(NASA-CR-143797) ERTS-C (LANDSAT 3) CRYOGENIC HEAT PIPE EXPERIMENT DEFINITION Final Report (B & K Engineering, Inc., Towson, Md.) 87 p HC $4.75 CSCL 13A

N75-23882

Unclas
G3/34 21436

BK005-1009

ERTS-C (LANDSAT III) CRYOGENIC HEAT PIPE EXPERIMENT DEFINITION

FINAL REPORT

March, 1975

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT, MD. 20771

Under

Contract No. NAS5-20968

Prepared by

P. J. Brennan
E. J. Kroliczek

B & K ENGINEERING, INC.
Towson, Maryland 21204

FOREWORD

This report describes the work performed under Contract No. NAS5-20968 for the National Aeronautics and Space Administration. Mr. Stan Ollendorf served as Technical Officer. Messrs. P. J. Brennan and E. J. Kroliczek of B & K Engineering, Inc. were Co-Investigators.

Special thanks to Dr. Allan Sherman of GSFC for his valuable inputs throughout the course of this work.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLES

ILLUSTRATIONS

1.0 REQUIREMENTS

1.1 General

The purpose of this effort was to define and evaluate a flight experiment designed to demonstrate current cryogenic heat pipe technology. The experiment package developed is specifically configured for flight aboard an ERTS type spacecraft.

Two types of heat pipes have been included as part of the experiment package: A transporter heat pipe and a thermal diode heat pipe. Each will be tested in various operating modes. Performance data obtained from the experiment will be applicable to the design of cryogenic systems for detector cooling, including applications where periodic high cooler temperatures are experienced as a result of cyclic energy inputs.

1.2 Objectives

The objectives of the experiment will be to obtain data in "Zero-G" to verify the performance of the two heat pipes and will include the following:

(a) Determination of the "Zero-G" start up performance for both heat pipes.

(b) Operate both heat pipes continuously over extended periods of time in a steady state forward mode to permit evaluation of long term system performance in space.

(c) Demonstrate diode operation including forward conductance, turndown ratio and transient behavior.

(d) Determine transport capability of each heat pipe at low and high operating temperatures.

1.3 Design Constraints

The following design constraints and guidelines were followed in the design of the experiment package.

1.3.1 Heat Pipes

Two basic heat pipe components are to be tested in the experiment as follows:

1.3.1.1 Transporter Heat Pipe

The purpose of the transporter heat pipe will be to demonstrate the application of NASA/GSFC developed low cost, high reliability axial groove technology to the cryogenic temperature range. The heat pipe will be an extruded axial groove design, fabricated from 6063 or 6061 aluminum alloy and designed to operate in the 150°K to 250°K range with ethane as the working fluid.

1.3.1.2 Thermal Diode Heat Pipe

A cryogenic diode heat pipe developed by NASA/ARC will be tested to establish forward mode performance, turndown ratio, and transient shut down energy. The diode will operate in the same temperature range as the transporter heat pipe component. NASA/ARC will be responsible for the thermal diode design and will furnish this experiment subsystem as GFE to the ERTS-C Experiment.

1.3.1.3 Pressure Retention

Both heat pipes will be designed to allow a minimum 5 to 1 pressure safety factor at 300°K temperature.

1.3.1.4 Configuration

The heat pipe configurations are consistent with the geometrical restrictions imposed on the Experiment by the spacecraft. Their lengths are maximized within experiment package constraints in order to permit burn-out with moderate heater power. Each heat pipe is being provided with sufficient evaporator and condenser sections to accomodate the various test modes.

1.3.1.5 Heaters and Instrumentation

Each heat pipe will be provided with redundant electrical heaters capable of effecting the various test modes. Temperature sensors will be provided in the evaporator, adiabatic and condenser sections in sufficient number to obtain the desired data.

1.3.2 Experiment Location

The experiment is to be mounted on the ERTS-C spacecraft sensory ring in the earth pointing direction. It is to be located between the MSS and the DCS antenna. A four (4) inch clearance off the sensory ring is required for cabling. The maximum height of the experiment is limited by the DCS antenna which is 23 inches below the sensory ring. The maximum outboard location of the experiment is defined by the maximum Tip-Off contour at 24 inches below the sensory ring. This is the required clearance for spacecraft separation under maximum allowable OFF nominal conditions. The maximum inboard location of the experiment is limited by the RBV cameras.

1.3.3 Thermal Environment

The experiment is configured to provide maximum heat rejection capacity within radiator size limitations and under the following thermal conditions.

1.3.3.1 Spacecraft Parasitic Heat Leaks

The experiment is thermally isolated to the best degree possible from the spacecraft. This will be accomplished by appropriate use of multi-layer thermal blankets and thermal isolators. Radiation coupling between the experiment radiator and the spacecraft was based on a spacecraft temperature of 300°K and a view factor of 1.0 between the back of the radiator and the spacecraft.

1.3.3.2 Earth Inputs

The surface of the experiment radiator is normal to the earth's surface. Earth inputs will be those associated with the 500 nautical miles, 9:30 A. M. orbit of the spacecraft. A deployable shield has been incoporated as part of the experiment design to minimize earth input.

1.3.3.3 Solar Input

The radiator surface will view deep space at all times and will not be subjected to solar inputs.

1.3.4 Structural Requirements

The experiment is designed to be self-sufficient in the ERTS dynamic load environment. The support structure for the experiment will withstand the dynamic loads as defined in Table 1-1 (Ref. 1)

Table 1-1. ERTS Dynamic Test Requirements-Qualification Level

(Below the torus on lo[illegible] mounts)

SINUSOIDAL

Frequency Range (Hz)	Amplitude - "g" 0-to-Peak	
	Thrust	Transverse
5-40	8.0 *	-
40-200	10.0	-
200-2000	5.0	-
5-60	-	6.0*
60-200	-	18.0
200-2000	-	5.0

RANDOM**

Frequency Range (Hz)	Power Spectral Density (g^2/Hz)	g-RMS	Duration
20-2000	0.09	13.4	4 Min/axis

* Exposure limited to 0.5" double amplitude.

** These levels apply to all three axes.

Sweep rate: 1 octave/minute

Reference: "Environmental Test Specification For The ERTS (A AND B) and Nimbus (E AND F) Observatory Systems, Subsystems and Experiments" S-320-EN-1, November, 1971

2.0 EXPERIMENT DESIGN DEFINITION

An experiment designed to test cryogenic heat pipe hardware in the 150°K to 250°K range and configured for flight aboard the ERTS-C spacecraft is shown in detail in Dwg. No. BK005-1006. The experiment will be mounted to the sensory ring of the spacecraft in the earth pointing direction. It will be located between the MSS and the DCS antenna as shown in Dwg. No. BK005-1002.

2.1 Design Description

The experiment package shown in Fig. 2-1. is designed to meet the requirements outlined in Section 1.0. The major components of the experiment are summarized in Table 2-1. Each component design and their operational mode are discussed in detail in Sections 3.0 and 4.0.

The experiment package is sized to fit within the allowable envelope identified in Section 1.3.2. The experiment is 70-cm (24.75-in.) wide, 48.2-cm (19-in.) high and 30-cm (11.75-in.) at its deepest point. The back of the experiment is indented in the center to clear the RBV cameras. Estimated weight of the experiment is 13.6-Kg (30-lbs.). A weight breakdown is given in Table 2-2.

The experiment is cantilevered off the spacecraft sensory ring by a stainless steel tubular structural frame. The structure is attached to the spacecraft at five points via Lexan isolators. The heat pipes and the radiator are in turn mounted to the frame via isolator pads (i.e. Lexan) to obtain additional thermal isolation. The back of the radiator, the heat pipes and the structure will all be insulated with MLI to minimize radiant heat inputs from the spacecraft.

