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STS-45 SPACE SHUTTLE MISSION REPORT

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SPACE SHUTTLE

MISSION REPORT

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INTRODUCTION

The STS-45 Space Shuttle Program Mission Report contains a summary of the vehicle subsystem operations during the forty-sixth flight of the Space Shuttle Program and the eleventh flight of the Orbiter vehicle Atlantis (OV-104). In addition to the Atlantis vehicle, the flight vehicle consisted of an External Tank (ET) designated as ET-44 (LWT-37); three Space Shuttle main engines (SSME's), which were serial numbers 2024, 2012, and 2028 in positions 1, 2, and 3, respectively; and two Solid Rocket Boosters (SRB's) designated as BI-049. The lightweight redesigned Solid Rocket Motors (RSRM's) installed in each of the SRB's were designated as 360L021A for the left SRM and 360W021B for the right SRM.

This report satisfies the Space Shuttle Program requirement, as documented in NSTS 07700, Volume VIII, Appendix E, which requires each major organization supporting the Space Shuttle Program to report the results of its evaluation of the mission and identify all related in-flight anomalies.

The primary objective of this mission was to successfully perform the planned operations of the Atmospheric Laboratory for Applications and Science-1 (ATLAS-1) and the Shuttle Solar Backscatter Ultraviolet Instrument (SSBUV) payloads. The secondary objectives were to successfully perform all operations necessary to support the requirements of the Space Tissue Loss-01 (STL-01) experiment, Radiation Monitoring Equipment-III (RME-III) experiment, Visual Function Tester-2 (VFT-2) experiment, Cloud Logic to Optimize use of Defense System (CLOUDS-1A) experiment, Shuttle Amateur Radio Experiment II (SAREX-II) - Configuration B, Investigation into Polymer Membranes Processing experiment; and the Get-Away Special (GAS) payload G-229. The Ultraviolet Plume Instrument (UVPI) was a payload of opportunity that required no special maneuvers. In addition to the primary and secondary objectives, the crew was tasked to perform as many as 10 Development Test Objectives (DTO'S) and 14 Detailed Supplementary Objectives (DSO's).

The sequence of events for the STS-45 mission, planned as an 8-day mission but lengthened to 9 days to obtain additional scientific data, is shown in table I, and the official Orbiter and GFE Projects Problem Tracking List is presented in table II. In addition, each Orbiter 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. The official ET, SRB, RSRM, and SSME anomalies are also discussed in their respective subsections of the report and the MSFC-assigned tracking numbers are also shown. 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-sixth Space Shuttle flight was Charles F. Bolden, Jr., Col., USMC, Commander; Brian K. Duffy, Lt. Col., USAF, Pilot; Kathryn D. Sullivan, Ph.D., Mission Specialist 1; David C. Leestma, Capt., USN, Mission Specialist 2; C. Michael Foale, Ph.D, Mission Specialist 3; Dirk D. Frimout, Ph.D., Payload Specialist 1; and Byron K. Lichtenberg, Ph.D., Payload Specialist 2. STS-45 was the third space flight for the Commander, Mission Specialist 1, and Mission Specialist 2; the second flight the Payload Specialist 2; and the first Space Shuttle flight for the remaining crew members.

SUMMARY

During the STS-45 launch countdown for the March 23 launch attempt, the liquid oxygen (LO_2) concentration in the aft compartment peaked at 860 ppm during the slow fill operation. This level exceeded the Launch Commit Criteria (LCC) limit of 500 ppm. The LO_2 concentration had decreased to 200 ppm before troubleshooting began. The liquid hydrogen (LH_2) concentration in the aft compartment peaked at 750 ppm during the fast fill, a level which also exceeded the LCC limit. As a result, the LH_2 flow was stopped, and the LH_2 concentration decreased to 100 ppm. After the LO_2 leak isolation test, similar LH_2 leak isolation procedures were also performed. After extensive troubleshooting, the LH_2 leak could not be isolated and it did not recur thereafter. However, the troubleshooting activities for the LO_2 and LH_2 concentration levels resulted in the launch being rescheduled for March 24, 1992.

During the countdown to the launch on March 24, the LO_2 concentration again exceeded the LCC value, but rapidly recovered to within the LCC limit. This behavior was anticipated and acceptable per a preflight agreement, and the loading continued. The LH_2 concentration never exceeded the LCC limit during this second countdown.

The STS-45 mission was launched from Kennedy Space Center (KSC) launch complex 39 A at 8:13:40 a.m. e.s.t (084:13:13:39.991 G.m.t.) on March 24, 1992. The launch phase was satisfactory with no Orbiter anomalies noted. The launch was delayed 13 minutes 40 seconds because of unacceptable weather conditions on the approach to the return-to-launch-site (RTLS) runway (Shuttle Landing Facility).

The total vehicle weight at lift-off was 4,495,720 lb. The Orbiter weight at that time was 233,652 lb of which the payload comprised 20,371 lb.

All SSME and RSRM start sequences occurred as expected and launch phase performance was satisfactory in all respects. First stage ascent performance was normal with SRB separation, entry, deceleration, and water impact occurring as anticipated. Both SRB's were successfully recovered. Performance of the SSME's, ET, and main propulsion system (MPS) was also normal with main engine cutoff (MECO) occurring approximately 510.4 seconds after lift-off.

The orbital maneuvering subsystem (OMS) 2 maneuver was performed satisfactorily at 084:13:49:59.9 G.m.t. (00:36:20 MET) with a 146.00-second firing that placed the Orbiter in a 160 by 152 nmi. orbit.

At MECO, a 5.7 ft/sec underspeed condition existed. This condition was most likely caused by the manner in which the onboard guidance treated the effect of gravity during tailoff. The effect of gravity during tailoff is assumed to be mission-independent by guidance software; whereas, in reality, the gravity effect is dependent on the specific orbital inclination of the mission. Therefore, higher flight-path-angle missions will generally have larger underspeed conditions than the lower flight-path-angle missions. Since this mission was a 57-degree inclination flight, the assumption by the guidance software that the effect of gravity at tailoff is mission independent is believed to be the cause of the underspeed that occurred. In addition to the

MECO underspeed condition, the orbital in-plane thrust from the main propulsion system (MPS) dump was less than planned because of the early attitude maneuver that was made to observe and photograph the ET in fulfillment of DTO 312 - ET Thermal Protection System Performance. As a result of these two conditions, a single engine OMS-3 maneuver of 12.0 ft/sec was performed at 084:16:03:42.8 G.m.t. (00:02:50:03 MET) to circularize the orbit at 160 nmi.

At 084:20:41 G.m.t. (00:07:01 MET), the APU fuel pump/gas generator B system heaters were activated. The APU 2 and 3 systems operated properly; however, no response was noted from the APU 1 gas generator bed heater. As a result, the APU system A heaters were activated. After verifying proper operation of the APU 1 A heaters, the B heaters were reactivated, and after two abnormal cycles, proper operation began. After three days of nominal operation, the APU 1 gas generator bed heater anomaly recurred with three abnormal heater cycles (temperatures dropped into the mid-200-degree range, but should have cycled on at ~350 °F), each of which was separated by several normal heater cycles. The APU heaters were reconfigured to the A system for the remainder of the mission in an attempt to isolate the intermittent component. The controller contains circuitry that is common to both the A and B heater systems. No recurrence of the heater anomaly was observed while operating on the A heaters.

Based on actual in-flight cryogenics usage data for the first five days in conjunction with the concerted effort made by the flight crew to conserve cryogenic consumables, the mission contingency (extension) capability had increased to greater than 3 days. On the morning of the sixth day, the Mission Management Team (MMT) decided to add a ninth day to the planned mission so that additional scientific data could be obtained.

Results of the flight control system (FCS) checkout using improved auxiliary power unit (IAPU) 2 were satisfactory. The APU operated for 5 minutes 3 seconds, and no water spray boiler cooling was required. The hydraulics subsystem operated nominally as did the improved APU.

The reaction control subsystem (RCS) hot-fire test was completed with the thrusters being fired twice. All thrusters performed as expected.

The crew completed Spacelab operations, as well as entry preparations and stowage. The payload bay doors were satisfactorily closed at 093:07:45:28 G.m.t. (08:18:32:28 MET). The deorbit maneuver was performed at 093:10:20:55.3 G.m.t. (08:21:07:16.3 MET). The maneuver was approximately 220.6 seconds in duration and the differential velocity was 408.3 ft/sec. Entry interface occurred at 093:10:51:49 G.m.t. (08:21:38:10 MET).

During entry, the APU 1 lubrication oil return temperature indicated an over-cooling condition by decreasing below the 250 °F set point to a minimum of 177 °F for about 12 minutes. The crew switched from the water spray boiler (WSB) B controller to the A controller. Lubrication oil temperatures appeared to be recovering toward the 250 °F set point before the controller switchover occurred. The temperatures did return to the set point after the switchover to the A controller. Similar occurrences have been observed during previous missions; however, the temperature decrease and time duration were less.

