Thermal Canister Experiment on OSS-1

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A thermal canister was flown aboard the OSS-1 pallet on the third Space Shuttle (STS-3) in order to demonstrate through the use of heat pipes and control electronics that simulated scientific instruments could be held within limits of ±2°C during changes in environmental temperatures of ±100°C. This control took place not only during changes in internal power levels, but during transitions from extremely cold to hot conditions. Sensors mounted on the canister measured total thermal flux and generally read higher than predicted levels. Two anomalies occurred during the flight: resets to a microprocessor from unknown sources and severe degradation to the Kapton insulating material from exposure to the atomic oxygen environment. Both of these anomalies are discussed briefly.

Introduction

THE long-term use of the Space Shuttle means that many scientific and technical investigations can be performed in the Orbiter bay. However, the extreme thermal environmental conditions ranging from equivalent sink temperatures of +100°C in full sun to −100°C in shadow may cause problems. In the past such conditions were accommodated using coatings, insulation, and heaters. With the Shuttle, an instrument designed for one set of conditions may have to survive in an entirely different environment if flown again with different orbit attitudes. If a thermal enclosure were provided which decoupled instruments from the wide extremes in external temperature while maintaining them in a benign environment, simpler thermal designs for instruments, with limited maintenance between flights, might be realized.

To this end the Thermal Canister Experiment (TCE) aimed to determine whether a device using controllable heat pipes could maintain simulated instruments at several selectable temperature levels in zero gravity and under widely varying internal and external thermal loads. It was hoped to demonstrate ±2°C temperature stability at various control points in the canister while dissipating up to 325 W in cold Orbiter attitudes (bay away from the sun) and 100 W in hot (bay towards the sun) conditions.

Description of Experiment

The Thermal Canister Experiment (Fig. 1) consisted of a rectangular enclosure 3 m high × 1 m long × 1 m wide with its aluminum sides equalized in temperature by a system of longitudinal fixed conductance heat pipes. These heat pipes collected the thermal energy dissipated internally by electric heaters simulating instruments in operation and the energy absorbed from direct and reflected sunlight. This heat was then conducted to variable conductance heat pipes mounted to external radiators at the upper end of the canister and radiated to space. The heat pipes are long, narrow, closed chambers with internal capillary wicking which provides pumping action.[1] The wick is saturated with a volatile liquid (ammonia) in equilibrium with its vapor. Heat transport is established by applying heat at one end (the evaporator) and providing cooling at the other end (the condenser) with the heat being transferred at latent heat of vaporization. The liquid is then returned to the evaporator by capillary forces in the wick.

The variable conductance heat pipes are more complex than the fixed conductance type in that they contain a noncondensible gas (nitrogen) stored in a reservoir at the condenser end of each pipe. As the temperature of the evaporator end of the pipe falls, a heating element raises the temperature of the reservoir, causing the gas to expand into the condenser, thus blocking the condenser region and effectively stopping heat pipe action. The length of condenser rendered inactive depends on the temperature level along the pipe. Conversely, with increasing evaporator-end temperature, the gas will recede into the reservoir making more active area of the radiators available for heat rejection to space. The signal for activating the reservoir heaters is supplied through a feedback loop consisting of a temperature control sensor and either a hardware proportional controller or a computer-driven controller. The sensors are attached to the canister side walls or on simulated instruments located in two different zones separated by an insulating barrier. The simulators are either radiatively or conductively coupled to the canister walls.[2]

Mission Objectives

The proof of technology flight of the TCE on the OSS-1 pallet was based upon demonstrating temperature control in each of the four thermal environments (Fig. 2) experienced by the STS-3 varying from the very cold tail-to-sun attitude, to the very warm, 70% sun with the cargo bay facing the sun.

The primary objectives of the experiment were 1) to maintain 15°C±2°C on all panels and 2) to maintain temperature control in cold, moderate, and hot environments over a range of internal power dissipations.