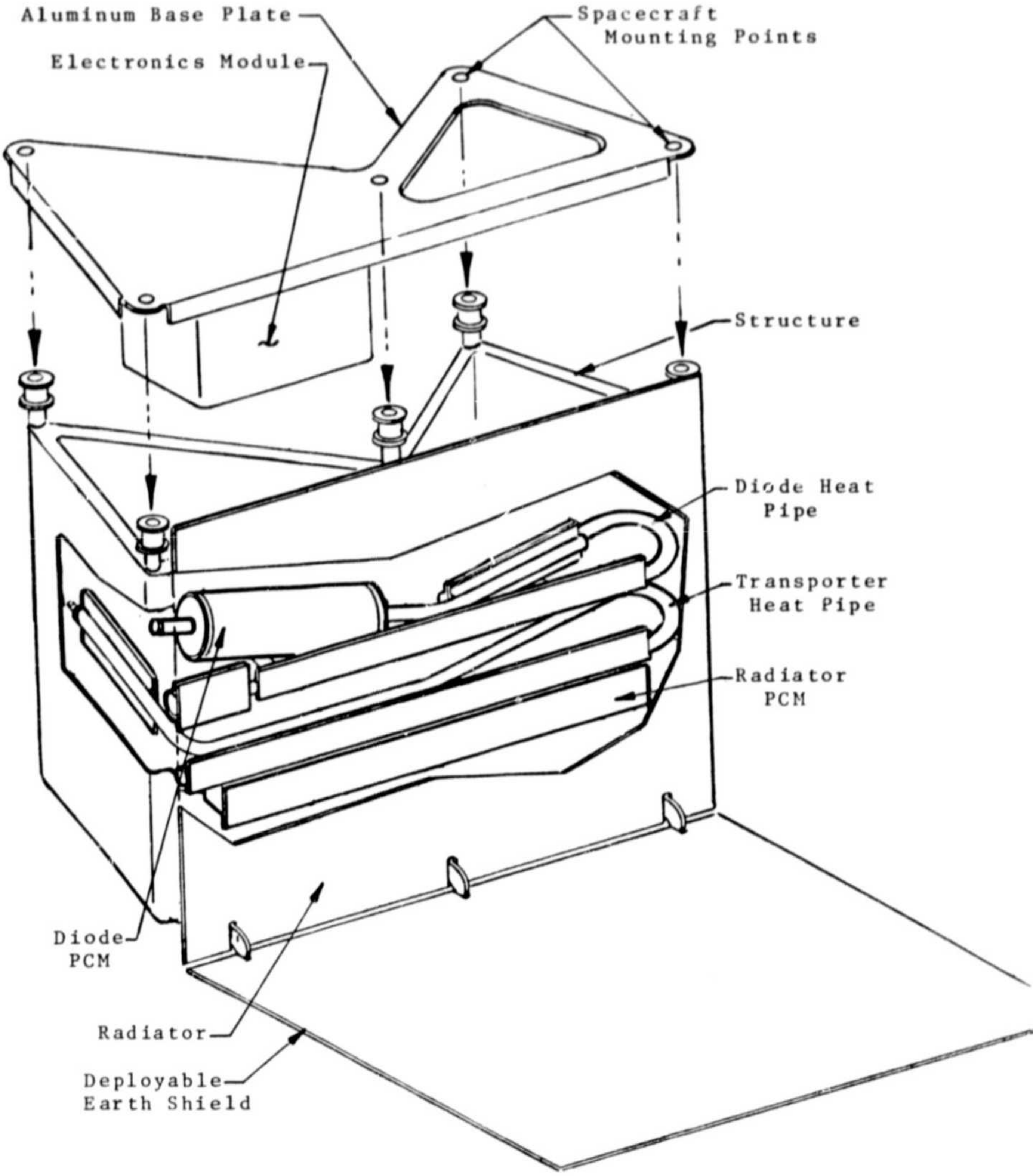


FIGURE 2-1. ERTS-C CRYOGENIC HEAT PIPE EXPERIMENT

Table 2-1. ERTS-C Cryogenic Heat Pipe Experiment Design Summary

ITEM	FUNCTION	DESCRIPTION
Transporter Heat Pipe Experiment	Performance testing of low cost, high reliability grooved heat pipe technology at cryogenic temperatures	Consists of a primary heat pipe and a back-up heat pipe. Baseline design is 6063 extruded Axial groove form with ethane working fluid. Integral saddle design extruded as part of the grooved tubing
Thermal Diode Heat Pipe Experiment	Performance testing of advanced heat pipe thermal control technology for cryogenic applications	Consists of a diode heat pipe, a PCM thermal mass and a PCM heat pipe. Design to be specified by NASA/ARC.
Radiator	Dissipation of heat to space	Aluminum flat plate design with white paint emissive coating.
Radiator Shield	Blockage of earth heat inputs	Design undefined at this point. Baseline design selected requires the shield to be deployable, equal in size to the radiator and to have a specular surface facing the radiator.
Radiator PCM	To augment the radiator during low temperature high power testing of the heat pipes	Aluminum container designed to be bolted to radiator. Design modeled after the ATFE design. Trans-2-Butene tentatively selected as the PCM.
Isolators	Minimize thermal conduction from the spacecraft	Isolator stand-offs designed with low-conductivity Lexan. Located between the S/C and the structure; the structure and the radiator; and between the heat pipes and the structure.
Insulation	Minimize radiant heat input from the spacecraft	ML1 insulation blankets covering the back of the radiator, the heat pipes and the structure and that portion of the sensory ring viewing the front-face of the radiator. PCM packages will also be covered.

Table 2-1 Continued

ITEM	FUNCTION	DESCRIPTION
Instrumentation	Monitor experiment temperatures and heater currents	Platinum transducers or thermistors for temperature; resistors for current.
Electrical Heaters	Provide heat to test heat pipes	Nichrome/kapton foil elements
Electronic Module	Provide signal conditioning, current sensors and command functions	Detailed design undefined at this point. Baseline design, size and weight consistent with ATFE design.

Table 2-2. ESTIMATED WEIGHT OF ERTS CRYOGENIC HEAT PIPE EXPERIMENT

	lb.	Kg
Structure, Isolators & Mt'g Hardware	7.2	3.27
Radiator	2.2	1.00
Radiator PCM	4.0	1.82
Transporter Heat Pipe (2)	1.9	0.86
Diode Heat Pipe & PCM Package	4.6	2.09
Deployable Shield	2.6	1.18
Insulation	1.5	0.68
Wire Harness, Instrumentation and Heaters	1.5	0.68
Electronics Module	4.5	2.04
Total Weight	30.0	13.62

The experiment package is designed to achieve a number of test conditions at various temperatures while minimizing the interaction between individual components and test modes. The design includes a "low temperature" ($\sim$ 170°K) PCM, for high power testing of the heat pipes at low temperatures, and a "high temperature" PCM ($\sim$ 190°K), for the "reverse mode" testing of the diode heat pipe. A wide temperature spread between these two points was selected to avoid any influence of one PCM system on tests related to the other PCM. During the cycling of the diode between its forward and reverse modes, for example, the heat of fusion of the radiator PCM should not interfere with the transient temperature rise of the radiator while the diode shut-down or turn-on is being effected. The operating temperature for long term steady state performance for each of the pipes was selected between the two PCM Control temperatures (i.e. 180°K.) After detailed analysis, the temperature spread between the two PCM may be narrowed in order to allow testing of the diode heat pipe at a lower temperature.

Experiment heater power and parasitic heat inputs will be dissipated to space by a passive radiator. The radiator will be aluminum and will be coated with white paint. An earth shield is provided as part of the experiment to minimize earth input. Also,a 170°K PCM package will be integrated with the radiator system to allow short term high power tests of the heat pipes at lower temperature. The predicted performance for the experiment is given in Section 2.2. A description of the operating modes is summarized in Section 3.0. Electrical heaters will provide the heat loads required to test the heat pipes. Individual heaters with separate commands will be used to affect a number of different operational modes. The number of heaters which will be required to perform the various tests together with power requirements are summarized in Table 2-3.

Experiment performance will be monitored with temperature sensors located throughout the experiment. The telemetry list is given in Table 2-4. Signal conditioning and command functions will be supplied by an electronics module which has been incorporated as part of the experiment package. The electronics module will be attached to an aluminum plate which is bolted to the spacecraft side of the Lexan isolators. Heat from the module will be conducted to the spacecraft.

2.2 Thermal Performance

The thermal performance of the experiment is dependent on the heat rejection capacity of the radiator. Net radiator capacity as a function of operating temperature is shown in Figure 2-2. Also shown in Figure 2-2 are the gross radiator capacity (total emittance) and parasitic heat inputs consisting of earth input, radiation from the shield and spacecraft, and conduction from the spacecraft. The radiator performance was based on an earth shield equal in size to the radiator. Details of the thermal analysis are summarized in Appendix A.

A minimum steady state radiator operating temperature of 160°K was calculated for the case of no electrical power input. At the melting point of the radiator PCM ($\sim$ 170°K), the net radiator capacity is approximately 3 watts. To freeze the radiator

Table 2-3. Command and Power Requirements

Experiment Component	Command Function*	Nominal Power** (watts)
Transport Heat Pipe	T1	3
	T2	3
	T3	20
	T4	20
Back Up Heat Pipe	B1	3
	B2	20
	B3	20
Diode Heat Pipe	D1	3
	D2	20
	D3	20
	D4	3
Diode PCM	P1	3
Radiator	R1	25
	R2	25
Experiment/Electronics Module	ON/OFF	5
Total ON/OFF Commands	15	

* Except for the Experiment Command, all commands are ON/OFF functions for distinct component heaters.

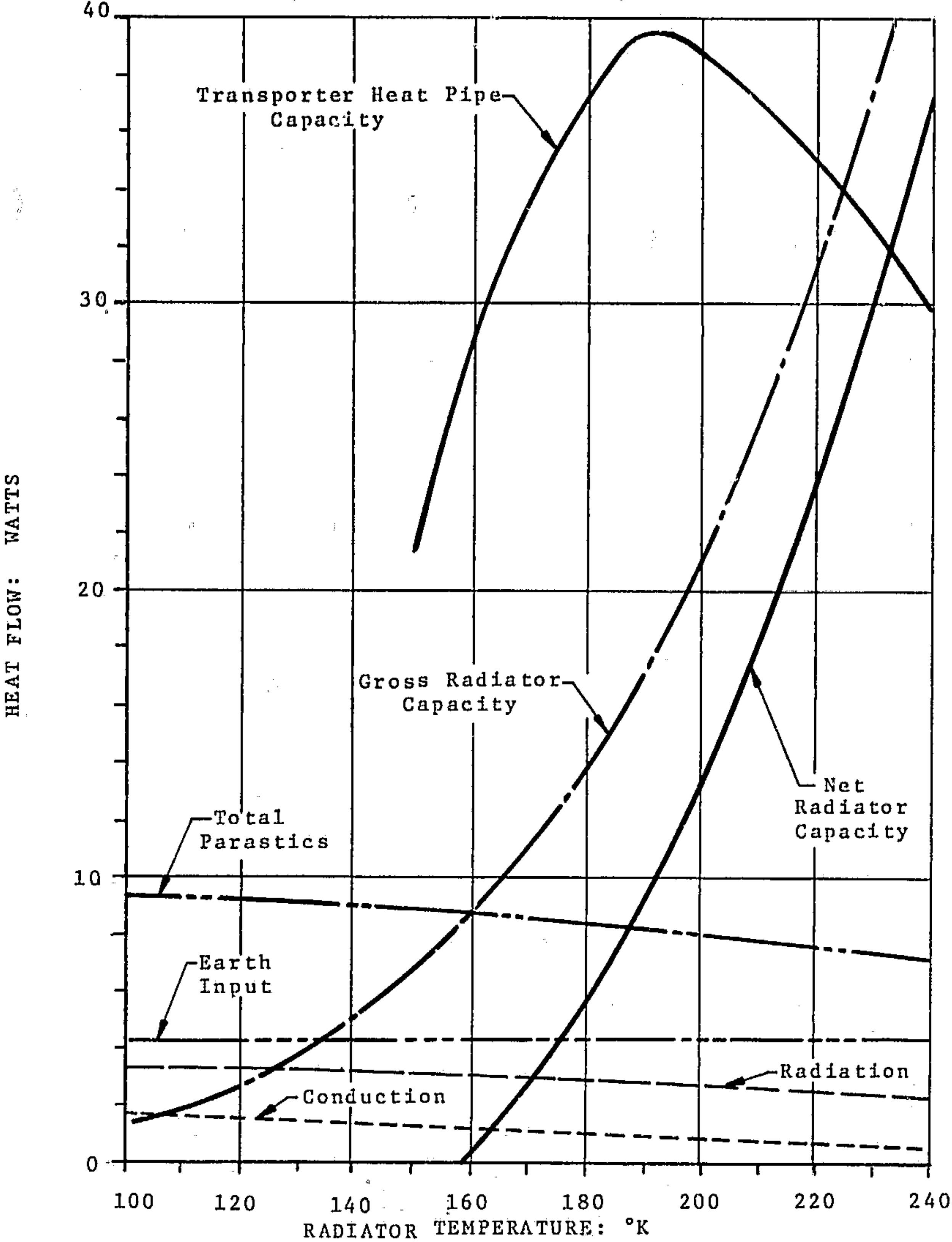
** Maximum total power for any operational mode including experiment telemetry is 45-watts.

Table 2-4. Telemetry List

Experiment Component	Preferred # of Channels	Minimum # of Channels
Transport Heat Pipe		
Evaporator	4	2
Adiabatic	2	1
Condenser	5	2
	11	5
Back-up Heat Pipe		
Evaporator	4	2
Adiabatic	2	1
Condenser	5	2
	11	5
Diode Heat Pipe		
Evaporator	4	2
Low K	4	2
Adiabatic	2	1
Condenser	4	2
Reservoir	1	1
	15	8
Radiator PCM		
3 axial x 3 circumferential	9	4
Diode PCM		
3 axial x 3 circumferential	9	4
Radiator	6	4
Total Temperature Sensors	61	30
Heaters:		
Max.- 1 current sensor/heater	13	--
Min.- 1 current sensor/heater less than 5 watts	--	6
Total Temperature & Current Sensors	73	34

FIGURE 2-2. EXPERIMENT THERMAL PERFORMANCE

(ONE TO ONE EARTH SHADE)



PCM, therefore, 14 hours will be required for a PCM capacity of 40 watt-hours and with no heat being applied to the heat pipes.

At the 180°K long term steady state operating temperature, the net radiator capacity is approximately 6.0 watts. This will allow testing either heat pipe at that power level or both the transporter and diode heat pipes can be test simultaneously at approximately 3 watts each for the diode and the transporter. The latter case is preferable and was selected for the baseline design since more test hours can be accumulated. Also the size of the heater for the diode heat pipe for such a test mode is more consistent with a limited diode PCM capacity.

