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SPACE SHUTTLE
MISSION REPORT

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STS-49

SPACE SHUTTLE

MISSION REPORT

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July 1992

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INTRODUCTION

The STS-49 Space Shuttle Program Mission Report contains a summary of the Orbiter, External Tank (ET), Solid Rocket Booster/Redesigned Solid Rocket Motor (SRB/RSRM), and Space Shuttle main engine (SSME) subsystem performance during the forty-seventh flight of the Space Shuttle Program and the first flight of the Orbiter vehicle Endeavour (OV-105). In addition to the Endeavour vehicle, the flight vehicle consisted of an ET designated as ET-43 (LWT-36); three SSME's which were serial numbers 2030, 2015, and 2017 in positions 1, 2, and 3, respectively; and two SRB's designated as BI-050. The lightweight RSRM's installed in each SRB were designated as 360L022A for the left RSRM and 360L022B for the right RSRM.

This STS-49 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement, as documented in NSTS 07700, Volume VIII, Appendix E, which states that each major organization supporting the Program will report the results of its hardware evaluation and mission performance plus identify all related in-flight anomalies.

The primary objectives of this flight were to perform the operations necessary to re-boost the International Telecommunications Satellite VI (INTELSAT VI) spacecraft and to fulfill the requirements of the Assembly of Station by Extravehicular Activity (EVA) Methods (ASEM) payload. The secondary objectives of the flight were to perform the operations of the Commercial Protein Crystal Growth (CPCG), Block II payload; the Air Force Maui Optical Site Calibration Test (AMOS); and the Ultraviolet Plume Instrument (UVPI); all of which were flown as payloads of opportunity. In addition, 18 development test objectives (DTO's) and 13 detailed supplementary objectives (DSO's) were assigned to this flight.

The sequence of events for the STS-49 mission, planned as a 7-day mission is shown in Table I, and the official Orbiter and GFE Projects Problem Tracking List is shown in Table II. In addition, each Orbiter, ET, SSME, and SRB/RSRM subsystem anomaly is discussed in the applicable subsystem section of the report, and a reference to the assigned tracking number is provided when the anomaly is mentioned in the report. All times shown in the text of the report are in both Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The crew for this forty-seventh Space Shuttle flight was Daniel C. Brandenstein, Capt., USN, Commander; Kevin P. Chilton, Lt. Col., USAF, Pilot; Richard J. Hieb, Mission Specialist 1; Bruce E. Melnick, Cmdr., USCG, Mission Specialist 2; Pierre J. Thuot, Cmdr., USN, Mission Specialist 3; Kathryn C. Thorton, Ph.D, Mission Specialist 4; and Thomas D. Akers, Lt. Col., USAF, Mission Specialist 5. STS-49 is the fourth space flight for the Commander, the second space flight for all of the mission specialists, and the first space flight for the Pilot.

SUMMARY

The STS-49 mission was launched from Kennedy Space Center launch complex 39B at 128:23:40:00.019 G.m.t. (7:40:00 p.m. e.d.t.) on May 7, 1992, on an inclination of 28.35 degrees. The launch phase was satisfactory in all respects. The successful launch of Endeavour was preceded by a flight readiness firing (FRF) of the SSME's, which was conducted on April 6, 1992, for the purpose of verifying that all subsystems onboard the new Orbiter were ready for flight. Although the Orbiter and integrated vehicle subsystems were successfully verified during the FRF, anomalies were identified that were associated with the three new SSME's. As a result, all three SSME's were replaced on the launch pad following the flight readiness firing.

The reaction control subsystem (RCS) thruster F4R heater was noted to be failed on when the heater switches were positioned to "on" during the prelaunch operations. The F4R heater was manually cycled throughout the mission, and the thruster temperatures were maintained within limits.

At T-29 minutes in the launch countdown, a transient master events controller (MEC) 2 Fire 2/Fire 3 command built-in test equipment (BITE) bit was found to be set. Two subsequent preflight BITE reads were performed and the bit was 0 (no failure indicated). Analysis of this occurrence revealed no concerns for flying as-is since the BITE was not a hard failure, and was most likely an intermittent BITE failure of the MEC. In addition, the failure would most likely affect only one core of MEC 2 and the remaining core in MEC 2 as well as both cores in MEC 1 provided adequate redundancy to perform all MEC functions even if this were a hard failure.

During and after ET cryogenics loading, the auxiliary power unit (APU) 3 fuel test line temperature 2 violated the lower Launch Commit Criteria (LCC) limit of 48 °F. The heater cycled to lows of 47 °F. Since the heater was operating normally with constant heater cycles, a waiver for this temperature violation was approved. After ascent, the heaters were activated and all temperatures remained in the nominal range throughout the mission.

At the completion of the orbital maneuvering subsystem (OMS) 2 maneuver at 129:00:22:02.6 G.m.t. (00:00:39:57 MET), Endeavour was placed in a 183 nmi. circular orbit. The payload bay door opening sequence was completed at 129:01:20:00 G.m.t. (00:01:40:00 MET), and the Ku-band antenna was deployed at 129:02:53:00 G.m.t. (00:02:13:00 MET). The first rendezvous maneuver was initiated at 129:04:52:44.2 G.m.t. (00:05:12:00 MET). Cabin depressurization to 10.2 psia was initiated at 129:19:00 G.m.t. (00:19:20:00 MET) in preparation for the planned EVA's.

The first EVA was performed on flight day 4. Airlock depressurization was initiated at 131:20:17 G.m.t. (02:20:37 MET), and the airlock outer hatch was opened 8 minutes later. Numerous attempts were made by the EV1 crew person to engage the INTELSAT satellite with the capture bar. The unsuccessful attempts resulted in the satellite being pushed away and wobbling. After the unsuccessful capture attempts, the capture bar was restowed and the payload bay cleanup was completed. Airlock repressurization was initiated at 132:00:51 G.m.t. (03:00:35 MET) with a total EVA duration of 3 hours 43 minutes.

The second EVA, performed on flight day 5, was initiated with airlock depressurization at approximately 132:20:30 G.m.t. (03:20:50 MET). The capture bar was again unstowed and the EV1 practiced satellite capture by bumping the capture bar against a payload bay handrail. Numerous capture attempts were again made, all of which were unsuccessful. After capture bar stowage and payload bay cleanup, the two crew persons entered the airlock and repressurization was initiated at 133:02:31 G.m.t. (04:02:51 MET) for a total extravehicular time of 5 hours 29 minutes. Communications operations throughout the EVA were excellent.

Day 6 was spent planning the third EVA details, which included a three-person EVA to capture the INTELSAT satellite. Chamber runs and Weightless Environment Training Facility (WETF) runs were performed at JSC in support of this EVA planning.

During the rendezvous with the INTELSAT prior to the third EVA, the fault message "TGT ITER 12" was unexpectedly annunciated when the attempt was made to compute the targets for the terminal phase initiation (TI) maneuver. As a result of this software problem, the TI maneuver was delayed one revolution, and Mission Control Center (MCC) computed targets were uplinked for the remainder of the rendezvous activities during the mission.

The third EVA, the first EVA ever performed with three EVA crew members, was performed on flight day 7 beginning with hatch opening at 134:21:06 G.m.t. (05:21:26 MET), and lasting for 8 hours 32 minutes. Manual INTELSAT satellite capture was completed at 134:23:55 G.m.t. (06:00:15 MET). The capture bar was attached and nominal satellite berthing activities began. The perigee kick motor was successfully attached and the satellite was deployed at 135:04:53 G.m.t. (06:05:13 MET). After the INTELSAT deployment, EV2 cleaned up the payload bay and returned to the airlock, after which airlock repressurization was initiated at 135:05:42 G.m.t. (06:06:02 MET) and completed nine minutes later.

As a result of the additional EVA's required to capture the INTELSAT satellite, the Mission Management Team (MMT) made the decision on the morning of flight day 7 to extend the mission 48 hours with landing to occur on Saturday, May 16, 1992, instead of Thursday, May 14, 1992.

The fourth EVA, which had a duration of 7 hours 43 minutes, was successfully completed on flight day 8, and limited ASEM activities were performed. Airlock depressurization was initiated at 135:20:54 G.m.t. (06:21:14 MET) with airlock egress occurring 36 minutes later at 06:21:50 MET.

Immediately following the selection of battery power by the EV3 crew person, a continuous "POWER RESTART" message was shown on the EMU DCM display. The EV3 crew person was instructed to return to the SCU power while an assessment of the condition was made. All real-time data received from the EMU showed that EMU performance was nominal. Based on the capability to monitor EMU performance on the ground, the decision was made to continue the EVA. Suit performance remained nominal throughout the EVA.

In addition to the ASEM and crew member propulsive device (CPD) evaluation, EVA crew members manually stowed the malfunctioning Ku-band antenna. The over-the-nose EVA operations were not performed due to time limitations. Airlock repressurization began at 136:04:52 G.m.t. (07:05:12 MET).

The STS-49 mission with its four EVA's had a total of 25 hours 27 minutes of EVA time and a total person hours of 59 hours 26 minutes in the EVA environment. The third EVA was not only the longest in history at 8 hours 32 minutes, but also the first EVA with three people outside the cabin environment. The fourth EVA was the one-hundredth EVA in recorded history of manned flight.

RCS primary thruster L4L failed leak at 136:18:23:06 G.m.t. (07:18:43:06 MET), immediately after the RCS hot-fire test. Approximately 1 hour 45 minutes after the leak indication, the fuel and oxidizer injector temperatures rose, indicating that the leak stopped. During entry, thruster L4L operated properly during the roll reversal maneuver and the leak indication did not recur.

Flight control systems (FCS) checkout was performed at 136:18:37:59 G.m.t. (07:18:57:59 MET) using APU 2. All system parameters were nominal during the 6-minute 19.6-second run. Approximately 15 lb of fuel were consumed.

The RCS interconnect operations with the OMS was discontinued (crossfeed valves closed) at approximately 136:15:34 G.m.t. (07:15:54 MET). The OMS propellant quantities were near the minimum redlines of 30.7 percent for the deorbit maneuver. The total RCS interconnect usage for the mission was 13.04 percent from the left OMS and 12.94 percent from the right OMS.

Both payload bay doors were closed by 137:17:37:55 G.m.t. (08:17:57:55 MET); however, during the port door closure, the aft bulkhead latch indications failed to indicate latched. The latches were driven to the released position in the nominal dual motor drive time of 24 seconds. The latches were then driven to the latched position, and a current spike was noted 20 seconds into the operation, indicating the existence of some type of obstruction. The port aft bulkhead latch indications never occurred, but the remaining bulkhead and centerline latches latched and the indications were nominal. Under the flight rules, entry can be performed with one latch gang unlatched; however, entry load minimization techniques were implemented in accordance with the flight rules.

The deorbit maneuver was performed at 137:19:55:14.9 G.m.t. (08:20:15:14.9 MET). The maneuver was approximately 167.5 seconds in duration and resulted in a differential velocity of 314.3 ft/sec. Entry interface occurred at 137:20:27:03 G.m.t. (08:20:47:03 MET).

Main landing gear touchdown occurred at Edwards Air Force Base. CA, on concrete runway 22 at 137:20:57:38 G.m.t. (08:21:17:38 MET) on May 16, 1992. Nose landing gear touchdown occurred 10 seconds later with wheels stop at 137:20:58:34 G.m.t. Preliminary indications are that the rollout was normal in all respects. The drag chute was deployed immediately following nose gear touchdown and was jettisoned at 137:20:58:17.4 G.m.t. The flight duration was 8 days 21 hours 17 minutes 38 seconds. The APU's were shut down by 137:21:11:46.77 G.m.t. The crew completed the required postflight reconfigurations and departed the Orbiter landing area at 137:22:02 G.m.t. (3:02 p.m. P.d.t.)

VEHICLE PERFORMANCE

An evaluation of vehicle ascent performance was made using vehicle acceleration and preflight propulsion prediction data. From these data, the average flight-derived engine specific impulse (Isp) determined for the time period between SRB separation and start of 3g throttling was 452.17 seconds.

