLSE down to 6 miles from the Earth. The two systems together provided ozone coverage data images and cross sections of the atmosphere showing ozone concentrations at different altitudes.

The objective of the SOLSE payload was to understand its behavior so that quantitative changes in the composition of the atmosphere can be predicted. SOLSE required one earth view and two limb views, with additional observations highly desired. In addition to the limb and earth observations, a SOLSE limb scan was requested that would sweep the instrument field-of-view through the area under observation. With proper analysis of the limb scan data, SOLSE could verify instrument pointing and optimize the attitude bias for subsequent observations.

The SOLSE earth view was performed on flight day 2, early due to the postponement of SPARTAN deployment. This earth view was unsuccessful because payload operations were performed without a properly initialized avionics unit. Science return from this earth view could not be verified as the anomalous configuration induced the transmission of invalid data to the payload general support computer (PGSC). To validate the theory behind the anomalous telemetry, a functional verification test was uplinked and performed on flight day 5. Analysis of the downlinked data file confirmed that the payload responded as designed and expected. This test provided the first on-orbit verification of SOLSE and LORE instrument operability.

A replacement earth view was scheduled on flight day 9. The SOLSE calibration measurements that are required prior to and following all SOLSE observations were incomplete during the second earth view.

The nominal SOLSE limb observation profiles originally planned for flight day 13 and 14 was rescheduled for flight day 13 due to timeline conflicts near the end of the mission. The flight day 13 operations of SOLSE included two orbits of data. The first consisted of an Earth limb view at a fixed attitude. All indications from the instrument pointing algorithm show that the SOLSE field-of-view was properly centered at a tangent altitude of 35 km. The data captured during this orbit by both SOLSE and its complimentary instrument LORE will be used to infer ozone profiles for the first time using a limb-viewing technique. A correlative measurement with a balloon instrument package launched from Reunion Island was also accomplished during this orbit and it will help to validate the science results.

The second orbit of data consisted of both a limb scan and a short fixed-attitude data take near the end of the orbit. Readouts of the pointing error correction during the scan were consistent with expectations and verified the instrument pointing. The fixed-attitude data at the end of the orbit was a bonus and will add to SOLSE science data. The team was very pleased to be able to exploit this real-time opportunity, once the pointing algorithm indications appeared nominal.

In summary, the re-planning requirements necessitated by the rescheduling of SPARTAN and EVA operations resulted in SOLSE not fully accomplishing the objectives scheduled in the preflight timeline. SOLSE could not properly capitalize on the limb scan as the team was not able to analyze pointing data prior to the other limb observation. In addition, SOLSE must wait to verify achievement of a successful earth view until the payload is returned for postflight processing. However, preliminary analysis of telemetry received during the limb views has been very promising. The instruments performed flawlessly and promise a significant science return. In light of the very ambitious re-planned timeline, the SOLSE team was pleased to have performed the critical limb observations.

### **Loop Heat Pipe Experiment**

The Loop Heat Pipe Experiment (LHP) provided a means of investigating a unique thermal energy management system. The two experiments used a common avionics package, although the experiments were mounted in separate locations on the payload bay side-wall.

The LHP, sponsored by the Center for Space Power and managed by Dynatherm Corporation, investigated a unique thermal energy management system using a loop

heat pipe. The purpose of the flight experiment was to verify system performance in microgravity, in particular start-up behavior, step power changes, and the ability to provide thermal control of the heat source. All objectives were met or exceeded during the 16-day mission.

The original test plan called for 6 major tests with a total test time of 60 hours. The tests included power profiles at three different temperatures spanning a typical operating range of the loop heat pipe. Environmental conditions were met for each of the six tests.

In addition to the original test plan, supplemental tests were requested and granted. Supplemental tests combined with the original test plan exceeded 200 hours of zero-g operation, an impressive number of hours in zero-g. All test were 100-percent successful.

The success of the flight experiment means that commercial satellite designers can now feel comfortable using this advantageous technology. The loop heat pipe enables the use of deployable radiators which will decrease satellite real estate and save in launch vehicle size (and therefore substantial savings of cost). The loop heat pipe's robust performance, high transport capacity, low weight, 1-g testing capability (without stringent orientation requirements of typical heat pipes) and versatility in design will make the loop heat pipe the thermal energy management system of choice for many applications.

### **Sodium Sulfur Battery Experiment**

The completion of the Sodium Sulfur Battery Experiment (NaSBE) marked the first time sodium sulfur (NaS) technology has been in space. The sodium sulfur cell is different from most battery cells in that its electrolyte is solid (Beta-Alumina ceramic), and its two electrodes (molten sodium and sulfur) are liquid. This battery has the highest operating temperature (350°C) of all rechargeable batteries, which forces a new paradigm in battery integration. But, among the many potential benefits, one is most impressive: Sodium sulfur has three times the specific energy (Wh/kg) as compared to conventional Nickel Hydrogen (NiH<sub>2</sub>) batteries. The NiH<sub>2</sub> technology is used in many spacecraft today, such as the Hubble Space Telescope, and is currently planned for International Space Station. A space station NiH<sub>2</sub> battery predicted to weigh 350 lb could be replaced by a NaS battery weighing only 120 lb. Also, the NaS cells have a projected cost ½ that of NiH<sub>2</sub>.

The NaSBE battery is the climax of the Air Force Research Laboratory (AFRL) Sodium Sulfur Technology Program, and the objectives were to demonstrate the capability for NaS cells to operate in microgravity, and investigate the effects of microgravity on cell performance, material transport, and interfacial reactions. The flight experiment portion of NaSBE successfully fulfilled the first objective, and has laid the groundwork for the second. In short, the cells were expected to perform nominally, just as they have on the ground, so that they can be compared to a control set. The differences (if any) will be investigated to gain insights into future cell improvements, and ultimately, achieve space operation of sodium sulfur batteries. The experiment was designed and built by Naval Research Laboratory's Center for Space Technology, who integrated four, flight quality, 40 Amp-hr cells into a Hitchhiker Canister. New techniques were developed while instrumenting the experiment for the high operating temperatures that NaS cells require. These techniques have now been proven with the successful flight of NaSBE.



The cells were taken through five phases of testing essential to validating their operation in space which were:

1. Cell warm-up;
2. Two verification cycles (40-percent DOD);
3. Two GEO cycles (60-percent DOD);
4. A total of 16 LEO cycles (40-percent DOD); and
5. Cell cool-down.

To gain more understanding of the electrodes, at the end of Phase 4, each cell was discharged to 0-percent, 20-percent, 40-percent, and 60-percent DOD before taken off line and cooled down.

The experiment was performed as planned with full completion of every phase. No microgravity effects were observed, and the cells performed as predicted. Of particular interest were the varied cell-cycling characteristics exhibited while on orbit, the good cell and experiment thermal characteristics, and the flawless performance of the experiment hardware itself. All flight objectives were realized.

### **Turbulent Gas-Jet Diffusion Flames**

The Turbulent Gas-Jet Diffusion Flames (TGDF) experiment was a Hitchhiker payload that was flown in a Get-Away Special (GAS) canister. The experiment provided data for a better understanding of the characteristics of transitional and turbulent gas-jet diffusion flames. The experiment cannot be conducted in normal gravity because buoyant (gravity-driven) convection causes flow instabilities that interfere with the experiment. The flame was video-taped using two cameras that were contained within the canister.

The data from this experiment will increase the understanding of the role of large-scale structures in transitional and turbulent gas jet diffusion flames. The payload was activated on flight day 1 and had completed operations by flight day 2. The experiment is assumed to have performed successfully. Postflight evaluation will determine the success of the TGDF experiment.

### **GET-AWAY SPECIAL PAYLOAD**

The Get-Away Special (GAS) canister G-036 was sponsored by El Paso (Texas) Community College and contained four separate experiments. The results of these experiments may be obtained by contacting the previously named College or the Goddard Space Flight Center. The four experiments were:

1. Cement Mixing Experiment (CME) - This experiment mixed cement with water in space and control samples on Earth were also mixed. Both sets of examples were compared to determine if the possibility exists for use of cement in space.
2. Configuration Stability of Fluid Experiment (CSFE) - This experiment investigated the effects of microgravity on the configuration stability of a two-phase fluid system. The experiment was video-taped and the data were returned to the College after the flight.

3. Computer (Compact) Disc Evaluation Experiment (CDEE) - This experiment investigated the effects of the exosphere, the outer fringe region of the Earth's atmosphere, on the ability of discs to retain their information.
4. Asphalt Evaluation Experiment (AEE) - This experiment investigated the effects of the exosphere on asphalt. Data will be used to determine improved and more durable ways of making asphalt.

All GAS experiment operations were completed on flight day 1 and are assumed to have been successful. Postflight evaluation will determine the success of the various experiments in the canister.

### **COLLABORATIVE UKRAINIAN EXPERIMENT**

The Collaborative Ukrainian Experiment (CUE) was a collection of 10 plant space biology experiments that were stowed and performed on the Orbiter middeck. The Ukrainian Payload Specialist Cosmonaut performed the experiments. In conjunction with the space-borne experiment, as many as 625,000 American students and teachers and a minimum of 20,500 Ukrainian students and teachers performed the same experiment on the ground.

CUE operations went extremely well with all planned CUE operations being successfully completed. A total of 61 mission kits, which contained everything from gas sampling apparatus to nutrient material to pollination tools, and over 100 new hardware elements were flown and all performed satisfactorily. The ground-control experiments, which were performed on a 48-hour delay from the in-flight operations, produced similarly successful results. The following paragraphs discuss individual experiment operations.

#### **Brassica rapa Seed Terminal Growth in Chambers**

The three Brassica rapa Seed Terminal Growth in Chambers (BSTIC) chambers were watered on three occasions using water from the galley to dilute the concentrated nutrient solution that was stowed onboard. The galley water was filtered by the CUE watering kit.

Eighteen plants were pollinated on nine different flight days. More than 80 individual flowers were marked and pollinated by the crew. In addition, 20 pollinated flowers were harvested for fixation at four time points on flight day 5 to study the early stages of plant embryo development under microgravity conditions.

#### **Brassica rapa Photosynthetic Apparatus in Chambers**

The Brassica rapa Photosynthetic Apparatus in Chambers (BPAC) experiment was initiated on flight day 2. Approximately 135 seeds were watered in three of the plant growth facility (PGF) plant growth chambers (PGCs). The first harvest was performed on flight day 8, and the plants had developed well. During this harvest, 18 six-day-old plants were fixed and 18 six-day-old plants were frozen. The second harvest involved the same operations on flight day 15 as on flight day 8 but with 14-day old plants. The remaining BPAC plants were pollinated once on flight day 15.

### **Soybean Metabolism**

Approximately 78 soybean seedlings were grown in six Biological Research in Canisters-60 (BRIC-60), and these seedlings were watered as planned. Gas samples were taken periodically from each canister to determine the levels of ethylene and carbon dioxide produced by the growing seedlings. These samples were placed in sealed bags for postflight analysis. Canisters 1 and 2 were frozen on flight day 13 in the GN<sub>2</sub> freezer for postflight analysis. These canisters represented plants from seeds grown and frozen entirely in space.

### **Space Moss Experiment - Parts A and B**

The Space Moss Experiment (SPM) - Parts A and B hardware functioned satisfactorily. The crew performed several planned reconfigurations of the light emitting diode (LED) light treatments. Six fixation operations were conducted over the course of the mission. All 47 petri-dish fixation units (PDFUs) were chemically fixed and the BRIC-LED hardware was down for landing.

### **Soybean Pathogen Interactions/Gene Expression Experiments**

The Soybean Pathogen Interactions (SOYPAT) soybean seedlings were harvested on three different flight days. Gas samples were taken on three separate days for the SOYPAT experiment and were stored for postflight evaluation of ethylene and carbon dioxide content. The final harvest for the SOYPAT soybean seedlings/pathogen interaction experiment was performed on flight day 7 when all the remaining seedlings for this experiment were harvested. A total of 72 plants were fixed and 72 plants were frozen in the GN<sub>2</sub> freezer.

