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STS-70 SPACE SHUTTLE MISSION REPORT

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NOTE

The STS-70 Space Shuttle Mission Report was prepared from inputs received from the Orbiter Project Office as well as other organizations. The following personnel may be contacted should questions arise concerning the technical content of this document.

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STS-70

SPACE SHUTTLE

MISSION REPORT

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INTRODUCTION

The STS-70 Space Shuttle Program Mission Report summarizes the Payload activities as well as the Orbiter, External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and the Space Shuttle main engine (SSME) systems performance during the seventieth flight of the Space Shuttle Program, the forty-fifth flight since the return-to-flight, and the twenty-first flight of the Orbiter Discovery (OV-103). In addition to the Orbiter, the flight vehicle consisted of an ET that was designated ET-71; three SSMEs that were designated as serial numbers 2036, 2019, and 2017 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-073. The RSRMs, designated RSRM-44, were installed in each SRB and were designated as 360L044A for the left SRB, and 360L044B for the right SRB.

The STS-70 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement as documented in NSTS 07700, Volume VII, Appendix E. The requirement stated in that document is that each organizational element supporting the Program will report the results of their hardware (and software) evaluation and mission performance plus identify all related in-flight anomalies.

The primary objective of this flight was to deploy the Tracking and Data Relay Satellite-G/Inertial Upper Stage (TDRS-G/IUS). The secondary objectives were to fulfill the requirements of the Physiological and Anatomical Rodent Experiment/National Institutes of Health-Rodents (PARE/NIH-R); Bioreactor Demonstration System (BDS); Commercial Protein Crystal Growth (CPCG) experiment; Space Tissue Loss/National Institutes of Health-Cells (STL-NIH-C) experiment; Biological Research in Canisters (BRIC) experiment; Shuttle Amateur Radio Experiment-II (SAREX-II); Visual Function Tester-4 (VFT-4); Hand-Held, Earth-Oriented, Real-Time, Cooperative, User-Friendly Location-Targeting and Environmental System (HERCULES); Microencapsulation In Space-B (MIS-B) experiment; Window Experiment (WINDEX); Radiation Monitoring Equipment-III (RME-III); and the Military Applications of Ship Tracks (MAST) payload.

The STS-70 mission was planned as an 8-day flight plus 2 contingency days, which were available for weather avoidance or Orbiter contingency operations. The sequence of events for the STS-70 mission is shown in Table I, and the Orbiter Project Office Problem Tracking List is shown in Table II. The Government Furnished Equipment/Flight Crew Equipment (GFE/FCE) Problem Tracking List is shown in Table III, and the Marshall Space Flight Center Projects Problem Tracking List is shown in Table IV. Appendix A lists the sources of data, both formal and informal, that were used to prepare this report. Appendix B provides the definition of acronyms and abbreviations used throughout the report. All times during the flight are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The five-person crew for STS-70 consisted of Terence T. Henricks, Col., USAF, Commander; Kevin R. Kregel, Civilian, Pilot; Donald A. Thomas, Ph.D., Civilian, Mission Specialist 1; Nancy J. Currie, Major, USA, Mission Specialist 2; and Mary Ellen Weber, Ph.D., Civilian, Mission Specialist 3. STS-70 was the third space flight for the Commander, the second space flight for Mission Specialists 1 and 2, and the first space flight for the Pilot and Mission Specialist 3.

MISSION SUMMARY

Liftoff for the STS-70 mission occurred at 194:13:41:55.020 G.m.t. One unplanned hold was called by Range Safety at T-31 seconds to verify the ET Range Safety System (RSS) receiver signal strength after it dropped below the Launch Commit Criteria (LCC) limits following vent arm retraction. The hold lasted for 55 seconds.

During the final countdown, it was noted that the liquid oxygen (LO_2) differential pressure (ΔP) transducer response was lost with the ΔP indicating off-scale low during and following ET loading. The potential failure modes were evaluated, and it was determined that the most probable cause of the off-scale low indication was a transducer failure. With this transducer failure, there was no mission impact.

The ascent phase was nominal in all aspects, and no orbital maneuvering subsystem (OMS) 1 maneuver was required. The OMS 2 maneuver was performed at 194:14:21:50.1 G.m.t. (00:00:39:55.1 MET). The differential velocity (ΔV) was 221.6 ft/sec, and the resultant orbit was circular at 160 nmi.

The payload bay doors were successfully opened at 194:15:11:15 G.m.t. (00:01:29:20 MET).

The Tracking and Data Relay Satellite-G/Inertial Upper Stage (TDRS-G/IUS) was successfully deployed at 194:19:54:55 G.m.t. (00:06:13:00 MET). Two separation maneuvers from the TDRS-G/IUS were performed, with the first being a reaction control subsystem (RCS) firing at 194:19:55:46 G.m.t. (00:06:13:51 MET). The maneuver was 7 seconds in duration, and a ΔV of 2.2 ft/sec was provided to the Orbiter. RCS thrusters F1F and F2F were used for this maneuver. The second separation maneuver was initiated at 194:20:09:46.3 G.m.t. (00:06:27:51.3 MET) using the left-hand OMS engine. The maneuver was 33.6 seconds in duration and imparted a ΔV of 30.5 ft/sec.

At 195:19:10:41.2 G.m.t. (01:05:28:46.2 MET), the right-hand OMS engine was successfully used to perform an orbit-adjust maneuver. The firing duration was 31.7 seconds and the ΔV was 28.9 ft/sec. The resulting orbit was 170 by 152.5 nmi.

At 197:16:43 G.m.t. (03:03:01 MET), when the operations (OPS) 2 recorder was being dumped through channel 2 of the Ku-band, the dump quality of track 3 was degraded. The recorder was dumped in both the forward and reverse directions with degraded quality on track 3. All other recorder tracks provided satisfactory data. Two test dumps of track 3 were also performed, and both provided degraded data. As a result, only tracks 4 through 14 were used for recording during the remainder of the mission. This condition did not impact the mission.

At 198:09:59 G.m.t. (03:20:17 MET) during the reconfiguration of heater systems on the water spray boilers (WSBs), no WSB 3 temperature data were seen after switching the B controller on. The crew checked the circuit breaker for the WSB 3B controller power and it was found open. At 198:10:10 G.m.t. (03:20:28 MET), WSB 3 was switched back to the A controller, and nominal performance was verified. Data review showed no evidence of a short, and the crew commented that the circuit breaker had a communications cord near it and the circuit breaker may have been inadvertently pulled. The circuit breaker was left open, and entry was performed on the A controller. The circuit providing power to the B controller was tested on the ground, and no problems were identified.

During filter cleaning at 198:16:34:58 G.m.t. (04:02:53:03 MET), a short was noted on the AC1 bus. The short was traced to the vacuum cleaner cord, which had been damaged when it was caught in a locker door. The crew spliced and secured the damaged areas of the cord. An additional procedure to perform a continuity check of the repaired cord was performed later in the day, and the results indicated a satisfactory repair. However, the vacuum cleaner was stowed and it was not used during the remainder of the mission. Gray tape was used for the remaining filter cleaning.

At approximately 199:11:24 G.m.t. (04:21:42 MET), the flight crew reported a debris impact to the right-hand-side thermal window, W6. The impact was located in the upper-forward corner of the window approximately 1/2 inch from the edge. The crew estimated that the size of the impact was approximately 1/16 inch (0.06 inch) in diameter and 1/32 inch (0.03 inch) deep. Based on the crew-estimated size, an evaluation of the condition determined it did not pose a safety concern for entry. The W6 window was new with no previous flights prior to STS-70. During postflight turnaround activities at Kennedy Space Center (KSC), the measured size of the impact was 0.116 inch by 0.104 inch in diameter and 0.0081-inch deep.