SOLID ROCKET BOOSTER/REDESIGNED SOLID ROCKET MOTOR

All SRB systems performed as designed. The SRB prelaunch countdown was normal, and no SRB or RSRM in-flight anomalies were identified. Likewise, no SRB or RSRM LCC or Operations and Maintenance Requirements and Specifications Document (OMRSD) violations occurred.

Power up and operation of all case, igniter, and field joint heaters was successfully accomplished. All heaters performed nominally, even though four interim problem reports (IPR's) were written on ground support equipment (GSE) that affected RSRM heater and sensor circuits. These IPR's were as follows:

1. Left igniter heater temperature dropped 20 °F when power was applied;

2. Heater controller failed to cycle at the 100 °F setpoint;

3. Secondary power supply for right RSRM joint heaters provided high voltage (235 Vac); and

4. Gaseous nitrogen (GN_2) purge heater controller failed.

None of these problems had any effect on the performance of the RSRM heaters.

All RSRM temperatures were maintained within acceptable limits throughout the countdown. For this flight, the heated ground purge in the SRB aft skirt was powered up and the case/joint and flexible bearing temperatures were maintained within the required LCC ranges.

The RSRM propulsion performance was well within the required specification limits, and the propellant burn rate for each RSRM was normal as shown in the table on the following page. RSRM thrust differentials during the buildup, steady state, and tailoff phases were well within specifications. All SRB thrust vector control prelaunch conditions and flight performance requirements were met with ample margins. All electrical functions were performed properly.

The SRB flight structural temperature response was as expected. Postflight inspection of the recovered hardware indicated that the SRB thermal protection system (TPS) performed properly during ascent with very little TPS ablation. Both SRB's were successfully separated from the ET at lift-off plus 127.1 seconds. Separation subsystem performance was normal with all booster separation motors expended and all separation bolts severed. Nose cap jettison, frustum separation, and nozzle extension jettison occurred normally on each SRB.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 69 °F		Right motor, 69 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	64.47	64.38	64.58	64.26
I-60, 10^6 lbf-sec	172.39	171.81	172.64	171.49
I-AT, 10^6 lbf-sec	296.78	296.69	296.77	296.17
Vacuum Isp, lbf-sec/lbm	268.5	268.2	268.5	267.8
Burn rate, in/sec	0.3647	0.3643	0.3651	0.3641
Event times, seconds				
Ignition interval	0.232	N/A	0.232	N/A
Web time	111.7	111.5	111.5	112.0
Action time	123.7	124.4	123.5	123.8
Separation cue, 50 psia	121.6	122.1	121.3	121.7
PMBT, °F	69.0	69.0	69.0	69.0
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	3.1	2.8	2.9

Tailoff imbalance	Predicted	Actual
Impulse differential, klbf-sec	N/A	588.4

The entry and deceleration sequence was properly performed on both SRB's. RSRM nozzle-extension jettison occurred after frustum separation, and subsequent parachute deployments were successfully performed with two problems identified:

a. The right frustum bipod strut clevis brackets and main parachute support structure (MPSS) leg C were damaged; and

b. The right main parachute no. 3 10-second reefing line cutter failed to fire.

These problems did not affect recovery system performance and are not considered to be in-flight anomalies.

The SRB's were returned to port at Cape Canaveral where disassembly and shipment to refurbishment facilities occurred.

EXTERNAL TANK

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

As expected, only the normal ice/frost formations for the May atmospheric environment were observed during the countdown. There was no frost or ice on the acreage areas of the ET. Normal quantities of ice or frost were present on the liquid oxygen and liquid hydrogen feedlines and on the pressurization line brackets. A small amount of frost was also present along the edge of the liquid hydrogen protuberance air load (PAL) ramps. All of these observations were acceptable based on NSTS 08303, the official Space Shuttle document for these conditions.

The ET pressurization system functioned properly throughout engine start and flight. The minimum liquid oxygen ullage pressure experienced during the period of the ullage pressure slump was 14.3 psid.

As usual, the ET tumble system was deactivated for this flight; radar data from Bermuda confirmed that the ET did not tumble after ET/Orbiter separation. ET separation was confirmed to have occurred properly, and based on the MECO time, ET entry and breakup occurred within the expected footprint. There were no significant ET problems identified.

SPACE SHUTTLE MAIN ENGINE

All prelaunch operations associated with the SSME's were executed successfully. Launch GSE provided adequate control for the SSME's during launch preparation. All SSME parameters were normal throughout the prelaunch countdown and compared well with expected values for this hardware. Engine ready was achieved at the proper time, all LCC 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 was normal. All three engines started and operated normally. High-pressure oxidizer turbopump (HPOTP) and high-pressure fuel turbopump (HPFTP) temperatures were normal throughout the period of engine operation with the exception of a disqualification failure of the high pressure fuel turbine discharge channel B temperature sensor at approximately lift-off plus 93 seconds on SSME 2. The sensor has been delivered to the vendor for failure analysis. Engine operation remained normal following the failure, and no other significant SSME problems were identified.

Analysis of the STS-49 data indicates the occurrence of two "pops". A "pop" occurred on SSME-2 at cutoff plus 3.15 seconds and measured 55g peak-to-peak at the gimbal bearing. The amplitude and time of occurrence indicates that the "pop" could have originated from either the main combustion chamber, fuel preburner, or oxidizer preburner. A "pop" also occurred on SSME-3 at engine start plus 1.16 seconds and measured 115g peak-to-peak at the gimbal bearing. The amplitude and time of occurrence indicates that the "pop" could have originated from either the main combustion chamber or the fuel preburner. However, neither of these possible oxidizer preburner "pops" were large enough to require inspection of the faceplate.

In addition, there were nine responses at approximately cutoff plus 1.7 seconds, indicating the occurrence of an event during the shutdown transient of SSME-2. The nine responses observed on the SSME-2 gimbal bearing accelerometers ranged in amplitude from 55g to 65g peak-to-peak. The responses were periodic and occurred approximately 0.012 second apart. The phenomenon has been observed previously and reported in postflight data reviews. In every incident, the phenomenon has occurred during the shutdown transient between approximately cutoff plus 1.7 and 1.8 seconds and is only observed on the gimbal bearing accelerometers, indicating that it probably originated from the main combustion chamber and not from the oxidizer or fuel preburners.

Postflight inspections revealed bluing of the aft manifold on SSME-3 (Flight Problem STS-49-I-02). Similar aft manifold bluing was noted on one SSME on STS-33 and STS-36, and it was determined that this bluing was caused by heating that occurred during entry. An insulation upgrade on the engine nozzle was baselined for STS-33 to prevent bluing. In addition, the Orbiter elevon/body flap schedules were revised to eliminate the heating source to the aft manifold. This problem was a re-flight issue, but was not a constraint to the next flight, STS-50. The entry profiles were assessed to determine possible causes for this heating. Hardness checks were performed to verify the integrity of the aft manifold.

The SSME controllers provided the proper control of the engines throughout powered flight. Engine dynamic data generally compared well with previous flight and test data. All on-orbit activities associated with the SSME's were accomplished successfully.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle range safety system (SRSS) operated nominally throughout the launch phase. 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 performance and signal strength were as expected throughout the launch phase.

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

A data "spike" was seen on the ET RSS Arm Command measurement 285 seconds after lift-off. There were no RSS arm/fire signals transmitted from the Range Safety Officer. The conclusion reached through the subsequent investigation was that this spike was a spurious data point and not a response from the RSS. This fact is supported by the last data update received from JSC, which does not contain the spike. Furthermore, if this had been a real response from the IRD, the pyrotechnic initiator controller (PIC) voltage would have increased. The PIC voltage showed no increase, therefore this was a spurious data spike. The conclusion was based on a review of the RSS hardware/system. Also, the IRD and the RSS have circuits in place to protect against spurious responses. In-flight anomaly STS-49-I-04 was opened for this anomaly and immediately closed by Systems Integration personnel as an explained condition.

ORBITER SUBSYSTEM PERFORMANCE

On this first flight of Endeavour (OV-105), the Orbiter performance was satisfactory. Although 36 anomalies were identified, none of the anomalies were of such concern as to potentially cause a shortened mission. In fact, the mission was lengthened two days to complete the planned activities.

Main Propulsion System

The overall performance of the MPS was excellent. All pretanking purges were properly performed and liquid oxygen and liquid hydrogen loading was completed satisfactorily with no stop-flows or reverts. The MPS helium system also performed satisfactorily. No LCC or OMRSD violations were noted.

Throughout the preflight operations, no significant hazardous gas concentrations were detected, and the maximum hydrogen concentration in the Orbiter aft compartment was 324 ppm, which compares well with the experience base for this Orbiter that was established during the FRF. The aft compartment helium concentration peaked at 5,580 ppm, and the aft compartment oxygen concentration remained at 0 ppm.

A comparison of the calculated propellant loads at the end of replenish versus the inventory loads resulted in a loading accuracy of +0.029 percent for liquid hydrogen and +0.031 percent for liquid oxygen.

Ascent MPS performance was normal. Data indicate that the liquid oxygen and liquid hydrogen pressurization systems performed as planned, and that all net positive suction pressure (NPSP) requirements were met throughout the flight.

Space Shuttle main engine cutoff occurred at lift-off plus 509.4 seconds. Liquid oxygen and liquid hydrogen propellant conditions were within specified limits during all phases of operation.

The gaseous oxygen pressurization system performed normally throughout the flight. The gaseous oxygen flow control valves were shimmed to a target position corresponding to a 77.6-percent flow area for OV-105. The minimum ullage pressure experienced during the period of ullage pressure slump was 14.3 psid. Propellant dump and vacuum inerting were accomplished satisfactorily.

Ullage pressures were maintained within the required limits throughout the flight. Feed system performance was nominal; however, at approximately lift-off plus 55 seconds, after SSME throttle up to 104 percent, the SSME-2 liquid hydrogen inlet pressure measurement (V41T1200C) ceased tracking the other two engine inlet pressures and the liquid hydrogen manifold pressure. The SSME-2 measurement dropped 3 psi while the other three measurements rose approximately 3 psi (Flight Problem STS-49-V-13). From 2 minutes 40 seconds to 4 minutes, the SSME 1 liquid hydrogen inlet pressure steadily decreased a total of 3.5 psi. SSME-3 inlet pressure was within the spread of the last three Orbiters' data.

Tentative rationales for these observations include bias/shifting of the pressure transducers, calibration curve inaccuracies, or contamination of the prevalve screens.

The STS-49 mission was the first flight use of the -0006 750-psi helium regulators and the -0006 850-psi helium relief valves. The regulators showed a slower response to flow demand than the -0005 regulators, but no problems were detected. The relief valves were never operated during the mission. STS-49 was also the first flight of the liquid hydrogen ET/Orbiter umbilical spacer modification, and no problems were identified concerning this modification.

Reaction Control Subsystem

The RCS performed nominally throughout the mission, except for the two anomalies discussed in the following paragraphs. Twenty-four major RCS maneuvers were performed in addition to the normal attitude maneuvers. Propellant consumption from the forward RCS module was 2067.4 lb, consumption from the left RCS module was 1737.4 lb, and consumption from the right RCS module was 1747.1 lb. In addition, 1689 lb (13.04 percent) was used from the left OMS module and 1676 lb (12.94 percent) was used from the right OMS module during RCS interconnect operations. Prior to the deorbit maneuver, a decision was made not to perform DTO 249 (Forward RCS Flight Test 12-Second Pulse) because of insufficient forward RCS propellant remaining for use during the entry phase.

The RCS thruster F4R heater was noted to be failed-on when the heater switches were positioned to on during the prelaunch countdown (Flight Problem STS-49-V-01). Review of the FRF data revealed that the failure occurred approximately 2 hours after the firing. Consequently, thruster F4R was reprioritized to last priority to preclude firing the thruster. The F4R heater was manually cycled, and the thruster temperatures were maintained within the desired limits of 60 °F and 170 °F. Powering the heater on and off also affected thruster F4D because the heater switch is common to F4R. Power cannot be removed from one without removing it from the other. On orbit, the F4R RCS thruster injector temperatures reached a maximum of 169 °F. The F4D injector temperatures never fell below 60 °F while the heaters were powered off.