The Gene Expression Experiment (GENEX) was initiated on flight day 10 with the planting of 192 seeds in the four empty BRIC-60 canisters. This planting provided six-day old seedlings for the GENEX. One gas sample was taken for the GENEX. The gas sample was stored in a sealed bag for postflight analysis of ethylene and carbon dioxide content.

### **MIDCOURSE SPACE EXPERIMENT**

During the course of the mission as appropriate opportunities became available, the Midcourse Space Experiment (MSX) obtained ultraviolet, infrared and visible light data of RCS thruster firings in the field of view of the MSX satellite that is already on-orbit.

The MSX RCS maneuver consisted of two firings. The first firing of 5 seconds duration occurred at approximately 338:08:29:06 G.m.t. (14:12:43:06 MET). RCS primary thrusters F3F and F2F were used for the -X axis firing. The second MSX RCS firing, which occurred at 338:08:29:21 G.m.t. (14:12:43:21 MET), used thrusters L3A and R3A for the 10-second +X axis firing. The principal investigator indicated that the satellite was configured to observe the firings. Analysis of the data was performed postflight, and the results of the experiment will be published in separate documentation.

## **SHUTTLE IONOSPHERIC MODIFICATION WITH PULSED LOCAL EXHAUST**

The purpose of this experiment was to observe ionosphere disturbances, which were caused by OMS thruster firings, using ground-based Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) radars. This payload of opportunity had no activity during the mission.

## **VEHICLE PERFORMANCE**

The flight evaluation results for the SRB, RSRM, ET, SSME, SRSS and Orbiter subsystems are discussed in this section of the report. Overall performance of the vehicle was satisfactory; however, five in-flight anomalies were noted and these are discussed in the appropriate subsystem sections of this portion of the report.

### **SOLID ROCKET BOOSTERS**

All Solid Rocket Booster (SRB) systems performed as expected. The SRB prelaunch countdown was normal, and no SRB Launch Commit Criteria (LCC) or Operational Maintenance Requirements and Specification Document (OMRSD) violations occurred.

First stage ascent performance was as expected. Both SRBs were successfully separated from the External Tank (ET) 123.720 seconds after liftoff. SRB entry, deceleration and water impact occurred as anticipated. All deceleration subsystems performed as designed. The SRBs were recovered and returned to KSC for inspection, disassembly, and refurbishment. At the time that this report was completed, the inspection and disassembly were completed and the refurbishment activities were underway. No in-flight anomalies were identified in the data analysis.

After the launch, the ground support equipment (GSE) gaseous nitrogen (GN<sub>2</sub>) purge line assembly for the aft skirt of each SRB was found damaged. The flex-line hose section on both purge assemblies separated at some time after T+2 seconds and became potential debris. This was a first occurrence of this condition, and an investigation into the cause is continuing as this report was being written. The Program Requirements Control Board (PRCB) decided not to declare this condition an in-flight anomaly.

An evaluation of the SRB thrust vector control (TVC) subsystem showed that it responded as expected to the SSME trim modifications, which were made as a part of the Shuttle Performance Enhancements. The SSME trim changes closed up the included angle between the SSME and the SRB thrust vectors. The SRB thrust vectors were trimmed to maintain moment balance, and this trimming resulted in the TVC actuator positions being outside of their experience base during certain specific time frames. The overall actuator position experience base was not exceeded, only certain areas of the time-specific (second-by-second) experience base were expanded.

### **REUSABLE SOLID ROCKET MOTORS**

The Reusable Solid Rocket Motor (RSRM) performance parameters were within Contractor End Item (CEI) specification limits. The RSRM countdown was nominal, and no RSRM LCC or OMRSD violations occurred. The calculated propellant mean bulk temperature (PMBT) was 69 °F at the time of launch. The maximum trace shape variation of pressure versus time during the 62-80-second time frame was calculated as -0.57 percent at 79.5 seconds for the left motor, and -0.36 percent at the 74.5-second time frame for the right motor. These values were well within the 3.2 percent requirement. No in-flight anomalies were identified from the review and analysis of the data. The propulsion performance for the RSRMs are shown in the following table.

### RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 69 °F		Right motor, 69 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 <sup>6</sup> lbf-sec	66.09	66.26	66.04	65.92
I-60, 10 <sup>6</sup> lbf-sec	175.96	177.09	175.84	176.64
I-AT, 10 <sup>6</sup> lbf-sec	296.75	297.83	296.61	297.15
Vacuum Isp, lbf-sec/lbm	268.5	269.5	268.5	269.0
Burn rate, in/sec @ 60 °F at 625 psia	0.3706	0.3708	0.3706	0.3709
Event times, seconds <sup>a</sup>				
Ignition interval	0.232	N/A	0.232	N/A
Web time <sup>b</sup>	108.9	108.4	109.0	108.7
50 psia cue time	118.6	118.6	118.7	118.7
Action time <sup>b</sup>	120.7	120.8	120.7	121.4
Separation command	123.6	123.7	123.6	123.7
PMBT, °F	69	69	69	69
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	2.9	2.8	3.5
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		268.7	

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

<sup>a</sup>All times are referenced to ignition command time except where noted by a <sup>b</sup>

<sup>b</sup>Referenced to liftoff time (ignition interval).

Power-up and operation of all igniter and field joint heaters was accomplished as planned. Power was applied to the field joint heaters 30 percent of the time, maintaining the field joints within the normal operating range. The power was applied to the igniter joint heaters approximately 56 percent of the time, and the igniter joints were maintained within the normal operating temperature range. All RSRM temperatures were maintained within acceptable limits throughout the countdown.

For this flight, the heated ground purge in the aft SRB skirts was used to maintain the case/nozzle joint temperatures within the required LCC ranges. During the LCC time frame, the aft skirt purge operated for 20 hours 56 minutes, and the nozzle/case joint sensor temperatures ranged from 80 to 85 °F on both motors. The calculated flex bearing mean bulk temperature (FBMBT) was 80 °F.

### EXTERNAL TANK

All objectives and requirements associated with the External Tank (ET) loading and flight operations were satisfactorily met. All ET electrical equipment and instrumentation operated satisfactorily. The ET purge and heater operations were monitored and all performed properly. No ET LCC or OMRSD violations occurred. One in-flight anomaly was identified and it is discussed in a later paragraph.

No unexpected ice/frost formations were observed on the ET during the countdown. There was no observed ice or frost on the acreage areas of the ET. Normal quantities of ice or frost were present on the LO<sub>2</sub> and LH<sub>2</sub> feed-lines, the pressurization line brackets, and along the LH<sub>2</sub> protuberance air load (PAL) ramps. All ice/frost observations were acceptable per NSTS 08303. The Ice/Frost personnel reported that there were no anomalous TPS conditions; however, the recurring crack in the thermal protection system (TPS) where the foam bridges between the vertical strut cable tray and fitting fairing was present.

STS-87 was the second flight with the composite nose cone. Once the gaseous oxygen (GO<sub>2</sub>) vent hood was removed, ice formation was observed in the area around the louvers that had not been observed on previous metal-substrate nose cones. The Ice/Frost Red Team deemed the condition acceptable.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO<sub>2</sub> ullage pressure experienced during the ullage-pressure slump was 13.7 psid.

ET separation occurred at 529.483 seconds MET. Main engine cutoff occurred within expected tolerances and ET entry and breakup were nominal. The postflight predicted ET intact impact point was within the footprint and approximately 103 nmi. uprange of the preflight predicted impact point.

Photography taken of the ET after separation from the Orbiter showed a significant amount of material loss on both thrust panels (Flight Problem STS-87-T-01). Additionally, there was an indication of minor material loss from a few stinger tops on the -Z axis area and one location in the +Z axis area of the intertank. As this report was written, an investigation was in progress to determine the cause of the material loss and the actions required on subsequent vehicles.

A post-landing inspection of the Orbiter revealed 244 hits on the lower surface, 109 of which had a major dimension on one-inch or greater. The distribution of hits on the lower surface suggests an unusual source of ascent debris. The TPS loss from the intertank area of the ET is suspected as the most probable cause of the damage. The total number of lower-surface hits was much greater than the average of 83, and the number of lower-surface hits one-inch or larger was also much greater than the average of 13.

## **SPACE SHUTTLE MAIN ENGINES**

All Space Shuttle main engine (SSME) parameters were normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights. Engine ready was achieved at the proper time; all LCC were met; and engine start and thrust build-up were normal. All ignition confirm limits and mainstage redline margins were satisfactory. All interface control document (ICD) start and shutdown transient requirements were met. Engine performance in all areas was as predicted. Cutoff off times for SSME 1, 2, and 3 were 517.21, 517.33, and 517.44 seconds, respectively. The  $I_{sp}$  was rated at 452.58 seconds, based on trajectory data. Controller and software performance was satisfactory with no problems identified. Likewise, the data analysis did not reveal any in-flight anomalies.

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 the high pressure fuel turbopump (HPFTP) temperatures were well within specification. The Space Shuttle main engine cutoff (MECO) occurred 509.69 seconds after liftoff.

## **SHUTTLE RANGE SAFETY SYSTEM**

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits turned off at appropriate times. All SRSS measurements indicated that the system operated as expected throughout the countdown. As planned, the SRB S&A devices were safed, and SRB system power was turned off prior to SRB separation. The ET system was deleted from this vehicle as well as a number of previous vehicles.

Postflight data analysis indicated nominal performance of the SRSS except that during ascent, the right-hand SRB SRSS signal strength B exceeded the range safety minimum requirement of -85 dBm when tracking with the Cape Kennedy Command Site, which was the only SRB tracking site. The lowest observed right-hand SRB SRSS signal strength B was -85.9 dBm (1.35 Vdc) at 51.7 seconds MET that did not exceed the right-hand SRB SRSS command sensitivity of -108.6 dBm and did not affect system operation. Data indicate that the combined signal strength of all four SRB SRSS integrated receiver decoders (IRDs) was always sufficiently high to maintain system operation to SRB separation.

## **ORBITER SUBSYSTEMS PERFORMANCE**

### **Main Propulsion System**

The overall prelaunch and in-flight performance of the main propulsion system (MPS) was nominal. The liquid oxygen (LO<sub>2</sub>) and liquid hydrogen (LH<sub>2</sub>) loadings were performed with no stop-flows or reverts. Also, there were no LCC or OMRSD violations.

No significant hazardous gas concentrations were detected during the preflight operations period. The maximum hydrogen concentration level in the Orbiter aft compartment, occurring just after the start of fast-fill, was approximately 164 ppm. This level compares favorably with previous data for this vehicle.

Based on an analysis of the loading system data, the LH<sub>2</sub> load at the end of replenish was 231,306 lbm, which when compared with the inventory (predicted) load of 231,339 lbm, yielded a small difference (-0.01 percent) that was well within the required MPS loading accuracy of  $\pm 0.37$  percent.

The LO<sub>2</sub> loading operations were normal through chill-down, slow fill, fast fill, topping and replenish. Based on an analysis of the loading system data, the LO<sub>2</sub> load at the end of replenish was 1,388,504 lbm. Comparison of the actual load with the planned load showed a difference of 224 lbm (-0.02 percent), which is well within the required loading accuracy of  $\pm 0.43$  percent.



Ascent MPS performance during the start, mainstage, and shutdown operations was nominal and all requirements were satisfied. Data indicate that the LO<sub>2</sub> and LH<sub>2</sub> pressurization and feed systems performed nominally and satisfied all tank ullage pressure and SSME inlet net positive suction pressure (NPSP) requirements. The minimum LO<sub>2</sub> ullage pressure experienced during the period of the ullage pressure slump was 13.65 psid. The gaseous hydrogen (GH<sub>2</sub>) system in-flight performance was nominal. The GO<sub>2</sub> fixed-orifice pressurization system performed as predicted. Reconstructed data from engine and MPS parameters closely matched the actual ET ullage-pressure measurements. Helium system performance was nominal and a nominal 58.9 lbm of helium was used during entry.