Part 1 of the flight control system (FCS) checkout was initiated at 201:07:47 G.m.t. (06:18:07 MET). Auxiliary power unit (APU) 1 was started at 201:07:49:31.3 G.m.t. (06:18:07:36.3 MET), ran for 6 minutes 22.2 seconds, and consumed 13 lb of fuel. No WSB cooling occurred because of the short run-time of the APU. Part II of the FCS checkout was initiated at 201:07:56 G.m.t. (06:18:14 MET). All parameters monitored during the FCS checkout were nominal.

The RCS hot-fire was performed at 201:08:33 G.m.t. (06:18:51 MET). Two sequences of firing each thruster were performed, and all thrusters operated nominally.

All entry stowage and deorbit preparations were completed in preparation for entry on the nominal end-of-mission landing day. The payload bay doors were successfully closed and latched at 202:08:18:35 G.m.t. (07:18:36:40 MET). However, both landing opportunities for the planned landing day at the KSC Shuttle Landing Facility (SLF) were waved off because of ground fog. The payload bay doors were reopened at 202:12:36:58 G.m.t. (07:22:55:03 MET) to accommodate the additional day on orbit.

The payload bay doors were closed at 203:06:48:04 G.m.t. (08:17:06:09 MET) in preparation for a landing on the first contingency day. The first landing opportunity was waved off because of marginal weather conditions. The deorbit maneuver for the second landing opportunity at the SLF on the first contingency day was performed on orbit 142 at 203:11:00:12.2 G.m.t. (08:21:18:17.2 MET), and the maneuver was 176.6 seconds in duration with a ΔV of 342.6 ft/sec.

Entry was completed satisfactorily, and main landing gear touchdown occurred on SLF runway 33 at 203:12:02:01.99 G.m.t. (08:22:20:06.97 MET) on July 22, 1995. The Orbiter drag chute was deployed at 203:12:02:03.3 G.m.t. and the nose gear touchdown occurred 5.7 seconds later. The drag chute was jettisoned at 203:12:02:34.8 G.m.t. with wheels-stop occurring at 203:12:02:03.4 G.m.t. The rollout was normal in all respects. The flight duration was 8 days 22 hours 20 minutes and 7 seconds. The APUs were shut down 14 minutes 14 seconds after landing.

With this successful landing, the most trouble-free mission of the Space Shuttle Program was completed. The crew, Orbiter subsystems, and payloads all performed in an outstanding manner.

PAYLOADS

TRACKING AND DATA RELAY SATELLITE-G/INERTIAL UPPER STAGE

The primary payload of this mission was the TDRS-G/IUS, which was planned as the last in a series of seven TDRS's which were to be placed in orbit and complete the Tracking and Data Relay Satellite System (TDRSS). However, one of the TDRS's was lost during the STS-51L (Challenger) accident, and the system is now composed of only six satellites. The TDRS-G/IUS was released from the Orbiter at 194:19:54:55 G.m.t. (00:06:13:00 MET). Both solid rocket motor (SRM) burns and associated RCS firings were performed as planned, resulting in a geosynchronous orbit at 179.88 degrees West longitude. The IUS performed superbly in providing a stable attitude for TDRS appendage deploy, and TDRS/IUS separation. The TDRS-G, renamed TDRS-7 upon achieving geosynchronous orbit, was handed over to White Sands for command and control. The checkout of the TDRS-7 will require about a month, after which the satellite will be moved to 171 degrees West longitude, where it will be stored as a "Ready Reserve" for subsequent use in the TDRSS.

PHYSIOLOGICAL AND ANATOMICAL RODENT EXPERIMENTS/NATIONAL INSTITUTE OF HEALTH-RODENTS

The Physiological and Anatomical Rodent Experiments/National Institute of Health-Rodents (PARE/NIH-R) experiment package was composed of the following five experiments:

1. Space Flight Effects on Mammalian Development;
2. Neuromuscular Development and Regulation of Myosin Expression;
3. Effect of Space Flight on the Development of the Circadian Timing System;
4. Effect of Microgravity on Bone Development; and
5. Histological Effects of Microgravity on Rat Body Wall Musculature.

All science expectations for the PARE/NIH-R were met. The data and information passed down by the crew were vital to the successful running of the ground controls. Ground simulations were enhanced by the good quality video that was sent down by the crew. STS-70 was the fifteenth flight of this hardware, and the preliminary analysis shows that the hardware performed well.

BIOREACTOR DEMONSTRATION SYSTEM

The Bioreactor Demonstration System (BDS) was designed to use ground-based and space-bioreactor systems to grow individual cells into organized tissue that is morphologically and functionally similar to the original tissue or organ. The

BDS uses a rotating cylinder to suspend cells and tissues in a growth medium, simulating some aspects of microgravity.

The BDS experiment was very successful. Phase I, the cell science portion of the experiment, provided results far beyond what was expected. All objectives for Phase I were met with the exception of less than 5 percent of the pH monitoring data. All cell and all media samples were collected successfully for postflight analysis.

Phase II, the fluid dynamics portion, experienced some difficulties; however, sufficient data were collected to evaluate the BDS design configuration.

COMMERCIAL PROTEIN CRYSTAL GROWTH EXPERIMENT

The commercial protein crystal growth (CPCG) experiment consisted of the protein crystallization facility. The objective for this flight was to crystallize human alpha interferon protein, which is a protein pharmaceutical that is used against human viral hepatitus B and C. This experiment has flown on eight previous Space Shuttle missions with very good results.

The CPCG experiment was successfully completed with no anomalies. Daily status checks verified exceptional thermal control of the experiment. The crew was trained to expect temperature excursions from the commercial refrigerator/incubator module (CRIM) on the first flight day. Only two excursions occurred, and these did not impact the crew or their timeline. Postflight analysis and assessment of the experiment samples will be performed to determine the size and quality of the crystals.

SPACE TISSUE LOSS EXPERIMENT

The objectives of the Space Tissue Loss-B (STL-B) experiment was to collect three video downlinks of fish embryos, provide life support to the fish embryos and recover the fish for postflight analysis. The payload met all of its objectives, and performed nominally throughout the mission. The customer learned that the programmed embryo locations did not hold very well through launch causing minimal operational impact. The customer will re-address the approach to the programmed embryo feature for future flights.

The ground-based embryo at KSC continued to develop normally as expected. The video downlinks of the in-flight embryo indicated that the embryos were developing more slowly than their ground counterparts. Confirmation of this result will be provided during postflight analysis.

BIOLOGICAL RESEARCH IN CANISTERS EXPERIMENT

The Biological Research in Canisters (BRIC) experiment provided microgravity data on plant growth and development, as well as research on the hormone system of insects. Each BRIC experiment was flown in one of a group of canisters that were located in lockers on the Orbiter middeck. No crew or ground interfaces existed during the flight with these experiments. The results of this experiment will be determined solely by postflight evaluation.

SHUTTLE AMATEUR RADIO EXPERIMENT-II

The Shuttle Amateur Radio Experiment-II (SAREX-II) was used to contact students in schools in the U. S. and Argentina. In addition, ham radio operators were provided an opportunity to make contacts with the Orbiter.

The SAREX planned to support five personal, seven bridge and one direct contact with three backup opportunities preplanned. All contacts were successful on the first attempt. The backup opportunities were released to the flight crew to use as they wished. One of the personal contacts was marginal due to poor signal quality, but was quite satisfactory to the participating school.