Secondary objectives were to demonstrate control at selected temperature levels in the range of 5 to 25°C and, finally, to operate in the passive mode with a variation of ±5°C with time about some nominal temperature, the nominal temperature depending upon thermal environment. Another objective was to demonstrate the performance of microprocessor-driven algorithms to perform thermal control functions.

Flight Results

Thermal Canister Performance

The TCE was launched as part of the OSS-1 complement of instruments at 11:00 a.m. Eastern Standard Time on March 22, 1982. The TCE was turned on 4 h 55 min after launch and an attempt was made to hold the walls at 15°C under

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microprocessor control during the initial stabilization of the Shuttle in the Passive Thermal Control (PTC) attitude. Unfortunately the microprocessor experienced reset problems which precluded the commanding of selected power, temperature, and control functions. It was decided to bypass the computer and use a backup hard wire system which utilized a limited number of relay commands. This enabled the experimentation to proceed and the majority of primary and secondary objectives to be met. A total of 11 steady-state data points were achieved during the seven day mission and are shown in Fig. 3. Control was either on the canister walls (points 1 to 3 and 5 to 11) or on the instrument simulators (point 4).

The set point variation ranged from 5 to 23°C with power changes of 325 W in the cold attitude (tail-to-sun) to 165 W in the hot attitude (bay-to-sun). The canister held temperatures to better than ±2°C on all panels at any control point over time with spatial gradients of 4°C. This was in contrast to ground testing, where as high as 8°C spatial gradients were noted, due largely to the maldistribution of liquid in the heat pipes in a 1 *g* field. When control was switched to the radiatively coupled instrument simulator, and the power duty cycled, a similar tolerance was maintained (point 4). This can be compared with a variation of ±5°C with time when the simulator was uncontrolled (MET 3:05:00). Actual flight data during this period is shown in Fig. 4. Passive thermal control, a mode of operation where the control system is deactivated, was also demonstrated at this time. Unlike other systems, which do not have the ability to handle a disabled controller, the variable conductance heat pipes will shut down partially and prevent excessive heat loss. Thus the TCE only fell to −5°C (point 6). The most important data was achieved during the transition periods when the Shuttle was passing from one attitude to another. During these periods, an attempt was made to hold the canister walls at a constant temperature with constant power, while the environment was drastically changing. This was successfully demonstrated through four transitions (Fig. 3), and has important meaning to missions where a pointing system, together with changing Shuttle attitudes, will expose instruments to continuously varying environmental conditions. Figure 5 shows flight data of this transition from moderate to hot conditions. Because of limited heat rejection capability in the hot case, the TCE could not hold 14°C. The set point was then changed to 23°C and stability achieved. Although the microprocessor continued to reset throughout the mission due to unknown reasons, there were several intervals where the control algorithms could be invoked. This occurred at least four times and demonstrated that the canister and simulated experiments could be con-