Propellant dump operations were initiated 122.4 seconds after MECO and nominal performance was noted. The LO<sub>2</sub> and LH<sub>2</sub> feed system inerting operations were performed as planned. However, after the OMS-2 maneuver and following vacuum inerting and helium repressurization of the main propulsion system (MPS), the LH<sub>2</sub> manifold pressure continued to rise indicating residual hydrogen still had not been expelled during the second vacuum inerting. Consequently, a decision was made to perform another vacuum inerting. This operation was performed at 324:21:02 G.m.t. (01:06:16 MET), and the manifold pressure was successfully brought to zero psia where it remained throughout the remainder of the on-orbit operations.

### **Reaction Control Subsystem**

The reaction control subsystem (RCS) performed nominally throughout the mission. One RCS thruster (R2D) heater failed off approximately three and one-half days after launch, and the anomaly is discussed in the following paragraph. A total of 6760 lbm of propellants were consumed by the RCS. Of this total propellants consumed by the RCS, 2327.8 lbm were provided by the orbital maneuvering subsystem (OMS) during left- and right-pod interconnect operations. The primary RCS had a total of 6640 firings, and a total firing time of 1600.84 seconds. The vernier RCS had a total of 24,531 firings, and a total firing time of 19,329.4 seconds.

At approximately 327:09:15:28 G.m.t. (03:13:29:28 MET), it was determined that the primary RCS thruster R2D heater had failed off (Flight Problem STS-87-V-03). RCS injector temperatures went below 70 °F, and the heater should have come on and given a sharp temperature rise. This failure condition required that special vehicle attitudes be used, as well as periodic firings of the thruster be performed to maintain acceptable injector- and valve-operating temperatures. Additionally, RCS injector temperatures were desired to be maintained above 40 °F to prevent leakage from the thruster valves. As of 328:00:00 G.m.t. (04:04:14 MET), the R2D temperature had dropped into the 45 to 50 °F range and was being maintained in that range by the external environment and the RCS stinger heater. The three thrusters on manifold 2 were removed and replaced during the postflight turnaround activity.

The major RCS maneuvers performed during the mission are shown in the table on the following page.

During the deployment and unsuccessful attempt to recapture the SPARTAN, more RCS propellants were used than had been budgeted. The propellant remaining was reduced as well as the amount of propellant used were as follows:

- a. Left RCS oxidizer from 82.1 percent to 56.2 percent (349.65 lbm);
- b. Left RCS fuel from 83.7 percent to 57 percent (226.95 lbm);
- c. Right RCS oxidizer from 82.1 percent to 58.6 percent (317.25 lbm);
- d. Right RCS fuel from 83.7 percent to 59 percent (209.95 lbm);
- e. Forward RCS oxidizer from 71 percent to 37.5 percent (452.25 lbm); and
- f. Forward RCS fuel from 72.1 percent to 37.1 percent (297.5 lbm).

### RCS MANEUVERS

Maneuver	Time, G.m.t./MET	$\Delta V$ , ft/sec	Duration, seconds
+X Trim 1	324:03:16:50 G.m.t. 00:07:30:50 MET	4.5	18.6
SPARTAN chase start/end	325:21:04 to 325:22:11 G.m.t. 02:01:18 to 02:02:25 MET	-	1hr 7 min
SPARTAN separation +X	325:23:10:23 G.m.t. 02:03:24:23 MET	-	3.5
NC-4	328:08:33:17 G.m.t. 04:12:47:17 MET	1.4	6
MC1	328:23:10:29 G.m.t. 05:03:24:29 MET	1.2	5
MC2	328:23:42:14 G.m.t. 05:03:56:14 MET	1.0	4
MC3	328:23:59:14 G.m.t. 05:04:13:14 MET	1.3	5
MC4	329:00:09:15 G.m.t. 05:04:23:15 MET	0.6	3
Trim (AADSF attitude)	331:00:49:57 G.m.t. 07:05:03:57 MET	6.7	29
Trim	335:15:44:21 G.m.t. 11:19:58:21 MET	4.0	17
MSX -X axis	338:08:29:06 G.m.t. 14:12:43:06 MET	-	5
MSX +X axis	338:08:29:21 G.m.t. 14:12:43:21 MET	-	10

The total amount of 1853.5 lbm of propellant were consumed during the deployment and attempt to recapture the SPARTAN. Also, the recapture operations after deployment resulted in all of the first-priority thruster injector temperatures getting relatively hot (above 120 °F) with the F1U fuel injector temperature reaching 166.5 °F. This high temperature was still below the maximum non-operating Shuttle Operational Data Book (SODB) -allowed thruster valve-seat limit of 175 °F, and no subsequent thruster firings were above the maximum thruster valve operating limit of 157 °F.

After the completion of the SPARTAN operations, five attitude options were assessed for the 72-hour long Advanced Automated Directional Solidification Furnace (AADSF) run. The attitudes were designed to be acceptable for AADSF crystal growth while protecting RCS thruster R2D with its failed heater, as well as honoring all other Orbiter thermal constraints. The options are summarized in the table on the following page.

### Attitude Options for the 72-hour AADSF Period

ATTITUDE OPTIONS	POTENTIAL ISSUE	
1) Baseline: bay down, nose forward -ZLV, +XVV	R2D cold thruster	
2) Bottom down, nose forward: +ZLV, +XVV	APU 1 service line exceeding 170°F	
3) Bay down, tail forward: -ZLV, -XVV with +10° pitch bias	Cold forward RCS vernier thrusters	<b>SELECTED OPTION</b>
4) Bay down, tail forward: -ZLV, -XVV with -10° pitch bias	Payload science	
5) Bay down, port wing forward: -ZLV, -YVV	Payload science	

At 331:00:49:45 G.m.t. (07:05:03:45 MET) an orbit adjust maneuver was executed to reach the AADSF orbital parameters. The maneuver was performed in the +X axis for approximately 29 seconds with a  $\Delta V$  of 6.7 ft/sec. RCS thrusters L1A and R1A were used for the maneuver.

The forward RCS vernier-thruster temperatures were continually approaching the fail-leak 130 °F limit. As a result, continual attitude adjustments were required, as were deadband collapses, and/or deselection of the aft yaw vernier thrusters to maintain the temperatures of the forward vernier thrusters above the 130 °F leak-detection limit. Cooling of the forward vernier thrusters, because of inadequate heaters, was prevalent during some of the extended attitude-hold periods.

The RCS hot-fire was performed immediately following FCS checkout. All primary thrusters fired nominally during the hot-fire.

#### Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the mission. No LCC or OMRSD deviations occurred prior to launch, and no in-flight anomalies occurred during the mission. A total of 13,766.4 lbm of OMS propellants were consumed during the mission, and of this total 2327.3 lbm were consumed by the RCS during interconnect operations. The table on the following page provides data concerning each of the OMS maneuvers.

At 324:06:16 G.m.t (00:10:30 MET), the crew repressed the right OMS engine gaseous nitrogen (GN<sub>2</sub>) accumulator because there was evidence of a recurring small GN<sub>2</sub> leak. This action was taken to preclude setting off the low-pressure alarm during the crew-sleep period. At 325:05:49 G.m.t (01:10:03 MET), the crew repressed the right OMS engine GN<sub>2</sub> accumulator for the second time. Following this second repressurization, the leak stopped. This leak has occurred on previous flights of this engine.

## OMS MANEUVERS

Maneuver/Engines	Time, G.m.t./MET	$\Delta V$ , ft/sec	Duration, seconds
OMS-1	Not required		
OMS 2/ 2	323:20:27:09 G.m.t. 00:00:41:09 MET	193.8	126.2
NC5/OMS 3/ 1 (right)	328:21:19:33 G.m.t. 05:01:33:33 MET	11.5	14.8
TI/OMS 4/ 1 (left)	328:22:50:38 G.m.t. 05:03:04:38 MET	9.0	11.8
Deorbit/ 2	339:11:21:28 G.m.t. 15:15:35:28 MET	250.5	152.2

The right OMS oxidizer low-point-drain line temperature exhibited unusual behavior during the prelaunch period. A rapid temperature rise of 3.1 deg/min for a 3.5-minute period was followed by about 6 hours of operations at a relatively constant temperature. The temperature signature returned to normal cycling prior to launch, and exhibited nominal operation throughout the mission.

### Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performance was nominal throughout the mission. The subsystem provided the fuel cells with 4296 lbm of oxygen and 541 lbm of hydrogen for the production of electricity. In addition, the environmental control and life support system (ECLSS) was supplied 192 lbm of oxygen. A 174-hour mission-extension capability existed at touchdown at the average mission power level. At an extension-day power level of 12.7 kW, a 229-hour mission extension was possible.

At 329:03:48 G.m.t. (05:08:01 MET), the hydrogen tank 4 quantity measurement failed to the off-scale high reading. At the time of the failure, the quantity in the tank was 32.6 percent. The tanks continued to be used to the residual quantity. All efforts to restore the measurement were unsuccessful. At 331:10:40:46 G.m.t. (07:14:54:46 MET), the quantity measurement began reading nominally when the measurement displayed 2.5 percent and the tank 5 quantity was 2.9 percent. The measurement remained stable for the remainder of the mission and throughout landing and detanking. Post-landing troubleshooting did not duplicate the problem.

The quantities in oxygen tanks 4 and 5 began diverging at 327:02:00 G.m.t. (03:06:14 MET), with the tank 5 quantity dropping below tank 4. These tanks were installed in these positions in 1995 and have flown seven flights. On the previous six flights, the tank 5 quantity was always equal to or greater than the tank 4 quantity. During STS-87, the tank 5 quantity decreased by as much as 6 percent below tank 4. Just prior to the quantity diverging, there was one heater cycle in which the tank 5 pressure dropped to 830 psia, about 20 psia lower than previous pressure band lower-cycling points. As expected, the quantities began converging when they fell below 30 percent, and the tanks were depleted nominally.

## **Fuel Cell Powerplant Subsystem**

Performance of the fuel cell powerplant subsystem was nominal throughout the mission with no in-flight anomalies identified from the data. The average electrical power level and load for the mission was 16.5 kW and 542 amperes. The fuel cells produced 6198 kWh of electrical energy and 4837 lbm of by-product potable water. Six purges of the fuel cells using both the automatic and manual systems were performed satisfactorily during the mission. The actual fuel cell voltages at the end of the mission were 0.05 volt above predicted for fuel cell 1, 0.15 volt above predicted for fuel cell 2, and 0.1 volt above predicted for fuel cell 3.

STS-87 was the first flight of the fuel cell monitoring system (FCMS), which was to display the individual cell voltage in a fuel cell. The system functioned properly each time it was powered. The system was powered continuously during the prelaunch period until liftoff minus 1 hour 40 minutes. The first on-orbit samples of FCMS data were gathered between 325:03:40:46 G.m.t. (01:07:54:46 MET) and 325:03:52:46 G.m.t. (01:08:06:46 MET) with a sampling rate of one sample per second. The second batch of on-orbit data from the FCMS began being recorded at 325:04:01:49 G.m.t. (01:08:15:49 MET), which was during the crew-sleep period. This 10-hour sample was taken at the rate of one sample every five minutes. The initial evaluation of the FCMS data indicated 288 healthy individual cells. The data were satisfactory for performing the primary function of providing individual cell voltages.

The third sample of on-orbit FCMS data was gathered between 338:05:57 G.m.t. (014:10:11 MET) and 338:06:09 G.m.t. (014:10:21 MET) with a sampling frequency of one sample per second. Evaluation of the data showed that the fuel cells were operating nominally with little or no change from the previous samples. The data are also similar to the first two samples in terms of offset of the calculated FCMS differential voltage versus the cell performance monitor (CPM) differential voltage.

The overall thermal performance of the fuel cell water relief, water line and reactant purge systems was nominal. Both the A and B heater systems were exercised during the flight.

## **Auxiliary Power Unit Subsystem**

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission. No in-flight anomalies or significant problems were noted during the course of the mission. The APU run times and fuel consumption are shown in the table on the following page.