Tests of the diode in the reverse/forward modes will be conducted at the 190°K melting temperature of the diode PCM. During this period, the transporter heat pipe heater (3 watts) can be either on or off. With the transporter heat pipe heater on, the time period will be approximately 8 hours for each of the two modes for a 24 watt-hr. diode PCM capacity. With the transporter heat pipe heater off, the time period will be 8 hours for the reverse mode and 4.0 hours in the forward mode.

Finally, the radiator capacity determines the lower level and/or operating temperature for heat pipe "burn-out" tests. The transporter heat pipe capacity is shown in Figure 2-2. As can be seen, it exceeds radiator capacity up to 230°K. Therefore, high capacity tests with only the radiator will be limited to that temperature range. To accomodate low temperature high power tests, a PCM has been included in the radiator as part of the baseline design. A 170°K melting temperature was selected to allow a sufficient temperature drop to conduct the heat from the heat pipe condenser to the PCM. This should allow the heat pipe vapor temperature to be approximately 180°K during high power testing.

3.0 OPERATIONAL MODES

The following summarizes the baseline operational modes of the experiment. These were defined on the basis of predicted radiator performance with a 1:1 shield, a radiator PCM and a diode PCM. It was assumed that up to 45 watts of power would be available to run the experiment package. Optional operational modes are also presented.

3.1 Baseline Operational Modes

The operating modes of the experiment are summarized in Table 3-1. Operating mode profiles are shown in Figure 3-1. Operating modes will be as follows:

3.1.1. Long Term Forward Mode

Both heat pipes will be tested in the Forward Mode over an extended period of time to establish long term operating characteristics. Tests in this mode will be performed continuously except when other short term test modes are being exercised. Slightly more than 3.0 watts of power, including parasitics, will be applied to both the diode heat pipe and the transporter heat pipe during this time. Operating temperature will be approximately 180°K.

3.1.2 Low Temperature Transport Test

Each heat pipe will be exercised to verify maximum capacity at low temperatures. The high power required to perform this test will be accommodated by a PCM package attached to the radiator. Heat pipe operating temperature will be in the 170°K to 180°K range. The radiator PCM capacity will be approximately 40 watt-hours.

Table 3-1 ERTS-C CRYOGENIC HEAT PIPE TEST MODES

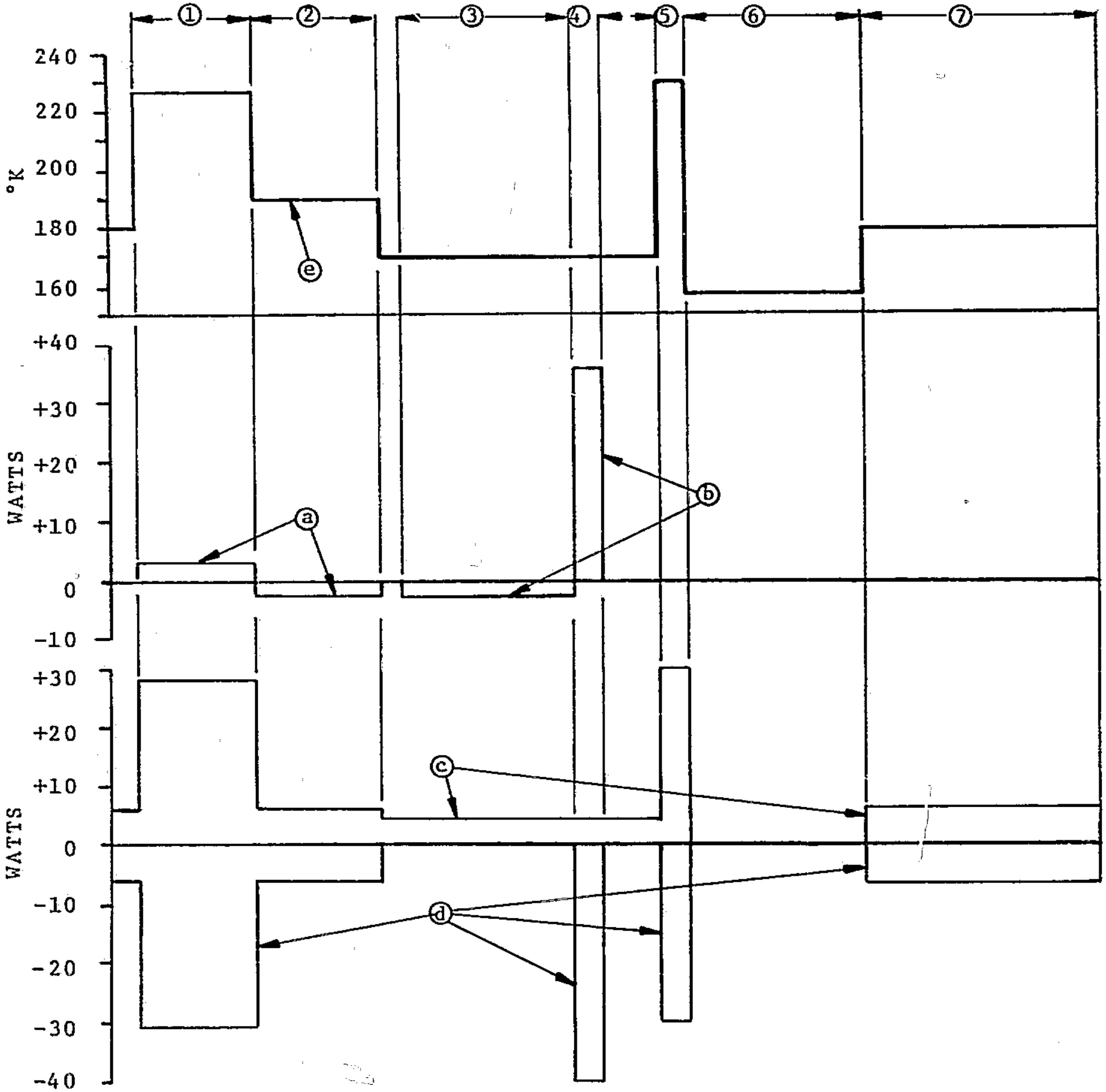
Test Mode	Heat Pipe Component*	Heat Pipe Heat Load (watts)	Total Heater Power (watts)	Heat Pipe Temp. (°K)	Duration** (hrs.)
Long Term Forward	Transporter	3	6	180	Continuous
	Diode	3			
Low Temp. Transport	Transporter or Diode	40	40	180	1.0
High Temp. Transport	Transporter or Diode	26	26	250	8.0
Transient Forward	Diode	9	3	190	8.0
Reverse	Diode	3	28†	190	8.0

* Any mode defined for the transporter is redundant to the back-up pipes.

** Each mode will be exercised at least once/30 days.

† D1 and R1 Heaters.

FIGURE 3-1. TENTATIVE OPERATING MODES PROFILE



LEGEND

① Diode Reverse Mode (~ 8 Hrs.)
② Diode Forward Mode (~ 8 Hrs.)
③ Radiator PCM Cooling (~ 14 Hrs.)
④ Low Temperature Transport Tests (1 to 2 Hrs.)
⑤ High Temperature Transport Tests
⑥ No Load Performance Test
⑦ Steady State Long Term

ⓐ Diode PCM Power Profile
ⓑ Radiator PCM Power Profile
ⓒ Net Radiator Power Profile
ⓓ Total Heater Power Profile
ⓔ Radiator Temperature Profile

3.1.3 High Temperature Transport Test

Maximum capacity at high temperatures for each heat pipe will be verified during this test mode. This will be performed by applying a heat load to the heat pipes, which will increase the radiator temperature to a point above the temperature at which the capacity of the heat pipes is less than the applied heat load.

3.1.4 Transient Forward Mode

This mode applies only to the diode and will occur during cooldown from reverse mode operation. The purpose of this test mode will be to characterize the diode forward mode transient performance. The operating temperature in this mode will be determined by the 190°K nominal melting temperature of the diode PCM (e.g. ethyl acetate). The heat loads during this mode of operation will include the heat dissipated from the simulated detector, parasitic heat loads to the PCM and heat pipe, and the heat of fusion of the PCM.

Combined simulated detector and parasitics will be approximately 3.0 watts. Estimated duration of this mode is 8 hours based on a 24 watt-hours PCM capacity. Beyond this time period the PCM will become sub-cooled and steady state operating temperature will be reached at approximately 180°K.

3.1.5 Reverse Mode

The objective of this test mode will be to characterize the diode shutdown properties including turn-down ratio and shutdown energy. This test will be performed with the diode PCM in a frozen state. A minimum of 25-watts of power will be applied to the radiator with an electrical heater attached to the inboard side of the radiator. This power will raise the temperature of the radiator to a steady state temperature of approximately 230°K. During this mode, heat from the simulated detector, parasitic heat leaks and diode reverse mode heat leaks will be absorbed by the PCM. Duration of the mode of operation will last up to 8 hours and will be dependent on shutdown energy, transient shutdown losses, if any, and diode reverse conductance (turndown ratio).

3.1.6 No Load Mode

Simulation of an actual single detector application where the parasitics to the heat pipes are the dominant heat loads will be performed during this test mode. This will allow evaluation of the basic radiator system including thermal performance verification. Operating temperature for this test mode will be approximately 160°K.

4.0 COMPONENT DEFINITION

4.1 Transporter Heat Pipe

The purpose of the transporter heat pipe will be to demonstrate the "Zero-G" performance of low cost, high reliability, cryogenic, axial groove technology. Two units are included as part of the experiment package (See Dwg. No. BK005-1006). The second unit is a back-up which has been included as a design option.

4.1.1 Design Description

The design selected for the transporter heat pipe (cf. Fig. 4-1) is an extruded ATS-axial groove tube with integral flanges and with ethane as the working fluid. A design summary is given in Table 4-1. This design has been extensively tested on ground with various cryogenic fluids including ethane. (Ref. 2). The performance is well established, and the design has been demonstrated to be cost effective and reliable and can be produced on a timely basis consistent with potential tight spacecraft schedule.

The configuration of the transporter heat pipe, shown in Figure 4-2, was designed to fit within the allowable envelope dimensions of the ERTS-C experiment package. Multiple in-plane bends are used in order to achieve maximum transport length and, hence, maximum heat transport stressing under steady state conditions. All bends are maintained in the same plane to allow "one-g" testing.

The heat pipe condenser is mechanically attached to the radiator via the integral flange as shown in Figure 4-1. Test heaters will be attached directly to the evaporator flange. In all other sections of the heat pipe, the flange is removed (by machining) to facilitate bending and save weight. Lexan thermal isolator supports are provided at four locations to attach the heat pipe to the experiment frame (See Dwg. No. BK005-1006).

4.1.2 Performance

Performance of the axially grooved transporter heat pipe with ethane as the working fluid is shown in Figure 4-3. This performance was derived from Ref. 2. Heat transport capacity with the present configuration ranges from 20 to 40 watts in the operating

TABLE 4-1.