The RCS operated nominally during rendezvous operations. Primary thrusters L3A and R3A injector temperatures reached 170 °F during rendezvous operations. However, subsequent firing times were greater than 0.5 second; thus, the valve seats should have been less than 150 °F when the valves closed due to the cooling effect of flowing propellant. In addition, slightly degraded chamber pressures (Pc) were observed on vernier R5D. This signature is consistent with past flight history and can be attributed to a build-up of iron nitrate in the oxidizer valve trim orifice or build-up of combustion residue in the Pc sense tube. In either case, the build-up was cleared when the thruster was fired for longer durations.

RCS primary thruster L4L failed leak at 136:18:23:06 G.m.t. (07:18:43:06 MET), about 30 seconds after the RCS hot-fire test (Flight Problem STS-49-V-18). The oxidizer valve temperature dropped to approximately 18 °F, and the fuel valve temperature dropped to 48 °F at its lowest point. Approximately 1 hour 45 minutes after the leak indication, the fuel and oxidizer injector temperatures returned to normal values, indicating that the leak stopped. The priority of this thruster was changed from third to last in the priority table. During entry, thruster L4L operated properly on the three occasions it was used during the roll reversal maneuver and the leak did not recur.

Orbital Maneuvering Subsystem

The OMS performed satisfactorily with no anomalies identified. A total of nine OMS maneuvers was performed during the mission, with a total of 382.54 seconds of firing on the left engine and 388.56 seconds of firing on the right engine. Six starts were made on each engine. Three of the maneuvers were dual-engine firings and the remaining six were single-engine firings.

The RCS interconnect operations with the OMS were discontinued (crossfeed valves closed) at approximately 136:15:34 G.m.t. (07:15:54 MET). The OMS propellant quantities were near the minimum redlines of 30.7 percent for the deorbit maneuver. The total RCS interconnect usage for the mission was 13.04 percent from the left OMS and 12.94 percent from the right OMS.

Power Reactant Storage and Distribution Subsystem

The PRSD performance was nominal. A total of 244.6 lb of hydrogen was consumed from the four-tank-set configuration, and a total of 2054.1 lb of oxygen was consumed of which 112 lb was used by the crew. An 87.6-hour mission extension at the average power level was possible with the reactants remaining at landing.

The oxygen manifold isolation valve 1 failed to close when commanded and remained open for the duration of the mission (Flight Problem STS-49-V-02). The valve is used only for leak isolation in the plumbing. On flight day 9, the crew was requested to cycle the PRSD oxygen manifold 1 isolation valve to close in an attempt to regain the valve's capability. The switch was taken to close and held; however, the valve remained open. The open valve did not impact mission operations.

The crew attempted to close the manifold valve twice on flight day 1, but without success. The pressure in the PRSD oxygen manifold spiked to 989 psia at 129:19:58:30 G.m.t. (00:20:18:30 MET). The depressurization of the cabin was completed at the same time. Cabin depressurization causes high flow from the oxygen cryogenic tanks. When the high flow demand was stopped, a pressure spike in the manifold developed as the fluid trapped downstream of the tank check valve warmed. The manifold relief valves opened to relieve the manifold pressure to either tank 1 or 2 or both tanks 1 and 2. Oxygen tank 1 experienced a 30-psi pressure rise and oxygen tank 2 experienced a 2-psi pressure rise. This condition repeated several times during cabin pressure maintenance at 10.2 psi.

Fuel Cell Powerplant Subsystem

The fuel cell powerplant subsystem performance was nominal throughout the mission with a total of 2877.6 kWh of electrical energy at an average power level of 13.49 kW supplied for Orbiter and payload operations. A total of 244.6 lb of hydrogen and 1942.1 lb of oxygen was used, and 2186.7 lb of water was produced. The average Orbiter electrical load was 432 amperes.

Auxiliary Power Unit Subsystem

The APU performance was nominal throughout the mission. Three APU in-flight anomalies were noted, but none of these impacted the satisfactory completion of the mission.

Flight Phase	IAPU 1 (S/N 303)		IAPU 2 (S/N 401)		IAPU 3 (S/N 207)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	19:46	47	19:46	48	19:46	49
FCS checkout			06:20	15		
Entry[a]	81:25	151	57:31	113	57:31	113
Total[a]	101:11	198	83:37	176	77:17	162

[a]The APU's were operated for 14 minutes 7 seconds after landing and a nominal hydraulic load test was performed during that time.

During and after cryogenics loading, the APU 3 fuel test line temperature 2 violated the lower LCC limit of 48 °F (Flight Problem STS-49-V-33). The heater cycled to lows of 47 °F. Since the heater was operating normally with constant heater cycles, an LCC waiver for this condition was approved. After ascent, the heaters were activated and all temperatures were nominal.

The APU 3 gearbox gaseous nitrogen pressure and lubrication oil outlet pressure were lower than normal throughout entry (Flight Problem STS-49-V-25). The lubrication oil outlet pressure reached 27 psia, but did not reach the fault detection and annunciation (FDA) limit of 25 psia. At the same time, the gearbox pressure decreased slowly to a low point of 6 psia. Both pressure measurements indicated erratic lubrication oil operation during this low pressure period. Although the gearbox pressure was low, no limits were violated and the pressure did not become low enough to activate the gearbox repressurization system. The lubrication oil system performed nominally with normal gearbox pressures during ascent and showed adequate lubrication oil flow during entry.

The APU 1 injector tube temperature measurement became erratic just prior to APU shutdown after landing and the temperature suddenly dropped from 1350 °F to 750 °F after APU shutdown (Flight Problem STS-49-V-26). The temperature then began to slowly decrease for about 1 hour 25 minutes, and then the temperature suddenly increased 300 °F to the normally expected level.

Hydraulics/Water Spray Boiler Subsystem

The water spray boiler (WSB) performance was nominal throughout the mission.

The WSB 2 regulator outlet pressure sensor did not immediately respond to relief valve crack and reseat (Flight Problem STS-49-V-09) during ascent. The sensor apparently hung up for one minute and then recovered. This same behavior was noted on the STS-44 and STS-45 (OV-104) flights. The sensor was removed and replaced during postflight turnaround activities.

During this flight, the brake isolation valves remained closed throughout the on-orbit period. The valves are normally opened for thermal conditioning, but the fluid in this area rarely gets cold enough to warrant heating. Also, a possibility exists that the brake isolation valve could become stuck in the open position, which would lead to uncommanded brake pressures during usage. As a result, the decision was made to leave the valves closed during the on-orbit period unless thermal conditioning was required.

During entry, the thrust vector control isolation valves cycled for engine positioning in preparation for the drag chute deployment. Also, the new landing gear isolation valve performed as expected. The brake isolation valves opened nominally at touchdown as part of the uncommanded brake pressure modification.

Electrical Power Distribution and Control Subsystem

At 135:06:58:24 G.m.t. (06:07:18:24 MET), a two-second 2.5-ampere increase was noted on ac bus 2 phase B. At the same time, a shorter two-ampere increase was noted on ac bus 2 phase C, and a slight increase was also noted on phase A. Analysis of the waveform showed it to be typical of a two-phase motor start-up with a stall to single-phase operation. Status bits indicated that no equipment from any of the motor control assemblies was operating at that time. Furthermore, all environmental control and fuel cell equipment which operates directly off the ac busses was operating nominally during the time of the waveform. The only candidate load left was the crew seats. The waveform could have resulted from an inadvertent operation of the crew seat position switch with the switch not fully actuated (i.e., all three contacts closed). However, since the crew seats do not have switch scan instrumentation, it cannot be conclusively shown that this hypothesis is correct.

Pyrotechnics Subsystem

All pyrotechnic devices associated with the vehicle operations performed nominally. The drag parachute mortar and retractor performed as expected with deployment and jettison of the drag parachute being nominal.

Environmental Control and Life Support Subsystem

The atmospheric revitalization subsystem (ARS) air and water coolant loop performance was nominal, and the carbon dioxide partial pressure was maintained below 5.4 mm Hg. The cabin air temperature and relative humidity peaked at 83 °F and 36.7 percent, respectively. The avionics bay 1, 2, and 3 air outlet temperatures peaked at 104.5 °F, 105 °F, and 90.75 °F, respectively. The avionics bays 1, 2, and 3 water coldplate temperatures peaked at 87.5 °F, 90.5 °F, and 81.5 °F, respectively.

After MECO, the avionics bay 3 ΔP exceeded the upper limit of 4.3 inches of water while operating on fan B (Flight Problem STS-49-V-08). Fan A was activated and the ΔP was higher than on fan B. Fan B was reactivated. The crew cleaned the filters and found no debris on the fan inlet and caution and warning unit inlet filters. However, the GPC 3 inlet filter was 20 percent covered by lint, which was removed. Also, an in-flight maintenance (IFM) procedure was performed to remove debris from the TACAN orifice filter in an unsuccessful attempt to reduce the fan ΔP. The ΔP remained high (3.22 at 10.2 psia), but avionics bay 3 temperatures remained within acceptable limits throughout the flight.

The cabin dp/dt sensor exhibited a slower response than expected to cabin pressure changes throughout the mission. The cabin dp/dt sensor was 2 to 5 times slower than typically seen (Flight Problem STS-49-V-16).

Cabin depressurization to 10.2 psia was successfully completed at 129:19:00 G.m.t. (00:19:20 MET) in preparation for the planned EVA's. During cabin depressurization, no oxygen flow registered on the system 2 oxygen flow sensor (Flight Problem STS-49-V-04). Data analysis confirmed oxygen was flowing; therefore, the sensor was failed. This failure did not impact the mission.

Manual pressure control was used as the primary means of cabin pressure control because of the 10.2-psia cabin pressure. Automatic cabin pressure control was used the last day of the mission when the cabin pressure was at 14.7 psia. A newly redesigned oxygen partial pressure sensor (position C) was flown on OV-105 and its operation was nominal throughout the mission.

The pressure control system (PCS) 1 nitrogen flow meter data signature was off-nominal during cabin repressurization (Flight Problem STS-49-V-24). Data analysis continues to determine the cause of the off-nominal indication.

The active thermal control system operation was nominal with three FES shutdowns due to reduced water pressure at the 10.2-psia cabin pressure. The shutdowns occurred at the start-up of the FES water dumps. These are expected at the 10.2-psia cabin pressure using the present procedures. A crew procedure change is being considered to preclude these shutdowns at 10.2 psia.

Small transient temperature oscillations were noted in the FES outlet temperature during ascent (Flight Problem STS-49-V-10). Also, the FES accumulator/high-load line heater on system 1 operated above the control temperature and did not cycle (Flight Problem STS-49-V-03). The high-load line temperature went off-scale high (>250 °F) at 1 hour 40 minutes MET and remained high until system 2 was selected. System 2 operated nominally for the remainder of the mission.

The supply water and waste management systems performed nominally throughout the mission. By the completion of the mission, all of the associated in-flight checkout requirements were performed and satisfied.

Supply water was managed through the use of the overboard dump system and the FES. Two supply water dumps were performed at an average dump rate of 1.38 percent/minute (2.28 lb/min). All dumps were performed at 10.2-psia cabin pressure. The supply water dump line temperature was maintained between 68 °F and 103 °F throughout the mission with the operation of the line heater.

Three waste water dumps were performed at an average dump rate of 1.8-percent per minute (2.97 lb/min). All dumps were performed at 10.2-psia cabin pressure.

The waste water dump line temperature was maintained between 53 °F and 80 °F throughout the mission, while the vacuum vent line temperature was between 57 °F and 82 °F.

The first dump of the supply water and waste water systems was performed simultaneously as a part of DTO 325. The dump nozzles were viewed with the RMS camera throughout the dump. Supply tank B was emptied to 10 percent and the waste tank was emptied to 5.29 percent. During bake-out of the supply nozzle, a temperature drop and subsequent sluggish recovery occurred for approximately 3 minutes. This condition was most likely due to the "popcorn" effect of water as it exits the nozzle at dump termination. A subsequent nozzle bake-out was performed with a nominal profile.