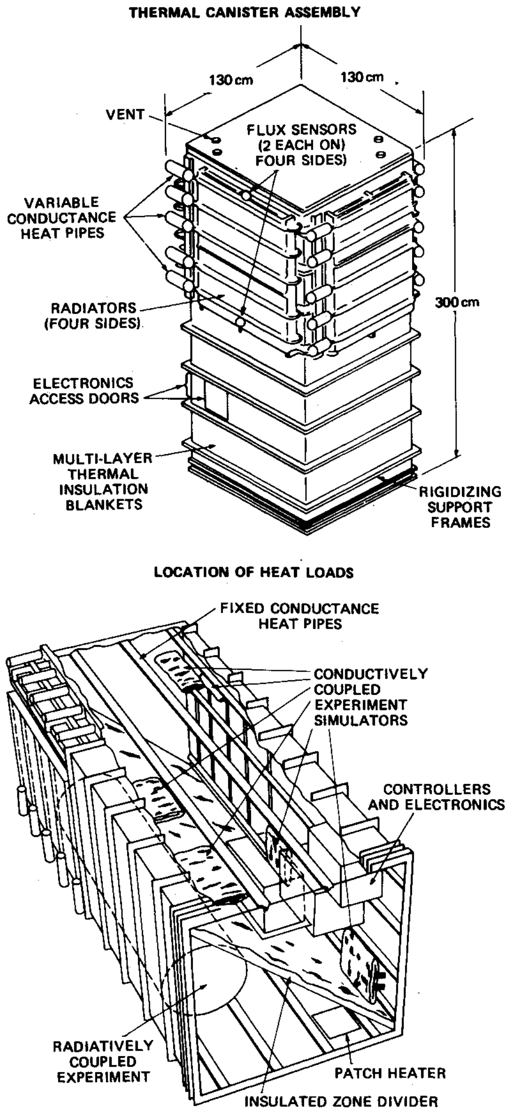


Fig. 1 Thermal canister assembly and location of heat loads.

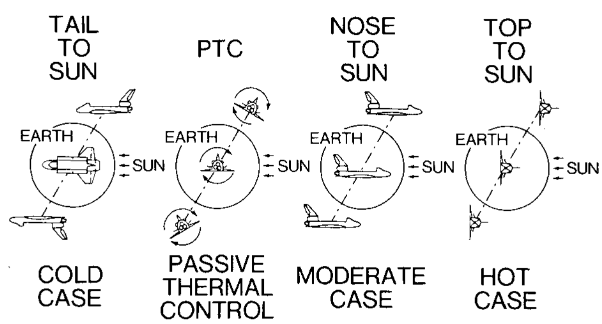


Fig. 2 STS-3/OSS-1 Shuttle attitudes.

Table 1 Orbital average fluxes

	$-Z_{LV}$, W/ft^2		$+X_{SI}$, W/ft^2		PTV, W/ft^2		$+Z_{SI}$, W/ft^2	
	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted
FWD$_L^a$	5.8	1.9	9.9	6.1	16.8	7.1	24.1	18.4
FWD$_U^b$	4.6		7.8		11.7		17.9	
PORT$_L^a$	5.4	1.9	11.9	4.3	17.3	8.8	27.7	17.5
PORT$_U^b$	4.7		8.8		12.5		17.9	
AFT$_L^a$	4.8	1.7	10.7	6.6	13.4	6.6	25.1	22.3
AFT$_U^b$	4.9		11.3		12.5		21.4	
STBD$_L^a$	6.1	2.8	9.8	6.6	15.7	8.3	24.8	16.1
STBD$_U^b$	6.2		9.3		12.5		15.7	

[a] L = Located on lower radiator segment. [b] U = Located on upper radiator segment.