TRANSPORTER HEAT PIPE DESIGN SUMMARY

Design Configuration (cf. Fig. 4-1) -	ATS Extruded Groove with integral saddle
Geometry (cf. Fig. 4-2)	
Overall Length	1.27 m (50 inches)
Evaporator	0.127 m (5 inches)
Condenser	0.483 m (19 inches)
Effective Transport Length	0.965 m (38 inches)
Material	6063 Extruded (6061 optional)
Working Fluid	Ethane
Transport Capacity (cf. Fig.4-3)	37 watts @ 180°K
Conductance	4.65 watts/°C
Internal Pressure @ 27°C (80°F)	631 psia
Burst Pressure @ 27°C-(80°F)	4800 psi as welded condition
Burst Pressure Safety Factor @ 80°F	7.6
Weight	0.43 kg (0.95 lb.)

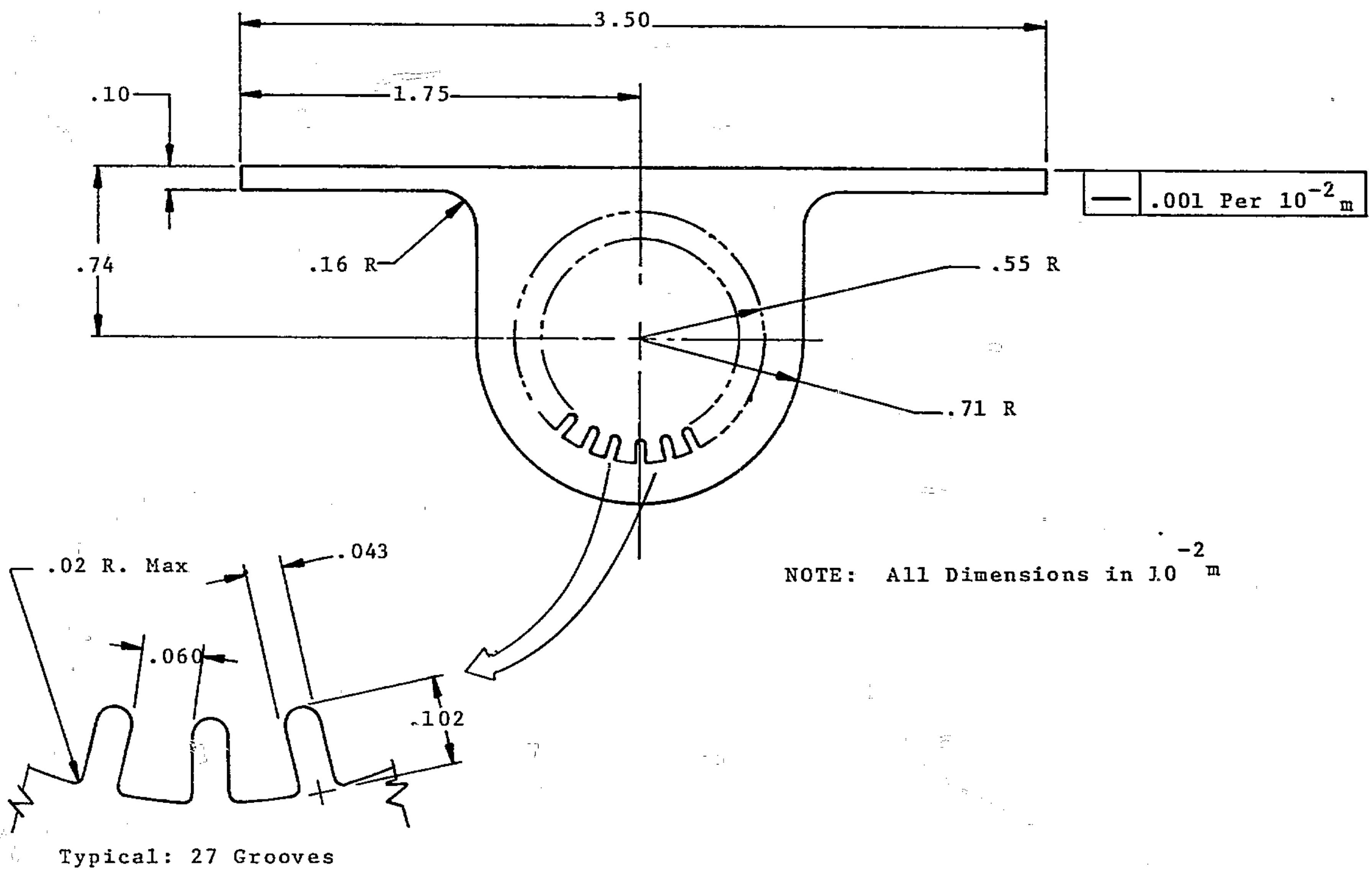
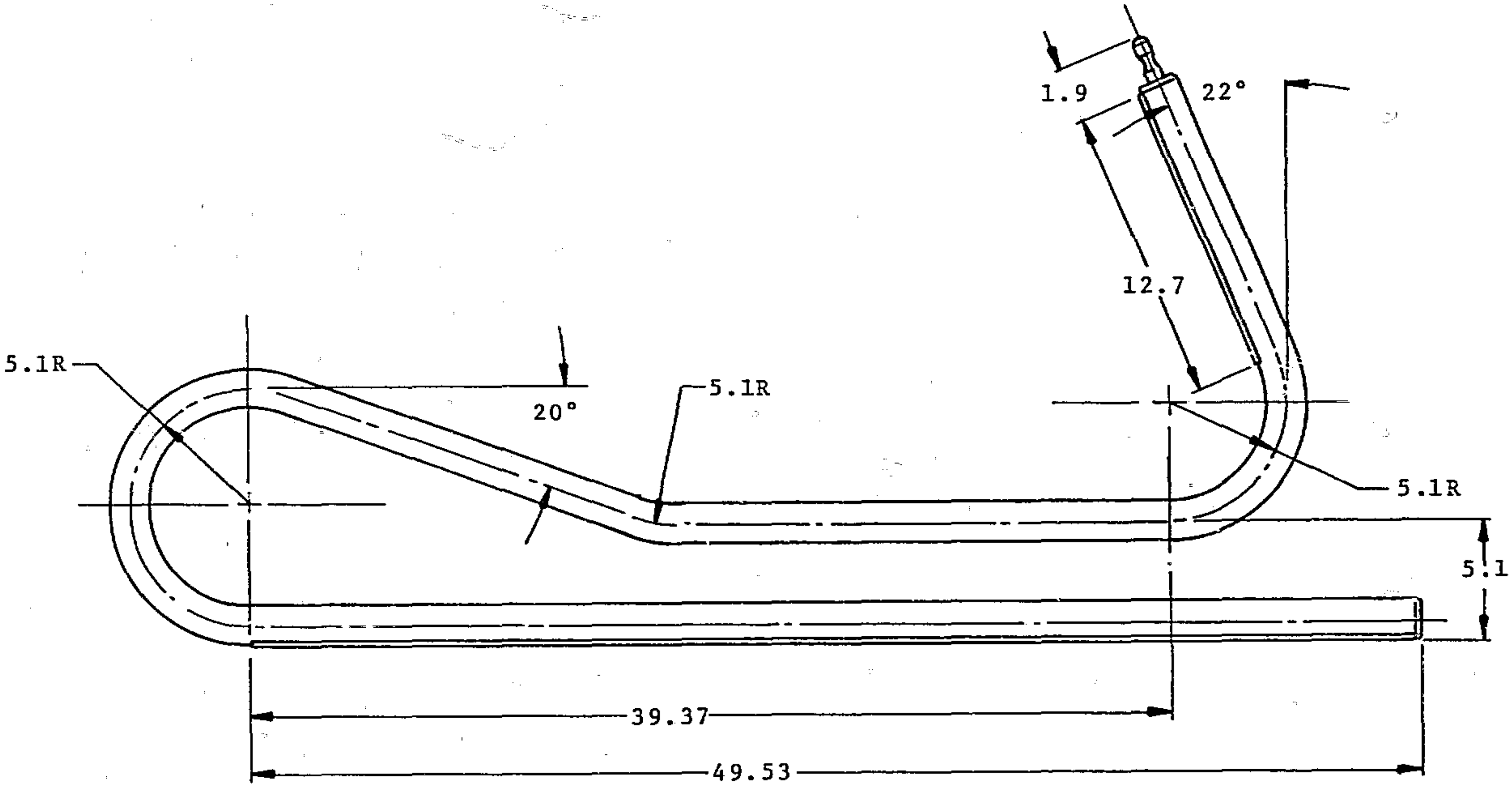


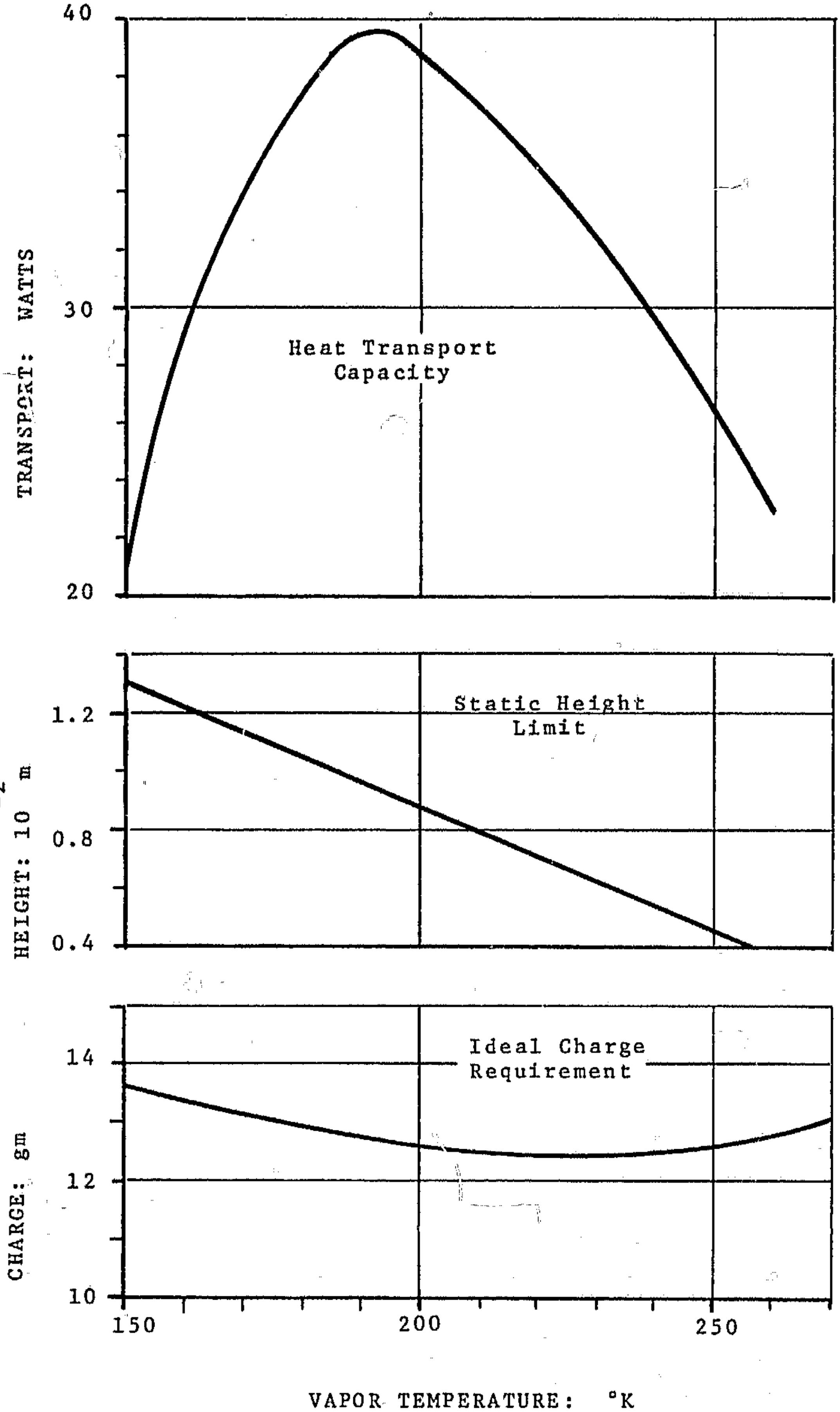
FIGURE 4-1. AXIAL GROOVE EXTRUSION



NOTE: ALL DIMENSIONS IN 10^{-2} m

FIGURE 4-2. TRANSPORTER HEAT PIPE CONFIGURATION

FIGURE 4-3. TRANSPORTER HEAT PIPE
PERFORMANCE CHARACTERISTICS



temperature range of 150°K to 250°K. For the most part, the transporter heat pipe capacity will far exceed the capability of the radiator. For "one-to-one" earth shielding of the radiator, steady state burnout of the transporter heat pipe can only be achieved at a temperature of 230°K or above.