The waste collection system (WCS) operation was acceptable. In addition to the normal WCS operations, the fan separator was also used throughout the mission to drain the EMU's and purge the personal hygiene station hose so that hot water could be delivered to the crew members. On flight day 8 during entry preparations, the WCS fan separator 1 failed to reach the nominal operational speed (Flight Problem STS-49-V-21). The crew reported during postflight debriefings that at the time of the failure when the WCS fan separator 1 was activated, the crew was able to hear the microswitch operate, but fan operation did not follow. The ac 1 bus current trace indicated only the stall current, an indication that the separator did not attain the nominal speed and was possibly flooded. The crew switched to fan separator 2 which operated nominally.

A redesign of the fan separator is currently being developed that will make the fan separator less likely to flood in flight. The design improvements include a redesigned bowl with dividers to prevent splashing and liquid bypass, and a delayed shutdown mechanism to ensure that all liquid is pumped out prior to shutdown.

The cabin humidity sensor did not respond as anticipated throughout the mission (Flight Problem STS-49-V-20). Also, during the postlanding operations, the humidity indication remained at 30.8 percent, but was expected to indicate above 50 percent.

Smoke Detection and Fire Suppression Subsystem

All smoke detection sensors indicated normal performance throughout the mission, and the use of the fire suppression system was not required.

Airlock Support Subsystem

The airlock support system operated nominally in support of the first mission during which four EVA's were performed, including the first three-crew-member EVA.

Avionics and Software Subsystems

At T-29 minutes in the launch countdown, a transient master events controller (MEC) 2 Fire 2/Fire 3 command built-in test equipment (BITE) bit was found to be set (Flight Problem STS-49-V-05). Two subsequent preflight BITE reads were performed and the bit was 0 (no failure indicated). Analysis of this occurrence revealed no concerns for flying as-is since the BITE was not a hard failure, and was most likely a intermittent BITE failure of the MEC. In addition, the failure would most likely affect only one core of MEC 2 and the remaining core in MEC 2 as well as both cores in MEC 1 provided adequate redundancy to perform all MEC functions even if this were a hard failure.

During the third rendezvous with the INTELSAT, the fault message "TGT ITER 12" was unexpectedly annunciated when the attempt was made to compute the targets for the TI maneuver onboard (Flight Problem STS-49-V-14). The crew was able to cause the annunciation to recur, even after a reload of the initial loads from the mass memory unit (MMU). Ten targeting attempts were made, five of which were successful. A GPC dump was performed and the data were as expected, indicating no hardware failure. As a result of this software problem, the TI maneuver was delayed one revolution and MCC-computed targets were uplinked for the remainder of the rendezvous activities throughout the mission.

Analysis determined conclusively that the targeting convergence failure experienced prior to the third rendezvous was due solely to mixed-precision calculations in the Lambert guidance algorithms. Subsequent analysis of the results of tests run on the double precision MIDVAL library routine and associated double precision microcode indicated an additional, unrelated problem in the AP101/S microcode (firmware). The compare extended data (CED) and compare extended data register (CEDR) will return a value of equal when the operands are not equal (Flight Problem STS-49-V-23). However, audits of the software revealed that the insignificant differences in the operands that result in the false equal-condition are such that the software is unaffected. In other words, the numbers are "equal enough" to allow proper performance of the software.

Postflight testing uncovered another microcode instruction that returns a wrong value in some cases. The divide extended data register (DEDR) will return an incorrect quotient when dividing two numbers in some cases. However, once again, the number returned is close enough for the purposes involved. The difference between the correct answer and the returned answer is insignificant.

None of the three instructions (CED, CEDR, and DEDR) mentioned were used on the AP101B machines, thus complicating the testing that had previously been done on AP101S machines. Software for STS-50, the flight after STS-49, has been audited, and there were no impacts. The problem has been closed, with audits being required for future OI's and any patches to OI-21. Other microcode instructions that were not used on the AP101B machines will also be thoroughly tested. Four additional instructions have not as yet been used in the software code; consequently, no software audits will be made.

While the crew was making entries to the GNC 201 display, cathode ray tube (CRT) 1 BITE was annunciated by GPC's 1 and 2 (Flight Problem STS-49-V-19). The crew performed a malfunction procedure and CRT 1 operation was recovered.

Communications and Tracking Subsystem

The performance of the communications and tracking subsystem was acceptable with several anomalies recorded. The Ku-band communications performance was nominal until the occurrence of the pointing failure, which is discussed in the following paragraph. The Ku-band radar performance was exceptional during each INTELSAT rendezvous. The text and graphics system (TAGS) operated very well with one jam which the crew quickly cleared and the TAGS operated nominally for the remainder of the mission. A total of 313 pages were successful received, and 50 of these were transmitted during an endurance test to determine whether that many pages could be loaded into the tray without a jam.

At 135:17:00 G.m.t. (06:17:20 MET), the Ku-band antenna lost its pointing capability with the telemetry pointing data disagreeing with the actual antenna pointing angles (Flight Problem STS-49-V-15). In addition, after many steering mode changes, an oscillation of the antenna occurred. The oscillation was similar to that observed on STS-41G in which the Beta axis was frozen and the Alpha axis was performing nominally. As a result of the antenna problems, the antenna was stowed at 136:00:09 G.m.t. (07:00:29 MET) using an IFM procedure developed for STS-41G by which an extravehicular crew person manually pointed the antenna to the lock position, and the middeck crew person bypassed the electronics assembly and powered the lock motors to lock the gimbals. The EV3 crew person, while manually pointing the antenna, reported a 3-inch to 4-inch pin exited the vicinity of the antenna and was not retrieved. An evaluation of this information shows that there are no known parts in the antenna (deployed assembly) or deployment assembly (mechanical) that fit this description. The antenna was stowed and safed for payload bay door closure.

CCTV camera D failed at approximately 131:22:40 G.m.t. (02:23:00 MET) (Flight Problem STS-49-V-12A). Attempts to recover camera function by ground procedure and by the crew were not successful. Camera D was removed during the first EVA and replaced with the middeck camera during the second EVA.

CCTV camera B video was degraded (an image was burned into the picture), but other camera and lens functions were nominal. Attempts to remove this burned-in image by exposure to a white scene were only partially successful. Likewise, camera C also had a burned-in image, but it was only visible during low-light operating conditions.

During checkout for the second EVA, the EV2 helmet-mounted television camera failed (Flight Problem STS-49-V-12B). The batteries were replaced, but this did not correct the problem, and the camera was not used for any subsequent EVA's.

STS-49 was the first flight of TACAN's that were manufactured by Collins. These TACAN's were flown in positions 2 and 3. Operation was nominal until about three hours prior to landing when TACAN 3 data indicated intermittent self-test failures (Flight Problem STS-49-V-30). Since the TACAN range and bearing data appeared to be good, the data would indicate a periodic self-test failure.

The crew reported that the radar-altimeter-1 indications were out-of-tolerance during the rollout after landing (Flight Problem STS-49-V-34). The radar altimeter was indicating 3.68 feet and should have indicated 6 $\pm$ 2 feet. The radar altimeter will be recalibrated during turnaround activities.

Displays and Controls Subsystem

During the second EVA at 132:21:12 G.m.t. (003:21:32 MET), the crew reported that the forward port payload bay floodlight would not illuminate at power up (Flight Problem STS-49-V-11A). About 49 minutes later, the crew repowered the floodlight and a 1.5-ampere spike was noted, but no additional electrical signature that would indicate nominal payload bay floodlight operation was observed. The light was again turned off and remained off for the rest of the mission. Premature failures have been found to be caused by the wire length in the lights' ballast, and the wires will be rerouted to eliminate this anomaly.

At 133:17:15 G.m.t. (04:17:35 MET), the crew reported that the forward starboard payload bay floodlight flickered and then failed to illuminate (Flight Problem STS-49-V-11B). The data showed that the crew had powered up two of the three floodlights on main bus B. The data also showed that only one of the two floodlights turned on while the other (crew reported the forward starboard light) flickered and failed off.

At 134:21:11 G.m.t. (05:21:31 MET), the crew reported that the aft starboard and forward bulkhead payload bay floodlights failed to illuminate when turned on (Flight Problems STS-49-V-11C and STS-49-V-11D). Analysis of the data indicates that the remote power controller (RPC) for the aft starboard floodlight tripped off. The most likely cause of the failure was a short within the floodlight electronics assembly that caused the RPC to trip.

The crew reported that the dc amperes signal strength meter was sticky, and on many occasions, the meter displayed numbers as high as 400 for signal strength during a period of low or no signal (Flight Problem STS-49-V-35). The crew also stated that by tapping on the glass face of the meter, the indication would return to zero.

Operational Instrumentation

The operational instrumentation subsystem operated nominally throughout the mission with no problems that affected the successful completion of the mission. At 133:04:16 G.m.t. (04:03:36 MET), the modular auxiliary data system (MADS) tape recorder did not respond to a snapshot run command. This condition was a known possibility discovered during preflight processing. Five additional commands were sent and the recorder began operating properly and continued to operate properly for the remainder of the mission. The data have a criticality of 3/3 and are processed after the flight.

Structures and Mechanical Subsystems

The prelaunch hatch electrical continuity check after hatch closure revealed that two of the continuity measurements were unsatisfactory. A workaround procedure, which involved reopening the hatch and visually checking the latches, verified that 17 of 18 latches were over center. The hatch was again closed and the continuity checks were completed with satisfactory results.

At 134:02:08 G.m.t. (05:02:28 MET), the B system payload retention latch assembly (PRLA) 4 ready-to-latch/latch indications were intermittent (Flight Problem STS-49-V-17). This was noted during the ASEM setup in preparation for INTELSAT capture. The latch was verified to have operated on two motors and to be firmly latched; consequently, there was no concern for these erroneous indications during the remainder of the mission. A loose connector is the most likely cause of the intermittent indications.

Both payload bay doors were closed by 137:17:37 G.m.t. (08:17:57 MET); however, during the port door closure, the aft bulkhead latch indications failed to indicate latched (Flight Problem STS-49-V-22). The latches were driven to the released position in the nominal dual motor drive time of 24 seconds. The latches were then driven to the latched position, and a current spike was noted 20 seconds into the operation, indicating the existence of some type of obstruction. The port aft bulkhead latch indications were not received.

The Orbiter drag chute performed well during the STS-49 landing. The door separated in accordance with the design and a successful pilot parachute deployment and inflation followed. The drag parachute was extracted by the pilot parachute and the drag parachute inflated to the reefed condition. Following the successful operation of the reefing line cutter, the drag parachute inflated to the fully inflated condition. Photographic analysis showed that the reefed drag parachute rode at a higher angle than expected, but after the disreef occurred, the parachute rode where it was expected. The trajectory of the door was also different than seen during the B-52 tests. The door cleared all Orbiter hardware as planned, but stayed in the air longer and was closer to the Orbiter centerline than expected. Both of these conditions have been attributed to the aerodynamic flow for the fully open speed brake.

All drag parachute hardware was recovered and showed no signs of abnormal operation. The drag parachute mortar cover was found approximately 5,650 ft from the Orbiter and 50 ft left of the runway centerline. The door was found approximately 50 ft closer to the Orbiter on the runway centerline. Four distinct door impact marks were observed to the left of the runway centerline. The sabot and attached pilot parachute bag were another 10 ft closer to the Orbiter and 10 ft left of the runway centerline. The pilot parachute was an additional 30 ft closer to the Orbiter and 15 ft right of the runway centerline. The main parachute was located approximately 750 ft from the Orbiter just to the right of the runway centerline.

The main landing gear tires were considered to be in good condition for a concrete runway landing. The braking data are shown in the table on the following page.

Aerodynamics, Heating, and Thermal Interfaces

The ascent and entry aerodynamics were nominal, and the integrated heating was within the experience data base. The control surfaces responded as expected and the angle of attack was nominal. DTO 249 (Forward RCS Flight Test) was not performed because the forward RCS propellant remaining was below the minimum required for that maneuver.

Thermal Control Subsystem

The thermal control subsystem operated nominally with the exception of two anomalous sensors, but all temperatures were maintained within acceptable limits.

The FES feedwater accumulator/high-load secondary line system 1 heater was noted to be failed on (Flight Problem STS-49-V-03). A more detailed discussion of this anomaly is located in the Environmental Control and Life Support Subsystem section of this report.