VISUAL FUNCTION TESTER-4

The DOD-sponsored Visual Function Test-4 (VFT-4) obtained data in an attempt to determine when the astronauts visual acuity at close range degrades while in space. The objective of obtaining VFT data on two crewmembers each day was met, and all data-takes were successfully completed with the exception of the last data take that may have been minimally affected by an errant toggle switch.

HAND-HELD, EARTH-ORIENTED, COOPERATIVE, REAL-TIME, USER FRIENDLY, LOCATION TARGETING AND ENVIRONMENTAL SYSTEM

The Hand-Held, Earth-Oriented, Cooperative, Real-Time, User-Friendly, Location Targeting, and Environmental System-B (HERCULES-B), was the third generation of a space-based geolocating system, and it was flown as a Department of Defense (DOD) sponsored experiment. The HERCULES-B calculates and tags every frame of video with latitude and longitude with an accuracy of three nautical miles.

The HERCULES-B payload experienced several difficulties during the mission; however, the impact was minimal. This payload had several objectives, the highest priority of which was the multispectral imaging at various focal lengths, and this appears to have been fully met. The performance of the geolocation function experienced several difficulties, but all objectives were also met. The customer was pleased with the results, but will re-address the flight procedures to clarify or simplify them and the training.

MICROENCAPSULATION IN SPACE - B EXPERIMENT

The Microencapsulation in Space - B (MIS-B) experiment was to produce a pharmaceutical (microencapsulated antibiotic) in weightless conditions using equipment that has been improved since the experiment's first flight in 1992 on STS-53.

The objective of manufacturing the microencapsulated antibiotic (ampicillian) in a microgravity environment was met. All experiment equipment performed nominally. The microcapsules have been returned to the experiment sponsor for evaluation and assessment.

WINDOW EXPERIMENT

The Window Experiment (WINDEX) objective was to obtain data to better understand the chemistry and dynamics near a low-Earth-orbit (LEO) satellite. The WINDEX was to record various observations external to the vehicle. These observations were thruster plumes, Shuttle glow, water dumps, atmospheric nightglow, aurora, and flash evaporator system (FES) releases.

The objective for the STS-70 mission was to collect 10 WINDEX observations. All WINDEX operations were nominal and the preliminary observations are that all objectives were met.

RADIATION MONITORING EQUIPMENT-III

The Radiation Monitoring Equipment-III (RME-III) consists of equipment which measures the exposure to ionizing radiation on the Space Shuttle. This experiment has been successfully flown on a number of missions since STS-31.

The objectives to monitor the ionizing radiation levels inside the Orbiter with the RME-III were met. The experiment operated satisfactorily, including the six memory module replacements.

MILITARY APPLICATIONS OF SHIP TRACKS

The Military Applications of Ship Tracks (MAST) experiment provided photographic data of ship tracks for use in determining how ship-generated pollutants modify the reflective properties of clouds. The objective of collecting photographic data on four ship tracks was met. Postflight analysis of the photography was performed by the sponsoring agency, the DOD.

VEHICLE PERFORMANCE

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. Data analysis indicates nominal performance of all SRB subsystems.

For the flight, the low-pressure heated ground purge in the SRB aft skirt was activated for 59 minutes to maintain the case/nozzle joint temperatures within the LCC ranges. At T - 15 minutes, the high-pressure purge was activated to inert the SRB aft skirt.

Both SRBs were satisfactorily separated from the ET at T + 122.76 seconds, and reports from the recovery area indicate all deceleration subsystems performed as designed. Both SRBs were retrieved and returned to KSC for disassembly and refurbishment.

REUSABLE SOLID ROCKET MOTORS

Power-up and operation of all Reusable Solid Rocket Motor (RSRM) igniter and field joint heaters was accomplished in a routine manner. All RSRM temperatures were maintained within acceptable limits throughout the countdown.

Data indicate that the flight performance of both RSRMs was well within the allowable performance envelopes (see table on following page) and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was 80 °F at liftoff. The maximum trace shape variation of pressure versus time was calculated to be approximately 0.9 percent at 65.5 seconds (left motor) and approximately 0.6 percent at 79.5 seconds (right motor) as compared with the 3.2-percent allowable

Postflight disassembly of the RSRMs at the vendor revealed a gas path through the room temperature vulcanizing (RTV) material at 229 degrees on the right-hand RSRM (360L044B) (Flight Problem STS-70-M-01). Soot was observed on the primary O-ring from 170 to 255 degrees. Heat-affected insulation and eroded adhesive were found at the gas-path location. Heat effect was observed at three locations, with slight heat erosion of the primary O-ring at two of these locations.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 80 °F		Right motor, 80 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	66.77	66.90	66.66	66.80
I-60, 10^6 lbf-sec	177.51	177.61	177.26	177.05
I-AT, 10^6 lbf-sec	297.12	297.05	297.14	296.67
Vacuum Isp, lbf-sec/lbm	268.6	268.6	268.6	268.2
Burn rate, in/sec @ 60 °F at 625 psia	0.3698	0.3699	0.3694	0.3701
Burn rate, in/sec @ 80 °F at 625 psia	0.3751	0.3753	0.3747	0.3754
Event times, seconds[a]				
Ignition interval	0.232	N/A	0.232	N/A
Web time[b]	108.0	107.6	108.2	107.8
50 psia cue time	117.6	117.5	117.8	117.9
Action time[b]	119.7	119.6	119.9	120.4
Separation command	122.7	122.8	122.7	122.8
PMBT, °F	80	80	80	80
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	2.9	2.8	3.5
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted		Actual	
	N/A		160.4	

Impulse Imbalance = Integral of the absolute value of the left motor thrust minus right motor thrust from web time to action time.
[a] All times are referenced to ignition command time except where noted by a [b].
[b] Referenced to liftoff time (ignition interval).

EXTERNAL TANK

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

Typical ice/frost formations were observed on the ET during the countdown. No ice or frost was observed on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen (LO_2) and liquid hydrogen (LH_2) feedlines, the pressurization line brackets and along the LH_2 proturberance air load (PAL) ramps. All observations were acceptable based on NSTS 08303.

ET loading and flight performance was excellent, and all flight objectives were accomplished. The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the ullage pressure slump was 14.72 psid.

Post-separation photography of the ET showed all 181 woodpecker damage repairs appeared to have performed successfully, there was no indication of divots from the intertank to the LH_2 tank splice or missing foam from intertank stringer tops, and the jack pad closeout design appears to have performed successfully for the second consecutive flight.

ET separation occurred nominally, and the ET entry and breakup was within the predicted footprint. The postflight predicted ET-intact impact point was approximately 12 nmi. uprange of the preflight prediction.

SPACE SHUTTLE MAIN ENGINES

All Space Shuttle main engine (SSME) parameters appeared to be normal throughout the prelaunch countdown and were typical of prelaunch parameters observed on previous flights, including SSME 2036, which was the first Block 1 engine to be flown. Engine-ready was achieved at the proper time; all LCC parameters were met; and engine start and thrust buildup were normal.

Flight data indicate that the SSME performance during mainstage, throttling, shutdown and propellant dump operations were normal. The specific impulse (Isp) was rated at 452.16 seconds based on trajectory data. The high-pressure oxidizer turbopump (HPOTP) and high-pressure fuel turbopump (HPFTP) temperatures appeared to be well within specification throughout engine operation. Controller and software performance was good with no anomalies. Space Shuttle main engine cutoff (MECO) occurred at T + 510.6 seconds. There were no failures or significant SSME problems identified.

SHUTTLE RANGE SAFETY SYSTEM

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

One unplanned hold was called by Range Safety at T-31 seconds to verify the ET Range Safety System (RSS) receiver signal strength after it dropped below the Launch Commit Criteria (LCC) limits following vent arm retraction. The hold lasted for 55 seconds.