During ascent, the auxiliary power unit (APU) 3 lubrication oil return temperature reached approximately 304 °F before the crew switched from the water spray boiler (WSB) 3B controller to the A controller. No spraying was evident after switching to the A controller. As a result, the crew was instructed to shut down APU 3 approximately one minute early. Evidence of spraying was observed after the APU 3 shut down and prior to shutting off the WSB 3A controller. In addition, WSB 2, which initially controlled the APU 2 lubrication oil return temperature at 246 °F, experienced an over-cooling down to a temperature of 203 °F approximately 1.5 minutes after spray initiation. The system recovered to 246 °F approximately 2.5 minutes later.

## APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 401)		APU 2 (S/N 410)		APU 3 (S/N 304)	
	(a) (b) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	21:56	58	22:00	60	18:36	47
FCS checkout					11:58	21
Entry <sup>a</sup>	60:00	112	79:00	152	60:10	113
Total	81:56	170	101:00	212	90:44	181

<sup>a</sup> APUs were shut down 15 minutes 31 seconds after landing.

<sup>b</sup> APU 3 was used for the FCS checkout.

The APU 2 drain-line pressure began decreasing from 15.5 psia at 331:01:05 G.m.t. (07:05:19 MET) and continued to decrease throughout the mission, eventually reaching 0.2 psia. The actual decay rate was 1.1 psi/day, which violates the File IX limit. The drain-line pressure increased as atmospheric pressure increased during entry, thus showing that the relief valve was open. The condition posed no problem.

The APU 1 drain line pressure decayed from 21.3 psia, measured during prelaunch activities, to 11.6 psia where it stabilized approximately eight days into the flight. The actual calculated decay rate was 0.3 psia per day which is within the File IX limit.

The flight control system (FCS) checkout was performed using APU 3. APU 3 was started at 338:09:51:25 G.m.t. (014:14:05:25 MET) and ran for 11 minutes and 58 seconds.

### Hydraulics/Water Spray Boiler Subsystem

The overall hydraulics and WSB subsystem performance was nominal, and no in-flight anomalies were identified from the data.

During ascent, the APU 3 lubrication oil return temperature reached approximately 304 °F before the crew switched from the WSB 3B controller to the A controller. No spraying was evident after switching to the A controller. As a result, the crew was instructed to shut down APU 3 approximately one minute early. The lubrication oil return temperature had reached 342 °F when the APU was shut down. Evidence of spraying was observed after APU 3 shut down and prior to shutting off the WSB 3A controller. In addition, WSB 2, which initially controlled the APU 2 lubrication oil return temperature at 246 °F, experienced an over-cooling down to a temperature of 203 °F approximately 1.5 minutes after spray initiation. The system recovered to 246 °F approximately 2.5 minutes later.

WSB system 2 also had a momentary over-cooling condition during ascent that occurred 1 to 1 ½ minutes after spray initiation. The over-cooling condition had a duration of approximately 2 to 2 ½ minutes. System 2 operated satisfactorily during entry operations.

The flight control subsystem (FCS) checkout was performed using APU 3. APU 3 was started at 338:09:51:25 G.m.t. (014:14:05:25 MET) and ran for 11 minutes and 59 seconds with 21 lb of fuel consumed. While APU 3 was running, a slight over-cooling was observed immediately after spray cooling was achieved on the WSB 3B controller. Spray cooling was observed for approximately 2 minutes and 24 seconds before switching to controller 3A. Steady-state cooling was nominal on controller 3A. Controller 3B was reselected immediately prior to APU shutdown. Water usage during FCS checkout was approximately 3.36 lb. Steam vent heater operation was nominal during FCS checkout.

### **Electrical Power Distribution and Control Subsystem**

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

During the prelaunch time-frame, a GSE power supply was changed because of erratic behavior while changing the set point. When bringing the new power supply on line, an operator error occurred that caused an over-voltage condition on main dc bus C. Extensive research and analysis were able to clear the vehicle for flight. All equipment powered by this bus during flight performed nominally.

### **Pressure Control Subsystem**

The atmospheric revitalization pressure control subsystem (PCS) performed nominally throughout the mission. During the redundant component checkout, the pressure control configuration was switched to the alternate subsystem. Both subsystems performed nominally.

During the prelaunch cabin leak checks, a seal on the port used to pressurize the cabin came off (Flight Problem STS-87-V-01). The seal was replaced and the cabin leak check was completed satisfactorily. The problem delayed the cabin leak check, thus causing a concern over residual O<sub>2</sub> concentration in the aft compartment exceeding the limits required to come out of the planned hold. However, the aft compartment O<sub>2</sub> readings did drop below the 500-ppm level just prior to the end of the planned hold period, and the countdown was resumed at the planned time.

The Freon coolant loop (FCL) 1 was switched to interchanger flow at 328:04:29 G.m.t. (04:08:43 MET) in preparation for the cabin depressurization to 10.2 psi. In addition, the regenerative carbon dioxide removal system (RCRS) was powered down at 328:04:55 G.m.t. (04:09:09 MET). The cabin depressurization was started at 328:04:59 G.m.t. (04:09:13 MET) and completed 22 minutes later. The RCRS was then reactivated at 328:05:33 G.m.t. (04:09:47 MET).

At 328:04:59 G.m.t. (04:09:13 MET), the cabin was depressurized to 10.2 psia to support the scheduled EVA, and the cabin was repressured to 14.7 psia at 329:00:01 G.m.t. (05:04:15 MET). The cabin was again depressurized to 10.2 psia at 336:14:53 G.m.t. (12:19:07 MET) in preparation for the second EVA, and the cabin was repressurized to 14.7 psia at 337:10:49 G.m.t. (13:15:03 MET).

A 10.2-psia cabin depressurization to prebreathe the crew in preparation for the second EVA was initiated at 336:14:54 G.m.t. (012:19:08 MET) and completed at 336:15:18 G.m.t. (012:19:32 MET). The deactivation of the RCRS occurred at 337:08:38 G.m.t. (013:12:52 MET) in support of the airlock depressurization. The airlock depressurization began at 337:08:47 G.m.t. (013:13:01 MET) and completed at approximately 337:09:05 G.m.t. (013:13:19 MET). The RCRS was reactivated at 337:09:18 G.m.t. (013:13:32 MET). The EVA began when the crew members placed their power switches to battery at 337:09:10 G.m.t. (013:13:24 MET). The cabin repressurization to 14.7 psia was completed at 337:11:03 G.m.t. (13:15:17 MET).

### **Atmospheric Revitalization Subsystem**

The atmospheric revitalization subsystem (ARS) performed satisfactorily throughout the mission.

The infrared carbon dioxide sensors were manifested for the first time on this flight, and its response in the 14.7-psia cabin environment was normal. The sensor data during the 10.2-psia cabin environment also appears to be normal. The new sensors have an improved response time and were calibrated at 14.7 psia and are not pressure compensated. At lower cabin pressures, the sensor detects slightly lower concentrations than actual and likewise at increased cabin pressures, the sensor reads slightly higher concentrations than the actual CO<sub>2</sub> concentration in the cabin. During the 10.2-psia cabin periods on this mission, the cabin experienced a partial pressure of 3.1 mmHg CO<sub>2</sub> during the first period and 3.3 mmHg during the second period of 10.2-psia cabin. The vendor for this sensor stated that indicated levels below 4.9 mmHg while operating in a 10.2-psia cabin environment would translate to a PPCO<sub>2</sub> safe limit of 7.6 mmHg in a 14.7-psia environment.

During the launch-ascent phase of the flight, the heat exchanger outlet temperature peaked at 77.38 °F with the cabin air temperature peaking at 77.72 °F and cabin humidity peaking near 40 percent. The on-orbit peak cabin heat exchanger outlet temperature of 65.1 °F was reached on flight day 1, whereas the peak cabin air temperature and cabin humidity of 80.2 °F and 50.4 percent, respectively, were reached on flight day 6. The cabin environment at landing had a temperature of 75.49 °F, and a humidity of 37.6 percent.

The RCRS was deactivated at 328:23:33 G.m.t. (05:03:47 MET), followed by airlock depressurization starting at 328:23:40 G.m.t. (05:03:54 MET). The depressurization was temporarily stopped at 328:23:42 G.m.t. (05:03:56 MET) for the 5.5-psia hold. Airlock depressurization was completed satisfactorily. The cabin repressurization to 14.7 psia was initiated at 329:00:02 G.m.t. (05:04:16 MET) and was completed at 329:00:15 G.m.t. (05:04:29 MET).

### **Active Thermal Control Subsystem**

The active thermal control subsystem (ATCS) operation was satisfactory throughout the mission.

The flash evaporator system (FES) high-load duct temperatures dropped sharply during ascent while operating on system A high-load duct heater during two of the last four flights (STS-78 and STS-83) of this vehicle. As a result, the last flight (STS-94) of



this vehicle (OV-102) was launched with both the system A and B high-load duct heaters activated. During ascent, the high-load inboard duct temperature dropped to 223 °F just prior to main engine cutoff (MECO) and recovered slightly before decreasing to 175 °F approximately 4 minutes later. To gather more data, the STS-87 vehicle was launched with both the system A and B high-load duct heaters activated and the FES in primary B mode. During ascent, the high-load inboard duct temperature dropped to 233 °F by 12 minutes after liftoff. The temperature normally remains above 190 °F with only one heater activated. The temperature response was not as smooth as would be expected for dual heater operations. However, the evaporator outlet temperatures were stable throughout the occurrence. It is believed that excess water carry-over was the cause of the duct-temperature drop. No mission impact resulted from this condition, and the FES performed nominally for the rest of the mission.

The radiator cold-soak provided cooling during entry through landing plus six minutes at which time the ammonia boiler system (ABS) secondary system A was activated. System A operated for 34 minutes after which it was disconnected in preparation for ground cooling.

The flow proportioning valve (FPV) on Freon coolant loop (FCL) 2 was taken to the payload position approximately 2 ½ hours after launch to support USMP cooling, and it remained in this position until USMP operations were completed. The Orbiter provided satisfactory cooling for the USMP throughout the flight. The FPV on FCL 1 was taken to the payload position approximately 18 hours later to provide more cooling to the warm Orbiter cabin during the first day operations. The radiators were deployed as necessary to support payload operations.

### **Supply and Waste Water Subsystem**

The supply and waste water subsystem performed satisfactorily throughout the mission, and all scheduled in-flight checkout requirements were met.

Supply water was managed using the FES and the water dump system. Ten water supply dumps were performed at an average rate of 1.55 percent/minute (2.56 lb/min). The supply water dump line temperature was maintained satisfactorily between 78 °F and 108 °F throughout the mission with the operation of the line heater. Waste water was gathered at about the predicted rate. Three waste water dumps were performed at an average rate of 2.10 percent/minute (3.47 lb/min). The waste water dump line temperature was maintained satisfactorily between 55 °F and 80 °F throughout the mission.

Recent medical findings that link iodine consumption to thyroid problems resulted in a new medical requirement to limit the amount of iodine consumed by the crew to 0.5 mg/day. To lower the iodine levels in the drinking water, iodine removal equipment was developed and used on this flight. The crew installed the Iodine Removal Mineral Injection System (IRMIS) cartridges at the ambient inlet to the galley drinking water, and the system operated satisfactorily. The IRMIS was to reduce the iodine levels to zero in the chilled water and to 1.5 to 2.0 ppm in the ambient hot water; however, it was learned postflight that the microbial check valve did not contain any iodinated resin. This anomaly is discussed in the following paragraph. The IRMIS cartridges are the same cartridges used to remove iodine and iodide from the water that is transferred to the Mir Space Station.

Postflight water samples showed a high level of bacteria from supply water tank A. A total of 130 colony forming units were observed, and the limit is 100. Only a trace of iodine (0.06 ppm) was measured. The normal level of iodine during postflight testing is 2 to 3 ppm. Postflight analysis of the microbial check valve (MCV) from the vehicle determined that the MCV was packed without iodinated resin. An investigation was made to determine the cause of this condition. It was determined that the MCV was packed without resin as requested because the valve was to be used for a fit check during an OMDP at Palmdale. The MCV was not a flight ready item; however, the documentation was separated from the valve, and the valve was erroneously declared flight ready. Action has been taken to ensure that this condition does not recur.