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2166	198.4	<1.0	n/a
Nose gear touchdown	5770	163.2	n/a	-2.9

Drag chute deploy	160 knots (keas)
Braking initiation speed	100.9 knots
Drag chute jettison	50.6 knots
Brake-on time	26.3 seconds
Rollout distance	9490 feet
Rollout time	54.7 seconds
Orbiter weight at landing	201,259.0 lb

Brake sensor location	Pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	1092	Left-hand outboard	16.88
Left-hand inboard 3	1056	Left-hand inboard	18.25
Left-hand outboard 2	1080	Right-hand inboard	13.81
Left-hand outboard 4	996	Right-hand outboard	13.04
Right-hand inboard 1	852		
Right-hand inboard 3	840		
Right-hand outboard 2	792		
Right-hand outboard 4	756		

The forward RCS thruster F4R heater failed on during prelaunch operations (Flight Problem STS-49-V-01). This anomaly is discussed in more detail in the Reaction Control Subsystem section of this report.

The improved APU (IAPU) 3 fuel test line sensor 2 violated the lower LCC limit of 48 °F during prelaunch operations. Likewise, the IAPU 1 fuel test line system B heater cycled close to the 48 °F lower limit during cryogenics loading and during on-orbit operations. The heater wrap configuration for these two IAPU's will be checked during the turnaround processing at KSC. The heater will also be checked at KSC.

The OMS oxidizer crossfeed low point drain line heaters cycled below the 50 °F fault detection and annunciation (FDA) limit while configured on system A.

Aerothermodynamics

The aerothermodynamics data for the STS-49 mission were within the previous experience base with no significant anomalies.

Thermal Protection Subsystem

The TPS performance was nominal compared to previous flights. This is based on structural temperature response data and some tile surface temperature measurements. The overall boundary layer transition from laminar flow to turbulent flow was symmetric, occurring at 1275 seconds after entry interface.

The Orbiter TPS sustained a total of 114 hits of which 11 had a major dimension of 1 inch or greater. This total does not include the numerous hits on the base heat shield that are attributed to engine vibro-acoustics and exhaust plume recirculation. A comparison of these numbers with statistics from 31 previous flights of similar configuration indicates that the total number of hits is slightly less than average and the number of hits 1 inch or greater is much less than average. No TPS damage was attributed to material from the wheels, tires, or brakes. The payload bay doors, upper wing surfaces, and OMS pod TPS performance was nominal.

The Orbiter lower surface sustained a total of 55 hits of which 6 had a major dimension of 1 inch or greater. The distribution of hits on the lower surface does not point to a single source of ascent debris, but indicates a shedding of ice and TPS debris from random sources.

The most significant hit observed measured 9 5/8 by 2 5/8 by 1/4 inch and was located on the right side of the vehicle immediately aft of the nose cap reinforced carbon carbon (RCC). The size and depth of this damage site is indicative of an impact by a low-density material such as ET TPS foam. Overall, all external inspections of RCC parts revealed nominal flight performance. Postflight internal inspections of the RCC chin panel revealed that the clevis bolt for the no. 6 lug had contacted the RCC, causing minor internal surface damage.

Damage to the base heat shield tiles was much less than normal. No indications of tile damage were noted in the center of the base heat shield that may have resulted from the oscillations observed in the launch photography. Several tiles on the centerline of the body flap stub upper surface and adjacent tiles on the body flap upper surface were damaged.

The redesigned mechanically attached ET door thermal barriers performed well and showed no sign of degradation. The room temperature vulcanizing (RTV) shims that had been installed to increase the pressure seal also showed no signs of deterioration. No evidence of flow paths was found, indicating that the door had sealed properly. The redesigned main landing gear door thermal barriers exhibited one minor breached 2-inch section of the right-hand aft outboard thermal barrier. The nose landing gear door thermal barrier also had one minor 3-inch breached segment. The main engine closeout blankets were in excellent condition and showed no signs of fraying.

All Orbiter windows exhibited typical hazing. A few small streaks were noted on windows 3 and 4. Samples were taken from the various windows for laboratory analysis. The crew reported that an impact had occurred window 1 on flight day 8, and the crew photographed the impact point (Flight Problem STS-49-V-36). During the turnaround activity, the window was removed and the impact point was evaluated. A new window was installed.

The TPS blankets covering both the right-hand and left-hand 9 vent doors showed a yellowish discoloration. This discoloration appeared similar to, although not as pronounced as, that observed on the OV-103 right-hand vent door 7 after the STS-42 mission.

A number of damage sites were noted on the perimeter tiles of the windows. Most of the impact sights were only surface coating losses or were no more than 1/16 inch in depth. This damage may have been caused by the RTV material used to bond paper covers to the forward RCS nozzles or by exhaust products from the SRB booster separation motors.

An infrared radiometer was used to measure the surface temperature of several areas of the Orbiter TPS after landing. The readings were taken 97 minutes after wheels stop at which time the nose-cap RCC was 162 °F and the right-hand wing leading edge RCC panel 17 was 140 °F. These temperatures are about 60 °F above normal. Analysis has shown that the temperature increase is due to the presence of the coating that was added this flight to protect the RCC from the external environment.

In the area where the drag parachute is located, two damaged tiles were noted. One was located on the lower (-Z) edge of the drag parachute opening and the other was on the left-hand lower edge of the vertical stabilizer "stinger". It is hypothesized that the damage occurred during the drag parachute deployment operations.

REMOTE MANIPULATOR SYSTEM

The RMS hardware performance was nominal. The RMS objectives for STS-49 involved EVA support during the capture and retrieval of the INTELSAT satellite, plus support during ASEM operations. Support during the INTELSAT EVA, which was planned as a one-day activity, was to utilize the RMS to grapple the capture bar after attachment to the INTELSAT and maneuver the satellite into the payload bay where a perigee kick motor could be attached by the crew members. The INTELSAT objective required three EVA's to accomplish, and as a result, the ASEM activities during the fourth EVA were severely curtailed. The RMS provided excellent support during the three INTELSAT EVA's and during the ASEM EVA, as well as during the observations of a simultaneous waste and supply water dump.

An RMS checkout was performed on flight day 1, followed by a payload bay photo survey. During the photo survey, five vernier consistency check (VCC) alarms were annunciated on the wrist joints for all three axes (Flight Problem STS-49-V-06). The VCC compares the commanded rate with the actual position. The difference between the two measured parameters is bounded in software. If the difference is exceeded for four GPC cycles, the RMS brakes are applied automatically, the RMS master alarm is sounded, and the failure is annunciated by the SM fault message. Each time the brakes were applied, the operator was required to cycle the brakes before the arm could be used again.

Analysis indicates that the alarms were caused by overly conservative VCC limits and that the RMS was functioning properly. An approved GMEM was uplinked that widened the VCC limits for one payload identifier (PLID) to the coarse limit values and no other problems occurred.

A payload deployment and retrieval system (PDRS) arm-based electronics (ABE) built-in test equipment (BITE) was annunciated when the RMS was powered up. The ABE failure warning was specifically a shoulder pitch tachometer fail flag. This bit indicates the health of the tachometer processing within the servo power amplifier (SPA) of each joint. This is one of four BITE bits sent from each SPA on the serial return data bus and 3N filtered in the MCIU before being sent to the GPC. The 3N filtering is to remove transients that occur on the data bus or in the SPA. The most likely cause of this annunciation was an EMI transient lasting longer than the 3N filter in the MCIU. No other annunciation of this kind occurred, and shoulder pitch rates were nominal throughout the remainder of the mission. A similar transient occurred with the wrist yaw commutator BITE flag on STS-3.

Operation of the RMS during the flight day 4 EVA was satisfactory, and no VCC false alarms were annunciated. Based on this experience, and to provide support for the rest of the flight activities, a second GMEM was uplinked that changed the VCC error thresholds on the remaining five PLID's.

On flight day 7, the RMS was used in support of the three-crew-member EVA to successfully capture and berth the INTELSAT satellite.

The RMS was used again on flight day 8 to support the fourth EVA, which was performed to evaluate the ASEM flight experiment. The RMS was used to maneuver a multipurpose experiment support structure (MPESS) into contact with the EVA assembled truss structure using EVA crew member voice commands and cues to the RMS operator rather than operator line-of-sight cues. This EVA was originally planned as RMS intensive; however, the RMS was used to accomplish only one ASEM operation. The timeline for the ASEM activities was also impacted when one EVA crew person was required to stow the failed Ku-band antenna.

EXTRAVEHICULAR ACTIVITIES

The extravehicular mobility units (EMU's) were checked out for the first planned EVA. During EMU checkout, the service and cooling umbilical (SCU) current recorded during fan operation on EMU 3 and 4 was lower than the values on the EVA checklist. Actual values recorded were 2.0 and 2.1 amps, respectively; checklist values are 2.4 to 3.6 amps. EMU 1 also experienced current readings below checklist values. The observed values were not considered to be a problem because this display and control module (DCM) has a lower current draw than the previous configuration DCM. Checklist criteria are presently under review.

The first EVA was performed on flight day 4. Airlock depressurization was initiated at 131:20:17 G.m.t. (02:20:37 MET), and the airlock outer hatch was opened 8 minutes later. The EVA was begun with the capture bar being unstowed and checked out, followed by installation of the portable foot restraint attachment device (PAD). The EV1 crew member then ingressed the PAD and the RMS operator moved EV1 to the capture position. Numerous attempts were made to dock and engage the capture bar, but the satellite was pushed away and appeared to be nutating. After the unsuccessful docking attempts, the capture bar was restowed and the payload bay cleanup was completed. Airlock repressurization was initiated at 132:00:15 G.m.t. (03:00:35 MET) with a total EVA duration of 3 hours 43 minutes.

EV2 experienced an alert tone and "SET PWR SCU" message at 131:20:37 G.m.t (02:20:57 MET), and received the same message approximately 19 minutes later during a status check (Flight Problem STS-49-V-07). During the post-EVA debriefing, EV2 reported that the "SET PWR SCU" message was acknowledged 10 to 15 times during the EVA. The "SET PWR SCU" message requires -13 volts to be sensed by the C/W software for 1 minute. The primary reason for the issuance of the message was either an optical coupler UV103 output short or a power mode switch short on any of four switch-contact combinations. Under any of these conditions, the C/W will sense that the SCU was apparently connected and the power mode switch was in the BATT position for more than 60 seconds. The "SET PWR SCU" message will then occur. Another remote possibility for the intermittent short was electromagnetic interference (EMI). A power mode switch short was considered to be the most probable cause of this condition. After a review of EVA data, it was observed that the EMU battery was not exposed to the worst-case potential overcurrent condition (caused by one of the identified switch short conditions). Upon successful charging on the middeck battery charger, it was recommended that the EMU 2 continue to be used. This anomaly did not recur during subsequent use.

The second EVA, performed on flight day 5, was initiated with airlock depressurization at approximately 132:20:30 G.m.t. (03:20:50 MET). The capture bar was again unstowed and the EV1 crew person practiced satellite capture by bumping the capture bar against a payload bay handrail. Numerous capture attempts were again made, all of which were unsuccessful. The satellite was successfully slowed, but capture bar docking could not be completed. After capture bar stowage and payload bay cleanup, the two crew persons entered the airlock and repressurization was initiated at 133:02:31 G.m.t. (04:02:51 MET) for a total extravehicular time of 5 hours 30 minutes. Communications operations throughout the EVA were excellent.

During this EVA, it was noted that EV2 lost electrocardiogram (EKG) data. When doffing the suit, the crew reported that the orange wire in the EKG harness had come loose. Also during suit doffing, EV1 received a "FAN SWITCH OFF" message. The most probable cause for this message was a sticky suit pressure transducer. This is a low priority message and was not a constraint to further use of the EV1 suit.

The third EVA, performed on flight day 7, included three EVA crew members. Each crew member configured the extravehicular communicator in the EMU to the backup mode, and selected voice-activated microphone keying (commonly known as VOX). Communications checks during EV1 and EV2 EMU purge revealed some feedback in VOX, but any difficulty could be cleared by switching to push-to-talk (PTT) mode. Prebreathe activities were begun and the external hatch was opened at 134:21:10 G.m.t. (05:21:30 MET).