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

ORBITER SUBSYSTEMS PERFORMANCE

Main Propulsion System

The overall performance of the main propulsion system (MPS) was satisfactory.

LO_2 and LH_2 loading were performed as planned with no stop-flows or reverts. No MPS LCC or OMRSD violations were identified. However, throughout loading, the LO_2 ΔP transducer indicated at the low end of the range, which is 40-70 psid. The potential failure modes were evaluated and it was determined that the most probable cause of the off-scale-low indication was a transducer failure. This problem did not impact the loading operations. KSC troubleshooting found two wires pulled from the transducer. The transducer was repaired.

Throughout the period of preflight operations, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration in the Orbiter aft compartment was approximately 140 ppm, which compares favorably with previous data for this vehicle.

The SSME vent modification was flown for the first time on STS-70, and vent operations were were satisfactory. This modification to the SSME results in venting approximately 2 scfm of helium per engine into the aft compartment whenever the MPS engine helium isolation valves are open and the SSME pneumatic shutdown solenoid is deenergized. This additional helium added 2,000-3,000 ppm to the overall aft compartment concentration. As expected, this modification also caused the SSME helium supply system pressure to decay faster than previously experienced following the post-MECO closure of the helium supply system isolation valves.

A comparison of the calculated propellant loads at the end of replenish, versus the inventory loads, results in a loading accuracy of 0.006 percent for LH_2 and 0.068 percent for LO_2.

Ascent MPS performance was completely nominal. Data indicate that the LO_2 and LH_2 pressurization systems performed satisfactorily, and that all net positive suction pressure (NPSP) requirements were met throughout the flight. The first flight with a Block 1 engine (SSME 1) was nominal. All MPS parameters affected by the Block 1 SSME were as expected.

Reaction Control Subsystem

The RCS performed very satisfactorily throughout the STS-70 mission with no anomalies or problems identified. A total of 4,837.1 lbm of propellants was consumed during the mission.

Orbital Maneuvering Subsystem

The OMS performance was satisfactory throughout the mission with no anomalies identified. A total of 13,462.1 lbm of propellants were consumed during the four OMS firings performed. The following table provides the data for the OMS firings.

OMS FIRINGS

OMS firing	Engine	Ignition time, G.m.t./MET	Firing duration, seconds	ΔV, ft/sec
OMS-2	Both	194:14:21:50.1 G.m.t. 00:00:39:55.1 MET	143.7	221.6
OMS-3	Left	194:20:09:46.3 G.m.t. 00:06:27:51.3 MET	33.6	30.5
OMS-4	Right	195:19:10:41 2. G.m.t. 01:05:28:46 2 MET	31.7	28.9
Deorbit	Both	203:11:00:12.2 G.m.t. 08:21:18:17.2 MET	176.6	342.6

The forward fuel probe in the left OMS fuel tank was inoperative throughout the mission. This same probe was failed during previous flights of this pod. The loss of this fuel probe did not impact the mission. The remaining probes of the OMS gaging system operated properly.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed nominally throughout the mission. The PRSD provided 1959 lbm of oxygen for fuel cell (1916 lbm) and crew breathing use (43 lbm), and 241 lbm of hydrogen for use by the fuel cells. At touchdown, a mission extension capability of 55 hours at an average power level of 13.1 kW was remaining.

Fuel Cell Subsystem

The fuel cell subsystem performed nominally throughout the mission with no anomalies or problems noted. The fuel cells used 241 lbm of hydrogen and 1916 lbm of oxygen in producing 2,816 kWh of electricity at an average power level of 13.1 kW. The water produced as a by-product of the electrical generation totaled 2157 lbm.

During the mission, fuel cell 3 (serial number 113) reached 2,400 hours of operating time at 202:17:14:15 G.m.t. (08:03:33:00 MET) and totaled 2,429 hours of operation when the fuel cell was shut down. This is the first fuel cell to reach 2,400 hours, which is the certified life limit of the fuel cells, during flight. Prior to STS-70, an exception was approved that extended the life limit for this fuel cell to 2,600 hours.

At 198:16:34:58 G.m.t. (04:02:53:03 MET), the fuel cell 1 pH meter came on for 21 seconds, the fuel cell 1 current momentarily increased from 160 to 281 amperes, the voltage decreased from 31.04 to 30.08 Vdc, and the hydrogen pump motor voltage increased from 0.46 to 0.50 Vdc. The problem was traced to a short in the vacuum cleaner cable, and this was not a fuel cell problem. The short was stopped when circuit breaker 28 on the AC1 utility outlet opened. This problem is discussed in the Flight Crew Equipment section of this report.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily during the mission, with no anomalies identified. Following ascent, the APUs were shut down in the desired order (3, 1, and 2) to fulfill the requirements of DTO 414 - APU Shutdown Test. The following table presents the APU run-times and fuel consumption during the mission.

APU 1 experienced three gearbox repressurizations during entry. This APU also experienced two gearbox repressurizations during entry on the previous flight of this vehicle (STS-63) and this APU. These repressurizations did not impact the operations of the APU during either mission.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 407)		APU 2 (S/N 401)		APU 3 (S/N 306)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	20:44	50	20:54	56	20:31	51
FCS checkout	6:23	13				
Entry[a]	58:14	99	80:54	151	58:14	121
Total	85:21	162	101:48	207	78:45	172

[a] The APUs ran for about 14 minutes 15 seconds after landing.

After two normal cycles post-ascent, the APU 3 fuel line/pump/gas generator valve module (GGVM) system A thermostat changed set points (narrowed bandwidth). This performance did not impact flight operations. The APUs will be returned to the vendor for flush and decontamination after this flight, and while at the vendor, the thermostat will be replaced.

The APU 1 exhaust gas temperature (EGT) 2 sensor operated erratically during entry. This erratic operation did not affect operations, and the sensor will be replaced during postflight operations. The APU 2 EGT 2 sensor failed prior to flight and it will also be replaced.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/water spray boiler (WSB) subsystem operated satisfactorily throughout the mission with no problems or anomalies identified.

The APUs were shut down in the order (3, 1, and 2) required by DTO 414 to investigate the rudder/speedbrake power drive unit (PDU) back-driving. No PDU back-driving was noted in the data.

At 198:09:59 G.m.t. (03:20:17 MET) during the reconfiguration of heater systems on the WSBs, no WSB 3 temperature data were seen after switching the B controller on. The crew checked the circuit breaker for the WSB 3B controller power and it was found open. At 198:10:10 G.m.t. (03:20:28 MET), WSB 3 was switched back to the A controller, and nominal performance was verified. Data review showed no evidence of a short, and the crew commented at the crew debriefing that the circuit breaker had a communications cord looped around it and the circuit breaker may have been inadvertently pulled. The circuit breaker was left open, and entry was performed on the A controller. The circuit providing power to the B controller was tested on the ground, and no problems were identified.

On six of the seven previous flights of this vehicle, WSB system 2 has consistently experienced over-cooling conditions during entry. These conditions are potentially due to a problem within the controller. In an effort to verify this condition, WSB system 2 controller operation was reversed for the previous flight of this vehicle (STS-63) and this flight (launch on controller B and entry on controller A). During this flight and STS-63, no over-cooling conditions occurred, and this tends to indicate the controller B is contributing to the over-cooling occurrences.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPDC) subsystem performed in a nominal manner throughout the mission with no anomalies or problems identified.

Environmental Control And Life Support System

The environmental control and life support system (ECLSS) performed satisfactorily and successfully met all requirements of the mission.