To achieve burnout at the selected operating temperature of 180°K, a PCM system will be required to augment the radiator (see Section 4.5). A 40 watt-hr. storage capacity should be provided by a PCM package attached to the radiator. Approximately 0.9 kg (2.0 lbs.) of Trans-2-Butene will satisfy this requirement.

Also shown in Figure 4-3 is the static wicking height of the transporter heat pipe in a "One-g" environment. At the operating temperature of 180°K, the theoretical static height is 1.05×10^{-2} M (0.41 inches). This will allow sufficient margin for ground testing and should provide reasonable data for "Zero-G" performance extrapolation. At 230°K, however, the static wicking height is down to 0.62×10^{-2} M (0.24 inches) and is in a range where, "Zero-G" extrapolation is difficult because of puddle flow contributions. Therefore, the best data correlation between ground testing and flight data should be obtained at test temperatures in the 180°K range.

Finally, the nominal fluid inventory for the transporter heat pipe is shown in Figure 4-3. As can be seen, fluid inventory requirements between 150°K and 250°K varies only by approximately 4% with respect to an "ideal charge" at 180°K. This will provide flexibility in testing the heat pipe over a wide temperature range without being too severely overcharged or undercharged. It should be noted, however, that if the heat pipe is charged with an "ideal charge" at 180°K, the fluid inventory required at higher temperatures (up to ~ 265°K) will be less than that required at 180°K, and hence excess fluid will form a puddle which will further complicate ground testing at elevated temperatures.

4.1.3 Pressure Retention

Ethane has a relatively low vapor pressure at room temperature (631 psia), therefore, pressure retention will not be a problem for the selected design. In the as welded condition, predicted burst pressure for the heat pipe configuration shown in Figure 4-1 (.06 inches wall thickness) with 6063 aluminum initially in the T-5 condition is approximately 4800 psi. Since a minimum burst safety factor of 7.6 can be attained, a simplified processing procedure can be employed to reduce cost and to insure weld leak tightness.

4.1.4 Design Options

The ability to test the heat pipe on the ground, to extrapolate "Zero-G" performance and to correlate this performance with subsequent flight data will be an important factor in determining the success of the experiment. This should, therefore, be a prime consideration in finalizing the design. Design options, in addition to the use of a thermal mass for testing at 180°K, which can be considered include the following:

(a) <u>Increased Transport Length</u>: Increased transport length will reduce the heat load required for maximum stressing of the heat pipe. This in turn will allow a lower burnout test temperature (if no radiator thermal mass is used), or a smaller thermal mass or it may even allow burnout under transient conditions since the rate of temperature rise would be reduced with a smaller heat load.

Longer transport length can only be achieved with a deeper experiment. It is possible that one of the RBV cameras will be removed, in which case adequate depth can be realized.

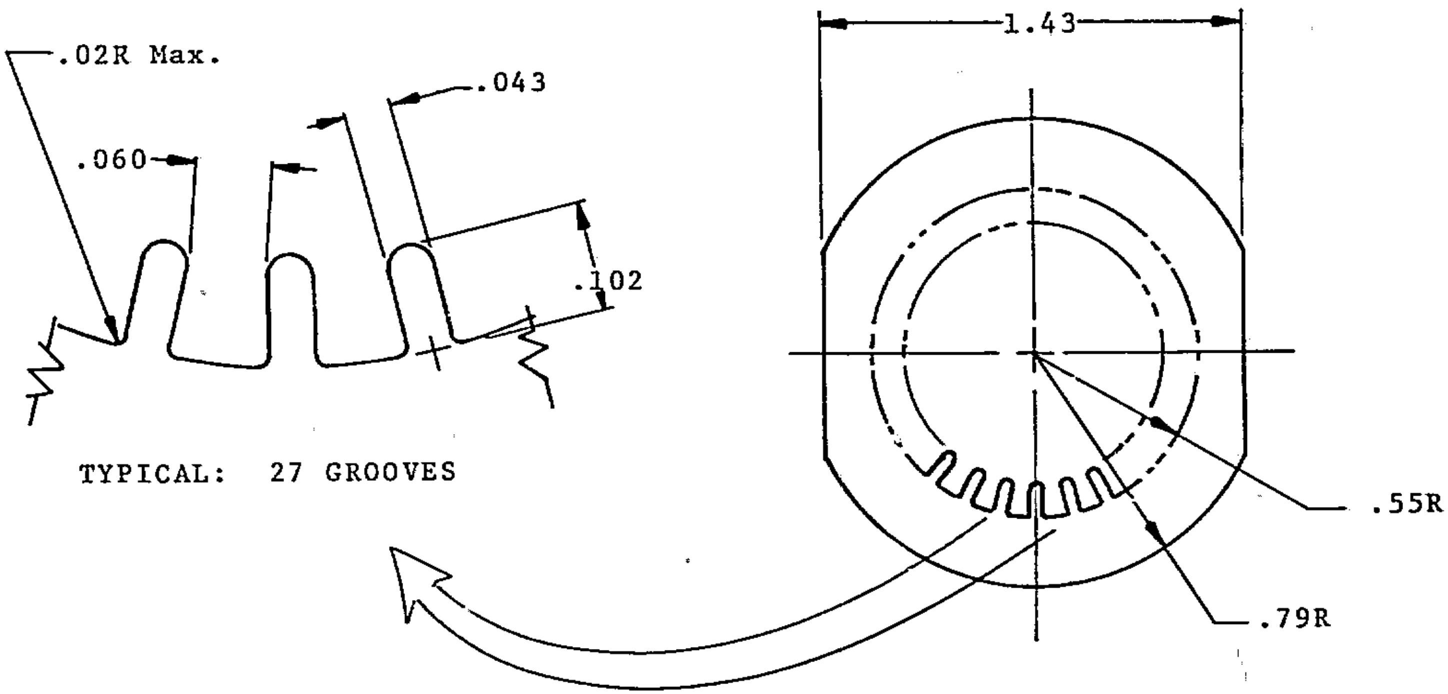
(b) Alternate Grooved Heat Pipe Design: The grooved heat pipe configuration selected for the baseline design includes an integral saddle extruded as part of the tubing. An alternate configuration, without integral saddle, is shown in Figure 4-4 . This configuration can be used provided that adequate thermal interfacing with the radiator is included as part of the final design.

(c) Back-up Transporter Heat Pipe: A back-up transporter heat pipe has been included in the design shown in Dwg. No. BK005-1006. This heat pipe is optional. It has been included to back-up the primary transporter heat pipe. It could also be used to test the same heat pipe configuration for different conditions, such as alternate charge, liquid slug, higher power density, etc.

4.2 Thermal Diode Heat Pipe

A thermal diode heat pipe will be included as part of the ERTS-C Cryogenic Heat Pipe Experiment. This portion of the experiment will be furnished as GFE by NASA/ARC.

The objective of the Ames Cryogenic Diode Heat Pipe will be to demonstrate "reverse mode" shutdown and "forward mode" heat transport capabilities of a heat pipe diode operating at cryogenic temperatures.



NOTE: All Dimensions in 10^{-2} m

FIGURE 4-4. ALTERNATE AXIAL GROOVE EXTRUSION DESIGN

The technology derived from this experiment will be applied to detector cooling applications where radiator coolers are periodically exposed to high temperatures resulting from intermittent energy inputs such as solar radiation.

4.2.1 Design Description

A baseline Cryogenic Diode Heat Pipe design configured to fit within the allowable ERTS-C envelope dimensions is shown in Dwg. No. BK005-1007. The design consists of a thermal diode heat pipe, a PCM container and a PCM heat pipe. The PCM heat pipe and the PCM container form an integral package with the PCM heat pipe extending out of both ends of the container. The PCM heat pipe is a conventional heat pipe. It has a heater attached to one end to simulate detector heat load and is interfaced with the thermal diode heat pipe at the other end.

Design requirements for the diode heat pipe, including heat pipe diameter, bend configuration, materials, reservoir design and performance will be in accordance with the limitations set forth in BK005-1008, "ARC Cryogenic Diode Heat Pipe Design Requirements" (Appendix C). Final design will be determined by NASA/ARC.

4.2.2 Performance

Performance requirements of the diode heat pipe will be in accordance with the requirements of BK005-1008.

4.2.3 Design Options

Design options will be in accordance with BK005-1008.

4.3 Radiator

A single radiator has been designed to provide the heat rejection area for both the transporter heat pipe (s) and the diode heat pipe. The radiator is mounted perpendicular to the plane of the sensory ring in the earth pointing direction. It is designed to provide maximum heat rejection area within the specified envelope dimensions.

4.3.1 Design Description

An aluminum radiator design, coated with white paint to achieve the desired optical properties, was selected to provide the high thermal efficiency required to meet experiment performance objectives. This design is consistent with low cost objectives. The white paint will be per GSFC MS-74 or equivalent. The radiator consists of a 6061 aluminum flat plate which is 0.127-cm (0.050-in.) thick, measures 58.5-cm (23-in.) wide by 47.7-cm (18.8-in.) high and weighs 1-kg.

The size of the radiator is consistent with the space available between the MSS and the DCS antenna. A 10-cm (4-in.) clearance off the sensory ring was allowed for cabling. The maximum height of the radiator was established by the DCS antenna which is 58.5-cm below the sensory ring. The size of the radiator was also restricted by a maximum outboard location defined by the maximum Tip Off contour at 41-cm. A 2.54-cm envelope inside the Tip Off contour was allowed for stowing the deployable shield.

4.3.2 Thermal Performance

The pertinent thermal properties of the radiator are as follows:

Emissivity	ϵ	=	.85
Absorptivity	α	=	.2
Fin Efficiency	η	=	.95
Thermal Conductivity	k	=	100 BTU/Hr-FT-°F
Thermal Mass	mc_p	=	0.26 watt-hrs/°C

The radiator fin efficiency is based on a centerline heat input and a nominal radiator temperature of 180°K (cf. Appendix A). It does not vary significantly over the operating temperature range of the heat pipes.