The satellite capture scenario began with building the bottom plane of the ASEM truss. A portable foot restraint (PFR) was attached to the truss along the centerline of the payload bay. A second foot restraint was attached along the side of the payload bay, and a PAD was attached to the RMS. The intent was to place the three extravehicular crew members in a triangle shape so that each could grab a different gearbox/motor on the satellite at the same time. Although satellite nutation was higher than expected, the satellite was successfully captured at 134:23:55 G.m.t. (06:00:15 MET). The capture bar was then attached and the nominal satellite berthing procedures were initiated. During the INTELSAT activities, EV2 crew person reported that his suit DCM was unreadable (Flight Problem STS-49-V-28). The EV2 crew person also reported the same problem while in the airlock.

The perigee kick motor was attached to the satellite, and all three crew members were in the airlock while the satellite was deployed at 135:04:53 G.m.t. (06:05:13 MET). After payload bay cleanup, airlock repressurization was initiated at 135:05:42 G.m.t. (06:06:02 MET). The time of the third EVA was 8 hours 29 minutes, which is the longest EVA on record.

The fourth and final EVA of the STS-49 mission was performed on flight day 8. The EV3 and EV-4 crew persons began airlock depressurization at 135:20:42 G.m.t. (06:21:14 MET). The EV3 crew member had a constant "PWR RESTART" message when the status check was attempted (Flight Problem STS-49-V-27). The alert tone and BITE light both cleared, but the EV3 crew person was instructed to return to the SCU power while an assessment of the condition was made. The EMU power draw was acceptable and the real time data system showed acceptable data and nominal performance. Based on the capability to monitor EMU performance on the ground, the decision was made to continue the EVA. Suit performance remained nominal throughout the EVA. Airlock egress occurred at 135:21:30 G.m.t. (06:21:50 MET). The EVA included nominal ASEM activities, a crew propulsion device (CPD) evaluation, and Ku-band antenna restow. Over-the-nose EVA operations were not performed because of time limitations. The ASEM truss base plane remained installed for landing. Airlock repressurization was initiated at 136:04:52 G.m.t. (07:05:12 MET). The duration of the fourth EVA was 7 hours 45 minutes.

During the third and fourth EVA's, a number of minor problems occurred that have been joined together as one in-flight anomaly. These problems are as follows:

a. Retractable tether reel - the retractable tether reel failed to retract (Flight Problem STS-49-V-32a);

b. Power tool tether - The retractable tether on the power tool broke (Flight Problem STS-49-V-32b);

c. Portable foot restraint (PFR) - One of the adjustable joints on the PFR lost its capability for adjustment (Flight Problem STS-49-V-32c). This loss was probably caused by a jammed adjustment knob;

d. Safety tether reel lock - The safety tether lock would not lock (Flight Problem STS-49-V-32d). The lock lever could not be moved to the lock position;

e. A loud noise was heard over the EMU headset when the EVA power tool was operated during the third EVA (Flight Problem STS-49-V-32e); and

f. Mini-workstation mechanism - The lock knob of the end effector tether stiffened up to a high actuation torque. Also, the lock knob of the end effector jaws spun too freely to positions opposite from the desired setting (Flight Problem STS-49-V-32f).

While EMU battery recharge operations were being performed with the middeck battery charger, it was noted that both the red and green lights on one side of the battery charger (S/N 1002) were out (Flight Problem STS-49-V-29). An attempt to use the spare battery charger yielded the same results. This indicates a potential problem with the battery (S/N 1181) that was being charged. The chargers and the battery have undergone ground testing, and the problem has not repeated during this testing.

When remounting EMU 2 to the airlock wall after completion of the EVA's, the crew were unable to insert a pin in the lower forward mount (Flight Problem STS-49-V-31). The crew had to loosen four bolts on the airlock adapter plate (AAP) joint, refit the AAP, and retighten the bolts to secure EMU 2.

GOVERNMENT FURNISHED EQUIPMENT AND FLIGHT CREW EQUIPMENT

The government furnished equipment and flight crew equipment performance was satisfactory with the exceptions noted in the following paragraphs.

The 35mm Nikon camera system databack batteries failed; however, spare batteries were available and nominal camera operation was regained. The 40mm lens focusing prism split image would not line up when used with the 70mm Hasselblad camera system, and use of the lens was lost for the remainder of the mission. The electronic still camera system battery pack failed; however, spare batteries were used and the camera function was regained.

The crew reported that the galley auxiliary hot water port dispensed cooler water than expected. The water temperature at this port is design-limited because of constraints placed by NASA Safety. However, the water temperature at that point may be improved by modifying (changing diameter, insulating, or shortening) the personal hygiene hose or flowing water into the WCS until the warmer water reaches the end of the hose.

CARGO INTEGRATION

All integration hardware performed nominally.

PAYLOADS/EXPERIMENTS

The five payloads/experiments flown on STS-49 are described in the following paragraphs.

INTELSAT SATELLITE

Rendezvous with the satellite was completed as planned on flight day 4; however, the capture bar could not be installed. A second rendezvous was completed on flight day 5, and similar capture bar results were attained. On flight day 7, three EVA crew members manually captured the INTELSAT, installed the capture bar, and mated the satellite to the perigee kick motor. Later the same day, (May 13, 1992, at 11:53 p.m. c.d.t.) the INTELSAT was deployed. The INTELSAT perigee kick motor fired nominally on May 14, at 12:25 p.m. c.d.t. At the time of this writing, INTELSAT is in geosynchronous orbit, all appendages have been deployed and the communications payload checkout is in progress. The satellite is currently planned to be in service in mid-July of 1992 for use in relaying the Barcelona Olympic Games to the United States.

ASSEMBLY OF STATION BY EVA METHODS

Due to the three EVA's required for INTELSAT activities, the ASEM operations were replanned to be performed in one EVA period. The ASEM base plane was installed on flight day 7 to support INTELSAT retrieval. During flight day 8, two EVA crew members performed the following ASEM activities:

a. The ASEM attachment fixture build was completed.

b. The crew propulsive device was evaluated.

c. Six of eight legs were installed on the MPESS

d. Three point pallet attachment was attempted, using both minimum and full-compliance berthing, but it was unsuccessful.

e. Some diminished lighting evaluation was accomplished in the payload bay because of the failure of two forward payload bay floodlights and the forward bulkhead floodlight. The non-extravehicular crew person provided assistance using a hand-held spotlight that was pointed out the aft flight deck windows.

f. The attachment fixture was partially disassembled and stowed; however, the bottom plane was left intact for landing.

An unexpected addition to this EVA was the stowage of the Ku-band antenna which had a positioning motor failure that prevented the antenna from being stowed automatically. No over-the-nose activities were performed. The extended duration of the ASEM EVA activities prevented complete stowage of the base plane. The base plane remained installed for landing and ferry flight.

COMMERCIAL PROTEIN CRYSTAL GROWTH

The Commercial Protein Crystal Growth (CPCG) performed well for most of the mission with temperature excursion alarms being the only exception. When a temperature alarm occurred, the crew cleaned the filter, reset the alarm, and operations then continued nominally until the next temperature excursion alarm. The crew cleaned the filter daily. The temperature anomaly that occurred on flight day 1 was early enough in the temperature profile that no damage to the crystal was expected. Assuming the temperature fluctuation on flight day 9 was real, a small degradation of the crystals is probable.

AIR FORCE MAUI OPTICAL SITE CALIBRATION

No night or twilight passes were available for The Air Force Maui Optical Site Calibration (AMOS) operations during the mission.

ULTRAVIOLET PLUME INSTRUMENT

The ultraviolet plume instrument (UVPI) objectives were not accomplished since there was no Orbiter observation opportunities during the mission.

DEVELOPMENT TEST OBJECTIVES AND DETAILED SUPPLEMENTARY OBJECTIVES

A total of 18 DTO's and 13 DSO's were assigned to the STS-49 flight. From this total, 14 DTO's and 13 DSO's were accomplished. The following paragraphs provide more details on each DTO and DSO.

DEVELOPMENT TEST OBJECTIVES

Ascent DTO's

DTO 301D - Ascent Structural Capability Evaluation - This DTO is a data-only DTO and the data were collected. The sponsor is evaluating the data and will publish a formal report in the future.

DTO 305D - Ascent Compartment Venting Evaluation - This DTO is a data-only DTO and the data were collected. The sponsor is evaluating the data and will publish a formal report in the future.

On-Orbit DTO's

DTO 312 - ET TPS Performance (Methods 1 and 2 - With No Maneuvers) - The attitudes after separation were not appropriate to observe the ET from the crew cabin; consequently, no hand-held photography of the ET was obtained. The umbilical well camera operated properly; however, the darkness at the time of film exposure made the photography unusable.

DTO 325 - Waste and Supply Water Dumps (Simultaneous Dump 1) - The first dump of the waste and supply water was performed simultaneously, and the dump was documented using the RMS wrist camera. The video data have been given to the sponsor for evaluation.

DTO 623 - Cabin Air Monitoring - Cabin air data were gathered for this DTO, and the data have been given to the sponsor for evaluation.

DTO 640 - Hydrazine Monitoring - The data were collected for this DTO, and the data have been given to the sponsor for evaluation.

Entry/Landing DTO's

DTO 249 - Forward RCS Flight Test (12-Second Pulse) - This DTO was not performed because the propellant remaining was not sufficient to support this test as well as entry.

DTO 306D - Descent Compartment Venting Evaluation - This DTO is a data-only DTO and the data were collected. The sponsor is evaluating the data and a formal report will be published in the future.

DTO 307D - Entry Structural Capability - This DTO is a data-only DTO and the data were collected. The sponsor is evaluating the data and a formal report will be published in the future.

DTO 519 - Carbon Brake System Test (Condition 6) - The DTO was performed and all aspects of the carbon brakes were satisfactory. Data have been given to the sponsor for evaluation.

DTO 520 - Edwards Lake Bed Runway Bearing Strength - This DTO was not accomplished because the landing took place on the concrete runway at Edwards.

DTO 521 - Orbiter Drag Chute System (System 1) - The drag chute was deployed in accordance with the preflight plans. All operational areas of the drag chute performed properly. Photographic and video data of the drag chute operation have been given to the sponsor for evaluation.

DTO 648 - Electronics Still Camera Photography Test (With Downlink) - This camera was used very successfully and data and photographs are in the possession of the sponsor.

DTO 651 - Cycle Ergometer Hardware Evaluation - The data were collected for this DTO and have been given to the sponsor for evaluation.

DTO 663 - Acoustical Noise Dosimeter Data - The acoustical noise data were collected throughout the mission, and the data have been given to the sponsor for evaluation.

DTO 700-2 - Laser Range and Range Rate Data - The laser range finder performed very well and the data are being evaluated by the sponsor. Initial conclusions indicate that the instrument performed excellently for rendezvous and proximity operations.

DTO 728 - Ku-band Antenna Friction - This DTO was not accomplished because of the failure of the Ku-band antenna.

DTO 805 - Crosswind Landing Performance - This DTO was not accomplished as the crosswind conditions at landing did not meet the minimum criteria of this DTO.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 469 - In-flight Radiation Dose Distribution - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 482 - Cardiac Rhythm Disturbances During EVA - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 603 - Orthostatic Function During Entry, Landing, and Egress - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 604 - Visual-Vestibular Integration as a Function of Adaptation - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 605 - Postural Equilibrium Control During Landing/Egress - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 613 - Endocrine Regulation - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 614 - Head and Gaze Stability During Locomotion - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 617 - Evaluation of Functional Skeletal Muscle Performance - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 621 - In-Flight Use of Florinef - EDO - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 802 - Educational Activities - Data were successfully collected, and the data have been given to the sponsor for evaluation.

DSO 901 - Documentary Television - This DSO was performed and the data have been given to the sponsor for evaluation.

DSO 902 - Documentary Motion Picture Photography - This DSO was performed and the photography data have been given to the sponsor for evaluation.

DSO 903 - Documentary Still Photography - This DSO was performed and the photography data have been given to the sponsor for evaluation.

PHOTOGRAPHIC AND TELEVISION ANALYSIS

LAUNCH DATA ANALYSIS

On launch day, all 23 of the expected videos were screened. On the following days, 60 of the 61 expected films were also reviewed. One item of interest was an unusual flexing of the Orbiter base heat shield observed at SSME ignition. Photographic analysts and Orbiter engineering personnel evaluated this condition and noted also that this same flexing had been seen in previous mission launch photography.