The active thermal control system (ATCS) performed in a nominal manner throughout the mission. There were no actively cooled payloads in the payload bay; consequently, both Freon loops remained in the interchanger position for the entire mission. The radiator coldsoak provided cooling during entry through touchdown plus 10 minutes when ammonia system B was activated using the secondary controller. The ammonia system B operated for 29 minutes prior to being turned off when ground cooling was established.

With the exception of one minor anomaly, the supply water and waste management system performed satisfactorily throughout the mission, and all in-flight checkout requirements were met prior to the completion of the flight. At 196:01:27 G.m.t. (01:11:45 MET), the supply water tank C quantity measurement began experiencing dropouts in the indicated tank quantity. The dropouts, many of which were to off-scale-low, had duration's ranging from one to four seconds. The dropouts occurred when the tank was approximately 42-percent full. Similar problems have been experienced on previous missions and have been attributed to corrosion on the reel-type potentiometer that is used to indicate water-tank-bellows position. Supply water tanks B and C were manifolded together and the tank B quantity transducer was available to measure the quantity in both tanks should the problem have worsened. There was no mission impact from this condition. All of the water tanks will be removed during the upcoming OV-103 Orbiter maintenance down period (OMDP). The quantity transducer will be replaced while the tanks are removed from the Orbiter.

Supply water was managed using the overboard dump system and the FES. Two supply water dumps were performed, one of which was a simultaneous dump with the waste water. The supply water dumps were performed nominally at an average rate of 1.58 percent/minute (2.61 lb/min). The supply water dump line temperature was maintained between 64 °F and 97 °F throughout the mission with the operation of the line heater.

Waste water was gathered at approximately the predicted rate. Three waste water dumps were performed nominally at an average dump rate of 1.89 percent/minute (3.1 lb/min). The waste water dump line temperature was satisfactorily maintained between 56 °F and 86 °F throughout the mission, while the vacuum vent nozzle was maintained between a nominal 145 °F and 170 °F.

STS-70 was the fourth flight of the supply water dump line purge assembly (SWDLPA). This device is designed to provide an automatic purge of the supply water dump line at the completion of each water dump to prevent the dump valve from "burping". On missions prior to the use of this device on this vehicle, the burping has been known to repeat as many as 10 times. This device provides an air purge of the line and this stops the burping condition. This device again worked very satisfactorily in preventing burping action on this flight.

The waste collection system performed normally throughout the mission.

The atmospheric revitalization pressure control system performed very satisfactorily throughout the duration of the mission. During the redundant component checkout, the alternate system was also exercised. Both systems exhibited normal operation.

Airlock Support System

Use of the airlock support system was not required on this mission because no extravehicular activity (EVA) was planned or required.

Smoke Detection and Fire Suppression System

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

Avionics and Software Systems

The integrated guidance, navigation and control system performed satisfactorily throughout the mission. STS-70 was the first mission that used the day of launch I-loads-II (DOLILU II), and these I-loads performed very satisfactorily.

The flight control system performed satisfactorily with no anomalies or problems noted. STS-70 was the first use of the -6 degree turnaround position for SSME pitch during postlanding engine positioning, and it worked properly.

Descent navigation sensors performed nominally throughout STS-70. External sensors (drag, TACAN, ADTA, and MSBLS) data were incorporated into the onboard navigation states at their expected region of operations. All external sensor measurement residuals and residual ratio values were nominal with no navigation drift edit observed, and no navigation aid line replaceable units were deselected by the redundancy management. The backup flight system navigation data also exhibited similar characteristics to the primary flight system.

Postflight error analysis has shown good comparison between primary flight system states and backup flight system states.

The inertial measurement units (IMUs) operated very satisfactorily with only one accelerometer uplink compensation required for each IMU. The star tracker also performed satisfactorily.

The data processing system (DPS) hardware and flight software performed satisfactorily. Also, STS-70 was the last flight of the OI-24 software.

The displays and controls operated nominally.

Communications and Tracking Subsystems

The communication systems performed satisfactorily during all phases of the mission. S-band communications through TDRS-West were degraded for about a 10-minute period during entry when antenna look angles were favorable.

The Orbiter was in the blackout region (250,000 ft. to 180,000 ft.) where signal attenuation can be expected due to the plasma effect; however, data analysis showed that the received signal strength was also lower than expected. Analysis of the problem is continuing as this report was being written.

All navigation aids equipment performed nominally during the ascent and entry phases.

A number of Government furnished equipment (GFE) communications and tracking subsystem hardware anomalies were identified and these are discussed in that section of the report.

Operational Instrumentation/Modular Auxiliary Data System

The operational instrumentation system performed acceptably throughout the mission.

At 197:16:43 G.m.t. (03:03:01 MET), when the operations (OPS) 2 recorder was being dumped through channel 2 of the Ku-band, the dump quality of track 3 was degraded (Flight Problem STS-70-V-01). The recorder was dumped in both the forward and reverse directions with degraded quality on track 3. All other recorder tracks provided satisfactory data. Two test dumps of track 3 were also performed, and both provided degraded data. As a result, only tracks 4 through 14 were used for recording during the remainder of the mission. This condition did not impact the mission.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. The landing and braking data are shown in the following table.

The drag chute performance was nominal.

Landing and Braking Parameters

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2696[a]	194.0	~ 1.6	N/A
Nose gear touchdown	5478[a]	156.3	N/A	~5.2

Brake initiation speed	92.3 keas
Brake-on time	31.7 seconds
Rollout distance	8,472 feet
Rollout time	58.4 seconds
Runway	33 KSC SLF
Orbiter weight at landing	194,280 lb

Brake sensor location	Peak pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	687	Left-hand inboard	12.81
Left-hand inboard 3	674		
Left-hand outboard 2	661	Left-hand outboard	11. 09
Left-hand outboard 4	674		
Right-hand inboard 1	674	Right-hand inboard	12.92
Right-hand inboard 3	819		
Right-hand outboard 2	661	Right-hand outboard	10.82
Right-hand outboard 4	648		

[a] Orbiter data.

Integrated Aerodynamics, Heating and Thermal Interfaces

The ascent and entry aerodynamics were nominal with no problems, anomalies, or unexpected conditions noted in the data.

The integrated heating during ascent and entry was nominal. Likewise, the entry aerodynamic heating was nominal; however, postflight analysis and heating calculations are continuing as this report was written.

The performance of the thermal interfaces was nominal with all temperatures within limits. No problems have been identified from the data.

Thermal Control System

The performance of the thermal control system (TCS) was nominal during all phases of the flight, and all Orbiter subsystem temperatures were maintained within acceptable limits.

Aerothermodynamics

The acreage heating during entry was within limits, and the local heating was nominal. The structural temperature rise was symmetrical on the right and left wing and within the experience base. Analysis is continuing as this report was being written.

Thermal Protection System and Windows

The thermal protection system performed satisfactorily. Based on structural temperature response data (temperature rise), the entry heating was much lower than average. Many of the measured structural-temperature rises and maximum temperatures were below previous minimums for OV-103. Boundary layer transition from laminar to turbulent flow was symmetric, occurring at 1225 seconds after entry interface at all measured locations [forward centerline of the vehicle (X/L = 0.3), and the aft right and left sides of the vehicle (X/L = 0.6).

The postlanding inspection of the vehicle identified a total of 127 debris impact damage sites on the vehicle. Of these sites, nine had a major dimension of 1 inch or greater. A comparison of the number of hits to statistics from previous flights indicates that STS-70 was below average.

The Orbiter lower surface had a total of 81 debris impact sites of which five had a major dimension greater than one inch. The number of hits on the lower surface with a major dimension of greater than one inch was below the average number of 14. The upper surface had 29 debris impact sites with only one site having a major dimension greater than one inch. The right and left side had 4 and 2 debris impact sites, respectively. The right OMS pod had four impact sites and the left OMS pod had seven impact sites, of which three had a major dimension greater than one inch.