Main landing gear touchdown occurred at Kennedy Space Center Shuttle Landing Facility runway 33 at 093:11:23:05 G.m.t. (08:22:09:25 MET) on April 2, 1992. Nose landing gear touchdown occurred 8 seconds later with wheels stop at 093:11:24:04 G.m.t. The rollout was normal in all respects. The flight duration was 8 days 22 hours 10 minutes 24 seconds. The APU's were shut down by 093:11:38:10.02 G.m.t., and the crew completed the required postflight reconfigurations and departed the Orbiter landing area at 093:13:03:40 G.m.t. (7:03:40 a.m. e.s.t.).

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTERS/REDESIGNED SOLID ROCKET MOTORS

All SRB systems performed as expected throughout ascent. All SRB thrust vector control prelaunch conditions and flight performance requirements were met with ample margins. All electrical functions were performed properly. No SRB or RSRM LCC or Operations and Maintenance Requirements and Specification Document (OMRSD) violations were identified.

Power-up and operation of all case, igniter, and field-joint heaters was accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. For this flight, the heated purge in the SRB aft skirt was powered up and the case/nozzle joint and flexible bearing temperatures were maintained within the required LCC ranges.

RSRM thrust differentials during the buildup, steady state, and tailoff phases were well within specifications. The SRB prelaunch countdown was normal, and no SRB or RSRM in-flight anomalies were identified. 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 acreage ablation. Both SRB's were successfully separated from the ET at 128.12 seconds, and all deceleration subsystems performed as designed. Booster separation motor performance was satisfactory and all separation bolts operated as designed. Nose cap jettison, frustum separation, and nozzle jettison occurred normally on each SRB.

The entry and deceleration sequence was properly performed on both SRB's. Both SRB's were recovered and returned to KSC for disassembly and refurbishment. The table on the following page provides key RSRM propulsion performance parameters.

EXTERNAL TANK

The 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.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 66 °F		Right motor, 66 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	63.85	63.37	64.12	63.37
I-60, 10^6 lbf-sec	171.01	170.40	171.61	170.17
I-AT, 10^6 lbf-sec	296.80	295.82	296.84	296.07
Vacuum Isp, lbf-sec/lbm	268.5	267.6	268.5	267.8
Burn rate, in/sec	0.365	0.3657	0.366	0.3652
Event times, seconds				
Ignition interval	0.232	N/A	0.232	N/A
Web time	112.7	112.4	112.2	112.8
Action time	124.7	124.7	122.1	125.6
Separation cue, 50 psia	122.6	122.7	122.1	122.8
PMBT, °F	66.0	66.0	66.0	66.0
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	2.8	2.8	3.5
Tailoff imbalance	Predicted		Actual	
Impulse differential, klbf-sec	N/A		-91.6	

As expected, only the normal ice/frost formations for the March atmospheric environment were observed during the countdown. Normal quantities of ice or frost were present on the liquid oxygen and liquid hydrogen feedlines and on the pressurization brackets. A small amount of frost was also present along the liquid hydrogen protruding air load (PAL) ramps. All of these observations were acceptable per Space Shuttle Program documentation. The Ice/Frost Red Team reported that no anomalous thermal protection subsystem (TPS) conditions existed.

The ET tumble valve was deactivated for this flight, and radar reports from Bermuda confirmed that the ET did not tumble. No significant ET problems or in-flight anomalies were identified.

The ET pressurization system functioned properly throughout engine start and flight. The minimum liquid oxygen ullage pressure experienced during the period of ullage pressure slump was 14.1 psid.

ET separation was confirmed to have occurred properly. The crew reported shortly after ET separation, as they were observing and photographing the ET to meet the DTO 312 requirements, continuous venting from the vicinity of the ET/Orbiter disconnects and also a pulsating venting from the intertank area. The crew photographed the ET extensively, and the photographs were analyzed in detail after landing.

There are five valves in the ET/Orbiter disconnect area. All of the valves are furnished to the ET Project by the Orbiter as part of the two disconnect assemblies. It is unlikely that the 17-inch feedline valves were open for two reasons.

a. The thrust of an open 17-inch valve would have caused the ET to tumble at a high rate and the crew reported that the tank was not tumbling at a very high rate.

b. The ET 17-inch valve has to be closed for the Orbiter valve to close and the position indicators on the Orbiter showed its valves to be closed.

The 4-inch LH_2 recirculation valve on the Orbiter is also mechanically coupled to the ET half of the valve, which has a spring backup. Data show that this valve closed normally within the maximum allowable travel time. The 2-inch pressurization valves are spring loaded and close when the disconnect separates.

Even though the 17-inch and 4-inch valves were closed, the valves could have been leaking because of improper seating; however, no way exists to verify this condition. The allowable leakage from the 17-inch LH_2 valve is 5,000 scims, and it is entirely possible that the crew saw only normal leakage. The condition of the 2-inch valves after separation is unknown. One possible source of the observed vapors could have been the normally trapped LH_2 between the Orbiter and ET halves of the 17-inch flapper valves. At separation, the hydrogen freezes into ice crystals, a fact that was noted by the umbilical cameras on OV-102 (Columbia) on a number of flights.

The fact that the ET did not have a functioning tumble valve, had among the highest LH_2 residuals yet flown at separation, and the fact that this was one of the closest crew observations of the ET after separation would indicate that the crew was observing normal cycling of the ET LH_2 relief valve (located in the intertank area). The LH_2 tank pressure is maintained at 32 to 34 psia prior to SSME shutdown. Forward migration of the LH_2 along the warm walls of the tank after separation results in increased hydrogen boiloff and a tank pressure rise. The relief valve opens at 35 psia and entrained liquid would exit the vent and relief valve duct at the intertank skin, forming a core of ice crystals visible from the Orbiter. Valve performance with venting liquid, intermittent exposure of entrained liquid or external lighting could account for the observed pulsating pattern.

ET entry and breakup also occurred within the expected area.

SPACE SHUTTLE MAIN ENGINE

All SSME parameters were normal throughout the prelaunch countdown, and the indications were typical of prelaunch parameters observed on previous flights. Engine ready was achieved at the proper time, all LCC were met, and engine start and thrust buildup were normal.

Preliminary flight data indicate that the SSME performance during mainstage, throttling, shutdown, and propellant dump operations was well within specifications. All three engines started and operated normally. High pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump temperatures were well within specification throughout engine operation.

An observation in the STS-45 digital data (oxidizer preburner pump discharge pressure and HPOTP discharge pressure) indicates a possible oxidizer preburner shutdown "pop" on main engine 1 (S/N 2024) and main engine 2 (S/N 2012) at shutdown + 2.3 seconds. The "pop" criteria is based upon dynamic accelerometer data and will be verified with accelerometer data when it becomes available.

The SSME controllers provided proper control of the engines throughout powered flight. Engine dynamic data generally compared well with previous flights and test data. All on-orbit activities associated with the SSME's were accomplished successfully, and no significant SSME problems were noted in the data.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits were turned off at the proper times. All SRSS measurements indicated that the system performance was as expected throughout the flight. 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. The system signal strength remained well within system requirements throughout the duration of the flight.

ORBITER VEHICLE SUBSYSTEMS

Main Propulsion System

During the first launch attempt on March 23, 1992, The LO_2 concentration in the aft compartment peaked at 870 ppm during the initial slow fill operation, and this level exceeded the LCC limit of 500 ppm (Flight Problem STS-45-V-02). Flow continued while troubleshooting the LH_2 anomaly described in the following paragraph. The concentration level had decreased to 200 ppm before troubleshooting began. After extensive troubleshooting, the leak did not recur and troubleshooting was terminated.

The LH_2 concentration peaked at 780 ppm about 3 minutes into the fast fill and this level also violated the LCC limit of 500 ppm (Flight Problem STS-45-V-01). The concentration decreased to 100 ppm after LH_2 stop flow and closure of the high-point bleed valve. Although the SSME's were cleared, the leak isolation procedures failed to reproduce or locate the sources of the leaks that occurred during loading. Analysis of the data indicates the most probable cause of the LH_2 and LO_2 leaks was a transient distortion of the disconnect/seal material in each system due to the thermal gradient that occurs early during fast fill. However, the troubleshooting activities for the LO_2 and LH_2 concentration levels resulted in the launch being rescheduled for March 24, 1992.

The overall performance of the MPS during the countdown and successful launch on March 24 was excellent. All pretanking purges were properly performed, and LO_2 and LH_2 loading was performed as planned with no stop flows or reverts. The MPS helium system performed satisfactorily.

Throughout the preflight operations, no significant hazardous gas concentrations were detected, and the maximum LH_2 level in the Orbiter aft compartment was 260 ppm, which compares very well with previous data for this vehicle. The aft compartment LO_2 concentration reached a maximum of approximately 1130 ppm early into the LO_2 fast-fill activity. The oxygen concentration stayed above the LCC limit of 500 ppm for about 6 minutes and stabilized at about 180 ppm during replenish. This momentary high concentration level was anticipated and acceptable per a preflight agreement. The aft compartment helium concentration peaked at 9000 ppm, which was not a violation of the LCC.