At approximately 324:02:25:26 G.m.t. (00:06:39:26 MET), after supply-water tank A reached full quantity, the tank A/B check/relief valve failed to open at the specification level pressure. The supply-water storage inlet-pressure increased from 33.21 psia to 39.58 psia over a 5-minute period before the relief valve opened. During this period, fuel cell water flowed through an alternate relief valve to tanks B, C, and D. The pressure rise to crack the check valve was approximately 6 psia, whereas past flights have shown a range between 0.4 and 0.8 psia for the crack pressure. Normal cracking pressure for the A/B check/relief valve should be less than 1.5 psid during the acceptance test procedure (ATP), and less than 4 psid according to the OMRSD. The check/relief valve stayed open until the level in tank A dropped below full near the end of the mission. At 339:07:07:29 G.m.t. (015:11:21:29 MET), the A/B check/relief valve cracked open after a 1.35 psia pressure rise. The check/relief valve was removed and replaced during the postflight turnaround activities.

The supply water dump line heater 2 thermostat began dithering about 10 hours after the mid-mission reconfiguration to redundant heaters and continued to dither for about 72 hours. The waste water dump line heater also dithered following the heater reconfiguration and continued to dither for the rest of the mission.

#### **Waste Collection Subsystem**

The waste collection system performed satisfactorily throughout the flight with no problems noted or reported by the crew.

#### **Airlock Support System**

The airlock depressurization valve was used to depressurize the cabin from 14.7 psia to 10.2 psia, and the airlock from 10.2 psia to vacuum twice in support of the EVA's. The airlock was depressurized for the first EVA at 328:23:40 G.m.t. (05:03:54 MET) and repressurized at 329:07:45 G.m.t. (05:11:59 MET). The airlock was depressurized for the second EVA at 337:08:46 G.m.t. and repressurized to 14.7 psia at 337:13:08 G.m.t (13:18:22 MET). The active system monitor parameters indicated normal output throughout the duration of the flight.

#### **Smoke Detection and Fire Suppression Subsystem**

The smoke detection system showed no indications of smoke generation during the flight. Use of the fire suppression system was not required.

### **Flight Data System**

The flight data systems performed satisfactorily during the mission, and no in-flight anomalies occurred during the mission.

### **Flight Software**

The flight software performed nominally throughout the mission with no in-flight anomalies identified from the review of the data. All software flight objectives were satisfied.

### **Flight Control Subsystem**

The FCS performance was nominal throughout the mission. No in-flight anomalies were identified during the review and analysis of the data. There were no component failures and no deselections by the Redundancy Management (RM).

The inertial measurement units (IMUs) performed satisfactorily throughout the mission. IMU drift compensations were made twice during the flight. This same ship-set of IMUs were deemed satisfactory for the next flight of the vehicle.

External sensor data were incorporated into the onboard navigation state vector at the expected times. Drag measurement processing started at approximately 225,400 feet and ended at approximately 84,800 ft. TACAN station acquisition occurred at approximately 151,700 ft. The air data transducer assembly (ADTA) data incorporation began at 82,500 ft and continued to approximately 16,400 ft. All sensor measurement residuals and residual ratio values were nominal with no data editing observed. The backup flight system (BFS) navigation data also exhibited similar characteristics to the primary flight system. The postflight error analysis has shown a good comparison between the primary avionics software system (PASS) state vector and the BFS state vector.

During the FCS checkout secondary actuator test, the speedbrake channel 3 secondary differential pressure ( $\Delta P$ ) showed a 1.43-second delay when the positive stimulus was applied. The pressure initially responded to approximately 1100 psid, then hesitated while maintaining a pressure between 800 and 1000 psid before reaching the 2800 to 2900 psid expected pressure. The nominal pressure was reached, and the failure detection system operated properly. The electro-hydraulic servovalve responded nominally and without any delay during the negative stimulus test. Following postflight troubleshooting and the conduct of a contingency desilting procedure, nominal responses were noted.

### **Displays and Controls Subsystem**

The displays and controls subsystem performed nominally throughout the mission. No in-flight anomalies were identified in the data or from crew comments.

### **Communications and Tracking Subsystems**

The communications and tracking subsystems performed nominally.

The Ku-band radio frequency (RF) power output telemetry measurement had erratic indications from 324:14:51 G.m.t. (00:19:05 MET) to 324:15:38 G.m.t. (00:19:52 MET), and from 324:16:50 G.m.t. (00:21:04 MET) to 324:17:13 G.m.t. (00:21:27 MET) (Flight Problem STS-87-V-02). However, during these time periods, the White Sands Ground Station reported a good Ku-band downlink signal. This measurement is normally relatively stable at about 4.5 Vdc; however, during the cited times the uncalibrated signal varied from 0 to 4.3 Vdc. No other indications of a power output problem or measurement problem occurred during the remainder of the mission. Troubleshooting during the postflight turnaround activity could not duplicate the condition.

At 328:22:20 G.m.t. (05:02:34 MET), the Ku-Band system was placed in the radar mode. The SPARTAN spacecraft was acquired at 328:23:14 G.m.t. (05:03:28 MET) at an approximate range of greater than 40,000 feet. The radar tracked SPARTAN until 329:00:53 G.m.t. (05:05:07 MET) when the range was approximately 85 feet.

### **Operational Instrumentation/Modular Auxiliary Data Systems**

The operational instrumentation (OI) and modular auxiliary data system (MADS) operated satisfactorily throughout the mission. No in-flight anomalies or significant problems were noted during the mission.

At 330:19:35 G.m.t. (06:23:49 MET), the left outboard tire pressure 2 measurement failed to the off-scale low value. The measurement began working again at 338:04:43 G.m.t. (014:08:57 MET).

### **Structures and Mechanical Subsystems**

The structures and mechanical subsystems performed satisfactorily throughout the mission. No in-flight anomalies were noted in the review of the data and inspection of the hardware. The landing and braking parameters for the mission are shown in the table on the following page.

The starboard forward radiators were deployed at 327:05:40 G.m.t. (03:09:54 MET). This was the first of several starboard and port radiator deployments and stows. These operations were nominal.

The tires, which exhibited some ply undercutting on the right main inboard tire, were reported to be in good condition for a landing on the KSC concrete runway.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. The EO-2 and EO-3 fitting retainer springs were in nominal configuration. No clips were missing from the "salad bowls". Virtually no umbilical closeout foam or white room temperature vulcanizing (RTV) dam material adhered to the umbilical plate near the LH<sub>2</sub> recirculation line disconnect.

## LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2635.2	195.8	-1.36	N/A
Nose gear touchdown	5596.8	151.9	N/A	-3.87
Brake initiation speed		123.7 knots		
Brake-on time		40.0 seconds		
Rollout distance		10638.1 feet		
Rollout time		57.7 seconds		
Runway		33 (Concrete) KSC		
Orbiter weight at landing		233,198.6 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	894.7	Left-hand inboard	14.58	
Left-hand inboard 3	894.7			
Left-hand outboard 2	945.6	Left-hand outboard	13.65	
Left-hand outboard 4	945.6			
Right-hand inboard 1	886.2	Right-hand inboard	14.87	
Right-hand inboard 3	886.2			
Right-hand outboard 2	1008.7	Right-hand outboard	16.67	
Right-hand outboard 4	1008.7			

### Integrated Heating and Thermal Interfaces

The prelaunch thermal interface purges were normal with no problems noted. The ascent aerodynamic and plume heating was normal. The entry aerodynamic heating on the SSME nozzles was higher than normal (metal blued); however, the nozzles met material-hardness test requirements.

Surface temperature data indicate a higher-than-normal level of acreage heating, but the levels are still within certification values. The thermocouple forward of the main landing gear door also indicates that an early transition from laminar flow occurred.

The vehicle exhibited a large number of damaged tiles along the forward fuselage chine and wing chine lower-surface areas, and these suffered erosion during entry. Based on this observation, the lower surface damage occurred during ascent.

### Thermal Control Subsystem

The OV-102 thermal control subsystem (TCS) performance was nominal with the exception of the thruster R2D heater that is discussed in the following paragraph. All subsystem temperatures were maintained within acceptable limits.

The heater on thruster R2D failed early in the mission, but the failure was not apparent until approximately 327:09:15:28 G.m.t. (03:13:29:28 MET), which was about 2 hours

after the Orbiter had maneuvered into the AADSF attitude. Heaters in the surrounding compartment provided enough heat to maintain the injector temperature above its 42 °F limit during earlier shorter periods in that attitude. As a result of the failure, the attitude was changed so that the R2D primary thruster was kept warm; however, this attitude resulted in a low firing frequency for RCS vernier thruster F5L.

The F5R and F5L forward vernier thrusters both got cold. The F5R vernier thruster temperature dropped to 110 °F while it was deselected. The F5L vernier thruster oxidizer injector temperature approached its leak detection limit of 130 °F due to lack of firing in the 72-hour AADSF attitude. Apparently this pitch-biased attitude was quite stable. The previous solution of deselecting the aft vernier thrusters and tightening the deadband slightly was insufficient to cause the F5L vernier thruster to fire. Approximately every 30 minutes throughout the attitude, the deadband was collapsed as the temperature approached its leak detection limit of 130 °F.

The attitude timeline was changed to add an additional 10 hours (for a total slightly greater than 20 hours) of bottom Sun to warm the main landing gear (MLG) tires. This change was necessary because of real-time attitude changes that caused the port tire to be colder than originally anticipated two days before landing, and because the end-of-mission (EOM) tire temperature limit had increased from 9 °F to 11 °F. The duration of the attitude that was used following the bottom Sun attitude was increased by two additional hours to allow the Orbiter lower surface bond-line temperatures to cool in preparation for entry. No violations of the entry interface temperature limits or tire pressure temperature landing-limit occurred.

In addition, a one minor thermal problem occurred and it involved the tire pressure 2 measurement for the left main gear (LMG) outboard tire failed from 330:19:35 G.m.t. (06:23:49 MET) to 338:04:43 G.m.t. (14:08:57 MET), when it returned to a nominal reading. The LMG tire pressure 1 measurement continued to provide insight into the tire pressure throughout this time.

### **Aerothermodynamics**

The Orbiter experienced an early transition from laminar flow, Mach 14.3 (1182 seconds after entry interface) as taken from data of aileron deviation from command. The transition was also asymmetric with the left side occurring first. The structural temperature rise on the left wing was 18 °F higher than the right wing. Data from an outboard lower-surface thermocouple showed indications of early irregular flow transition (Mach 15) while centerline thermocouple measurements showed that the temperature rise associated with transition occurred later at Mach 9. The asymmetric transition was confirmed by the RCS data. The lower-surface tile damage may have caused the asymmetric transition.

### **Thermal Protection Subsystem and Windows**

The thermal protection subsystem (TPS) and windows performed nominally with no in-flight anomalies identified. Entry heating was normal based on structural temperature rise data. MADS data showed transition to occurred early, Mach 14.3, at 1182 seconds after entry interface. Asymmetric transition was experienced with the left side occurring first.

The Orbiter TPS sustained a total of 308 hits (damage sites) of which 132 had a major dimension of 1 inch or larger. The total number of hits and their distribution, shown in the following table, does not include the numerous hits on the base heat shield that are attributed to the SSME vibration/acoustics, exhaust plume recirculation, and the flame

**TPS DAMAGE SITES**

<b>Orbiter Surfaces</b>	<b>Hits &gt; 1 Inch</b>	<b>Total Hits</b>
Lower Surface	109	244
Upper Surface	0	7
Right Side	5	6
Left Side	3	4
Right OMS Pod	7	13
Left OMS Pod	7	20
Window Area	1	14
<b>Total</b>	<b>132</b>	<b>308</b>

arrestment sparkler system. Based on data from the postflight debris inspection team reports as well as the comparison with statistics from 71 previous flights of similar configuration, the total number of damage sites was out-of-family, and the number of damage sites that were 1 inch or larger were also out-of-family.