ON-ORBIT PHOTOGRAPHY ANALYSIS

Analysis of electronic still camera images that had been downlinked by the crew was performed. These photographs were of the INTELSAT satellite, and the analysis revealed no sharp edges that could cause suit damage during the three-crew-member EVA when the INTELSAT was manually captured.

LANDING DATA ANALYSIS

Nine landing videos including an infrared view and NASA Select were received about 2.5 hours after landing for review. The videos provided good coverage of the drag chute deploy and jettison. No anomalous conditions or events were noted in the landing video analysis.

TABLE I.- STS-49 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU activation	APU-1 GG chamber pressure	128:23:35:10.27
	APU-2 GG chamber pressure	128:23:35:11.60
	APU-3 GG chamber pressure	128:23:35:12.75
SRB HPU activation	LH HPU system A start command	128:23:39:32.16
	LH HPU system B start command	128:23:39:32.32
	RH HPU system A start command	128:23:39:32.48
	RH HPU system B start command	128:23:39:32.64
Main propulsion System start	Engine 3 start command accepted	128:23:39:53.472
	Engine 2 start command accepted	128:23:39:53.561
	Engine 1 start command accepted	128:23:39:53.693
SRB ignition command (lift-off)	SRB ignition command to SRB	128:23:40:00.019
Throttle up to 104 percent thrust	Engine 3 command accepted	128:23:40:04.152
	Engine 2 command accepted	128:23:40:04.121
	Engine 1 command accepted	128:23:40:04.133
Throttle down to 89 percent thrust	Engine 3 command accepted	128:23:40:18.873
	Engine 2 command accepted	128:23:40:18.841
	Engine 1 command accepted	128:23:40:18.853
Throttle down to 73 percent thrust	Engine 3 command accepted	128:23:40:29.753
	Engine 2 command accepted	128:23:40:29.721
	Engine 1 command accepted	128:23:40:29.734
Throttle up to 104 percent thrust	Engine 3 command accepted	128:23:40:55.193
	Engine 2 command accepted	128:23:40:55.161
	Engine 1 command accepted	128:23:40:55.174
Maximum dynamic pressure (q)	Derived ascent dynamic pressure	128:23:41:03
Both SRM's chamber pressure at 50 psi	LH SRM chamber pressure mid-range select	128:23:42:01.58
	RH SRM chamber pressure mid-range select	128:23:42:01.78
End SRM action	RH SRM chamber pressure mid-range select	128:23:42:04.11
	LH SRM chamber pressure mid-range select	128:23:42:04.61
SRB separation command	SRB separation command flag	128:23:42:07
SRB physical separation	LH rate APU A turbine speed LOS	128:23:42:07.14
	RH rate APU A turbine speed LOS	128:23:42:07.14
Throttle down for 3g acceleration	Engine 3 command accepted	128:23:47:32.003
	Engine 2 command accepted	128:23:47:32.005
	Engine 1 command accepted	128:23:47:31.981
3g acceleration	Total load factor	128:23:47:32.95
MECO	MECO shutdown command accept	128:23:48:29
	MECO confirm flag	128:23:48:29
SSME shutdown	Engine 3 command accepted	128:23:48:29.444
	Engine 2 command accepted	128:23:48:29.446
	Engine 1 command accepted	128:23:48:29.422
ET separation	ET separation command flag	128:23:48:48

TABLE I.- STS-49 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
OMS-1 ignition	Left engine bi-prop valve position	Not performed - direct insertion trajectory flown
	Right engine bi-prop valve position	
OMS-1 cutoff	Left engine bi-prop valve position	
	Right engine bi-prop valve position	
APU deactivation	APU-1 GG chamber pressure	128:23:54:55.30
	APU-2 GG chamber pressure	128:23:54:56.88
	APU-3 GG chamber pressure	128:23:54:58.56
OMS-2 ignition	Left engine bi-prop valve position	129:00:19:57.8
	Right engine bi-prop valve position	129:00:19:57.8
OMS-2 cutoff	Left engine bi-prop valve position	129:00:22:02.6
	Right engine bi-prop valve position	129:00:22:02.6
Payload bay door open	PLBD right open 1	129:01:15:54
	PLBD left open 1	129:01:20:00
OMS-3 ignition	Left engine bi-prop valve position	129:04:52:44.2
	Right engine bi-prop valve position	N/A
OMS-3 cutoff	Left engine bi-prop valve position	129:04:53:00.6
	Right engine bi-prop valve position	N/A
OMS-4 ignition	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	129:20:45:12.8
OMS-4 cutoff	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	129:20:45:30.6
OMS-5 ignition	Left engine bi-prop valve position	130:20:11:01.0
	Right engine bi-prop valve position	130:20:11:01.0
OMS-5 cutoff	Left engine bi-prop valve position	130:20:11:47.2
	Right engine bi-prop valve position	130:20:11:47.2

TABLE I.- STS-49 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
OMS-6 ignition	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	130:21:17:39.6
OMS-6 cutoff	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	130:21:17:52.1
OMS-7 ignition	Left engine bi-prop valve position	131:15:42:50.0
	Right engine bi-prop valve position	N/A
OMS-7 cutoff	Left engine bi-prop valve position	131:15:43:08.6
	Right engine bi-prop valve position	N/A
OMS-8 ignition	Left engine bi-prop valve position	132:16:58:07.0
	Right engine bi-prop valve position	N/A
OMS-8 cutoff	Left engine bi-prop valve position	132:16:58 16.0
	Right engine bi-prop valve position	N/A
Intelsat capture	Voice call	134:23:59
Intelsat deployment	Voice call	135:04:53
OMS-9 ignition	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	135:05:39:21.9
OMS-9 cutoff	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	135:05:39:41.9
Intelsat perigee kick motor firing	Voice call	135:17:25
Flight control system checkout		
APU start	APU-2 GG chamber pressure	136:18:37:59.06
APU stop	APU-2 GG chamber pressure	136:18:44:18.67
Payload bay door close	PLBD left close 1	137:17:17:23
	PLBD right close 1	137:17:37:55
APU activation for entry	APU-1 GG chamber pressure	137:19:50:20.36
	APU-2 GG chamber pressure	137:20:14:15.45
	APU-3 GG chamber pressure	137:20:14:16.38

TABLE I.- STS-49 SEQUENCE OF EVENTS (Concluded)

Event	Description	Actual time, G.m.t.
Deorbit maneuver ignition	Left engine bi-prop valve position	137:19:55:15.1
	Right engine bi-prop valve position	137:19:55:14.9
Deorbit maneuver cutoff	Left engine bi-prop valve position	137:19:58:02.5
	Right engine bi-prop valve position	137:19:58:02.4
Entry interface (400K)	Current orbital altitude above reference ellipsoid	137:20:27:03
Blackout ends	Data locked at high sample rate	No blackout
Terminal area energy management	Major mode change (305)	137:20:51.31
Main landing gear contact	LH MLG tire pressure	137:20:57:38
	RH MLG tire pressure	137:20:57:38
Main landing gear weight on wheels	LH MLG weight on wheels	137:20:57:38
	RH MLG weight on wheels	137:20:57:38
Nose landing gear contact	NLG tire pressure	137:20:57:48
Nose landing gear weight on wheels	NLG WT on Wheels -1	137:20:57:48
Drag chute deployment	Drag chute deploy -1 cap volts	137:20:57:49
Drag chute jettison	Drag chute jettison -1 cap volts	137:20:58:17.4
Wheels stop	Velocity with respect to runway	137:20:58:34
APU deactivation	APU-1 GG chamber pressure	137:21:11:45.36
	APU-2 GG chamber pressure	137:21:11:46.17
	APU-3 GG chamber pressure	137:21:11:46.77

TABLE II.- STS-49 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-49-V-01	RCS Thruster F4R Heater Failed On	128:03:50 G.m.t. IM49RF01 FRCS-01-0021	The RCS F4R thruster injector temperature for fuel (V42T1514C) and oxidizer (V42T1513C) continually increased since the thruster heater was turned on at 128:03:50 G.m.t. The forward RCS module has been removed and sent to HMF for thruster repari. KSC: Vendor will repair thruster (bench work) at the HMF.
STS-49-V-02	Oxygen Manifold 1	129:05:50 G.m.t. IM49RF02 IPR-47V-0014	The PRSD oxygen manifold 1 isolation valve failed to close when commanded. An additional attempt to close on-orbit was unsuccessful. KSC: Troubleshooting complete. No anomaly found. Potential UA.
STS-49-V-03	FES Accumulator Hi-Load Line B Heater 1 Failed	129:08:30 G.m.t. IM49RF03 IPR 47V-0012	The FES accumulator/high load line B heater 1 appears to be failed on. Heater B was selected. Indicative of a loose thermostat on the accumulator line. KSC: Vendor at KSC reworking the heater thermostat.
STS-49-V-04	PCS Oxygen System 2 Flowmeter Failed	129:19:31 G.m.t. IM49RF04 IPR 47V-0013	No oxygen flow was registered on sensor V61R2205A throughout the mission. Secondary indications satisfactory. Sensor failed. KSC: Panel MO10W has been removed and sent to MBMR. Troubleshooting complete. Defer flow meter replacement until panel is returned.
STS-49-V-05	Master Events Controller 2 BITE Failure	Prelaunch IPR 47V-0005 IM49RF21	During the T-20 minute preflight BITE READ of master events controller (MEC) 2, word 10 bit 9 was set to 1 when it should have been 0. Two subsequent reads showed the bit to be 0. Flew as is due to no hard failure and adequate MEC redundancy. KSC: Plan for troubleshooting has been developed. No chit required. Replaced by vendor per OEL-0683.
STS-49-V-06	RMS False Alarms	129:22:00 G.m.t.	Control errors were experienced during RMS checkout and again during Intelsat capture attempt. KSC: No action required.
STS-49-V-07	Extravehicular crew person -2 "SET PWR SCU" Message (GFE)	131:21:15 G.m.t.	Extravehicular crew person (EV) -2 received an alert tone and the "SET PWR SCU" message on DSM. This message was received 10 to 15 times during the EVA. Unit returned to JSC KSC: No action required.
STS-49-V-08	Avionics Bay 3 ΔP	128:23:57 G.m.t. IPR 47V-0011	Avionics bay 3 differential pressures indicating higher than expected values at 14.7 and 10.2 psia cabin pressure. KSC: Removed, cleaned, and reinstalled TACAN 3 filter. ΔP returned to normal.
STS-49-V-09	Water Spray Boiler System 2 Regulator Outlet Pressure Sensor (V58P0204A)	128:23:42 G.m.t. IM49RF05	The pressure sensor did not immediately respond to relief valve crack and reseat. The sensor apparently hung up for one minute and then recovered. KSC: No troubleshooting required. Hamilton-Standard removed and replaced sensor during postflight activities.