A comparison of the calculated propellant loads at the end of replenish versus the inventory loads results in a loading accuracy of +0.04 percent for liquid hydrogen and +0.035 percent for liquid oxygen.

Ascent MPS performance was completely normal. Data indicate that the liquid oxygen and hydrogen pressurization systems performed as planned, and that all net positive suction pressure (NPSP) requirements were met throughout the flight. Space Shuttle MECO occurred 510.4 seconds after lift-off.

The GO_2 pressurization system performed normally throughout the entire flight. The GO_2 flow control valves were shimmed to a target position corresponding to 77.2 percent flow area. The minimum ullage pressure during the period of the ullage pressure slump was 14.1 psid.

Ullage pressures were maintained within the required limits throughout the flight. Feed system performance was normal, and LO_2 and LH_2 propellant conditions were within specified limits during all phases of operation. All net positive suction pressure (NPSP) requirements were met. Propellant dump and vacuum inerting were accomplished satisfactorily.

Following ET separation, the crew reported venting from the 17-inch disconnect area of the ET. A review of Orbiter data showed that all Orbiter valve positions and timings were nominal after MECO.

Reaction Control Subsystem

The RCS performed excellently with almost 200 firings being made during the mission, and no anomalies or irregularities were reported or noted in the data. Propellant consumption from the forward RCS was 1184.0 lb, from the left RCS was 1471.8 lb, and from the right RCS was 1427.8 lb. In addition, 1024.2 lb of OMS propellants were used by the RCS during interconnect operations. During entry, a single 10-second firing of all four forward RCS yaw thrusters was made at Mach 4.0 in support of DTO 250 (Forward RCS Flight Test - Control Surface Effects).

A few occurrences of degraded chamber pressure on the vernier thrusters, particularly F5L, L5L, and R5R, were noted. This condition has been noted on previous flights with high vernier thruster usage. The lowest noted chamber pressure was 70 psia on L5L (nominal pressure is 110 psia). These low chamber pressure occurrences were most likely caused by either combustion residue building up in the chamber pressure sensing tube, or nitrates accumulating in the oxidizer valve trim orifice resulting in an off-nominal mixture ratio. Either case is cleared by a long-duration firing of the thruster.

Orbital Maneuvering Subsystem

The OMS performance was excellent throughout the mission with no anomalies or irregularities reported or noted in the data. Three maneuvers (OMS-2, OMS-3, and deorbit) were performed with a total firing time of 381.4 seconds. In addition, the RCS was interconnected to the OMS for an extended period during which 2.90 percent (376.6 lb) of the propellant from the left OMS tanks and 5.0 percent (647.6 lb) of the propellant from the right OMS tanks was used. Total propellant consumption by the OMS including the RCS interconnect usage was 9581 lb of oxidizer and 5778 lb of fuel.

A single engine (left) OMS 3 maneuver of 12.0 ft/sec was required because of the under-speed conditions existing at MECO. This maneuver was performed at 084:16:03:42.8 G.m.t. (00:02:50:03 MET) to circularize the orbit at 160 nmi. A discussion of the conditions that required this maneuver is presented in the Avionics and Software Subsystem section of this report.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performance was excellent throughout the mission with an excess of 31 hours of mission extension capability at an average power level of 15.8 kW remaining at landing. On flight day 5, consumables remaining would support an additional day while still maintaining the necessary contingency days, and the decision was made by the MMT to extend the mission 24 hours.

One irregularity was noted when the oxygen tank 3 control pressure was biased 15 psi high. Since both oxygen tanks (3 and 4) were controlling lower than the other tanks, a telemetry problem was not indicated. This bias had no impact on mission operations and has been observed on previous flights of this vehicle.

Total consumables usage from the PRSD was 289.0 lb of hydrogen and 2,291.0 lb of oxygen. In addition, 125 lb of oxygen were supplied for consumption by the crew.

Fuel Cell Powerplant Subsystem

The fuel cell powerplant (FCP) subsystem performance was nominal throughout the mission with a total of 3,378 kWh of electrical energy at an average power level of 15.8 kW supplied for Orbiter and payload operations. A total of 289.0 lb of hydrogen and 2,291.0 lb of oxygen were consumed and 2,580 lb of water were produced during the 9-day mission. The average Orbiter electrical power load was 510 amperes during the mission.

At 084:14:30 G.m.t. (00:50:00 MET), the fuel cell 3 cell performance monitor (CPM) substack differential voltage remained at the periodic self-test value of 50 mV for up to 3.5 minutes instead of the normal 2.3 seconds (Flight Problem STS-45-V-04). The flight day 1 occurrence continued for 3 hours and the flight day 2 occurrence continued for 2 hours before the CPM began operating properly. Main busses B and C had previously been tied together in accordance with normal procedures for this mission, a condition which would have provided an insight into fuel cell performance had a total failure of the CPM occurred. The CPM performed nominally for the remainder of the mission after the flight day 2 occurrence. Preliminary analysis indicates a leaking capacitor in the CPM as the cause of the erratic operation.

Auxiliary Power Unit Subsystem

The APU performance was nominal throughout the mission with an improved APU (IAPU) flown in the 2 position. The IAPU performance was excellent with significantly less heat soakback after IAPU shutdown. Three APU anomalies were noted and are as follows:

a. APU 3 Z-axis vibration sensor (accelerometer) showed no output (read off-scale low) throughout the mission (Flight Problem STS-45-V-03). This accelerometer provides data for engineering evaluation and has no effect on the operation of the unit. Postflight testing and analysis showed that the condition was caused by a shorted connector pin.

b. At 084:20:41 G.m.t. (00:07:01 MET), the APU fuel pump/gas generator B system heaters were activated. The APU 2 and 3 systems operated properly; however, no response was noted from the APU 1 gas generator (GG) bed heater (Flight Problem STS-45-V-05). The GG bed temperature measurement indicated 220 °F, approximately 140 °F below the heater control circuit lower set point, when the heaters were selected.

   During this same time period, the APU 1 fuel line heater system also failed to respond. As a result, the APU system A heaters were activated. After verifying proper operation of the APU 1 system A heaters, the system B heaters were reactivated. The GG bed temperature decreased initially from 400 °F to 385 °F after which it rose to 430 °F indicating normal heater operation. Data showed that the GG bed temperature heater responded at the same time as the fuel system heater cycled. After one more irregular cycle, the GG heater functioned properly until flight day 6. Over a 6-hour period on flight day 6, the APU 1 gas generator bed heater anomaly recurred with three abnormal heater cycles (temperatures dropped into the mid-200-degree range, but should have cycled on at ~350 °F), each of which was separated by several normal heater cycles. The APU heaters were reconfigured to system A for the remainder of the mission and the heaters operated properly. Postflight troubleshooting has isolated the failure to a nicked wire near a clamp, and the wire will be repaired in place.

c. During ascent and FCS checkout, the IAPU 2 gearbox nitrogen pressure measurement was erratic. This condition was initially attributed to the relocation of the sensor on the IAPU. However, during entry, both the nitrogen and lubrication oil outlet pressure measurements were erratic and low (Flight Problem STS-45-V-11). A few minutes after IAPU 2 was started, the nitrogen pressure dropped to approximately 5.5 psi and the gearbox was repressurized. Initially, both the nitrogen and lubrication oil outlet pressures increased and became smoother. However, over the next 38 minutes, the pressures slowly decreased and another repressurization was required. This condition did not impact entry operations; however, during postflight checks, the lubrication oil quantity in the gearbox was found to be 150 cc's less than the level recorded during preflight preparations.

Fuel consumption and run time for each APU is presented in the following table.

Flight Phase	APU 1 (S/N 312)		IAPU 2 (S/N 407)		APU 3 (S/N 307)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
Ascent	19:12	49	19:13	50	19:13	52
FCS checkout			04:56	15		
Entry	82:19	154	59:10	130	59:10	130
Total[a]	101:31	203	83:19	195	78:23	182

[a] The total includes 15 minutes 05 seconds of APU operation after landing during which a hydraulics load test was performed.

In addition to the three anomalies, two other irregularities occurred in the subsystem performance. The exhaust gas temperature (EGT) on APU 2 failed after landing; however, it was an old design of the sensor which has failed regularly on previous missions. Since this loss occurred after landing, it did not impact the mission.

During entry, APU 1 experienced a period of lubrication oil overcooling (see Flight Problem STS-45-V-10 discussed in the following section), and during this period, the seal cavity drain pressure exhibited a sudden 5-psi decrease. Postflight data analysis indicated that the pressure was relieved from the seal cavity into the gearbox. A postflight sample of the lubrication oil has shown a large quantity of fuel contamination mixed in the oil, and this condition indicates that leakage across the cavity drain seal into the gearbox occurred.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/water spray boiler (WSB) subsystem performance was nominal during the mission. There were no WSB freeze ups during ascent, and no circulation pump runs were required for thermal circulation or accumulator recharge. An APU hydraulics load test was also satisfactorily performed after landing.

During prelaunch activities before APU start, the ready indication was lost 27 minutes before lift-off for APU 2 because the vent temperature dropped below 130 °F. This condition was not unexpected as it has occurred on many of the previous missions.