The Orbiter lower surface sustained at least 244 significant hits, of which 109 had a major dimension of 1-inch or larger. Virtually all of this unusual damage was concentrated in the area between the nose landing gear and the main landing gear and more or less symmetrically divided between the left and right outboard sides. The largest lower surface tile damage site was located on the left glove. The site measured 15-inches long by 2-inches wide by 0.25-inch deep. The deepest lower surface tile damage site was located just forward of the left main landing gear well and measured 4-inches long by 2-inches wide by 1.5-inches deep. Tile material in the damage sites showed signs of glazing and the heat effects from entry. The damage sites with significant depth appeared to be generally aligned in a fore to aft direction. Many of these sites were affected by entry aerodynamic erosion.

Unusual tile damage occurred on the lower outboard leading edges of both OMS pods. There were 33 total hits and 14 of these were larger than one-inch in size. However, there was not significant tile damage on the leading edge of the vertical stabilizer.

In an effort of determine the cause of this unusual damage, the ET/Orbiter umbilical separation films were reviewed. The ET/Orbiter LH<sub>2</sub> umbilical 16 mm films provided views of both SRBs and the ET +Z side during SRB separation. No missing ablator was detected on the SRB forward skirts or frustums. The ablator on the nose caps, which are not recovered, appeared to be intact. No significant TPS anomalies on the ET were observed that would be the likely cause of the extensive tile damage. Likewise, the 35 mm films from the ET/Orbiter LO<sub>2</sub> umbilical did not show any condition that would cause the extensive damage noted on the Orbiter.

Tile damage sites around and aft of the LH<sub>2</sub> and LO<sub>2</sub> ET/Orbiter umbilicals were less than usual. This damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The SSME 2 and 3 dome mounted heat shield (DMHS) closeout blankets were in good condition. However, the blanket panels on SSME 1 at the 4-6:00 o'clock position were missing. The underlying batting material was torn and frayed. Loss of this material during the flight was detected in the launch tracking films at liftoff+39 seconds MET.

Several very small holes, damage sites, were detected on the leading edges of the right-wing reusable carbon-carbon (RCC) panels 11 and 19.

Hazing and streaking of forward-facing Orbiter windows was less than usual. Damage sites on the window perimeter tiles also appeared to be less than usual in quantity and size.

The postlanding walkdown of runway 33 was performed immediately after landing. No debris concerns were identified. All drag parachute hardware was recovered and appeared to have functioned normally. The pyrotechnic devices on the reefing line cutters had been expended.



## EXTRAVEHICULAR ACTIVITY

Two EVAs were performed successfully during the flight. Because of the replanning of the first EVA so that the SPARTAN could be captured and berthed in the payload bay as well as comments on the crane operations, a decision was made to perform a second EVA to perform additional crane operations.

The extravehicular mobility unit (EMU) checkout was completed satisfactorily. Both units were found ready to support the scheduled extravehicular activity (EVA). The crew reported that the EMU helmet floodlight, one of four lights on the helmet that was used by the EV2 crewmember, was flickering during the EMU checkout (Flight Problem STS-87-X-01). Later, the crew removed and replaced the bulb, but the light continued to flicker. The EV2 crewmember used an EMU helmet spot light during the EVA to replace the failed floodlight.

The first EVA started when the crew members placed their power switches to the battery position at 329:00:01 G.m.t. (05:04:15 MET). The airlock B hatch was opened nominally for the EVA egress at 329:00:02 G.m.t. (05:04:16 MET). The RMS was moved to an observation position for the manual SPARTAN retrieval at 329:01:04:00 G.m.t. (05:05:18:00 MET). When the SPARTAN proved to be difficult to manually berth, the arm was maneuvered to grapple SPARTAN at 329:02:39:04 G.m.t. (05:06:53:04 MET). SPARTAN was berthed with the RMS at 329:03:23:22 G.m.t. (05:07:37:22 MET) and un-grappled at 329:03:26:36 G.m.t. (05:07:40:36 MET). Following completion of the SPARTAN capture activities, some of the originally planned EVA Demonstration Flight Test (EDFT-05) tasks were performed.

The airlock depressurization for the second EVA began at 337:08:47 G.m.t. (013:13:01 MET) and completed at approximately 337:09:05 G.m.t. (013:13:19 MET). The RCRS was reactivated at 337:09:18 G.m.t. (013:13:32 MET). The second EVA began when the crew members placed their power switches to battery at 337:09:10 G.m.t. (013:13:24 MET). The cabin repressurization to 14.7 psia was completed at 337:11:03 G.m.t. (13:15:17 MET).

The second EVA was concluded with the start of airlock repressurization at 337:14:08 G.m.t. (013:18:22 MET) for a total time of 4 hours and 59 minutes. Airlock repressurization was completed at 337:14:17 G.m.t. (013:18:31 MET). Astronauts Winston Scott and Takao Doi completed the (EDFT-05) tasks successfully and satisfactorily deployed and retrieved Autonomous EVA Robotic (AER) Camera/Sprint during this second EVA. The total STS-87 EVA time was 12 hours and 42 minutes.

## REMOTE MANIPULATOR SYSTEM

The remote manipulator system (RMS) performed satisfactorily throughout the mission. A discussion of the major activities performed in the mission is contained in the following paragraphs.

The RMS was activated at 324:00:50 G.m.t. (00:05:04 MET). The on-orbit checkout commenced at 324:02:05 G.m.t. (00:06:19 MET), and was completed at 324:04:46 G.m.t. (00:09:00 MET). Data indicated that all operations were nominal.

The RMS arm was powered up and uncradled at 325:19:19 G.m.t. (01:23:33 MET). The arm was then maneuvered to the SPARTAN pre-grapple position at 325:19:29 G.m.t. (01:23:43 MET), and SPARTAN capture occurred at 325:19:32 G.m.t. (01:23:46 MET). The payload was unberthed and maneuvered to the Video Guidance System (VGS) acquire/verification position at 325:20:18 G.m.t. (02:00:32 MET), and was then moved to the SPARTAN release position at 325:20:25 G.m.t. (02:00:39 MET). The derigidize/rigidize command sequence to initialize the SPARTAN was issued at 325:21:04 G.m.t. (02:01:18 MET), and the end effector immediately derigidized and released the SPARTAN. When the SPARTAN failed to perform its pirouette attitude maneuver (Flight Problem STS-87-P-01), an attempt to re-grapple the SPARTAN was made at 325:21:10 G.m.t. (02:01:24 MET). The re-grapple maneuver was not successful and a tip-off rate of approximately 2 deg/sec was imparted to the SPARTAN. The subsequent attempt by the Orbiter to reduce the relative rates to allow re-capture had to be terminated because of propellant limitations. The arm was returned to the precradle position at 325:22:28 G.m.t. (02:02:42 MET), cradled and powered down 4 minutes later.

After the SPARTAN operations problem, the RMS was selected at 326:01:42:31 G.m.t. (02:05:56:31 MET) to perform a test of the end effector. The end effector checkout was completed successfully. A visual inspection using closed circuit television (CCTV) camera B confirmed that the snare wires operated properly and were not damaged. The RMS was deselected at 326:01:58:35 G.m.t. (02:06:12:35 MET). The RMS arm was cradled in the manipulator positioning mechanisms (MPMs), and the arm was placed in the temperature-monitoring mode.

The RMS arm was powered up at 328:22:52 G.m.t. (05:03:06 MET). The three manipulator retention latches (MRL's) were released nominally in dual-motor time at 328:22:56:39 G.m.t. (05:03:10:39 MET). In preparation for the SPARTAN rendezvous, the RMS was maneuvered to the modified Poise-for-Capture position at 328:23:07 G.m.t. (05:03:21 MET).

The RMS was moved to an observation position for the manual SPARTAN retrieval at 329:01:04:00 G.m.t. (05:05:18:00 MET). When the SPARTAN proved to be difficult to manually berth, the arm was maneuvered to grapple SPARTAN at 329:02:39:04 G.m.t. (05:06:53:04 MET). SPARTAN was berthed with the RMS at 329:03:23:22 G.m.t. (05:07:37:22 MET) and un-grappled at 329:03:26:36 G.m.t. (05:07:40:36 MET).

The RMS arm was moved to the pre-cradle position at 329:07:35:00 G.m.t. (05:11:49:00 MET) and latched in the MPMs at 329:07:45:00 G.m.t. (05:11:59:00 MET).

The RMS was powered up at 337:03:29 G.m.t. (013:07:43 MET) in support of the SPARTAN/VGS operations. The Spartan grapple occurred at 337:04:52 G.m.t. (013:09:06 MET), and the SPARTAN was unberthed at 337:05:52 G.m.t. (013:10:06 MET). The SPARTAN was berthed at 337:09:11 G.m.t. (013:13:25 MET) and latched at 337:09:12 G.m.t. (013:13:26 MET) after a successful completion of VGS operations. The RMS was parked in the EVA hatch-viewing position for monitoring EVA egress and ingress.

After supporting SPARTAN/VGS operations, the RMS arm was latched in the MPMs at 337:14:08:09 (013:18:22:09 MET). At 337:14:11:08 G.m.t. (013:18:25:08 MET), the MPM's were stowed, and all RMS activities were completed for this mission.

## GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The Government furnished equipment/flight crew equipment performed nominally throughout the mission. Minor problems were encountered, but none of them affected the successful completion of the mission. The most significant problems are discussed in the following paragraphs.

The Pilot Point-of-View (PPOV) camera operated erratically during the ascent portion of the mission. The problem involved an apparent loose wire in the power cable of the PPOV camera. Inspection and tests of this camera and associated wiring will be performed in the Orbiter Processing Facility (OPF), and repairs will be made as required.

The middeck microphone headset assembly appeared to have failed during the flight. The results of the initial postlanding tests were inconclusive. This assembly is used by the middeck crewman during launch and entry. Further inspections and tests of the associated hardware are planned.

The crew reported that one of the Hasselblad cameras stopped in the midst of taking pictures. The crew noticed that the battery was dead, took the film magazine off, changed the batteries, verified that the camera was functioning and installed a new film magazine. Two photographs were taken and then the camera stopped with the lens shutter half-closed. The crew performed some in-flight maintenance (IFM) procedures, but camera operation was not restored. Later in the flight, the crew reported that the Hasselblad camera lens that was jammed with the camera body had been freed and removed from the camera body. However, efforts to restore camera operation were unsuccessful. The second Hasselblad camera remained operational throughout the remainder of the flight.

## **CARGO INTEGRATION**

The cargo integration hardware performance was nominal throughout the mission with no anomalies or issues identified.

## DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

### DEVELOPMENT TEST OBJECTIVES

**DTO 312 - External Tank Thermal Protection System Performance** - The External Tank (ET) Thermal Protection Subsystem (TPS) Performance development test objective (DTO) received both video and photographic data of the post-separation behavior of the ET. Because of the roll-to-heads-up maneuver, one-minute and 43 seconds of video was downlinked early in the mission for evaluation. Vapor venting from the intertank region near the GH<sub>2</sub> vent of the ET was visible in the video. Numerous pieces of debris, more than typically seen, are visible throughout the video sequence. Some of the debris (probably ice) was out of focus, which suggests a close proximity to the Orbiter window. The tumbling and rolling motion of the ET appears greater than typically seen on previous missions.

Hand-held photography of the ET, using a 35 mm camera and 400 mm lens, provided 37 views of the ET. The pictures were taken approximately 45 minutes after liftoff and the final exposure was taken approximately 6 minutes later. The views were of the sides, nose and aft dome of the ET. The ET was 14.1 kilometers from the Orbiter, and the distance hindered the analysis. These views did not show any anomalous conditions.

**DTO 671 - EVA Hardware for Future Scheduled EVA Missions, Test 13 End-to-End Maintenance and Assembly Evaluation** - The DTO 671 - EVA Hardware for Future Scheduled EVA Missions (EDFT-05) - activities were planned for flight day 6 to demonstrate the capability to perform International Space Station (ISS) end-to-end maintenance assembly tasks using the EVA crane [On-orbit Replaceable Unit (ORU) Transfer Device (OTD)] with large and small ORUs. Because of the manual capture and berthing of the SPARTAN spacecraft, the EVA planning and timeline was altered. Consequently, all of the EDFT-05 planned crane activities were not completed because of time constraints.