The inspection of the lower surface revealed that there was minimal problems from the ET ice, failed woodpecker damage repairs, and intertank TPS divots during ascent. There were no unusually large or unique damage sites and most of the sites showed signs of thermal erosion that is typically associated with entry.

No tile damage from micrometeorites or on-orbit debris was identified; however, a deep hole, 1/16 inch in diameter, near the leading edge of the left-hand main landing gear door was noted.

Small tile damage sites were noted on the leading edge of the left-hand OMS pod, and at the base of the vertical stabilizer.

The main landing gear tires and brakes were in good condition; however, four pieces of rubber that were missing from the nose landing gear tires were found on the runway. The cluster of tile damage sites behind the nose wheel well was most likely caused by tire-material impacts during rollout.
The ET/Orbiter separation devices functioned nominally. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly.

At approximately 199:11:24 G.m.t. (04:21:42 MET), the flight crew reported a debris impact to the right-hand-side thermal window, W6. The impact was located in the upper-forward corner of the window approximately 1/2 inch from the edge. The crew estimated that the size of the impact was approximately 1/16 inch (0.06 inch) in diameter and 1/32 inch (0.03 inch) deep. Based on the crew-estimated size, an evaluation of the condition determined it did not pose a safety concern for entry. The W6 window was new with no previous flights prior to STS-70. During postflight turnaround activities at Kennedy Space Center (KSC), the measured size of the impact was 0.116 inch by 0.104 inch in diameter and 0.0081-inch deep.

FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

At 196:07:07 G.m.t. (01:17:25 MET), it was noted that closed circuit television (CCTV) camera B was occasionally exhibiting slight horizontal shifts in the downlinked image. About an hour later at 196:08:10 G.m.t. (01:18:28 MET), the camera B downlink image brightness was also noted to be changing intermittently (Flight Problem STS-70-F-01). CCTV camera B remained usable, although the camera experienced intermittent problems throughout the mission. The camera performance was best when operated at temperatures below 14 °C.

At approximately 198:08:45 G.m.t (03:19:03 MET), while the crew was working an experiment problem, scratchy and broken audio was received when the crew was using a hand-held microphone (Flight Problem STS-70-F-02). The crew switched to a spare hand-held microphone. The hand-held microphone will be tested postflight.

During filter cleaning at 198:16:34:58 G.m.t. (04:02:53:03 MET), a short was noted on the AC1 bus. The short was traced to the vacuum cleaner cord, which had been damaged when it was caught in a locker door (Flight Problem STS-70-F-03). The crew spliced and secured the damaged areas of the cord. An additional procedure to perform a continuity check of the repaired cord was performed later in the day, and the results indicated a satisfactory repair. However, the vacuum cleaner was stowed and it was not used during the remainder of the mission. Gray tape was used for the remaining filter cleaning. The vacuum cleaner will be repaired.

The crew reported that the onboard video playback from the TEAC video tape recorder was degraded (Flight Problem STS-70-F-04), and the video recorded on the TEAC recorder was downlinked for evaluation. The video appeared slightly washed out, but it was not objectionable. Based on the crew description, the video appeared worse onboard than it did on the ground. Payload personnel stated that the quality of the video was acceptable. As a result, the crew continued using the TEAC recorder. The recorder will be tested postflight.

At approximately 199:18:49 G.m.t. (05:05:07 MET), difficulty was being experienced by ground controllers while uplinking a message to the thermal impact printer system (TIPS), and the crew was requested to cycle the power to the TIPS. The crew reported that the Ku-band extension cable had been pinched in a middeck locker door (Flight Problem STS-70-F-05). The crew freed the cable and cycled the power to the TIPS, and the TIPS functioned nominally for the remainder of the mission. The cable was removed and will be inspected for damage during postflight testing.

CARGO INTEGRATION

Cargo integration hardware performance was acceptable throughout the mission. One anomaly was noted and it is discussed in the following paragraphs.

At 194:20:55 G.m.t. (00:07:17 MET), while performing the IUS post-deployment closeout procedures, the flight crew reported that both the primary and secondary circuit breakers, located on the aft flight deck payload station L-11 IUS power control panel (PCP), had switched to the open position (Flight Problem STS-70-P-01).

Data from the mid power controller assemblies 1 and 2 showed an electrical current increase of 10 amperes for about 3 seconds. The maximum rating of the circuit breakers was 3 amperes. The current spike had occurred at 194:20:06 G.m.t. (00:06:24 MET), and ended at the same time as the IUS/airborne support equipment (ASE) tilt table rotation to the down and locked position was completed. Analysis during flight showed that the configuration was safe for continuing the mission as well as for entry and landing.

Extensive postflight inspections of the PCP and the payload bay revealed no physical damage to any electrical cables or hardware. However, resistance tests did reveal an unplanned electrical path in the wiring of the IUS ASE. Efforts are underway to resolve this condition.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

A total of 12 development test objectives (DTOs) and 12 detailed supplementary objectives (DSOs) were assigned to the STS-70 mission. Preliminary results are presented, where available, in the following paragraphs.

DEVELOPMENT TEST OBJECTIVES

The following were data-only DTOs, for which the data have been given to the sponsor for evaluation. Subsequent to the evaluation, the results will be published in separate documentation:

1. DTO 301D - Ascent Structural Capability Evaluation;
2. DTO 305D - Ascent Compartment Venting Evaluation;
3. DTO 306D - Descent Compartment Venting Evaluation;
4. DTO 307D - Entry Structural Capability; and
5. DTO 319D - Orbiter/Payload Acceleration and Acoustics Environment Data.

DTO 312 - ET TPS Performance (Method 3) - The ET was photographed using the hand-held Nikon camera with a 300mm lens and a 2X extender. A total of 37 excellent quality views of the ET were acquired. No ET anomalies were noted during the film evaluation, nor were any unusual markings noted from the thermal protection system (TPS) repairs made prior to flight.

DTO 414 - APU Shutdown Test (Sequence A) - The APU shut down order was 3, 1, and 2, as required by the DTO. No back-driving of the rudder speedbrake PDU was noted in the data analysis.

DTO 524 - Landing Gear Loads and Brake Stability Evaluation - Data were collected during landing and rollout, and these data have been given to the sponsor for evaluation. Following the analysis, the results will be published in separate documentation.

DTO 656 - PGSC Single Event Upset Monitoring (Configuration A) - Data were collected as planned for this DTO. These data have been given to the sponsor for evaluation and subsequent publication.

DTO 677 - Evaluation of Microbial Capture Device in Microgravity - Data were collected by the crew for this DTO. The crew did not report any unusual difficulties in performing this DTO. The data have been given to the sponsor for evaluation and publication of the results.

DTO 779 - STS Orbiter Attitude Control Translational Thrusting - The planned activities in support of this DTO were completed. The data have been given to the sponsor for evaluation and subsequent publication.

DTO 805 - Crosswind Landing Performance - This DTO was not accomplished as wind conditions did not meet the minimum criteria for the DTO.