TABLE II.- STS-49 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-49-V-10	FES Temperature Oscillations	128:23:42 G.m.t. IM49RF06 IPR 47V-0021	There were small transient FES outlet temperature oscillations during ascent and entry, primary A and primary B controllers. KSC: Vendor on-site repacking sensors.
STS-49-V-11	Floodlight Failures		
	A. Forward Port	132:21:12 G.m.t. IM49RF07 IPR 47V-0027	Forward port floodlight would not illuminate at power up. Light remained off for remainder of the mission.
	B. Forward Starboard	133:17:15 G.m.t. IM49RF08 IPR 47V-0028	Forward starboard flickered and then failed to illuminate. Data indicates that the most likely cause is a malfunctioning lamp.
	C. Aft Starboard	134:21:11 G.m.t. IM49RF09 IPR 47V-0029	Aft starboard floodlight failed to illuminate when turned on. Analysis indicates that the associated RPC tripped off. Probable a short in the FEA caused the RPC to trip.
	D. Forward Bulkhead	134:21:11 G.m.t. IM49RF10 IPR 47V-0030	The forward bulkhead light signature had numerous spikes and did not come on. KSC: Floodlights have been replaced. Retesting al all floodlights is complete with good results.
STS-49-V-12	Camera Failures (GFE)		
	A. Camera D	131:21:40 G.m.t.	Crew reported that camera D, located in payload bay, had failed. Camera D was replaced by the cabin camera during the second EVA.
	B. EV-2 EMU Helmet Camera Failed	132:17:27 G.m.t.	During the EMU checkout for EVA 2, the EV-2 helmet had no picture. Either the camera or the transmitter had failed. KSC: Return cameras to JSC for evaluation.
STS-49-V-13	SSME 1 and 2 Hydrogen Prevalve Pressure Drop	Ascent IPR 47V-0006 IM49RF11	Difference between manifold pressure and pressure downstream of the prevalve is larger than seen on previous flights. Suspect faulty transducers. Melon sample taken - results inconclusive. KSC: Transducers removed and replaced. Removed transducers sent to Rockwell-Downey for tests.
STS-49-V-14	Orbit Targeting TI Computation Failure	134:18:30 G.m.t.	Orbit targeting specialist function failed several times to compute a proper TI targeting solution. KSC: No action required.
STS-49-V-15	Ku-band Antenna Pointing Problem	135:17:00 G.m.t. IM49RF12 IPR 47V-0031	The Ku-band antenna experienced pointing problems and after steering mode changes, an oscillation of the antenna started. Also,actual angles did not agree with the physical location of the antenna. KSC: Beta motor binding. Removed and replaced deployed assembly (DA). EA-1 to be replaced with EA from OV-103.

TABLE II.- STS-49 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-49-V-16	Cabin dp/dt Sensor Slow Response	135:02:54 G.m.t. IPR 47V-0022 IM49RF14	The cabin dP/dT sensor exhibited a slower response than expected. No specification on response rate, but data showing 3-4 times slower than in-flight experience. KSC: Vendor will remove and replace at KSC using sensor from spare panel. No chit required.
STS-49-V-17	Payload Retention Latch Assembly (PRLA) 4 Latch/ Unlatch Indicator B Failed	135:22:54 G.m.t. IPR 47V-0017	During ASEM bottom plane installation, power to the ASEM STBD aft PRLA 4 microswitches became intermittent. PRLA operated nominally on both motors. PRLA wiring and connectors appear to be nominal. KSC: Troubleshooting plan at KSC revealed no anomaly. (ASEM removed)
STS-49-V-18	RCS Thruster L4L Leaked	136:18:23 G.m.t. IPR 47V-0015 IM49RF15	After firing thruster L4L during the RCS hot fire test, the oxidizer injector temperature cooled to 18 °F. This violated the RCS redundancy management (RM) oxidizer fail leak limit temperature of 30 °F and thruster L4L was declared fail leak. The thruster stopped leaking, the injector temperatures warmed above 65 °F, and thruster L4L was put in last priority and reselected. Fired three times during entry without leak. No vapors after landing. Slight leak seen after GSE installation. KSC: Monitoring thruster in OPF.
STS-49-V-19	CRT 1 BITE	130:16:23 G.m.t. IM49RF16	A CRT 1 BITE message was annunciated by general purpose computers (GPC's) 1 and 2. Hardware status word 2 indicated keyboard adapter B bit set. CRT 1 recovered with DEU 1 hardware BITE Register clear command on the OTP display. KSC: DEU fuel 1 was removed and replaced.
STS-49-V-20	Cabin Humidity Sensor Failure	IPR 47V-0024 IM49RF17	Sensor reading stuck at about 30.8 percent throughout mission. The sensor should have read at least 50 percent during the mission. KSC: Troubleshooting requiqred. Potential sensor replacement. Spares available.
STS-49-V-21	WCS Fan Separator 1 Failed	137:16:25 G.m.t. IPR 47V-0025	Several unsuccessful attempts were made to start WCS fan separator .1. The crew selected fan separator 2 and reported good air flow. KSC: Fan removal from the WCS was completed prior to WCS removal from the Orbiter. Vendor will rework
STS-49-V-22	Port Aft Bulkhead Payload Bay Door (PLB) Latch	137:17:37 G.m.t. IM 49RF13 IPR 47V-0026	During payload bay door (PLBD) closure, the port aft bulkhead PLBD latch indications were not obtained. After manually attempting to latch, the port PLBD closed indication was obtained. KSC: PLBD latch functional test successfully performed. Left-hand door popped into place when latch was released. Additional troubleshooting (which requires radiator removal) is scheduled.
STS-49-V-23	General Purpose Computer		During troubleshooting of the orbit targeting failure, a problem was

TABLE II.- STS-49 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
	AP101S Microcode Error		found in the AP101S microcode (firmware). Two microcode instructions, and CEDR, will compare equal, even with a difference in bit 40. KSC: No action is required. Constraints to STS-50 cleared.
STS-49-V-24	PCS System 1 Nitrogen Flowmeter Signature Off-Nominal	IPR 47V-0023	PCS system 1 nitrogen flowmeter signature was off-nominal during cabin repressurization. KSC: Calibration checks will be performed after panel is reinstalled in vehicle.
STS-49-V-25	APU 3 Gearbox Gaseous Nitrogen Pressure Low	137:20:50 G.m.t. IPR 47V-0019 IM49RF20	APU 3 gearbox gaseous nitrogen pressure and lubrication oil outlet pressure were lower than normal during entry. KSC: Ullage check indicates that there is a 110 cc more oil in the box than prior to the mission. Ullage checks repeated. The The results were within specification. Initial ullage check was not performed properly.
STS-49-V-26	APU 1 Injector Temperature Measurement Erratic	137:21:30 G.m.t. IPR 47V-0016	APU 1 injector temperature measurement (V46T0174A) became erratic just prior to APU shutdown. Temperature dropped from about 1350 °F to to 750 °F and stayed low after APU shutdown for 1 hour 25 minutes, then returned to normal. KSC: Repinned connector J-9 to backup sensor (Primary sensor debonded. Retest complete with good results.
STS-49-V-27	EV-3 "PWR RESTART" Message Frozen on DCM (GFE)	135:21:11 G.m.t.	Immediately following selection of battery power, EV-3 received a continuous "POWER RESTART" message on the DCM display. The BITE light and all tones cleared nominally. KSC: No action required. Suit returned to JSC.
STS-49-V-28	EV-2 Loss of DCM Display (GFE)	135:02:10 G.m.t.	When EV-2 tried to check the EMU status during the third Intelsat EVA, the display was unreadable. This same problem was also reported during airlock ingress. KSC: No action required. Suit returned to JSC
STS-49-V-29	EMU Battery S/N 1181 Bad (GFE)	136:18:03 G.m.t.	Middeck and backup battery chargers would not charge battery S/N 1181. It was assumed that the battery had failed. KSC: No action required. Battery returned to JSC.
STS-49-V-30	TACAN 3 (Collins) Self-Test Failure Identifications	137:17:55 G.m.t. IM49RF19	TACAN 3, manufactured by Collins, data indicated an intermittent self-test failure about 3 hours prior to landing. Although TACAN range and bearing data were good, data indicates a periodic self-test failure. KSC: TACAN removed and sent to vendor for rework. TACAN's back at at KSC for reinstallation.
STS-49-V-31	EMU 2 Difficult to Mount On Airlock Wall	136:18:03 G.m.t.	Crew was unable to install pin in lower forward mounting V bracket on EMU 2 mount during reinstallation to the airlock wall.

TABLE II.- STS-49 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-49-V-32	EVA Equipment Failures A. Retractable Tether Reel B. Power Tool Tether C. Portable Foot Restraint D. Safety Tether Reel Lock E. Power Tool Noise and EVA Communications F. Mini-Workstation Mechanism Problems	 134:22:45 G.m.t. 135:03:59 G.m.t. 135:04:07 G.m.t. 136:04:20 G.m.t.	A. Retractable tether reel failed to retract. B. Retractable tether on power tool broke. C. One adjustable joinf on portable foot restraint lost its capability for adjustment. Probably a jammed adjustment knob. D. Safety tether reel would not lock. The lock lever could not move to the lock position. E. A loud noise was heard over the EMU headset when the EVA power tool was operated during the third EVA. F. The lock knob of the end effector tether stiffened up to a high actuation torque. The lock knob of the end effector jaws spun too freely to positions opposite from the desired setting.
STS-49-V-33	APU 3 Fuel Test Line Temperature	PR APU-5-0047	After tanking, APU 3 fuel test line temperature cycled below the LCC lower limit of 48 °F. KSC: Plan to inspect the heater and insulation
STS-49-V-34	Radar Altimeter 1 Out Of Tolerance During Rollout		Radar altimeter 1 average reading during rollout was 3.68 feet. It should be 6 ±2 feet. OMRSD test to recalibrate radar altimeter 1 to be performed.
STS-49-V-35	Panel F9 Dc Amps Signal Strength Meter Sticky		Several times during the flight, the meter displayed signal strength during LOS periods. KSC: Meter removed, replaced, and retest complete with good results.
STS-49-V-36	Window 1 Chipped On-Orbit		Crew photographed a chip in the upper right corner of the thermal window pane. Crew reported that impact occurred on or around flight day 8. Window has been removed and sent to NSLD for thermal pane replacement. The window assembly has been returned and is ready for reinstallation.

ACRONYMS AND ABBREVIATIONS

ABE	arm-based electronics
AGT	adaptive guidance/throttling
AMOS	Air Force Maui Optical Alignment Site Calibration Test
APU	auxiliary power unit
ARS	atmospheric revitalization subsystem
ASEM	Assembly of Station by Extravehicular Activity Methods
BFS	backup flight system
BITE	built-in test equipment
CCTV	closed-circuit television
CED	compare extended data
CEDR	compare extended data register
CPCG	Commercial Protein Crystal Growth
CPD	crew propulsion device
CRT	cathode ray tube
C/W	caution and warning
DCM	display and control module
ΔP	differential pressure
DSO	detailed supplementary objective
DTO	development test objective
e.d.t.	eastern daylight time
EKG	electrocardiogram
EMI	electromagnetic interference
EMU	extravehicular mobility unit
ET	External Tank
EVA	extravehicular activity
FCS	flight control system
FDA	fault detection annunciator
FES	flash evaporator system
FRF	flight readiness firing
GMEM	GPC memory write
G.m.t.	Greenwich mean time
GPC	general purpose computer
GSE	ground support equipment
HPOTP	high pressure oxidizer turbopump
HPFTP	high pressure fuel turbopump
IAPU	improved auxiliary power unit
IFM	in-flight maintenance
IPR	interim problem reports
Isp	specific impulse
JSC	Lyndon B. Johnson Space Center
LCC	Launch Commit Criteria

MADS	modular auxiliary data system
MCC	Mission Control Center
MCIU	manipulator controller interface unit
MEC	master events controller
MECO	main engine cutoff
MER	mission evaluation room
MET	mission elapsed time
MMT	Mission Management Team
MMU	mass memory unit
MPESS	multipurpose experiment support structure
MPS	main propulsion system
MPSS	main parachute support structure
MSFC	George C. Marshall Space Flight Center
MSR	Mission Support Room
NPSP	net positive suction pressure
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
PAD	portable foot restraint attachment device
PAL	protuberance air load
PASS	primary avionics software system
PCS	pressure control system
PDRS	payload deployment and retrieval system
P.d.t.	Pacific daylight time
PFR	portable foot restraint
PLID	payload identifier
PRLA	payload retention latch assembly
PRSD	power reactant storage and distribution subystem
PTT	push-to-talk
RCC	reinforced carbon carbon
RCS	reaction control subsystem
RMS	remote manipulator system
RSRM	redesigned solid rocket motor
RTV	room temperature vulcanizing
S&A	safe and arm
SCU	service and cooling umbilical
SM	system management
SPA	servo power amplifier
SRB	Solid Rocket Booster
SRSS	Shuttle Range Safety System
SSME	Space Shuttle main engine
STS	Space Transportation System
TACAN	tactical air navigation
TAGS	text and graphics system
TI	terminal phase initiation
TPS	thermal protection system/subsystem

UVPI	Ultraviolet Plume Instrument
VCC	vernier consistency check
VOX	voice operated relay
WCS	waste collection system
WETF	Weightless Environment Training Facility
WSB	water spray boiler

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