One anomaly was noted during entry when WSB 1 was overcooling while operating on the B controller (Flight Problem STS-45-V-10). When cooling was initiated, the lubrication oil return temperature dropped from 249 °F to 177 °F (72 °F drop), which is indicative of overcooling during a 5 1/2-minute period. Control was switched back to the A controller 1.5 minutes later and the temperatures returned to normal.

The WSB 2 gaseous nitrogen relief valve failed the in-flight checkout, and the problem is believed to be an intermittent condition within the pressure transducer. This same signature was noted on STS-44.

Electrical Power Distribution and Control Subsystem

The performance of the electrical power distribution and control subsystem was nominal during all phases of the mission.

Pyrotechnics Subsystem

The pyrotechnics subsystem operated nominally during the mission. One expended umbilical separation system NASA Standard Initiator (NSI) with an attached connector coupling ring fell to the runway when the right-hand (LO_2) ET umbilical door was opened. A coupler retaining ring from the same initiator was found adhered to the room temperature vulcanizing (RTV) material on the inner surface of the right-hand door.

ET/Orbiter separation ordnance device plungers 1 and 2 appeared to have functioned properly; however, plunger 3 was obstructed by a detonator booster (Flight Problem STS-45-V-12).

Environmental Control and Life Support Subsystem

The atmospheric revitalization subsystem (ARS) performed nominally throughout the mission. The redundant component check exercised the alternate subsystem, and normal operation was exhibited. The air and water coolant loops performance was normal. The carbon dioxide partial pressure was maintained below 7.6 mm Hg. Cabin air temperature and humidity peaked at 82.0 °F and 65.0 percent, respectively. Avionics bays 1, 2, and 3 air outlet temperatures peaked at 103 °F, 105 °F, and 81.5 °F, respectively. Avionics bays 1, 2, and 3 water coldplate temperatures peaked at 87.5 °F, 90.5 °F, and 81.5 °F, respectively.

The atmospheric revitalization pressure control subsystem (ARPCS) performed nominally. Performance of the supply and waste water management systems was nominal with the supply water tank quantity maintained using the flash evaporator system (FES) for all supply water dumps as planned. Four waste water dumps were performed at an acceptable average dump rate of 1.93 percent/minute. The waste collection system operated nominally throughout the mission.

The active thermal control system performance was nominal with no anomalous performance noted. The flash evaporator provided satisfactory cooling during ascent and entry while the radiators provided most of the cooling on-orbit. On-orbit cooling was shared with the payload by placing the flow proportioning module into the payload position. The flash evaporator was used to perform supply water dumps as planned. Radiator cold-soak was used for vehicle cooling during the last phase of entry until about 10 minutes after landing when ammonia boiler system A was activated for cooling until the ground support cooling was initiated 43 minutes after landing.

Smoke Detection and Fire Suppression Subsystem

The smoke detection subsystem operated nominally and showed no indications of smoke during the mission. Use of the fire suppression subsystem was not required.

Airlock Support Subsystem

Use of the airlock support subsystem was not required because no extravehicular activity was planned or performed. The active system monitor parameters indicated normal output levels throughout the mission.

Avionics and Software Subsystems

At MECO, a 5.7 ft/sec under-speed condition existed. This condition was most likely caused by the manner in which the onboard guidance treats the effect of gravity during tailoff. The effect of gravity during tailoff is assumed to be mission independent by guidance software; whereas, in reality, the gravity effect is dependent on the specific orbital inclination of the mission. Therefore, higher flight-path-angle missions will generally have larger under-speed conditions than the lower flight-path-angle missions. In addition to the MECO under-speed condition, the orbital in-plane thrust from the MPS dump was less than planned because of the early attitude maneuver that was made to observe and photograph the ET in fulfillment of DTO 312 (ET Thermal Protection System Performance). As a result of these two conditions, a small OMS-3 maneuver was performed to circularize the orbit at approximately 160 nmi.

The avionics subsystem performance was nominal. The new high accuracy inertial navigation system (HAINS) inertial measurement unit (IMU) (S/N 203) was flown in position 2, and the unit experienced a 120 micro-g shift in the Z-axis acceleration channel between the ground calibration and on-orbit prior to being turned off for the group B powerdown (Flight Problem STS-45-V-09). The same bias was noted when the unit was turned on prior to entry. The bias is believed to have been caused by an accelerometer attitude sensitivity phenomenon. The bias was compensated via uplink prior to entry and performance during entry was nominal.

The -Z star tracker unexpectedly failed the on-orbit self-test. Data analysis revealed that the BITE star was not acquired within the first two scan frames (2.4 seconds). A second -Z star tracker self-test was successful. Similar self-test failures have occurred during the STS-35 and STS-40 missions. All star alignments were nominal during the mission. The -Y star tracker also failed self-test; however, this was expected because of a known problem with this particular unit.

During the postflight crew debriefing, the crew reported that on several occasions, no audible tone was present when using the systems management (SM) alert as a time alert for maneuvers and other time dependent activities (Flight

Problem STS-45-V-13). The crew also stated that all other SM alert functions were normal. Postflight functional tests of the caution and warning system showed nominal operation.

Communications and Tracking Subsystem

The communications and tracking subsystem performance was acceptable.

Ku-band frequency shifts of 1 to 20 MHz in the downlink were noted by the White Sands ground station. The first occasion of the shifts caused a short loss of channels 1 and 2. Later in the mission, the White Sands ground station was able to make a video recording of the spectrum analyzer during a Ku-band frequency shift. The shift occurred during a video and instrumentation tape recorder (VITR) dump at approximately 089:07:20 G.m.t. (04:18:06:20 MET). An analysis of the data shows no apparent correlation between the Ku-band frequency shift and the SEPAC electron beam firing. Onboard troubleshooting showed that each time the VITR playback command was sent, the Ku-band frequency shifted 20 MHz.

At 085:16:24 G.m.t. (01:03:11 MET), the Ku-band antenna did not automatically track after lock-up on the forward link while in the GPC acquisition mode (Flight Problem STS-45-V-07). Several instances of auto track failure occurred during the mission, and the problem was cleared each time by selecting the GPC designate mode. This same problem also occurred on this unit (S/N 107) during the STS-37 mission and was cleared each time by momentarily selecting the GPC designate mode.

Postflight troubleshooting could not duplicate the STS-37 problem, although metal shavings were found on the Ku-band antenna dish. This problem did not recur on the STS-43 or STS-44 missions when this unit was also flown.

In addition, the Ku-band transmitter RF power output telemetry indication was erratic in that the indicated power would drop from 31 W to -22 W, but the antenna continued to perform its function satisfactorily. This was an indication-only problem that also occurred on STS-43 and did not impact mission operations.

Because of the problems with the Ku-band, a decision was made to perform two Ku-band self tests, both of which indicated self-test failures. Both self tests failed the returned signal strength portion of the range and range-rate test (task 7) and the second self-test also indicated an EA-2 fail signature. These self-test failures occurred as a result of known deficiencies in the self-test system, and the problem was not indicative of a Ku-band problem.

The crew reported at 086:02:15 G.m.t. (01:13:02 MET), that CCTV camera A was exhibiting degraded performance (Flight Problem STS-45-V-06A). The poor performance was also noted by the ground controllers on a subsequent reception, and was characterized as being severely out-of-focus with lines and "snow." The camera later began providing acceptable video images and was used throughout the remainder of the mission, although the problem recurred intermittently. In addition, CCTV camera C downlink video was intermittently noisy and contained colored noise lines across the image (Flight Problem STS-45-V-06B). The condition later cleared. The crew also reported that camera D did not operate in low-light conditions on a number of occasions and the crew could not control pan and tilt (Flight Problem STS-45-V-06C).

During the uplink of the third page of the morning mail on flight day 3, the text and graphics system (TAGS) indicated a jam condition. The jam was cleared by the crew, and the TAGS operated satisfactorily for the remainder of the flight. This condition did not impact mission operations.

Operational Instrumentation

The operational instrumentation subsystem operated nominally except for the loss of the APU 3 Z-axis vibration sensor prior to lift-off, and the loss of the APU 2 EGT 2 sensor after landing. Neither of the failures had any impact on the successful completion of the mission and the failures are discussed in the subsystem sections of the report.

Structures and Mechanical Subsystems

All structures and mechanical subsystems operated nominally during the mission with no irregularities noted. The landing and braking data are presented in the following table.

The debris found under the right-hand ET/Orbiter umbilical door was a connector and initiator for expended pyrotechnics. The debris originated from one of the

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, knots	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	1844	187.7	1.0	n/a
Nose gear touchdown	4402	162.6	n/a	3.56

Braking initiation speed	135.3 knots
Brake on time	42.8 seconds
Rollout distance	9227 feet

Brake sensor location	Pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	1032	Left-hand outboard	27.26
Left-hand inboard 2	1044	Left-hand inboard	29.32
Left-hand outboard 3	1008	Right-hand inboard	29.10
Left-hand outboard 4	1044	Right-hand outboard	25.90
Right-hand inboard 1	972		
Right-hand inboard 2	1104		
Right-hand outboard 3	936		
Right-hand outboard 4	972		

umbilical attach points which currently have no debris containment system. The modification to add the new debris containment system to the OV-104 vehicle is scheduled for the Orbiter Maintenance Down Period (OMDP) after STS-46.