DETAILED SUPPLEMENTARY OBJECTIVES

The results of the DSOs require a significant amount of time to evaluate and present the results. Data were collected for each of the DSOs and these data have been given to the sponsor for evaluation. The release or publication of the results is the responsibility of the sponsor. The DSOs performed on the STS-70 mission are as follows:

1. DSO 328 - In-Flight Urine Collection Absorber Evaluation;
2. DSO 491 - Characterization of Microbial Transfer Among Crewmembers During Spaceflight;
3. DSO 603 - Orthostatic Function During Entry, Landing and Egress (Configuration C);
4. DSO 604 - Visual-Vestibular Integration as a Function of Adaptation;
5. DSO 621 - In-Flight Use of Florinef to Improve Orthostatic Intolerance Postflight;
6. DSO 624 - Pre and Postflight Measurement of Cardiorespiratory Responses to Submaximal Exercise;
7. DSO 626 - Cardiovascular and Cerebrovascular Responses to Standing Before and After Spaceflight;
8. DSO 802 - Educational Activities (Heat Pack);
9. DSO 901 - Documentary Television;
10. DSO 902 - Documentary Motion Picture Photography;
11. DSO 903 - Documentary Still Photography; and
12. DSO 904 - Assessment of Human Factors.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

On launch day, 23 of 24 expected videos were screened. Following launch day, 53 films were reviewed. No potential anomalies were found in the video or photographic data.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

Analysis of the micrometeoroid debris impact on window 6 was completed at the request of the STS-70 Mission Evaluation Team; An enhanced image of the window was provided.

LANDING PHOTOGRAPHY AND TELEVISION ANALYSIS

Twelve videos of the approach and landing operations were reviewed. No evidence of any anomalous condition was found in the review.

TABLE I.- STS-70 MISSION EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	194:13:36:11.149 194:13:36:12.084 194:13:36:13.267
SRB HPU Activation[a]	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	194:13:41:27.090 194:13:41:27.250 194:13:41.27.410 194:13:41:27.570
Main Propulsion System Start[a]	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	194:13:41:48.462 194:13:41:48.576 194:13:41:48.716
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	194:13:41:55.020
Throttle up to 104 Percent Thrust[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	194:13:41:58.856 194:13:41:58.862 194:13:41:58.876
Throttle down to 67 Percent Thrust[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	194:13:42:23.176 194:13:42:23.182 194:13:42:23.196
Maximum Dynamic Pressure (q)	Derived ascent dynamic pressure	194:13:42:45
Throttle up to 104 Percent[a]	ME-2 Command accepted ME-3 Command accepted ME-1 Command accepted	194:13:42:55:977 194:13:42:55.982 194:13:42:55.997
Both SRM's Chamber Pressure at 50 psi[a]	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	194:13:43:52.500 194:13:43:52.860
End SRM [a] Action[a]	LH SRM chamber pressure mid-range select RH SRM chamber pressure mid-range select	194:13:43:54.850 194:13:43:55.660
SRB Physical Separation[a]	LH rate APU turbine speed - LOS RH rate APU turbine speed - LOS	194:13:43:57.780 194:13:43:57.780
SRB Separation Command	SRB separation command flag	194:13:43:58
Throttle Down for 3g Acceleration[a]	ME-2 command accepted ME-3 command accepted ME-1 command accepted	194:13:49:28.302 194:13:49:28.305 194:13:49:28.325
3g Acceleration	Total load factor	194:13:49:30.2
Throttle Down to 67 Percent Thrust[a]	ME-1 command accepted ME-2 command accepted ME-3 command accepted	194:13:50:19.166 194:13:50:19.183 194:13:50:19.185
SSME Shutdown[a]	ME-1 command accepted ME-2 command accepted ME-3 command accepted	194:13:50:25.647 194:13:50:25.663 194:13:50:25.665
MECO	MECO command flag MECO confirm flag	194:13:50:26 194:13:50:26
ET Separation	ET separation command flag	194:13:50:45

[a]MSFC supplied data

TABLE I.- STS-70 MISSION EVENTS (Continued)

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-3 GG chamber pressure APU 1 GG chamber pressure APU 2 GG chamber pressure	194:13:56:44.229 194:13:56:55.023 194:13:57:05.636
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	194:14:21:50.1 194:14:21:50.1
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	194:14:24:13.6 194:14:24:13.8
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	194:15:09:56 194:15:11:15
TDRS-IUS Deployment	Voice call	194:19:54:55
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	194:20:09:46.3 Not applicable
OMS-3 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	194:20:10:19.9 Not applicable
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	Not applicable 195:19:10:41.2
OMS-4 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	Not applicable 195:19:11:12.9
Flight Control System Checkout APU Start APU Stop	 APU-1 GG chamber pressure APU-1 GG chamber pressure	 201:07:49:31.299 201:07:55.53.990
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	202:08:16:52 202:08:18:35
Payload Bay Doors Open (Wave off)	PLBD right open 1 (BFS) PLBD left open 1 (BFS)	202:12:35:38 202:12:36:58
Payload Bay Doors Close	PLBD left close PLBD right close	203:06:46:25 203:06:48:04
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	203:10:55:18.093 203:11:17:55.862 203:11:17:59.579
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	203:11:00:12.2 203:11:00:12.4
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	203:11:03:08.8 203:11:03:08:8
Entry Interface (400K feet)	Current orbital altitude above	203:11:30:41
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	203:11:55:31
Main Landing Gear Contact	LH main landing gear tire pressure 1 RH main landing gear tire pressure 2	203:12:01:59.805 203:12:01:59.844
Main Landing Gear Weight on Wheels	RH main landing gear weight on wheels LH main landing gear weight on wheels	203:12:02:01.994 203:12:02:04.823

TABLE I.- STS-70 MISSION EVENTS (Continued)

Event	Description	Actual time, G.m.t.
Drag Chute Deployment	Drag chute deploy 1 CP Volts	203:12:02:03.3
Nose Landing Gear Contact	NLG LH tire pressure 1	203:12:02:09
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	203:12:02:09
Drag Chute Jettison	Drag chute jettison 1 CP Volts	203:12:02:34.8
Wheel Stop	Velocity with respect to runway	203:12:03:04
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	203:12:16:10.031 203:12:16:12.395 203:12:16:13.759

TABLE II.- ORBITER PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-70-V-01	Operations Recorder 2 Track 3 Degraded	197:16:43 G.m.t. 03:03:01 MET CAR 70RF01	At 197:16:43 G.m.t. (03:03:01 MET), OPS recorder 2 was being dumped through Ku-band channel 2. The recorder quality degraded while on track 3. The recorder was dumped in both the forward and reverse directions with degraded quality. Dumps of other tracks on this recorder were satisfactory. At 197:17:07 G.m.t. (03:03:25 MET), data were recorded on track 3 for testing purposes. At 197:20:01 G.m.t. (03:06:21 MET), the test data were dumped in both the forward and reverse directions with the recorder dump quality being degraded. An additional test was performed at 197:20:41 G.m.t. (03:07:01MET), with the dump occurring at 197:20:57 G.m.t. (03:07:17 MET) resulting in the same signature. The Mission Control Center (MCC) will only record on tracks 4 through 12 for the remainder of the mission to avoid using track 3. The recorder was installed in OV-103 in 1988 prior to the STS-33 mission. KSC: The recorder was removed from the vehicle and sent to the NASA Shuttle Logistics Depot (NSLD) for troubleshooting and repair.