4.3.3 Structural Design

The radiator is supported along its entire periphery by a stainless steel tubular structure. (cf. Dwg. No. BK005-1006). It is attached to this structure via Lexan thermal isolators. In addition, the radiator plate is stiffened by the two transporter heat pipe condensers, by the diode condenser and by the PCM box. A similar design was used on the ATFE heat pipe experiment onboard the ATS. This design was qualified to similar (more severe) dynamic levels and therefore no structural analysis was performed for this radiator plate behavior under dynamic loads.

4.3.4 Design Options

Larger radiator area should be considered if more space becomes available. A larger radiator area would allow burnout testing at lower temperatures.

Other design options include:

(a) Radiator Plate Thickness: A thicker radiator plate would achieve higher fin efficiency. However, since the fin efficiency is already high, the gain would be small. For example, doubling the thickness would increase the fin efficiency by only 2% (See Appendix A). A weight savings can be obtained by reducing the radiator thickness without seriously affecting thermal performance. Reducing thickness by one-half would reduce fin efficiency only by 3%. Total System weight, however, would also only be reduced by a small percentage (approximately 4%).

Structural integrity would have to be verified for any thickness reduction.

(b) Emmisive Coating: White paint has an absorpitivity of α = .2. Alternate coatings may be considered in the final design including OSR's and silver teflon. Earth input would be reduced with such coatings, however, total radiator emittance would also be lower because of lower emissivity.

4.4 Earth Shield

In its present location on the spacecraft, the radiator would be viewing the earth and deep space. There will be no direct solar inputs throughout the mission.

In order to achieve the desired operating temperatures, an earth shield will be required.

4.4.1 Design Description

The design of an earth shield was not undertaken within this effort. It was assumed that existing shield designs, including deployment mechanisms, can be applied to the requirements of this experiment.

The experiment configuration and performance were determined for a shield which has the following characteristics:

- Planar (flat plate) Geometry
- Weight, including deployment mechanisms 1.18 kg
- Emissivity of surface facing radiator:

  ϵ = .05 (Specular)
- Maximum envelope dimension in the stowed position of 2.54-cm.
- Deployed position of 90% to the surface of the radiator.

• Equilibrium temperature of shield equals 230°K.

4.4.2 Performance

Various shield configurations, as shown in Figure 4-5 were evaluated. The configurations considered ranged from no shield (configuration A) to a shield with corner panels (configuration D). Estimated radiator performance with each type of shield is shown in Figure 4-6. A summary of the analysis is given in Appendix A.

As can be seen in Figure 4-6, a major radiator performance improvement is achieved with a shield size equal to the radiator (1:1 shield). Additional performance gains can be made with larger shields, however, stowage and deployment design of larger shades is complicated by the need to fold the shield against the radiator. For this reason, the 1:1 shield size has been tentatively selected as the baseline design.

4.4.3 Design Options:

Additional design and analysis of the shield is required in order to finalize experiment performance. Design options which should be considered include the following:

(a) Optimization of the angle between the shield and radiator.

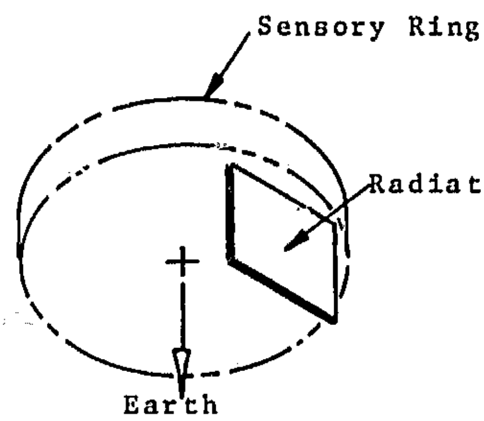
(b) If a simple folded shield design is available, a larger shield should be considered. Cost impact should be considered as part of this option.

(c) Trade-offs as derived from a detailed shield/radiator analysis.

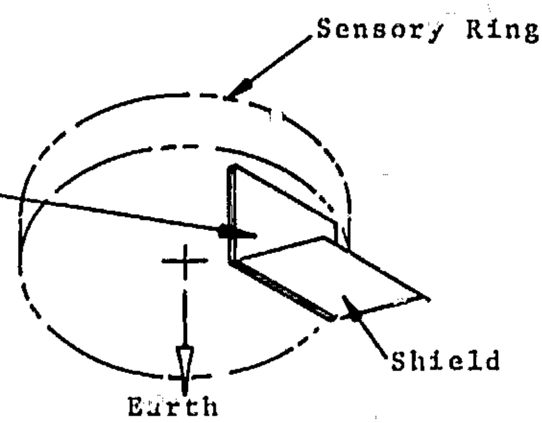
4.5 Radiator PCM

The radiator capacity at low temperatures limits the maximum power that can be applied to the heat pipes. Since it is desirable to verify the full heat pipe capacity in "Zero-G" at low temperatures,

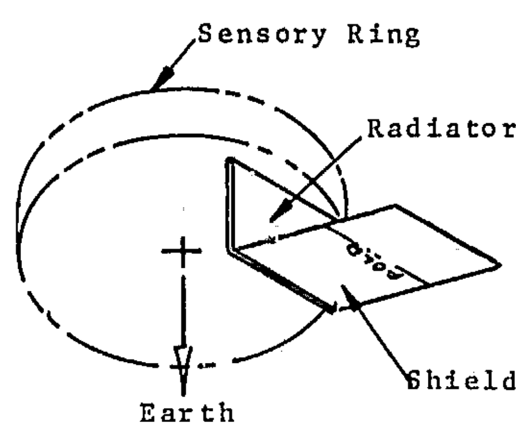
FIGURE 4-5. EARTH SHIELD CONFIGURATIONS



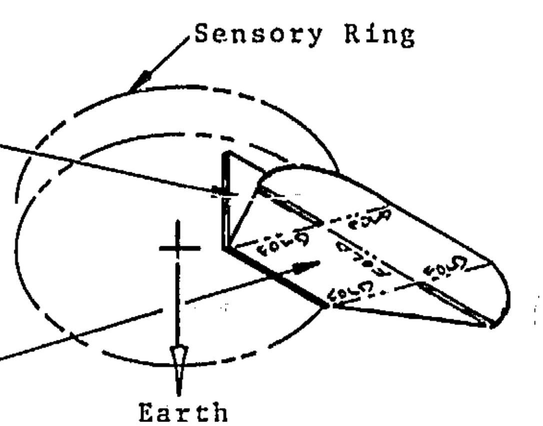
A. NO SHIELD



B. 1:1 SHIELD

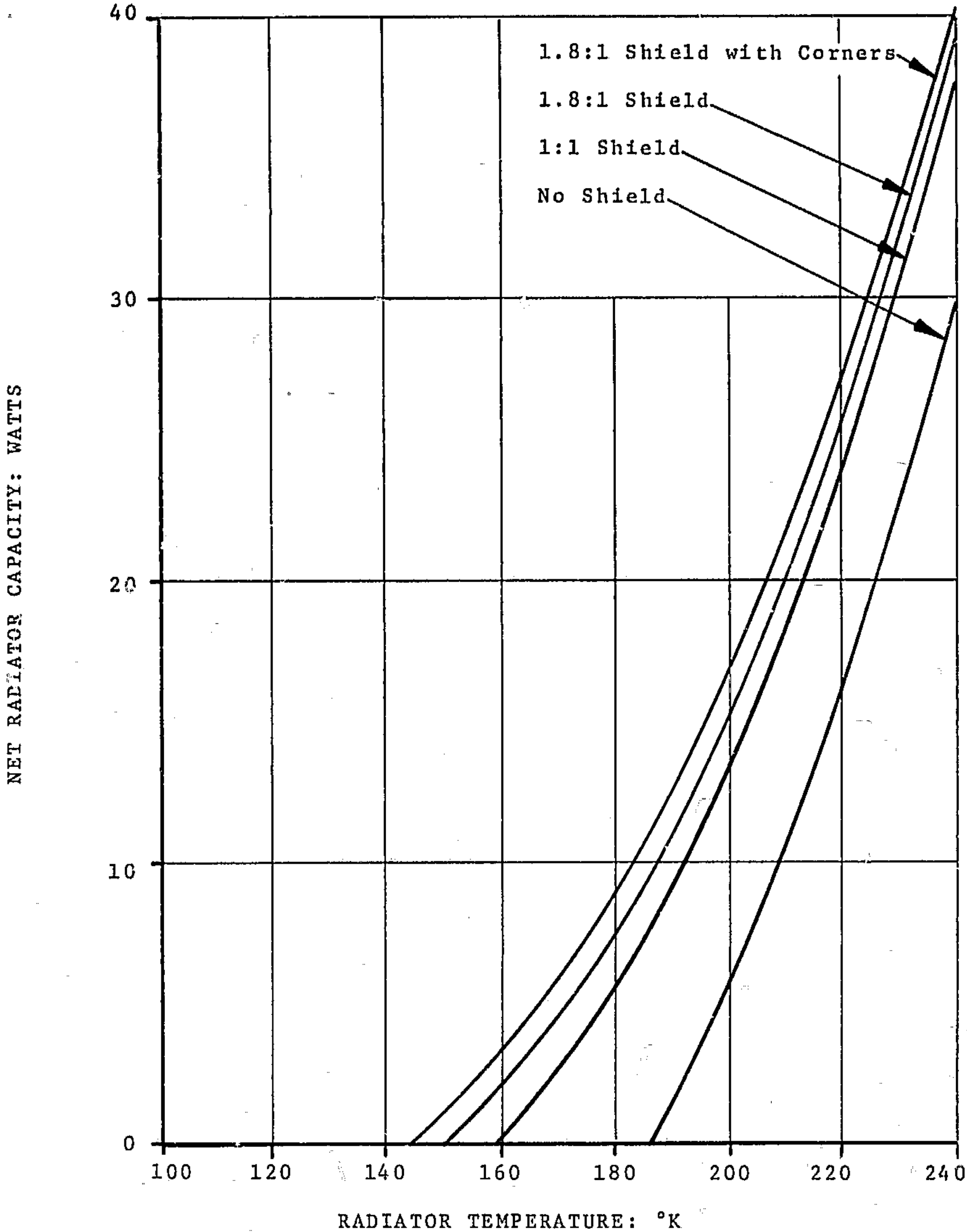


C. 18:1 SHIELD



D. 1:8:1 SHIELD WITH CORNER SHIELDS

FIGURE 4-6. EARTH SHIELD EFFECTIVENESS



a PCM package has been included as part of the radiator design. The PCM will enable the test of the heat pipes at high power levels over sufficient periods of time to determine performance.

4.5.1 Design Description

The selected radiator PCM package design is similar to the ATFE design which has been in operation in space onboard the ATS-6 spacecraft since June, 1974. The package consists of an aluminum box which is bolted to the radiator adjacent to the transporter heat pipe. The PCM box extends over most of the radiator width. Internally, the box has a heat conduction web and aluminum honeycomb to conduct the heat to and from the PCM. The box is closed-off with a lid which is hermetically sealed to prevent leakage. Also included within the box is a void to allow for expansion and contraction of the PCM.