The postflight inspection revealed that the ET/Orbiter hole plugger was jammed by a booster cartridge. A booster cartridge was also found in the door mechanism. Some debris was missing and is assumed to have been lost on orbit.

Aerodynamics, Heating and Thermal Interfaces

Ascent and entry aerodynamics were satisfactory with all responses as expected. Nominal aerodynamic and plume heating occurred during ascent. Entry aerodynamic heating was within the thermal protection subsystem (TPS) limits. The prelaunch temperatures on both the launch attempt and the actual launch were within limits.

Thermal Control Subsystem

The performance of the thermal control subsystem (TCS) was nominal during the mission with all temperatures being maintained within acceptable limits. The system B APU GG heater operation was intermittent, failing off on several occasions prior to recovering apparently concurrently with the activation of the fuel pump heater.

Aerothermodynamics

The aerothermodynamics for STS-45 were nominal with acreage heating nominal. Localized heating was also nominal. Damage was found to one wing leading edge reusable carbon carbon (RCC) panel. This damage is reported in detail in the next section of this report (Thermal Protection Subsystem).

Thermal Protection Subsystem

The TPS performance was nominal, based on structural temperature response data, and some tile surface temperature measurement data. The overall boundary layer transition from laminar to turbulent flow was symmetric, occurring at 1290 seconds after entry interface.

Debris impact damage was worse than normal with the total number of hits greater than normal, and the total number of hits larger than 1 inch also above normal. The assessment of the TPS showed 122 hits on the lower surface of which 18 had a major dimension greater than 1 inch. Twenty-seven impacts, seven of which had a major dimension of greater than 1 inch, were located on the forward fuselage lower surface and starboard chine areas. The majority of the debris hits were shallow in depth, indicating that the damage was caused by a low density material. No TPS damage was attributed to material from the wheels, tires, or brakes. Damage to the base heat shield tiles was less than average. The main engine closeout blanket on SSME 3 was badly torn and frayed from the 7:30 to 12:00 o'clock position. Three of the sacrificial patches from this area were missing. A patch was also missing from the 12:00 o'clock position on SSME 2. Two of the missing patches were found near launch pad A during the postlaunch inspection, indicating the damage to the blankets occurred during launch.

Two impact damage sites were found on the upper surface of the right wing RCC panel 10 (Flight Problem STS-45-V-08). These two gouges were 1.9 inch by 1.6 inch and 0.4 inch by 1.0 inch, and the substrate was exposed. An evaluation is being made to determine the cause of this damage and the time of occurrence.

The main landing gear door thermal barriers exhibited minor damage, the most notable being protrusion at the forward location.

A portable Shuttle thermal imager was used to measure the surface temperature of three areas on the Orbiter TPS after landing. At 21 minutes after wheels stop, the Orbiter nose cap RCC was 140 °F, the right-hand wing leading edge RCC panel 9 was 77 °F, and the right-hand wing leading edge RCC panel 17 was also 77 °F.

Window hazing was less than normal, with light hazing observed on windows 3 and 4. Greater than typical tile damage was sustained on the periphery of all windows; however, in most cases the damage was surface coating loss only. The ET thermal barriers performed nominally. The payload bay doors, upper wings, and OMS pod TPS performance was nominal.

GOVERNMENT FURNISHED EQUIPMENT AND FLIGHT CREW EQUIPMENT

The overall performance of the government furnished equipment (GFE) and flight crew equipment was very satisfactory except for the 16-mm Arriflex camera on/off switch which operated intermittently. One other item of note was the operation of the vacuum cleaner when the thermal cutoff switch opened. The crew reported that the vacuum cleaner had been operating continuously with the filter cleaning tool attached for 45 minutes at the time of the thermal cutoff. After cooling, the vacuum cleaner operated satisfactorily for the remainder of the mission.

PAYLOADS/EXPERIMENTS

The STS-45 mission enabled the study of the Sun, the upper reaches of the Earth's atmosphere, and astronomical objects using an international array of instruments. The ATLAS-1 payload consisted of 12 instruments from the United States, France, Germany, Belgium, Switzerland, the Netherlands, and Japan with which 14 experiments were conducted to study the chemistry of the atmosphere, solar radiation, space plasma physics, and ultraviolet astronomy. ATLAS-1 was the first of several planned ATLAS flights that will occur during the entire 11-year solar cycle, which is the regular period of energetic activity by the Sun. Co-manifested with ATLAS-1 was the Shuttle Solar Backscatter Ultraviolet Instrument (SSBUV), which provided highly calibrated measurements of ozone to further refine measurements made by other NASA and NOAA satellites. The ATLAS-1 and the SSBUV were located in the payload bay.

Secondary experiments included Space Tissue Loss (STL), which was a study of the effects of weightlessness on body tissues; the Visual Function Tester-II (VFT-II), which studied the effects of weightlessness on human vision; the Radiation Monitoring Equipment-III (RME-III), which has been flown on a number of occasions to measure radiation aboard the Orbiter; Investigations into Polymer Membrane Processing (IPMP), which was used to develop polymer membranes for use as filters in many industries and in space; and the Cloud Logic to Optimize Use of Defense Systems (CLOUDS-1A), which was an investigation into quantifying the variation in apparent cloud cover as a function of the angle at which the clouds were viewed. All of these experiments were located on the middeck during the mission.

In addition, the Shuttle Amateur Radio Experiment (SAREX) provided amateur radio operators throughout the world, plus selected students at several selected sights, the opportunity to converse with crew members aboard Atlantis. This experiment was also located on the middeck.

One GAS payload (G-229 - Experiment in Crystal Growth) was also flown. This was the second flight of a very successful GAS experiment that was performed on STS-40, but with additional features included to enhance the ability to analyze convection effects on crystal growth in microgravity.

Integration of the cargo (payloads) into the Orbiter involved the use of mission kits, which consisted of standard payload bridges, latches and attach fittings, the payload bay 13 GAS beam, and other miscellaneous hardware. All equipment performed properly and there were no anomalies recorded for this hardware. Verification analyses were performed in the areas of loads, thermal characteristics, and electrical power, including electromagnetic compatibility. Data confirmed that performance was within predicted ranges, and no out-of-limit conditions occurred.

SCIENTIFIC ACTIVITIES

Spacelab activation was completed at 2 hours 49 minutes MET, and payload activation was started about 30 minutes later. The 13-minute 40-second delay in the launch shifted the shadow times approximately 1 degree 34 minutes and the experiment times were adjusted accordingly. During the remainder of the first day's activities, all scheduled instruments were activated and calibration activities completed. Atmospheric science instruments gathered data and the solar instruments were prepared for the first of three solar observation periods.

The solar experiments completed during the second day of activities included the first of three solar observation periods during which simultaneous observations of the Sun's total radiant output and the solar spectra were made. The atmospheric science teams were able to perform ultraviolet astronomy operations for a longer period of time than planned, and as a result, observed a larger-than-expected natural aurora. Remote commanding from the European Space Agency (ESA) ESTEC Center in the Netherlands was implemented successfully. The Far Ultraviolet Space Telescope (FAUST) high-voltage sources were not providing the necessary voltage to conduct scientific operations. The first SEPAC electron beam assembly (EBA) firings were conducted.

The focus during the third day of scientific activities was on space plasma physics experiments as SEPAC fired its electron beam to produce the first artificial auroras, and the Atmospheric Emissions Photometric Imaging (AEPI) photographed natural and artificial auroral activity. Shortly after one of the

SEPAC virtual antenna experiments, the operation of the EBA was lost because a fuse was blown in the EBA, which is located in the payload bay. The SEPAC science team reported that the EBA achieved its objective. The orbital path allowed the atmospheric instruments to make correlative measurements of the same part of the atmosphere being observed by the Upper Atmosphere Research Satellite (UARS). The FAUST high-voltage sources began operating properly, and ultraviolet astronomy observations resumed.

Atmospheric science, space plasma physics, and ultraviolet astronomy experimentation continued during the fourth day of data gathering. The Atmospheric Trace Molecule Spectroscopy (ATMOS) and Grille Spectrometer (GRILLE) data and video showed clear evidence of aerosol bands that are probably the effect of the Mt. Pinatubo eruption last year. The SSBUV experiment started its observations, measuring the global ozone in the stratosphere. The SEPAC used its plasma contactor for experimentation that will help verify a theory that underlies the basic physics on the formation of the universe.

The fifth day was excellent from the aspect of obtaining scientific data. The scientists believe that the data collected will provide unprecedented information about the Earth's atmosphere. Atmospheric stations in India, Indonesia, Japan, and New Zealand made simultaneous observations with the instruments aboard the ATLAS payload. The GRILLE instrument detected hydrogen chloride at higher levels of the atmosphere than previously measured. Plasma physics and ultraviolet astronomy instruments were also active. Data were collected on a brilliant red and purple natural aurora stretching from Africa to Australia, and a payload low-light camera photographed blue clouds of xenon gas as the gas was released into the area around the Orbiter by one of the experiments. One of the major items completed this fifth day was the second of three solar observation periods to gain information on the solar spectra and variations in the Sun's energy output.