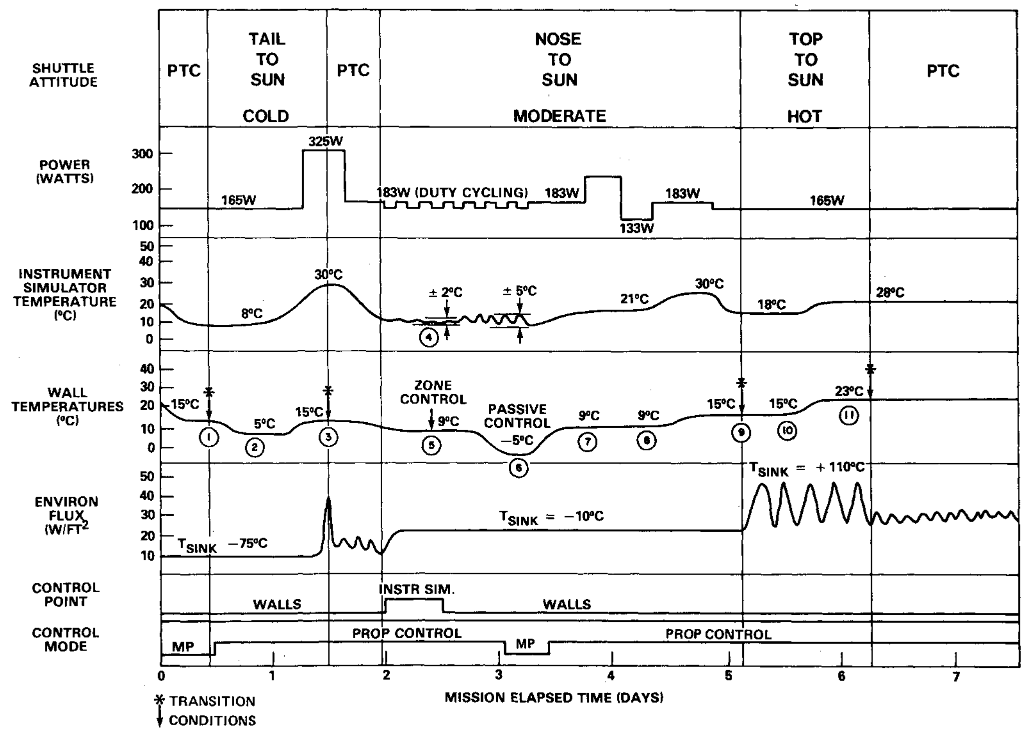
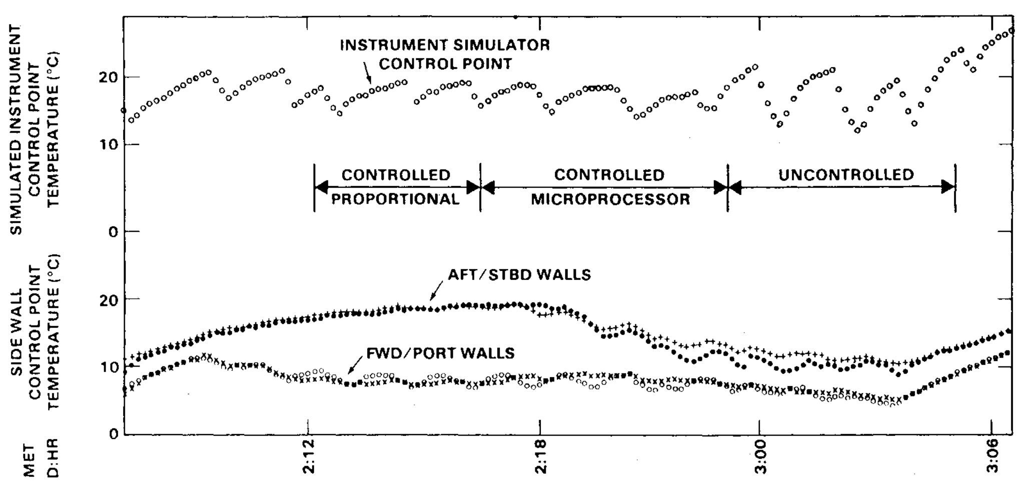


Fig. 3 Thermal canister experiment flight profile achieved on STS- 3/OSS-1.



RAD PWR (CYCLE)	80W 0W 80 0 80 0 80 0 80 0 80	80 0 80 0 80 0 80 0 80	0 80 0 80 0 80	0 80 0 80
COND PWR	105W	93W	83	105
CONT POINT	W/I	W/I	W/W	W/W
CONT MODE	PC	MP	MP/PASSIVE	PC
CONT TEMP	9/-1°C	9/0°C	10/26	10/26
ORB. ATT	+XSI			

KEY: W/I = WALL/INSTRUMENT, MP = MICROPROCESSOR CONTROL
PC = PROPORTIONAL CONTROL, W/W = WALL/WALL

Fig. 4 Flight data thermal canister experiment instrument simulator control.

trolled utilizing the software built into the computer.[3] Reservoir heater power on the variable conductance heat pipes was not measured but the fact that control was maintained indicates that the 5-W heaters on each variable conductance heat pipe (VCHP) were sufficient in size.