The incomplete crane activities, as well as the EVA crew comments during and after the EVA concerning crane operations, resulted in a second EVA being planned and performed. The EVA was planned to concentrate on high-priority EDFT tasks and objectives using the small ORU, which would better characterize crane performance and crane/ORU interface mating techniques. The second EVA was performed on flight day 14 and all of the planned tasks for the second EVA were accomplished. The video record combined with crew comments were used to evaluate the EDFT-05 crane operations. A more complete discussion of the EVA is found in the Extravehicular Activity section of this report.

**DTO 685 - Onboard Situational Awareness Displays for Ascent and Entry** - DTO 685 was not successful because of problems with each of the four battery packs used to power the personal digital assistant (PDA) which was to provide the DTO displays. Preflight battery testing showed an appropriate amount of shelf life on all battery packs; however, this was apparently not the case. The postflight investigation of the battery-pack performance is continuing.

**DTO 805 - Crosswind Landing Performance** - The Crosswind Landing Performance DTO was not accomplished because its performance was contingent on the presence of a 10 to 15 knot steady-state crosswind. The crosswinds were well below this level at the time of landing.

**DTO 844 - Robotics Situational Awareness Displays** - STS-87 was the second flight of the Robotics Situational Awareness Displays (RSAD) DTO. The RSAD software runs on a payload and general support computer (PGSC). The RSAD provided cues and data to improved situational awareness during remote manipulator system (RMS) operations. Two displays were flown on STS-87: the hand controller display (HCD); and the joint information display (JID). The HCD provided hand controller input cues to assist the RMS operator in maneuvering the manipulator arm to a target position and attitude as well as monitoring automatic arm trajectories. The JID presents joint data to assist the operator in avoiding joint limits and singularities. For this flight, the RSAD displays were placed in the field-of-view of the RMS operator, and were monitored by the crew as appropriate for the task being performed. The final evaluations of the RSAD performance will be published in separate documentation.

An operational version of RSAD is scheduled to be flown on STS-88 and will include updated displays. Following the STS-88 mission, the RSAD will become an operational tool on all RMS flights.

#### **DETAILED SUPPLEMENTARY OBJECTIVES.**

**DSO 206 - Effect of Space Flight on Bone and Muscle** - This detailed supplementary objective (DSO) was comprised of only preflight and postflight activities. All required activities were accomplished. The results of this DSO will be published in separate documentation.

**DSO 496 - Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance** - This DSO was comprised of only preflight and postflight activities. All required activities were accomplished. The results of this DSO will be published in separate documentation.

**DSO 802 - Educational Activities** - Video recordings of the educational activities that were accomplished in conjunction with the Collaborative Ukraine Experiment as well as other crew activities and demonstrations that were made for educational purposes were scheduled and accomplished. The results of this DSO will be reported in separate documentation.

## **PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

### **LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

The launch photography consisted of 24 video cameras and twenty-one 16-mm and 35-mm cameras. A review of all of these films showed one anomaly. A dome-mounted heat shield (DMHS) closeout blanket was seen to detach and fall away from the vehicle approximately 38 seconds after liftoff. The debris and debris-induced orange-colored streaks were seen in the exhaust plume. The loss of the blanket did not impact the entry in any manner.

Other hand-held photography of the ET, taken after separation, is discussed in the Development Test Objective 312 section of this report.

### **ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

No requirements or requests for review and analysis of on-orbit photography were made.

### **LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS**

Twelve videos of landing were reviewed and no anomalous conditions or events were noted during the review.



## STS-87 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	323:19:41:10.309 323:19:41:11.949 323:19:41:13.297
SRB HPU Activation <sup>a</sup>	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	323:19:45:32.113 323:19:45:32.273 323:19:45:32.433 323:19:45:32.593
Main Propulsion System Start <sup>a</sup>	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	323:19:45:53.434 323:19:45:53.558 323:19:45:53.678
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	323:19:45:59.993
Throttle up to 104 Percent Thrust <sup>a</sup>	ME-3 Command accepted ME-1 Command accepted ME-2 Command accepted	323:19:46:03.834 323:19:46:03.838 323:19:46:03.839
Throttle down to 67 Percent Thrust <sup>a</sup>	ME-3 Command accepted ME-1 Command accepted ME-2 Command accepted	323:19:46:27.355 323:19:46:27.358 323:19:46:27.359
Maximum Dynamic Pressure (g)	Derived ascent dynamic pressure	323:19:46:51
Throttle up to 104 Percent <sup>a</sup>	ME-3 Command accepted ME-1 Command accepted ME-2 Command accepted	323:19:46:58.555 323:19:46:58.558 323:19:46:58.559
Both RSRM's Chamber Pressure at 50 psi <sup>a</sup>	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	323:19:47:58.553 323:19:47:58.593
End RSRM <sup>a</sup> Action <sup>a</sup> Time	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	323:19:48:00.983 323:19:48:01.643
SRB Physical Separation <sup>a</sup>	LH rate APU B turbine speed - LOS RH rate APU A turbine speed - LOS RH rate APU B turbine speed - LOS LH rate APU A turbine speed - LOS	323:19:48:03.713 323:19:48:03.713 323:19:48:03.713 323:19:48:03.713
SRB Separation Command	SRB separation command flag	323:19:48:04
Throttle Down for 3g Acceleration <sup>a</sup>	ME-1 command accepted ME-2 command accepted ME-3 command accepted	323:19:53:32.322 323:19:53:32.324 323:19:53:32.324
3g Acceleration	Total load factor	323:19:54:08.7
Throttle Down to 67 Percent Thrust <sup>a</sup>	ME-1 command accepted ME-2 command accepted ME-3 command accepted	323:19:54:22.882 323:19:54:22.885 323:19:54:22.885
SSME Shutdown <sup>a</sup>	ME-1 command accepted ME-2 command accepted ME-3 command accepted	323:19:54:29.682 323:19:54:29.685 323:19:54:29.685
MECO	MECO command flag MECO confirm flag	323:19:54:30 323:19:54:31
ET Separation	ET separation command flag	323:19:54:50

Note:

<sup>a</sup> = Times determined by Marshall Space Flight Center

## STS-87 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-3 GG chamber pressure APU 1 GG chamber pressure APU 2 GG chamber pressure	323:19:59:48.590 323:20:03:05.835 323:20:03:12:148
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	323:20:27:09.0 323:20:27:09.1
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	323:20:29:15.2 323:20:29:15.3
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	323:21:15:42 323:21:17:02
SPARTAN Grapple	Payload captured	325:19:32:13
SPARTAN Unberthing	Payload SEL 1 Latch 3A Release	325:20:05:45
SPARTAN Release	Payload Captured	325:21:04:37
SPARTAN Re-grapple (attempted)	End effector closed	325:21:10:37
Starboard Radiator Deployment	Starboard radiator latch no. 1-6; latch 1	327:05:37:42
Cabin Depressurization (End)	Cabin Pressure	328:05:20:42
Starboard Radiator Stowed	Starboard radiator latch no. 1-6; latch 1	328:20:40:28
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 328:21:19:33.2
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 328:21:19:48.0
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	328:22:50:38.1 N/A
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	328:22:50:49.9 N/A
Airlock Depressurization - from 10.2 psia	Airlock differential pressure	328:23:42:25
Cabin Repressurization - Start from 10.2 psia	Cabin pressure	329:00:01:54
SPARTAN Grapple	Payload Captured	329:02:38:50
SPARTAN Berthing	Payload SEL 1 latch 3A Ready-to-Latch	329:03:23:09
SPARTAN Latching	Payload SEL 1 latch 4B Latched	329:03:23:09
SPARTAN Ungrapple	Payload captured	329:03:26:24
Airlock Repressurization - Start	Airlock differential pressure	329:07:45:40
Port Radiator Deployment	Port radiator deployment 2	330:23:29:57
Port Radiator Stowed	Port radiator stowed 1	334:03:34:56
Starboard Radiator Deployment	Starboard radiator deployment 2	334:16:24:42
Port Radiator Deployment	Port radiator deployment 1	336:10:21:06
Cabin Depressurization - to 10.2 psia	Cabin pressure	336:15:17:30
Starboard Radiator Stowed	Starboard radiator latch no. 1-6; latch 1	336:15:30:18
Port Radiator Stowed	Port radiator stowed 1	336:15:30:55
SPARTAN Grapple	Payload captured	337:04:42:53
SPARTAN Unberthing	Payload SEL 1 Latch 3A Release Ind.	337:04:56:19

## STS-87 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
SPARTAN Berthing	Payload SEL 1 latch 3A Ready-to-Latch	337:09:11:27
SPARTAN Latching	Payload SEL 1 latch 4B Latched	337:09:12:02
SPARTAN Ungrapple	Payload captured	337:09:14:54
Cabin Repressurization - Start from 10.2 psia	Cabin pressure	337:09:10:49
Airlock Depressurization - from 10.2 psia (end)	Airlock differential pressure	337:09:11:05
Airlock Repressurization -Start	Airlock differential pressure	337:14:08:24
Flight Control System Checkout APU 1 Start APU 1 Stop	APU 3 GG chamber pressure APU 3 GG chamber pressure	338:09:51:23.940 338:10:03:21.243
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	339:08:39:10 339:08:42:16
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	339:11:16:35.381 339:11:35:26.423 339:11:35:33.133
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	339:11:21:28.2 339:11:21:28.2
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	339:11:24:00.4 339:11:24:00.4
Entry Interface (400K feet)	Current orbital altitude above	339:11:48:10
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	339:12:13:42
Main Landing Gear Contact	RH main landing gear tire pressure 2 LH main landing gear tire pressure 2	339:12:20:05 339:12:20:05
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels RH main landing gear weight on wheels	339:12:20:05 339:12:20:05
Drag Chute Deployment	Drag chute deploy 1 CP volts	339:12:20:07.6
Nose Landing Gear Contact	NLG LH tire pressure 2	339:12:20:15
Nose Landing Gear Weight On Wheels	NLG weight on wheels	339:12:20:15
Drag Chute Jettison	Drag chute jettison 1 CP Volts	339:12:20:37.7
Wheel Stop	Velocity with respect to runway	339:12:21:02
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	339:12:35:25.993 339:12:35:35.109 339:12:35:43.380

TABLE II.- SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-87-V-01	Side Hatch Test Port Seal Came Off During Cabin Leak Check	323:18:48 G.m.t. Prelaunch 87RF01 IPR 87V-0164 PR ECL-2-24-1189	<p>During the prelaunch cabin leak checks, the KC103-24 Teflon seal at the end of the Orbiter test port used to pressurize the cabin off. The seal was replaced and the cabin leak check was completed satisfactorily. The problem delay the cabin leak check, thus initiating a concern over the residual oxygen concentration in the aft compartment. However, the aft compartment oxygen readings did drop below the 500-ppm level just prior to the end of the planned hold period, and the countdown resumed at the planned time.</p> <p>The seal was recovered and it looked good. Dimensional inspections of the other Orbiter vehicles test ports will be performed.</p>
STS-87-V-02	Ku-Band RF Power Output Telemetry Erratic	324:14:51 G.m.t. 00:19:05 MET CAR 87RF04 IPR 90V-0001	<p>The Ku-band RF power output telemetry measurement was erratic from 324:14:51 G.m.t. (00:19:05 MET) to 324:15:38 G.m.t. (00:19:52 MET), and from 324:16:50 G.m.t. (00:21:04 MET) to 324:17:13 G.m.t. to 324:17:13 G.m.t. (00:21:27 MET). During these time periods, the White Sands Ground Station reported a good Ku-band downlink signal. This parameter should be relatively stable at about 4.5 Vdc; however, during the cited times the uncalibrated signal varied from 0 to 4.3 Vdc. The erratic output repeated a third time for several minutes starting at approximately 326:23:43 G.m.t. (03:03:57 MET).</p> <p>A similar signal occurred on this same deployable assembly (DA) (s/n 107) on STS-43 and STS-45. Corrective Action Report (CAR) 43RF05 recorded repairs made that were thought to have fixed the problem. These repairs included the repair of a broken shield on a coaxial cable and the repair of a connector that had excessive bonding material, which resulted in an improperly mated condition. It then flew on STS-83 and STS-94 with no problems.</p> <p>KSC: Troubleshooting did not duplicate the problem.</p>
STS-87-V-03	RCS Primary Thruster R2D Heater Failed Off	327:08:00 G.m.t. 03:12:14 MET CAR 87RF05 IPR 90V-0003	<p>At approximately 327:08:00 G.m.t. (03:12:14 MET), it was determined that the RCS primary thruster R2D heater had failed off. A review of the data indicate that the heater had probably been failed off throughout the mission and the thruster injector temperatures had been maintained above 75 °F by the external environment and thruster firings. Throughout the mission, the injector temperatures were maintained above 45 °F by the external environment and the RCS stinger heater.</p> <p>Thruster valves are certified for operation down to 40 °F (32 °F injector), but failure history indicates increased risk of thruster-valve leakage below 50 °F. Injector temperatures are expected to be at approximately 42 °F when the thruster valve temperature equals 50 °F. Redundancy Management (RM) will deselect the thruster as failed leak if the oxidizer injector temperature drops below 30 °F or the fuel injector drops below 20 °F.</p> <p>KSC: Troubleshooting isolated the problem, and the three thrusters on manifold 2 were removed and replaced.</p>