The sixth day of activity was spent by many of the science teams in planning the activities for the ninth day that was added to the flight plan by the MMT. Atmospheric science, space plasma physics, and ultraviolet astronomy dominated the day's activities. The atmospheric instruments completed over a dozen UARS-coincident measurements. The plasma contactor experiment of the SEPAC created a phenomena called "double layers" for the first time in space, and this phenomena is associated with the acceleration mechanism responsible for auroras. The FAUST instrument experienced an anomaly that left the instrument without power and the door stuck open. Evaluation showed that a fuse was blown and that condition prevented the instrument from being reactivated.

The seventh day was spent collecting data and preparing for the extension day of the mission. The scientific community expressed their satisfaction with not only the amount of data but also the quality of the data. The crew reported the vibrant colors that were being observed in the natural auroras.

The third solar observation period measuring the solar irradiance and spectra was completed on the eighth day. The bonus science day (ninth) began with the atmospheric instruments operating at special attitudes gathering data from new viewing angles and in unique modes. The teams also completed science objectives that had been devised based on analysis of data from this mission. In the realm of space plasma physics, the SEPAC plasma wave instrument detected a phenomena called "whistlers", which is a radio wave signature of lightning in the atmosphere.

ATLAS-1 EXPERIMENTS

The primary objectives of the 12 ATLAS-1 instruments that were located on the Spacelab pallet in the payload bay were to measure the variation in solar output; measure the Earth's middle atmospheric constituents over the course of one solar cycle; and supplement the measurements from the Upper Atmosphere Research Satellite.

Atmospheric Science

In the field of atmospheric science, the Imaging Spectrometric Observatory (ISO) measured spectral features in determining the composition of the atmosphere down to the trace amounts of chemicals measured in parts-per-trillion. The investigation, which previously flew on Spacelab 1, added data about the varied reactions and energy transfer processes that occur in the Earth's environment.

The ATMOS and the Grille Spectrometer experiments mapped trace molecules, including carbon dioxide and ozone, in the middle atmosphere. The mapping was accomplished from orbital sunrise to orbital sunset, which occurred about every 90 minutes throughout the flight, by measuring the infrared radiation that the molecules absorb. Both of these experiments have flown previously, ATMOS on Spacelab 3 in 1985 and GRILLE on Spacelab 1 in 1983.

The Atmospheric Lyman-Alpha Emissions (ALAE) experiment measured the abundance of two forms of hydrogen -- common hydrogen and deuterium (heavy hydrogen). ALAE observed ultraviolet light, called Lyman-Alpha, which hydrogen and deuterium radiate at slightly different wavelengths. Deuterium's relative abundance compared to hydrogen at the altitudes ALAE studied is an indication of atmospheric turbulence in the lower thermosphere. After determining the hydrogen/deuterium ratio, scientists can better study the rate of water evolution in the Earth's atmosphere. This experiment was previously flown on the Spacelab 1 mission.

The Millimeter-Wave Atmospheric Sounder (MAS) measured the strength of millimeter-waves radiating at the specific frequencies of water vapor, chlorine monoxide, and ozone. Observations of these gases enables scientists to better understand their distribution through the upper atmosphere. These MAS data are particularly valuable because the data should be unaffected by the presence of aerosols, the concentrations of which have increased by the eruption of Mount Pinatubo. An earlier version of the MAS experiment was flown on the Spacelab 1 mission.

Shuttle Solar Backscatter Ultraviolet Experiment

The SSBUV experiment, which measured atmospheric ozone levels, served as calibrating experiment for the ATLAS-1 experiments. The SSBUV measurements were compared with those from ozone-observing instruments aboard the National Oceanic and Atmospheric Administration's NOAA-9 and NOAA-11 satellites and NASA's

NIMBUS-7 satellite to ensure that the most accurate readings were obtained of atmospheric ozone trends. The SSBUV assessed instrument performance by directly comparing data from identical instruments aboard the NOAA satellites and the NIMBUS-7 satellite as the Shuttle and satellite passed over the same Earth location. SSBUV data also will be compared with data from the UARS launched in September 1991 to study the processes that lead to ozone depletion. The solar data taken by SSBUV also will be compared with data from the four solar instruments.

The SSBUV was physically separate from the ATLAS-1 payload, housed in two GAS canisters mounted in the payload bay. This mission was the fourth for the SSBUV, having previously flown in October 1989, October 1990, and August 1991.

Solar Science

Four solar science investigations measured the Sun's energy output to determine its variations and spectrum. The Active Cavity Radiometer (ACR) and the Measurement of Solar Constant (SOLCON) experiments measured the total amount of light and energy emitted by the Sun. These data are especially important in the study of Earth climates.

The Solar Spectrum Measurement (SOLSPEC) and the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) investigations along with the SSBUV discussed previously added significantly to the scientists' understanding of how variations in the Sun's energy output affects the chemistry of the atmosphere. All four of these experiments have previously flown on the Shuttle.

Space Plasma Physics

Two space plasma physics instruments, the Atmospheric Emissions Photometric Imaging (AEPI) and SEPAC studied the charged particle and plasma environment. A third investigation, Energetic Neutral Atom Precipitation (ENAP) was conducted using data from the ISO instrument discussed previously. Active and passive probing techniques investigated key cause-and-effect relationships that link the Earth's magnetosphere, ionosphere, and upper atmosphere. Electron and plasma beams were injected into the surrounding space plasma for the study of phenomena such as aurora Q (visible signatures of magnetic storms) that can disrupt telecommunications, power transmission, and spacecraft electronics Q as well as spacecraft glow.

Spacecraft glow is a recently discovered phenomenon. On Shuttle missions, the surfaces facing into the direction of travel were covered with a faintly glowing, thin orange layer. Understanding spacecraft glow is very important because of its potential impact on experiments in the cargo bay and on other satellites, as well as the possible interference with sensitive data-collecting instruments.

The AEPI and SEPAC experiments were flown on the Spacelab 1 mission.

Astronomy

Little is known about the stages and rate of star formation in other galaxies. Young stars reach very high temperatures and emit intense ultraviolet radiation, which cannot be detected by ground-based astronomers. However, this radiation was detectable by the FAUST. FAUST, which flew on Spacelab 1, studied astronomical radiation sources at ultraviolet wavelengths.

INVESTIGATIONS INTO POLYMER MEMBRANE PROCESSING

The IPMP, a middeck payload, was flown for the sixth time on the STS-45 mission. The IPMP investigated the physical and chemical effects induced by microgravity such that the improved knowledge base can be applied to commercial membrane processing techniques. Polymer membranes have been used by industry in separation processes for many years. Typical applications include enriching the oxygen content of air, desalination of water, and kidney dialysis.

Polymer membranes frequently are made using a two-step process. A sample mixture of polymer and solvents is applied to a casting surface. The first step involves the evaporation of solvents from the mixture. In the second step, a non-solvent (typically water) is introduced and the desired membrane is precipitated, completing the process. Previous flights of IPMP where the complete process was flown were STS-41, -43, -48, and -42, and the evaporation step alone was flown on STS-31. The precipitation step was the only portion of the experiment that was flown on STS-45.

GET-AWAY SPECIAL EXPERIMENT

The GAS Program has sponsored the flight of 77 GAS canisters on 17 missions during the Shuttle Program. The Experiment in Crystal Growth (G-229), flown on STS-45, was designed to grow crystals of gallium arsenide (GaAS). The GaAS is a versatile electronic material used in high-speed electronics and opto-electronics. A crystal approximately 1 inch in diameter and 3.5 inches long was planned for growth during a 11-hour period of this mission.

The payload is entirely self-sufficient and includes its own power system, growth system, and control and data acquisition systems. The experiment was activated by a crew member closing a switch, the only human interaction necessary for this payload.

This experiment was a reflight of a successful GAS experiment conducted on STS-40 in June 1991, but with additional features included to enhance the ability to analyze convection effects on crystal growth in microgravity.

SHUTTLE AMATEUR RADIO EXPERIMENT

The SAREX demonstrated the feasibility of amateur shortwave radio contacts between the Space Shuttle and ground amateur radio operators, often called ham radio operators. Four of the STS-45 crew members were licensed amateur radio operators, and two of the four were fluent in several European languages. Ham operators used the VHF FM link to communicate with the crew. The SAREX has flown on four previous Shuttle missions.

RADIATION MONITORING EQUIPMENT-III

The RME-III measured ionizing radiation exposure to the crew within the Orbiter cabin. RME-III measured gamma ray, electron, neutron, and proton radiation and calculated in real-time the exposure in RADS-tissue equivalent. The data were stored in memory modules for postflight analysis, which is in progress.

