Engineering Notes

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NASA Skylab I Airlock Module Thermal Capacitor

JOHN L. STAFFORD* AND MICHAEL G. GROTE†
McDonnell Douglas Astronautics Company, Saint Louis, Mo.

Introduction

SKYLAB I is a manned Earth orbiting research laboratory scheduled to be launched by NASA in 1973. It consists of a cluster of modules, including the Airlock Module and the Orbital Workshop. The Airlock Module and Orbital Workshop active cooling systems employ space radiators augmented by thermal capacitors.

Airlock thermal control systems employ surface radiation coatings, thermal curtains, and electric heaters to provide a favorable heat balance with the external environment and an active coolant system to remove, transport, and dissipate internally generated heat loads. The coolant system is comprised of two separate and redundant loops and provides active cooling to the suit cooling module, environmental control equipment, and coldplate mounted equipment. The suit cooling requirements are the most demanding, requiring the lowest temperature coolant and most accurate control of the coolant temperature. The Airlock thermal capacitor, located downstream of the radiator, acts to reduce the coolant temperature variations due to fluctuation in the radiator heat dissipation capability. A 40°F temperature control valve regulates coolant flow through the radiator by mixing capacitor outlet and radiator bypass coolant.

Low-Temperature Coolant Requirement

When an astronaut is performing duties outside the pressurized Skylab (EVA), or certain experiments within the Skylab cluster (IVA), his body temperature control is accomplished by a liquid cooled garment using water as coolant. The suit cooling heat load is transferred by heat exchangers from the cooling water to the space radiator coolant system.

The design heat loads imposed on the radiator coolant system are continuous, resulting in the specification of radiator performance in terms of the maximum continuous heat rejection capability. For EVA or IVA operation, this is 12,000 BTU/hr. The design suit cooling heat load is distributed such that approximately 2440 BTU/hr must be transferred upstream of the 40° temperature control valve. This requires the radiator outlet or upstream heat exchanger inlet to not exceed 28.8°F. This design point exceeds the capability of the radiator system without the thermal capacitor (Fig. 1). The total heat load on the radiator determines the radiator outlet temperature and thus the allowable upstream heat exchanger heat load. The Earth orbiting vehicle external environment is not continuous, but has a large periodic fluctuation due to the changing relative positions of the vehicle, Earth, and sun. The continuous radiator heat rejection is thus limited to the minimum instantaneous capability for any given orbit definition. This leaves a significant excess of available cooling during the "dark" side of the orbit which, if a means could be devised to store it, would be useful for "sun" side cooling. Increasing radiator performance requirements may have been satisfied by increased radiator area or by the addition of a heat storage device upstream of the suit cooling heat exchangers. A greater confidence of achieving the low-delivery temperature requirement was provided by the orbital averaging effect on the radiator outlet temperature of the heat storage device.

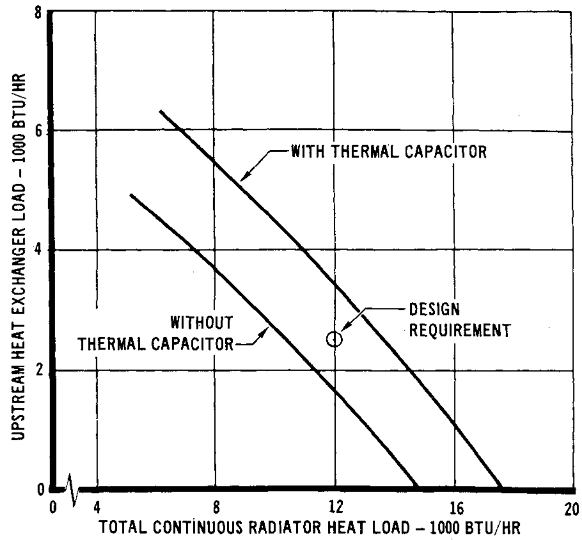

Fig. 1 Maximum heat load upstream of temperature control valve.

Phase Change Material Application

Phase change materials had been previously studied and to a very limited extent used, to provide heat sink for periodically loaded electronic component cooling. Potentially such a device could be used to provide heat storage to dampen the cyclic radiator capability. The capacitor was required to exchange heat with the Airlock liquid coolant loops. In previous research, it had been determined that a high-conductivity matrix embedded in a PCM (Phase Change Material) greatly improved its heat-transfer performance. These investigations had also evaluated several matrix candidates: Sponge Metal, Honeycomb, and Aluminum Fins. Aluminum Fins, similar to those used in the coldplates were selected for Airlock since they were easy to fabricate and could be rigidly attached to the face plate of the coldplates by existing fabrication (brazing) techniques. Alternating the direction of corrugation within the core (Fig. 2), made the fins self-locating for the brazing process, and the gap between the core and the frame allowed the PCM to flow freely within the chambers. The PCM selected had to be readily available, nontoxic, compatible with aluminum coldplates and fins, and have a melting point sufficiently less than the 28.8°F coolant temperature to provide the heat transfer required for the design suit cooling heat load. Although water was an obvious candidate, it failed to meet two basic requirements. One, water expands on freezing raising the possibility of local failures in the structure. Secondly, water, with the additives necessary to lower its freeze point below 28°F, is corrosive to aluminum.