The PCM tentatively selected for this application is Trans-2-Butene. This material has the following properties (Ref.3):

Freezing Point	168°K
Heat of Fusion	41 cal/gm
Boiling Point	275°K
Pressure at 25°C	30 psia
Handling Consideration	Flammable, however, not classified as hazardous

4.5.2 Performance

With the low freezing point of the selected PCM, a 12°C temperature drop can be allowed for conduction between the PCM and the heat pipe without exceeding a 180°K test temperature on the heat pipe. This temperature drop should be more than enough to manage the required heat loads.

The thermal capacity of the PCM will be 40 watt-hours for a 0.9-kg PCM package weight. This should allow approximately 1-hr. of high power testing for either the transporter or diode heat pipe.

4.5.3 Design Options

(a) Alternate PCM

(b) Packaging details

(c) Radiator location

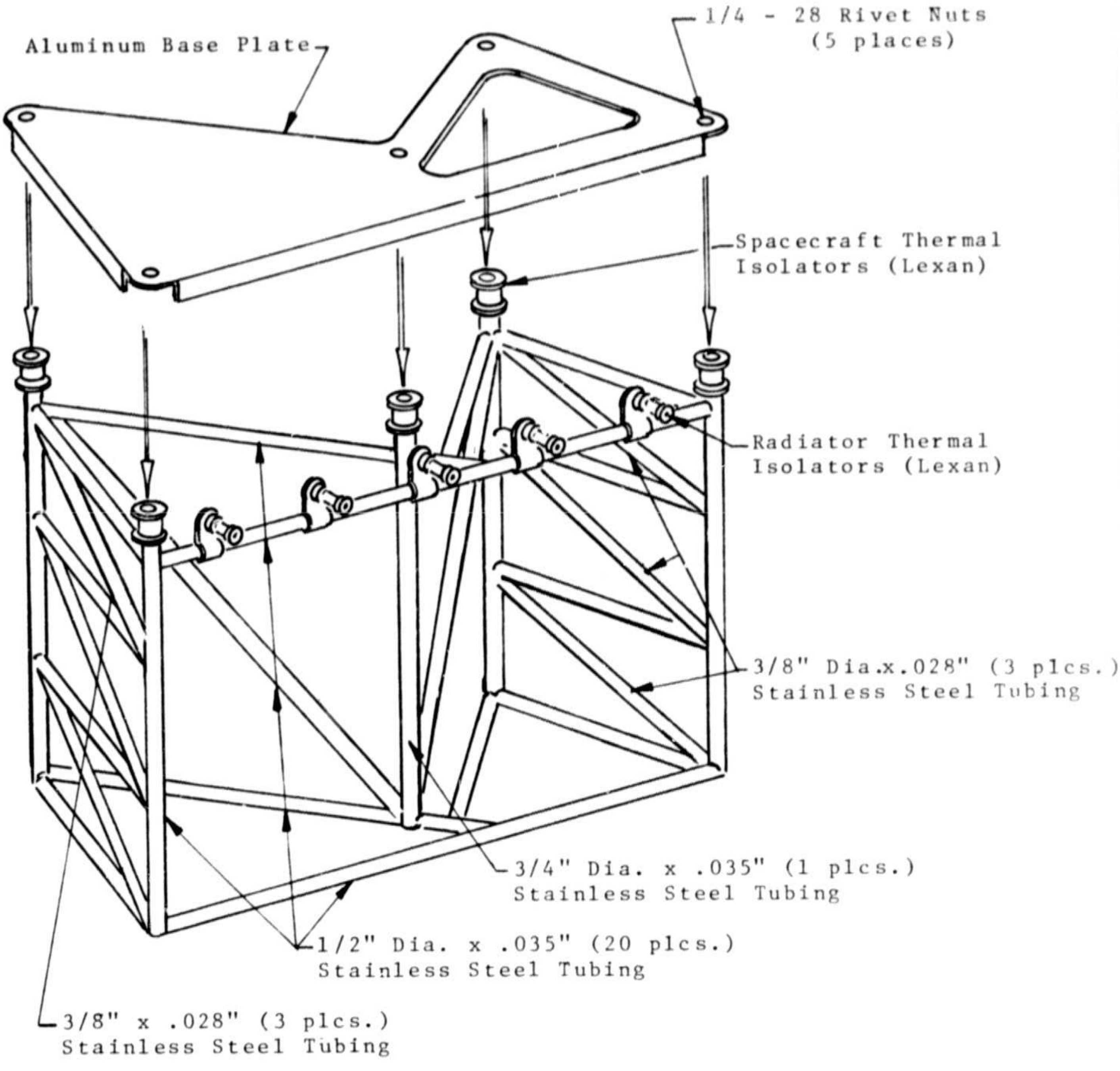
4.6 Structure

A frame is provided as part of the experiment design to achieve structural self-sufficiency in the ERTS-C dynamic load environment as specified in Table 1-1. The frame provides the attachment points to the spacecraft and is designed to allow the experiment to be cantilevered off the spacecraft sensory ring. The heat pipe experiments, radiator and electronics module are in turn mounted to the structural frame. Isolators (Lexan) are provided as part of the frame design to minimize conduction between the experiment and the spacecraft and between the components within the experiment.

The design of the structural frame is shown in Figure 4-7. Design details of the frame are shown in Dwg. No. BK005-1006. The frame consists of tubular stainless steel structural members welded to form a "$\overline{W}$" cross-sectional shape. The geometry of the frame was determined on the basis of available space at the specified location on the spacecraft. Stainless steel was selected because of its high strength, low thermal conductivity, and weldability.

A static stress analysis was performed to determine size requirements of the structural members (cf. Appendix B). The tubing sizes identified in Figure 4-7 provides a minimum margin of safety of 2.5 under maximum "g-load" (cf. Appendix B).

FIGURE 4-7. EXPERIMENT STRUCTURE



Five attachment points are provided for mounting the structural frame to the spacecraft. Each mounting point is provided with a Lexan isolator to minimize heat conduction from the spacecraft to the experiment. Each Lexan isolator is attached to a common aluminum plate. The aluminum plate is provided with five (5) rivet nut (1/4-28) at each of the five Lexan isolator locations. These will provide the attachment points to the spacecraft.

The electronics module has been included as an integral part of the experiment. It is mounted to the experiment aluminum mounting plate. This will allow direct heat sinking to the spacecraft while the Lexan isolators will minimize heat conduction from the module to the experiment.

Mounting points for the heat pipes and the radiator are provided on the stainless steel frame as shown in Dwg. BK005-1006. Each of these mounting points are also provided with Lexan isolators to further minimize heat conduction. A thermal analysis of the structural frame and the Lexan isolators is given in Appendix A.

4.7 Insulation

Multilayer thermal insulation blankets have been included as part of the design to minimize radiant parasitic inputs from the spacecraft and to minimize component interaction. An effective emissivity of 0.02 was assumed in determining experiment performance.

4.8 Electrical

Temperature transducers will be employed to monitor the experiment temperatures. Performance of the experiment will be determined on the basis of these measurements. To accommodate these measurements, a minimum of 34 telemetry channels will be required. Additional channels for current sensors as well as more temperature measurements are desirable. All channels will be analog and have a sampling rate of once per 16 seconds. Minimum telemetry functions are as listed previously in Table 2-4.

Electrical heater power will be required to simulate thermal loads to exercise the heat pipes during testing. Heater functions and power requirements are as defined previously in Table 2-3. Heater power will be obtained from the regulated spacecraft power supply. A minimum of 45-watts will be required to meet all experiment objectives.

A total of fifteen ON/OFF commands will be required to activate the Experiment and the individual heaters.

Signal conditioning, current sensors and command functions will be supplied by an electronics module which will provide the electrical interface between the Experiment and the spacecraft. The design of the module is baselined on the current ATFE module. It will be mounted directly to the experiment structural frame on the spacecraft side of the Lexan thermal isolators to minimize parasitics to the experiment.

5.0 REFERENCES

1. "Environmental Test Specification For ERTS (A & B) and Nimbus (E & F) Observatory Systems, Subsystems and Experiments" S-320-EN-1, November, 1971.
2. Schlitt, K. F., Kirkpatrick, J. P., and Brennan, P. J., "Parametric Performance of Extruded Axial Grooved Heat Pipes from 100° to 300°K" AIAA Paper No. 74-724.
3. Private correspondence: Jim Galaski, Lockheed Missile and Space Co.
4. Kreith, F., "Principles of Heat Transfer" 3nd Ed., International Textbook Co., 1966
5. "Alcoa Structural Handbook" Pages 102 through 105.
6. Bruhn, E., "Analysis And Design Of Flight Vehicle Structures" Tristate Offset Company, 1965.

APPENDIX A. THERMAL PERFORMANCE ANALYSIS

A-1. Radiator Performance

Thermal performance of the experiment is dependent on the heat rejection capacity of the radiator. This capacity was determined on the basis of steady state energy balance at the surface of the radiator as follows:

Total Radiator Emittance		Electrical Power Input (Heat Pipe)		Earth (Partially Shielded) Input		Earth Shield Input		Spacecraft Radiant Parasitic Input		Structure Parasitic Conduction
	=		+		+		+		+	

$$Q_r = Q_h + Q_e + Q_s + Q_{scr} + Q_{mli} + Q_{scc}$$

where:

$$Q_r = \sigma \varepsilon_r A_r T_r^4$$

$$Q_e = \dot{q}_{ir} \varepsilon_r F_{re} A_r + \dot{q}_s \alpha_r F_{re} A_r$$

$$Q_s = \sigma \mathcal{F}_{sr} A_s T_s^4$$

$$Q_{scr} = \sigma \mathcal{F}_{scr} A_{sc} T_s^4$$

$$Q_{mli} = \sigma \varepsilon_{mli} A_r (T_{sc}^4 - T_r^4)$$

$$Q_{scc} = U_{sc} (T_{sc} - T_r)$$

Each of the terms in the above equations are defined in Table A-1.

Table A-1. Radiator Analysis Components Definition and Values

Component	Value	Units	Definition
σ	5.67×10^{-8}	$\frac{\text{watts}}{m^2\ ^\circ K^4}$	Stefan-Boltzmann's Constant
Q_r	1.34 x 10	watts	Total radiator emittance
ϵ_r	0.85	--	Radiator emissivity
	0.2	--	Radiator absorptivity
A_r	0.279	m^2	Radiator Area
T_r	--	°K	Radiator Temperature
Q_e	4.35	watts	Unshielded earth input
$\dot{q}_{ir}$	44.8	$\frac{\text{watts}}{m^2}$	Earth I.R. input - Orbital avera
$\dot{q}_s$	26.2	$\frac{\text{watts}}{m^2}$	Earth solar reflection - Orbital average
F_{re}	0.36	--	Fraction of unshielded earth vie
Q_s	0.44	watts	Earth shield I.R. input
$\mathcal{F}_{sr}$	0.01	--	Shield to radiator shape factor
A_s	0.279	m^2	Shield area.
T_s	230	°K	Shield surface temperature.

Table A-1. Continued

Component	Value	Units	Definition
Q_{scr}	0.26	watts	Radiant parasitic inputs from the sensory ring to front of the radiator.
$\mathcal{F}_{scr}$	0.013	--	Shape factor from spacecraft sensory ring to the radiator front surface area.
A_{sc}		m^2	Spacecraft sensory ring area viewing the radiator front surface area.
Q_{mli}	300	°K	Spacecraft temperature.
ε_{mli}	0.02	--	Multilayer insulation equivalent emissivity.
Q_{scc}	$2.48-.000825T_r$	watts	Parasitic heat conduction from spacecraft via mounting structure
U_{sc}	8.25×10^{-3}	watts/°K	Mounting structure conductance.