TABLE II.- SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-87-V-04	Water Tank A/B Check/Relief Valve High Cracking Pressure	324:02:20 G.m.t. 00:06:34 MET CAR 87RF09 PR WMM-2-25-0036	<p>The supply water inlet pressure reached 39.58 psia when supply water tank A reached full quantity and the tank A/B check/relief valve cracked open. The supply water storage inlet pressure increased from 33.21 psia to 39.58 psia over a 5-minute period before the relief valve opened. The pressure rise to crack the check valve was approximately 6 psid, where past flights have shown a range of 0.4 to 0.8 psid for cracking pressure. The relief valve cracking specification is between 0.8 and 2.5 psid, and the valve reseats at 0.8 psid. The check/relief valve will stay open until the tank A quantity level drops below full. During the time that the A/B check/relief valve was stuck closed, fuel cell water flowed through the alternate path into tank B.</p> <p>At 339:08:07:09 G.m.t. (15:11:21:09 MET), the supply water inlet pressure went from 31.65 psia to 33.0 psia in 33 seconds before the check/relief valve was reopened. This was a 1.35 psid cracking pressure.</p> <p>KSC: Troubleshooting indicated a valve problem, and the valve was removed and replaced.</p>

TABLE III.-STS-87 MSFC PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-87-T-01	Post-Separation Crew Photography Showed Significant Areas of Missing Foam on the +Y and -Y Intertank Thrust Panels.	Ascent and Post-flight Inspection	Inspection of the Orbiter following STS-87 revealed an out-of-specification amount of Orbiter TPS tile damage with 109 damage sites greater than one-inch in diameter. An integrated investigation team determined that the damage was primarily caused by the loss of TPS from the ET thrust panels in the intertank at the SRB attachment locations. STS-87 was the second flight for a new foam (TPS) which was developed in response to environmental concerns with the old foam's blowing agent. Investigation by the ET Project has not positively identified the loss mechanism, but the most probable cause is thought to be a combination of low (but within specification) foam mechanical properties and shock wave impingement across the thrust panel rib tops. The MSFC qualification program used flat panels with no ribs to characterize a curved panel with ribs. In retrospect, this was not a good decision; however, it was the same method used to qualify the prior foam with good results. Thrust panels for the ET assigned to the next flight were machined to remove the tough outer rind on the foam. This action has been shown to improve foam strain-at-failure capabilities and should eliminate the foam loss problem. Investigations are continuing to positively determine the cause of TPS loss and to establish appropriate corrective actions.

TABLE IV.- STS-87 EVA IN-FLIGHT ANOMALY LIST

No.	Title	Time	Comments
STS-87-X-01	EMU 1 Power Mode Switch Incomplete Actuation	047:02:57 G.m.t. 04:18:02 MET	<p>Prior to the start of the third EVA, EV1 did not have an indication that EMU 1 was on battery power after the power mode switch (PMS) had been moved from the SCU position to the BATT position. The PMS has three separate microswitches, one of which provides a battery-on discrete to the EMU caution and warning system. In this case, the batter/SCU indicator microswitch in the PMS did not adequately throw when the switch was actuated. The microswitch not being made is a known condition involving the PMS. Note that the EMU was actually on battery power, and the EVA could have proceeded without the battery power-on indication. The crew was trained to correct this condition by a firm recycling of the PMS. After recycling the switch, the EMU reset and the proper indication was received. No further problems were encountered during the EVA or subsequent EVAs. The current switch design will be replaced during EMU display and control module (DCM) retrofits that are due for completion in mid-1998, with the first flight as early as STS-86.</p>

TABLE V.- STS-87 PAYLOAD IN-FLIGHT ANOMALY LIST

No.	Title	Time	Comments
STS-87-P-01	SPARTAN Attitude Control System Failure	Deployment	<p>Following SPARTAN deployment, the SPARTAN did not perform the pre-programmed pirouette maneuver following derigidization. An attempt was made to regrabble the payload, but it resulted in inducing a tip-off rate of approximately 2 deg/sec in the +X direction to the payload. The crew was unable to capture the SPARTAN before the propellant lower limit for the operation was reached. The crew was instructed to back-away from the SPARTAN. A re-rendezvous and manual capture of SPARTAN was performed on flight day 6. This anomaly resulted in the total loss of the science mission. The data analysis has determined that there is no evidence of a SPARTAN payload malfunction. All indications are that the spacecraft remained healthy and performed as expected in the off-nominal conditions.</p>



## 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 (CSR) Daily Science Reports, and Final CSR Report
4. Mission Evaluation Room (MER) Daily Reports
5. MER Landing 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
15. STS-87 Summary of Significant Events
16. Contractor Reports of Subsystem Operation
17. SSVEO In-Flight Anomaly Lists

## ACRONYMS AND ABBREVIATIONS

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

AADSF	Advanced Automated Directional Solidification Furnace
ADTA	air data transducer assembly
AERCAM	Autonomous EVA Robotic Camera/Sprint
AEE	Asphalt Evaluation Experiment
AFRL	Air Force Research Laboratory
Amp-hr	ampere-hour
APU	auxiliary power unit
ARS	atmospheric revitalization system
ATCS	active thermal control system
BFS	backup flight system
BPAC	Brassica rapa Photosynthetic Apparatus in Canisters
BSTIC	Brassica rapa Seed Terminal Growth Chambers
CCTV	closed circuit television
CDEE	Computer Disc Evaluation Experiment
CEI	contract end item
CHeX	Combined Helium Experiment
CME	Concrete Mixing Experiment
CPM	cell performance monitor
CSFE	Configuration Stability of Fluid Experiment
CUE	Collaborative Ukraine Experiment
dBm	decibel per meter
DMHS	dome-mounted heat shield
$\Delta P$	differential pressure
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
$\Delta V$	differential velocity
ECLSS	Environmental Control and Life Support System
EDFT-05	EVA Demonstration Flight Test-05
ELF	Enclosed Laminar Flames Experiment
EMU	extravehicular mobility unit
EO	ET/Orbiter
EOM	end-of-mission
EPDC	electrical power distribution and control
ET	External Tank
EVA	extravehicular activity
FCE	Flight Crew Equipment
FCL	Freon coolant loop
FCMS	fuel cell monitoring system
FCS	flight control system/subsystem
ft/sec	feet per second
g	gravity
GAS	Get-Away Special
GENEX	Gene Expression Experiment
GFE	Government furnished equipment

GH <sub>2</sub>	gaseous hydrogen
G.m.t.	Greenwich mean time
GN <sub>2</sub>	gaseous nitrogen
GO <sub>2</sub>	gaseous oxygen
GSE	ground support equipment
GSFC	Goddard Space Flight Center
H <sub>2</sub>	hydrogen
HCD	hand controller display
Hg	Mercury
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
ICD	Interface Control Document
IDGE	Isothermal Dendritic Growth Experiment
IFM	in-flight maintenance
IMU	inertial measurement unit
IRD	Integrated receiver decoders
IRMIS	Iodine Removal Mineral Injection System
I <sub>sp</sub>	specific impulse
ISS	International Space Station
JID	joint information display
keas	knots estimated air speed
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lb	pound
lbm	pound mass
LCC	Launch Commit Criteria
LED	light emitting diode
LHP	Loop Heat Pipe
LH <sub>2</sub>	liquid hydrogen
LMG	left main gear
LMSMS&S	Lockheed Martin Space Mission Systems and Services
LO <sub>2</sub>	liquid oxygen
LORE	Limb Ozone Retrieval Experiment
MADS	Modular Auxiliary Data System
MC	midcourse correction (maneuvers)
MECO	main engine cutoff
MEPHISTO	Materials for the Study of Interesting Phenomena of Solidification on Earth and In Orbit
MET	mission elapsed time
MGBX	microgravity glove box
MLG	main landing gear
mm	millimeter
MPM	manipulator positioning mechanism
MPS	main propulsion system
MRL	manipulator retention latches
MSFC	Marshall Space Flight Center
MSX	Midcourse Space Experiment
MS2	Mission Specialist 2

mV	millivolt
NAS	sodium sulfur
NASA	National Aeronautics and Space Administration
NasBE	Sodium Sulfur Battery Experiment
NASDA	National Space Development Agency of Japan
N <sub>2</sub>	nitrogen
NC4	rendezvous maneuver
NCC	corrective combination maneuver
NiH <sub>2</sub>	Nickel Hydrogen
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O <sub>2</sub>	oxygen
OARE	Orbital Acceleration Research Experiment
OI	operational instrumentation
OME	orbital maneuvering engine
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPF	Orbiter Processing Facility
ORU	on-orbit replacement unit
OTD	ORU
PAL	protuberance air load
PASS	Primary Avionics Software System
P <sub>c</sub>	chamber pressure
PCS	pressure control subsystem
PDA	personal digital assistant
PDFU	petri dish fixation unit
PEP	Particle Engulfment and Pushing by a Solid/Liquid Interface Experiment
PGC	Plant Growth Chambers
PGF	Plant Growth Facility
PGSC	payload general support computer
PI	Principal Investigator
PIMS	Principal Investigator Microgravity Services
PMBT	propellant mean bulk temperature
PPOV	Pilot point of view (camera)
ppm	parts per million
PRCB	Program Requirements Control Board
PRSD	power reactant storage and distribution
psi	pound per square inch
psia	pound per square inch absolute
psid	pound per square inch differential
PVA	pivalic acid
RCRS	Regenerative Carbon Dioxide Removal System
RCS	reaction control subsystem
RF	radio frequency
RM	redundancy management
RME	Risk Mitigation Experiment
RMS	Remote Manipulator System
RSAD	Robotics Situational Awareness Display

RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAMS	Shuttle Acceleration Measurement System
SEEDS-II	Seeds in Space-II
SEU	single event upset
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SLF	Shuttle Landing Facility
S/N	serial number
SODB	Shuttle Operational Data Book
SOHO	Solar Heliospheric Observatory
SOLSE	Shuttle Ozone Limb Sounding Experiment
SOYPAT	Soybean Pathogen Interaction
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SPM	Space Mass Experiment
SPSR	Space Portable SpectroReflectometer
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STS	Space Transportation System
TACAN	tactical air control and navigation
TCS	thermal control subsystem/trajectory control sensor
TDRSS	Tracking and Data Relay Satellite System
TGDF	Turbulent Gas-Jet Diffusion Flames
TI	terminal phase initiation
TPS	thermal protection system/subsystem
TVC	thruster vector control
USMP	United States Microgravity Payload
UV	ultraviolet
UVCS	Ultraviolet Coronal Spectrometer
Vdc	Volts direct current
VGS	video guidance system
WCI	Wetting Characteristics of Immiscibles Experiment
wh/kg	specific energy
WLC	White Light Coronagraph
WSB	water spray boiler