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* Senior Thermodynamics Engineer.

† Thermodynamics Engineer. Associate Member AIAA

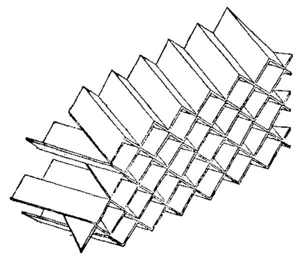

Fig. 2 PCM chamber fins.

Reference 1 showed the normal paraffins to have adequate heats of fusion and melt temperatures in the range of interest. In addition, the paraffins are compatable with aluminum and contract upon freezing. Two paraffins were particularly promising; Tridecane and Dodecane. Their properties are tabulated in Table 1.

Preliminary analysis of the two paraffins showed that Tridecane provided a greater radiator/capacitor combined heat rejection capability for the Airlock coolant loop, primarily due to the phase change temperature being near the required 28.8°F suit cooling module inlet temperature. Studies showed the need for a heat storage capability of 1200 BTU, requiring approximately 20 lb of Tridecane. From a detailed thermal analysis considering the PCM-to-fins-to-coldplate conductance, it was shown that a 1 in. thick PCM chamber achieved adequate conduction heat transfer to meet these requirements and provide an ullage space for expansion of the PCM.

Capacitor Prototype Tests

Two types of tests were conducted. The first test objective was to develop a thermal model. The capacitor inlet temperature was varied from +40°F to −15°F and back to 40°F at a constant flow rate of coolant.

Heat-transfer coefficients from the fluid to the coldplate faceplate were calculated using available coldplate data. An effective conductance of wax was found by calculating a conductance from the faceplate through the aluminum matrix core fin in series with a conductance from the fin into the wax. When the thermal model was run, the results did not agree with test data. At first, it was thought that the simplified conduction model was in error, but after trying other effective conductances, the data still could not be correlated. Finally, by changing the melt and transition temperatures to 20.5°F and 0.0°F, respectively, the correlation was excellent.

In the second test, the thermal capacitor inlet temperature and flow rate profiles were made to correspond to conditions that the thermal capacitor would encounter during a normal orbit. The inlet temperatures were varied from 36°F to −13°F while the coolant flow rate was varied. Figure 3 shows the capacitor inlet and outlet temperatures measured and the thermal model predicted outlet temperature for the prototype tests.

Radiator/Capacitor Performance Predictions

The test-correlated thermal model of the thermal capacitor was incorporated into the Airlock radiator coolant loop thermal model with the results shown in Fig. 1, showing that the original suit cooling design conditions can be met and even exceeded.

Table 1 Candidate paraffin phase change properties

	Tridecane	*Dodecane*
Melting temperature	22.3°F	14.7°F
Heat of fusion	65.4 BTU/LBM	93.0 BTU/LBM
Structural transition temperature	−0.6°F	—
Heat of transition	17.9 BTU/LBM	—

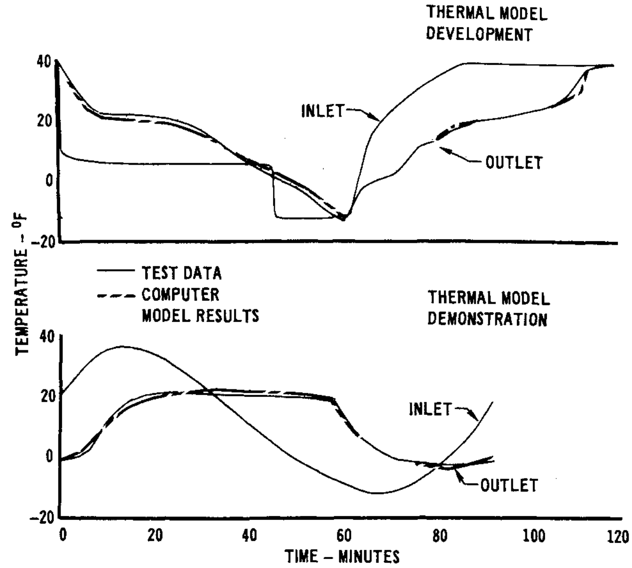

Fig. 3 Capacitor prototype test results.

Conclusions

The Airlock thermal capacitor development has demonstrated the feasibility of a new concept in the application of phase-change materials to the temperature control of an Earth orbiting vehicle. As a result of the averaging effect of the thermal capacitor, the radiator performance in terms of potential for heat rejection was increased for the same radiator area. The thermal capacitor was not optimized with respect to usual design parameters, but conservative estimates were made and tried in the interest of limiting time spent in the development.

References

[1] Broadhurst, M. G., "An Analysis of the Solid Phase Behavior of the Normal Paraffins", *Journal of Research of the National Bureau of Standards—A. Physics and Chemistry*, Vol. 66, No. 3, May–June 1962, pp 241–249.

Thermal Control of a Jovian Survivable Probe

Bruce G. Schelden*
Martin Marietta Corporation, Denver, Colo.

Introduction

A STUDY was conducted to determine the technical feasibility of a 1978 atmospheric probe mission to Jupiter.[1] A part of that study was an evaluation of thermal protection

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* Group Engineer, Thermophysics Section.