VISUAL FUNCTION TESTER-II

The VFT-II experiment measured changes in a number of vision parameters of subjects exposed to microgravity. The device measured changes in the contrast ratio threshold of the subjects who were the payload specialists. The test subjects were tested prior to the flight, daily during the flight, and twice during the week following the mission. This experiment was flown on three previous Shuttle missions.

CLOUD LOGIC TO OPTIMIZE USE OF DEFENSE SYSTEMS

The overall objective of the CLOUDS-1A program was to quantify the variation in apparent cloud cover as a function of the angle at which clouds of various types were viewed and to develop meteorological observation models for various cloud formations. A Nikon camera was used to obtain high-resolution photographs of individual cloud scenes over a wide range of viewing angles.

SPACE TISSUE LOSS

The STL experiment was a life sciences experiment that studied cell growth during spaceflight. The objective of the experiment was to study the response of muscle, bone, and endothelial cells by evaluating various parameters including shape, cytoskeleton, membrane integrity and metabolism, activity of enzymes that inactivate proteins, and the effects or change of response to various drugs on these parameters. The experiment was contained in a middeck locker.

DEVELOPMENT TEST OBJECTIVES AND DETAILED SUPPLEMENTARY OBJECTIVES

Eleven development test objectives and 15 detailed supplementary objectives were assigned to the STS-45 mission. Preliminary results are provided in the following paragraphs on the DTO's for which results have been received.

DEVELOPMENT TEST OBJECTIVES

DTO 250 - Forward RCS Test - Control Surfaces Effects.- A single 10-second firing of all four forward RCS yaw thrusters was made during entry at Mach 4.0 in support of this DTO. DTO 250 data are being evaluated by the sponsor.

DTO 301D - Ascent Structural Capability Evaluation.- This experiment was a data-only experiment, and the data are being evaluated by the sponsor.

DTO 312 - ET Thermal Protection Subsystem Performance (Method 2).- Thirty-eight high quality photographs of the ET were acquired by the crew using the handheld Hasselblad camera with a 250-mm lens. Excellent views of the ET after separation were also acquired with a 16-mm Arriflex handheld motion picture camera. Results from the initial screening of the 16-mm film shows evidence of venting from the LH_2 umbilical during three distinct periods. The first venting that is noted lasted approximately 4.75 seconds, followed by a pause in the venting of 2.46 seconds. The second period of venting lasted 6.79 seconds and the venting paused again for 1.46 seconds. The third period of venting lasted 5.38 seconds at which time the ET was lost from view. Several small white objects, assumed to be ice, were seen in the vapor during the first venting. After further photographic enlargement at JSC, venting from the ET intertank was observed on frame 31 of the Hasselblad film. Also noted on the enlargements was a noticeable change in the ET rotation rate between frames 34 and 35 of the Hasselblad film.

DTO 520 - Edwards Air Force Base Lakebed Bearing Strength Evaluation.- This DTO was not performed since the landing was made at KSC.

DTO 623 - Cabin Air Monitoring.- Instruments for this DTO were set up for operation on flight day 1 and were stowed on flight day 8. Samples were gathered during the flight and these data are being evaluated by the sponsor.

DTO 624 - Radiator Deployment Performance.- This DTO was not performed as it required the space radiators to be deployed. Conditions were such onboard the vehicle that no need arose to deploy the radiators.

DTO 633 - VTR Demonstration.- Data were gathered for this DTO from flight day 1 until the equipment was stowed just before the deorbit maneuver. Data are being evaluated by the sponsor.

DTO 648 - Electronic Still Camera (No downlink).- Activities in support of this DTO were conducted from flight day 1 until the equipment was stowed just before the deorbit maneuver. The data are being evaluated by the sponsor.

DTO 728 - Ku-band Antenna Friction.- This DTO was performed after completion of the science objectives for the ATLAS/SSBUV. The data are being evaluated by the sponsor.

DTO 805 - Crosswind Landing Performance.- This DTO was not accomplished as crosswinds were not of sufficient strength to meet the DTO criteria.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 317 - Collection of Shuttle Humidity Condensate for Analytical Evaluation.- Four sample bags of water were collected from the humidity separator to evaluate for contaminants. An additional bag was also collected on the extension day. The water samples have undergone preliminary analysis and have yielded good results. The sponsor is very happy with the data received.

DSO 603B - Orthostatic Function During Entry, Landing, and Postflight.- The data have been collected and are being evaluated by the sponsor.

DSO 604 - Visual Vestibular Integration as a Function of Adaptation.- The data have been collected and are being evaluated by the sponsor.

DSO 607 - Lower Body Negative Pressure Following Space Flight.- The planned number of runs were performed in the lower body negative pressure device and the data are being evaluated by the sponsor.

DSO 608 - Effects of Space flight on Aerobic and Anaerobic Metabolism at Rest and During Exercise.- The data were collected and are being evaluated by the sponsor.

DSO 611 - Air Monitoring Instrument Evaluation and Atmospheric and Atmospheric Characterization (Configurations A and B).- The first sample for this DSO was taken at 05:45:00 MET. Samples were taken throughout the mission and are being evaluated by the sponsor.

DSO 612 - Energy Conservation.- The data were collected and are being evaluated by the sponsor.

DSO 613 - Changes in Endocrine Regulation of Orthostatic Tolerance to Space Flight.- The data were collected as planned and are being evaluated by the sponsor.

DSO 614 - Head and Gaze Stability During Locomotion.- The data were collected and are being evaluated by the sponsor.

DSO 621 - In-Flight Use of Florinef to Improve Orthostatic Intolerance Postflight.- The medications were taken as planned and the data were taken from the two crewmembers. The data are being evaluated by the sponsor.

DSO 802 - Educational Activities (The Atmosphere Below).- The DSO was completed with good results.

DSO 901 - Documentary Television.- The DSO was completed with good results and the video data are being evaluated by the sponsor.

DSO 902 - Documentary Motion Picture Photography.- This DSO was completed with good results, and the data are being evaluated by the sponsor.

DSO 903 - Documentary Still Photography.- The data were collected as a part of normal flight activities and are being evaluated by the sponsor.

PHOTOGRAPHIC AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY EVALUATION

On launch day, 23 videos of launch were evaluated and no anomalous conditions were noted. Additionally, 60 of the 61 expected launch films were reviewed. No anomalous conditions were found during the review of the films.

LANDING PHOTOGRAPHY EVALUATION

Seventeen videos of the Orbiter approach and landing were reviewed including infrared views. Seven films of landing were also reviewed and no anomalous conditions were noted.

TABLE I.- STS-45 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU activation	APU-1 GG chamber pressure	084:13:08:56.51
	APU-2 GG chamber pressure	084:13:08:57.47
	APU-3 GG chamber pressure	084:13:08:58.27
SRB HPU activation	LH HPU system A start command	084:13:13:12.17
	LH HPU system B start command	084:13:13:12.32
	RH HPU system A start command	084:13:13:12.49
	RH HPU system B start command	084:13:13:12.65
Main propulsion System start	Engine 3 start command accepted	084:13:13:33.429
	Engine 2 start command accepted	084:13:13:33.585
	Engine 1 start command accepted	084:13:13:33.701
SRB ignition command (lift-off)	SRB ignition command to SRB	084:13:13:39.991
Throttle up to 100 percent thrust	Engine 3 command accepted	084:13:13:44.549
	Engine 2 command accepted	084:13:13:44.585
	Engine 1 command accepted	084:13:13:44.582
Throttle down to 89 percent thrust	Engine 3 command accepted	084:13:14:01.990
	Engine 2 command accepted	084:13:14:02.025
	Engine 1 command accepted	084:13:14:02.022
Throttle down to 74 percent thrust	Engine 3 command accepted	084:13:14:09.510
	Engine 2 command accepted	084:13:14:09.545
	Engine 1 command accepted	084:13:14:09.542
Throttle up to 104 percent thrust	Engine 3 command accepted	084:13:14:42.951
	Engine 2 command accepted	084:13:14:42.986
	Engine 1 command accepted	084:13:14:42.983
Maximum dynamic pressure (q)	Derived ascent dynamic pressure	084:13:14:50
Both SRM's chamber pressure at 50 psi	LH SRM chamber pressure mid-range select	084:13:15:42.59
	RH SRM chamber pressure mid-range select	084:13:15:42.47
End SRM action	RH SRM chamber pressure mid-range select	084:13:15:45.75
	LH SRM chamber pressure mid-range select	084:13:15:44.94
SRB separation command	SRB separation command flag	084:13:15:47
SRB physical separation	LH rate APU A turbine speed LOS	084:13:15:48.11
	RH rate APU A turbine speed LOS	084:13:15:48.11
Throttle down for 3g acceleration	Engine 3 command accepted	084:13:21:05.201
	Engine 2 command accepted	084:13:21:05.189
	Engine 1 command accepted	084:13:21:05.191
3g acceleration	Total load factor	084:13:21:05.97
SSME shutdown	Engine 3 command accepted	084:13:22:10.443
	Engine 2 command accepted	084:13:22:10.430
	Engine 1 command accepted	084:13:22:10.432
MECO	MECO shutdown command accept	084:13:22:10
	MECO confirm flag	084:13:22:10
ET separation	ET separation command flag	084:13:22:28