TABLE III.- GOVERNMENT FURNISHED EQUIPMENT PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-70-F-01	CCTV Camera B Horizontal Shifts and Brightness Changes Level III Closure	196:07:07 G.m.t. 01:17:25 MET	At 196:07:07 G.m.t. (01:17:25 MET), it was noticed that CCTV camera B was occasionally experiencing slight horizontal shifts in the downlinked image. At 196:08:10 G.m.t. (01:18:28 MET), the CCTV camera B downlink image brightness was changing. The condition recurred at 198:05:30 G.m.t. (03:15:48 MET) and 198:10:30 G.m.t.(03:20:48 MET). The camera did not experience problems when operated at temperatures below 14° C. Both of these CCTV camera B conditions will be investigated.
STS-70-F-02	Hand-Held Microphone Faulty. Level III Closure	198:08:45 G.m.t. 03:19:03 MET	At approximately 198:08:45 G.m.t. (03:19:03 MET), the crew was working a HERCULES experiment problem when the Mission Control Center (MCC) not broken and scratchy downlink from the hand-held microphone that was in use on the flight deck. The crew swapped out the faulty microphone with a spare. Troubleshooting will be performed postflight.
STS-70-F-03	Vacuum Cleaner Utility Power Cord Abrasion Level III Closure	198:16:52 G.m.t. 04:03:10 MET	On flight day 5, the flight crew reported that the utility power cord had been pinched in a middeck locker door. This resulted in an abrasion which led to a short, causing circuit breaker CB28 on the AC1 utility outlet to open. This short was evident on AC bus 1 phases A and C with a slight load carry on phase B. The utility cord was repaired by the flight crew and tested for continuity. The test indicated a good repair. The vacuum cleaner was stowed and not used for the remainder of the mission. Gray tape was used to clean the cabin filters. The vacuum cleaner and power cord will be tested postflight.
STS-70-F-04	TEAC Recorder Degraded Playback Level III Closure	199:19:10 G.m.t. 05:05:28 MET	At approximately 199:19:10 G.m.t. (05:05:28 MET), the crew reported several cases of poor quality playback from the TEAC VTR. The crew also reported that recordings made on the WINDEX experiment camcorder and another camcorder looked poor when played back on the TEAC, exhibiting vertical green stripes, variations in overall intensity (washout), flashing and tearing (distortion). Downlink of the TEAC playback video did not seem as bad as what the crew reported, showing slight

TABLE III.- GOVERNMENT FURNISHED EQUIPMENT PROBLEM TRACKING LIST

STS-70-F-04 (Continued)	TEAC Recorder Degraded Playback (Continued)	199:19:10 G.m.t. 05:05:28 MET	tearing at the bottom of the image and washout. The last time a similar problem occurred (STS-67), troubleshooting found that the problem was caused by mechanical misalignment. Troubleshooting will be performed postflight.
STS-70-F-05	TIPS Ku-band Extension Cable Damage Level III Closure	199:18:49 G.m.t. 05:05:07 MET	After experiencing difficulty uplinking a TIPS message, the crew was asked to power cycle the TIPS. The crew reported that the Ku-band extension cable had been pinched in a middeck locker door. The cable was freed, the power cycle was performed, and the TIPS performed nominally for the remainder of the mission. The extent of the damage to the cable was not known during flight, and the cable was removed postflight for troubleshooting, repair and checkout.

TABLE IV.- MSFC PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-70-M-01	Gas Path Through Joint 3 RTV With Heat-Affected Primary O-Ring	Postflight inspection	<u>Description</u>: A gas path was observed through the RTV on the right-hand motor at 229 degrees with soot on the primary O-ring from 170 to 255 degrees. Heat-affected CCP, GCP, and eroded adhesive were found at the gas-path location. Heat effect observed at three small locations with slight erosion (approximately 0.0006 in.) at two locations on the primary O-ring. <u>Closure Rationale:</u> Assessment to date has identified the closeout during RTV back-fill was the most likely cause of gas paths in more recent deeply filled joints. All dispositions/rework/repairs for the affected flight sets will be handled per MRS paperwork. When non destructive testing (NDT) is not used to detect voids, the repair process consists of removing the RTV down to the inflection point of the joint for the full 360 degrees, visually inspecting the residual RTV surface at the inflection point for voids, and re-backfilling the joint with new RTV (except for areas where voids are identified in the old material). After the new backfilled RTV is cured, the edges of the RTV backfill opening, where voids were identified in the old RTV, will be excavated to accommodate the backfill repair closeout. The repair closeout will incorporated a vacuum-assisted backfill. If no pigtail void is found, the vacuum-assisted backfill method will be used to closeout the excava ted region. The repair closeout will be in a location away from the original backfill closeout location. When NDT is used to detect voids in the joint, the repair process consists of removing the RTV down to the inflection point of the joint at each location where a void is identified and replacing it with new RTV using vacuum assist to reduce the chance of new voids. This process was developed and testing on sub-scale plexiglass

TABLE IV.- MSFC PROBLEM TRACKING LIST

STS-70-M-01 (Continued)	Gas Path Through Joint 3 RTV With Heat-Affected Primary O-Ring.(Continued)	Postflight Inspection (Continued	test blocks and on full-up HPM and RSRM hardware joints which were then disassembled and inspected until the process was proven. The processes used for the repair work were analyzed with a process FEMA. The process FEMA systematically identified repair concerns and controls to mitigate risk. The process FEMA work is documented in TWR-73177. The flight-sets repair work was analyzed with a process FEMA. The process FEMA systematically identified repair concerns and controls to mitigate risk. The process FEMA work is documented in TWR-73177. The flight sets affected by these DRs are 360X046 through 360X050 and 360X050 through 360X055.

DOCUMENT SOURCES

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

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

ACRONYMS AND ABBREVIATIONS

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

AC1	alternating current bus 1
APU	auxiliary power unit
ASE	airborne support equipment
BDS	Bioreactor Demonstration System
BRIC	Biological Research in Canisters
CCTV	closed circuit television
CPCG	Commercial Protein Crystal Growth
DOLILU II	day of launch I loads II
DPS	data processing system
DSO	Detailed Supplementary Objective
DTO	Developmental Test Objective
ΔP	differential pressure
ΔV	differential velocity
ECLSS	environmental control and life support system
EGT	exhaust gas temperature
EPDC	electrical power distribution and control subsystem
ET	External Tank
EVA	extravehicular activity
FCE	flight crew equipment
FCS	flight control system
FES	flash evaporator system
ft/sec	feet per second
GFE	Government furnished equipment
GGVM	gas generator valve module
G.m.t.	Greenwich mean time
HERCULES-B	Hand-Held, Earth-Oriented, Real-Time, Cooperative, User-Friendly Location-Targeting and Environmental System-B
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
IUS	inertial upper stage
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt hour
LCC	Launch Commit Criteria
LEO	low Earth orbit
LMES	Lockheed Martin Engineering and Science
LH_2	liquid hydrogen
LO_2	liquid oxygen
MAST	Military Applications of Ship Tracks
MECO	main engine cutoff
MET	mission elapsed time
MIS-B	Microencapsulation in Space-B
MPS	main propulsion system

MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
nmi.	nautical mile
NPSP	net positive suction pressure
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
O_2	oxygen
OMDP	Orbiter Maintenance Down Period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	Operations
PAL	protuberance air load
PARE/NIH-R	Physiological and Anatomical Rodent Experiment/National Institutes of Health-Cells
PDU	power drive unit
pH	Hydrogen-Ion concentration
PMBT	propellant mean bulk temperature
ppm	parts per million
PRSD	power reactant storage and distribution
RCS	reaction control subsystem
RME-III	Radiation Monitoring Equipment-III
RSRM	Reusable Solid Rocket Motor
RSS	Range Safety System
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAREX-II	Shuttle Amateur Radio Experiment-II
SLF	Shuttle Landing Facility
SRB	Solid Rocket Booster
SRM	solid rocket motor
SRSS	Shuttle range safety system
SSME	Space Shuttle main engine
STL-NIH-C	Space Tissue Loss-National Institutes of Health-Cells
SWDLPA	supply water dump line purge assembly
TCS	thermal control system
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TPS	thermal protection subsystem
USA	United States Army
USAF	United States Air Force
Vdc	Volts, direct current
VFT-4	Vision Function Tester-4
W	window
WINDEX	Window Experiment
WSB	water spray boiler

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