Flux Measurements

Thermal flux impinging on the thermal canister was measured through the use of sensors mounted on the upper and lower segments of the radiators. These sensors were decoupled from the radiators and were coated with silverized Teflon, the same coating used on the radiators. By measuring the temperature of these sensors, the total absorbed thermal flux from direct and indirect sources could be calculated. As can be seen in Table 1, the orbital average fluxes absorbed by the canister were higher than predicted. This is generally due to higher thermal input from the Shuttle cargo bay in the cold and moderate cases and coatings uncertainties in the hot case. The ramifications of these warmer environments were that during the flight in the moderate and hot Shuttle attitudes either the internal power or set point temperature had to be adjusted to accomplish control stability. Figure 6 shows the achieved stable heat rejection conditions compared to predictions.

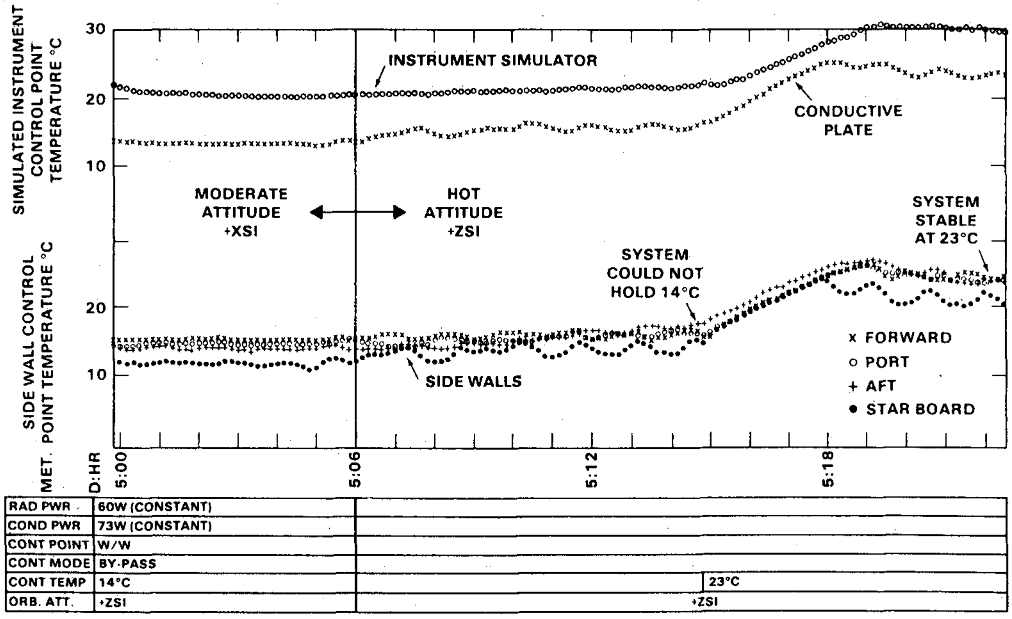


Fig. 5 Flight data thermal canister experiment moderate to hot transition.

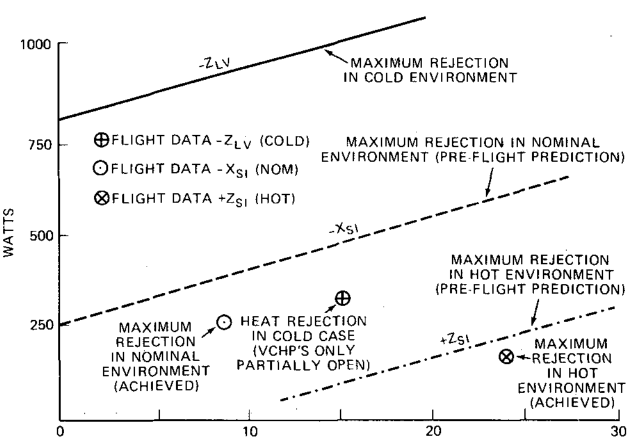


Fig. 6 Thermal canister STS-3/OSS-1 heat rejection capability.