TABLE I.- STS-45 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
OMS-1 ignition	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
OMS-1 cutoff	Left engine bi-prop valve position	N/A
	Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
APU deactivation	APU-1 GG chamber pressure	084:13:28:08.29
	APU-2 GG chamber pressure	084:13:28:09.99
	APU-3 GG chamber pressure	084:13:28:11.01
OMS-2 ignition	Left engine bi-prop valve position	084:13:49:59.9
	Right engine bi-prop valve position	084:13:49:59.9
OMS-2 cutoff	Left engine bi-prop valve position	084:13:52:25.9
	Right engine bi-prop valve position	084:13:52:25.9
Payload bay door open	PLBD right open 1	084:14:53:49
	PLBD left open 1	084:14:55:07
OMS-3 ignition	Left engine bi-prop valve position	084:16:03:42.8
	Right engine bi-prop valve position	N/A
OMS-3 cutoff	Left engine bi-prop valve position	084:16:03:57.6
	Right engine bi-prop valve position	N/A
Flight control system checkout		
APU start	APU-2 GG chamber pressure	092:08:54:10.31
APU stop	APU-2 GG chamber pressure	092:08:59:06.03
Payload bay door close	PLBD left close 1	093:07:43:32
	PLBD right close 1	093:07:45:28
APU activation for entry	APU-1 GG chamber pressure	093:10:15:58.80
	APU-2 GG chamber pressure	093:10:38:58.66
	APU-3 GG chamber pressure	093:10:38:59.68
Deorbit maneuver ignition	Left engine bi-prop valve position	093:10:20:55.3
	Right engine bi-prop valve position	093:10:20:55.3
Deorbit maneuver cutoff	Left engine bi-prop valve position	093:10:24:35.9
	Right engine bi-prop valve position	093:10:24:35.9

TABLE I.- STS-45 SEQUENCE OF EVENTS (Concluded)

Event	Description	Actual time, G.m.t.
Entry interface (400K)	Current orbital altitude above reference ellipsoid	093:10:51:49
Blackout ends	Data locked at high sample rate	No blackout
Terminal area energy management	Major mode change (305)	093:11:16.38
Main landing gear contact	LH MLG tire pressure	093:11:23:05
	RH MLG tire pressure	093:11:23:05
Main landing gear weight on wheels	LH MLG weight on wheels	093:11:23:08
	RH MLG weight on wheels	093:11:23:08
Nose landing gear contact	NLG tire pressure	093:11:23:13
Nose landing gear weight on wheels	NLG WT on Wheels -1	093:11:23:13
Wheels stop	Velocity with respect to runway	093:11:24:04
APU deactivation	APU-1 GG chamber pressure	093:11:38:08.64
	APU-2 GG chamber pressure	093:11:38:09.09
	APU-3 GG chamber pressure	093:11:38:10.02

TABLE II.- STS-45 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-45-V-01	Liquid Hydrogen Leak During First Launch Attempt	083:05:10 G.m.t. IPR 45V-0138 (deferred UA)	Aft compartment hydrogen concentration rose to 750 ppm (LCC = 500 ppm) 3.5 minutes into fast fill. Terminated fill at that time. Leak condition could not be reproduced. Concentration was within limits on second attempt. KSC: Troubleshooting plan available. Inspect and photograph umbilicals at landing site. Further inspections in OPF. No chit required.
STS-45-V-02	Liquid Oxygen Leak During First Launch Attempt	083:05:10 G.m.t. IPR 45V-0139 (deferred UA)	Aft compartment oxygen concentration rose to 850 ppm (LCC = 500 ppm) during slow fill. Later decreased. Exceeded limit on second attempt, but minutes later stabilized within the LCC limit. KSC: Same action as specified in STS-45-V-01.
STS-45-V-03	APU 3 Z-axis Vibration Sensor Failed (V46D0381A)	Prelaunch CAR 45RF-01 IPR 46V-0002	Data showed no response from Z-axis sensor. X-axis nominal at approximately 5g peak to peak. Criticality 3 measurement. Acceptable to fly as is until planned APU 3 changeout. KSC: Wire wiggle and continuity checks. Repair if possible. No chit required.
STS-45-V-04	Fuel Cell 3 Cell Performance Monitor (CPM) Anomaly	083:14:22 G.m.t. CAR 45RF-02 IPR 46V-0003	Cell performance monitor hung up in 50 mV self-test mode for periods up to 3 minutes. No impact to fuel cell performance. Suspect leaky capacitor. Last flight occurrence was on flight day 2. KSC: Remove and replace CPM. Spare is available. No chit required.
STS-45-V-05	APU 1 Gas Generator Bed Heater System B Erratic	084:20:41 G.m.t. CAR 45RF-03 IPR 46V-0001	Heater B failed to respond when initially activated. Fuel pump/line heaters are operating satisfactorily. Switched to system A and bed heater responded. Switched back to system B. Initial erratic behavior, then operated normally. Erratic behavior recurred on flight day 5. Data indicates abnormal fuel system heater operation also. Switched to system A on flight day 6. Possible controller problem, thermostat problem, or aft load controller assembly (LCA) problem. KSC: Postflight troubleshooting required. Troubleshooting plann available. No chit is required. Problem did not recur during troubleshooting.
STS-45-V-06	a) CCTV Camera A Quality Poor	086:02:15 G.m.t. BFCE-029F049	a) Camera A picture quality suddenly became very poor (fuzzy), later recovered. Intermittent throughout flight.
	b) CCTV Camera C Noisy Video	BFCE-029F050	b) Camera C downlink video was intermittently noisy, containing colored noise lines across the image. The camera later recovered. A burn spot on the camera C video image was noticed on the upper left part of the picture.
	c) CCTV Camera D performance poor.		c) Crew reported that camera D seldom worked in low light. Also, occasionally could not control pan and tilt. KSC: Remove cameras A, C, and D and ship to Boeing FEPC.

TABLE II.- STS-45 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-45-V-07	a) Ku-Band Antenna Loss of Track in Acquisition Mode	085:16:24 G.m.t. IM 45RF-04	a) Repeat of STS-37-V-04 with DA 107. Loss of lock in acquisition mode. Normal operations in GPC designate mode. Investigating effects of the characteristics of payload data transmitted via Ku-Band channel 3. Ku-Band required next flight of OV-104 (TSS mission).
	b) Ku-Band RF Power Out Intermittently Failed	IPR 46V-0008	b) Loss of lock possibly associated with RF power monitor problem. Observed on previous flight (CAR 37RF-04). KSC: Approximately two shifts OPF testing required prior to deployed assembly (DA) removal and replacement. Spare available (S/N 102). OPF testing scheduled for April 16. Postflight antenna inspection normal. Payload data not required for troubleshooting. OPF test data required to supplement vendor analysis. Coordinated test/troubleshooting plan in work. No chit required.
STS-45-V-08	Damage on Right RCC Panel No. 10	Postlanding PR-TES-4-12-0115 IM 45RF-05	Two gouges (1.9 inch by 1.6 inch, and 0.4 inch by 1.0 inch) noted on upper portion of right wing leading edge RCC panel no. 10. Substrate exposed and tiles are not repairable. Panel removed and shipped to Downey.
STS-45-V-09	Inertial Measurement Unit 2 Z-Axis Accelerometer Bias Shift	Post ascent IM 45RF-06 IPR 46V-0012	HAINS S/N 203 experienced a Z-axis bias shift of 120 micro-g during ascent (1 sigma = 30 micro-g). Suspect sensitivity to attitude. New compensation value uplinked for entry. KSC: Perform hangar calibration and preflight alignment
STS-45-V-10	Water Spray Boiler 1 Overcooling on B Controller	093:11:00 G.m.t.	When cooling was initiated, the lube oil return temperature dropped from 249 °F to 177 °F over a period of approximately 5 1/2 minutes. Switched to A controller 1 1/2 minutes later when lube oil temperature was 181 °F. Violated OMRSD File IX requirement DV58AKO.050. Suspect problem related to concurrent decrease noted in drain cavity pressure. Indications of high N_2H_4 vapor content during gearbox lube oil offload. KSC: Perform APU/HYD hot oil flush.
STS-45-V-11	APU 2 Nitrogen Pressure Low	093:10:38 G.m.t. IPR 46V-0006	Nitrogen pressure decayed from 15.5 psia to 11.5 psia between FCS Checkout and APU start for entry. Pressure dropped to 7.5 psia after APU start. Two repressurizations were made during entry. KSC: Troubleshooting plan available.
STS-45-V-12	ET/Orbiter 3 Hole Plugger Jammed	Postflight inspection PR PYR4-12-0150	Hole plugger was jammed by a booster cartridge. Booster cartridge also found in door mechanism. Some debris is missing and is assumed to have been lost while in orbit.
STS-45-V-13	SM Alert Time/Tone Audible Alarm Intermittent	On-Orbit	The crew reported that on several occasions there was no audible tone when using the SM Alert as a time alert for maneuvers, etc. All other SM Alert indications were normal. Postflight C&W functional test was nominal.

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