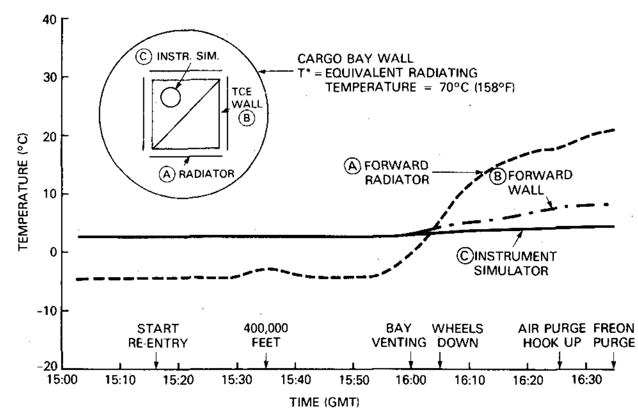


Fig. 7 Thermal canister experiment (TCE) re-entry data.

Re-entry and Landing

The canister has a unique feature not found in passive or cooling loop systems, in that the variable conductance heat pipes will automatically shut down when the environmental sink temperature exceeds the evaporator temperature. A shutdown occurs when the noncondensible gas in each heat pipe reservoir floods the condensor and enters the original evaporator site, causing a diode action which prevents any reverse heat flow from the radiators into the canister. This is especially important to instruments using temperature sensitive film where overheating during re-entry could affect the images. Data taken during re-entry, immediately following landing but before the auxiliary cooling system startup (Fig. 7) shows the radiators outside the canister heating up to 28°C while the instrument simulator remained at nearly a constant temperature. Although the temperature levels for this flight are not extreme, higher extremes could be expected had the Shuttle not been preconditioned to a cool temperature prior to re-eentry.

Anomalies

During and after the flight two anomalies were observed: the microprocessor resets and considerable Kapton erosion. The microprocessor, containing a Z-80 chip, reset 28 times during the flight, making internal sequencing almost impossible. The resets could not be correlated to any known Shuttle-induced conditions or orbital environments, such as sunspot activity or passages through the trapped radiation belt over the southern Atlantic ocean. Upon return, the canister was operated for 14 days with no resets being recorded. It is therefore still unknown what caused the problem. Aside from this reset problem, the computer provided excellent data acquisition and temperature control functions.

After experiment deintegration, it was noticed that the Kapton surrounding the heat pipe reservoirs and exposed to the environment had changed texture. Further investigations with samples revealed significant weight loss (16-35%), a change in α/ϵ from 0.62 to 0.83, and severe embrittlement. Other samples of Kapton taken from the Contamination Monitor Package (CMP) and camera "C" on the Shuttle showed similar erosion. This degradation is thought to be caused by the interaction of the material with atomic oxygen, ultraviolet radiation, and temperature.[4] The degree of erosion is heavily dependent on the relative position of the surface with respect to the vehicle velocity vector. Further ground and flight tests of Kapton samples are planned to isolate and overcome this problem.

Conclusions

The Thermal Canister Experiment achieved all its primary objectives and the majority of its secondary objectives. No heat pipe dryouts could be discerned and their performance exceeded ground testing. It is felt that through this flight test, the thermal canister concept has been proven and it is ready for operational use to house scientific instruments which will be flown on future Shuttle missions.

References

[1]"Heat Pipe Design Handbook," NTIS N-81-70112, Vol. 1, June 1979.

[2]Harwell, W., "The Thermal Canister Approach to Instrument Thermal Design," ASME Paper 80-ENAS-23, July 1980.

[3]"Thermal Canister Experiment Flight Performance Report," NAS-5-26970, Feb. 1983.

[4]Leger, L.J., "Oxygen Atom Reaction with Shuttle Materials at Orbiter Attitudes – Data and Experiment Status," AIAA Paper 83-0073, Jan. 1983.