On the basis of the values listed in Table A-1, the net heat rejection capacity of the radiator (maximum electrical power rejection capacity) as a function of temperature will be as follows:

$$Q_n = C_1 T_r^4 + C_2 T_r - C_3$$

where $C_1 = 1.37 \times 10^{-8}$ watts/°K^4

$C_2 = 8.25 \times 10^{-3}$ watts/°K

$C_3 = 10.0$ watts

Computed values for net heat rejection capacity as a function of radiator temperature are shown in Figure 2-2.

Values for the above equation were determined as follows:

a. Partially Shield Earth Input

Partially shielded earth input was determined on the basis of 1:1 shield and orbital average heat fluxes ($\dot{q}_{ir}$ and $\dot{q}_s$) from the earth intercepting a flat surface, perpendicular to the earth and in a 500 nautical miles - 9:30 orbit. These fluxes were derived from the GSFC heat flux program. The unshielded portion of the earth input for a 1:1 shield was determined as follows:

- The view factor from the radiator to the earth was determined on the basis of an equivalent disc defined by the earth's limiting ray. For a 500 nautical miles altitude this view factor was determined to be 0.328.

- The view factor from the shield was determined for a 1:1 shield. The view factor (Ref. 4) was determined to be 0.21.
- The unshielded view of earth is the difference between the two (.118).

Therefore, the fraction of unshielded earth energy is

$$F_{re} = \frac{.118}{.328} = 0.36$$

b. Earth Shield Input

The shape factor for the earth shield was determined with the Monte Carlo program. Shield emissivity in the radiator viewing direction was assumed to be .05 and the radiator emissivity was .85. Shield equilibrium temperature for an earth viewing side emissivity of .85 was determined to be approximately 230°K.

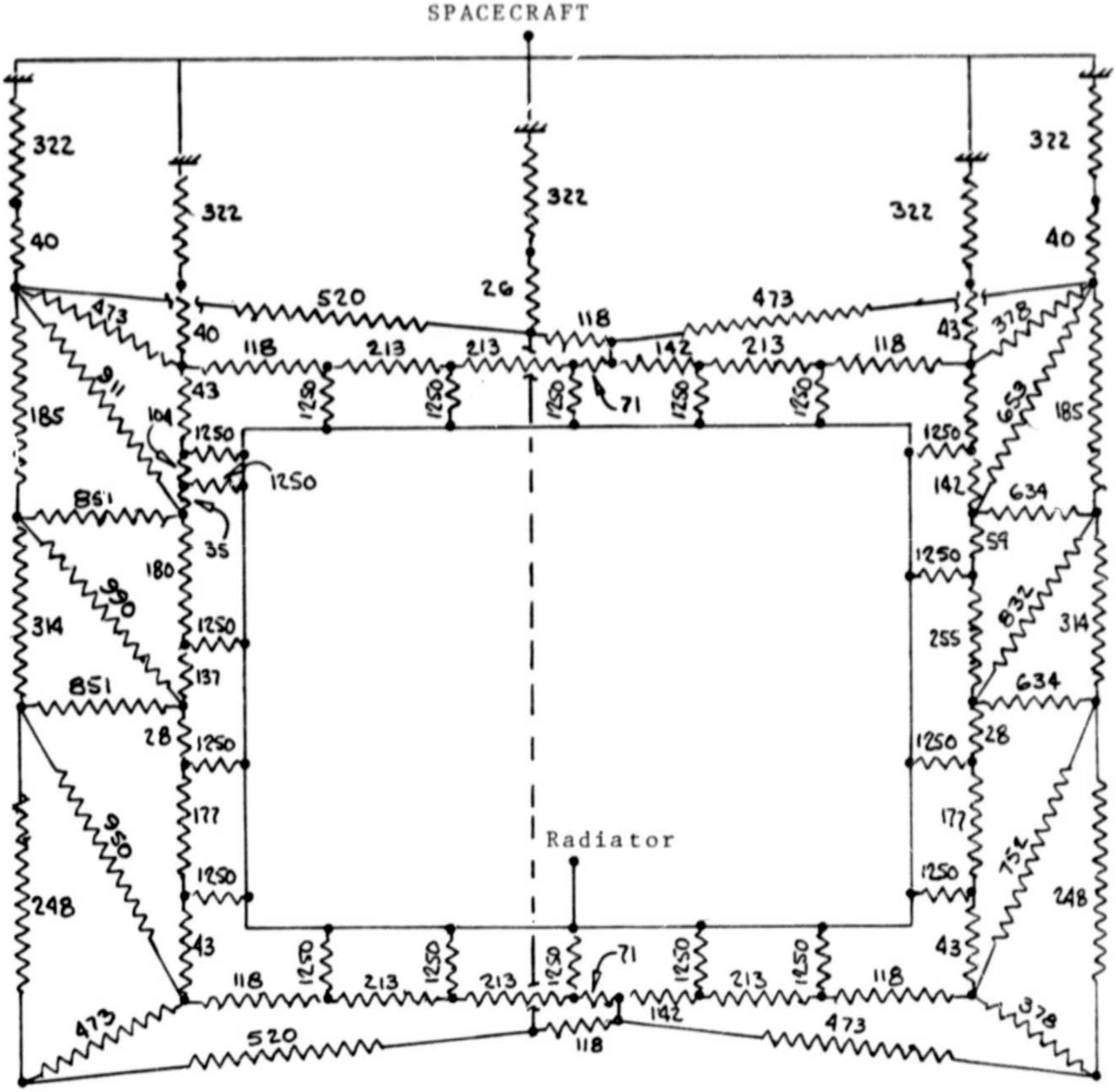
c. Spacecraft Radiant Parasitic Input

The spacecraft radiant input consists of two components. Input to the front face of the radiator from the sensory ring was determined on the same basis as the earth shield, i. e., by establishing a shape factor from the Monte Carlo program. For the inboard radiator input, MLI insulation with an equivalent emissivity of .02 was assumed.

d. Spacecraft Conduction Parasitic Input

To determine parasitic conduction to the radiator from spacecraft, an impedance schematic for the structural frame and the isolators (Lexan) was developed as shown in Figure A-1. Property values used in generating impedances were as follows:

FIGURE A-1. STRUCTURE THERMAL IMPEDANCE SCHEMATIC



NOTE: All Impedances in °c/watt

Stainless Steel Conductivity = 9.4 BTU/HR-FT-°F

Isolator Conductivity (Lexan) = 0.11 BTU/HR-FT-°F

Based on these values, the following impedances were developed:

Spacecraft Lexan Isolators (See Figure A-2)	= 322°C/Watt
Radiator Lexan Isolators (See Figure A-3)	= 1250°C/Watt
3/4" O.D. x .035" wall Tubular Structure	= 30.8 °C/watt-in.
1/2" O.D. x .035" wall Tubular Structure	= 47.3 °C/watt-in.
3/8" O.D. x .028" wall Tubular Structure	= 79.2 °C/watt-in.

The impedance schematic shown in Figure A-1 was programmed and an equivalent conductance of .0055 Watts/°C was determined. To account for other conduction paths, such as cabling, 50% was added to this value in the radiator performance analysis.

NOTE: All Dimensions in Inches

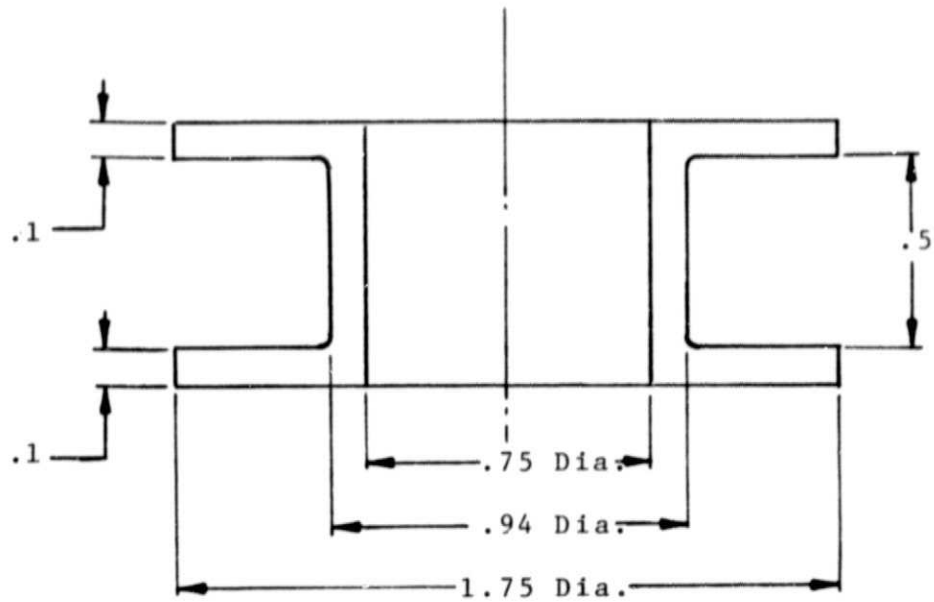


FIGURE A-2. SPACECRAFT LEXAN ISOLATOR

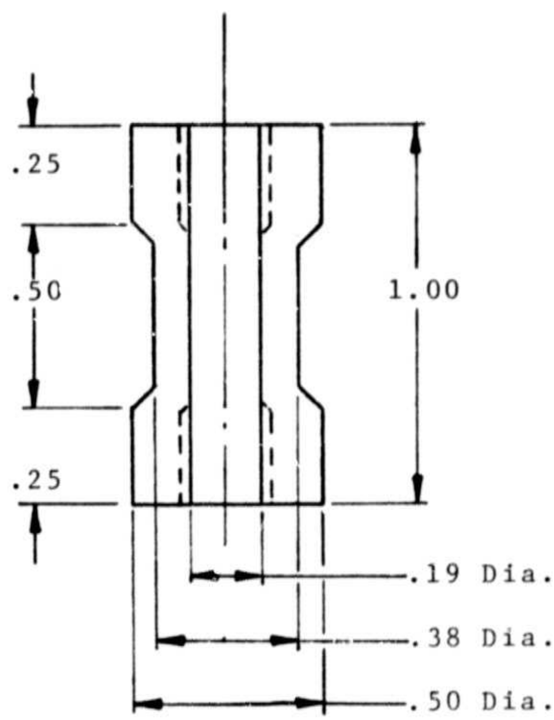


FIGURE A-3. RADIATOR LEXAN ISOLATOR

A-2 Radiator Fin Efficiency

Radiator fin efficiency was determined on the basis of an equivalent film coefficient defined as follows:

$$h_r = \sigma \, \varepsilon \, F \, (T_r^2 + T_s^2) \, (T_r + T_s)$$

Where: σ = Stefan-Boltzmann's Constant = 0.1714×10^{-8} $\frac{BTU}{HR - FT^2 - {}^\circ R^4}$

ε = Emissivity = 0.85

F = View Factor = 1.0

T_s = Sink Temperature = 0°R

T_r = Radiator Temperature = (In °R)

The fin efficiency was determined from the equation for a rectangular fin rejecting heat from one side only

$$= \frac{\text{Tanh}\ (m)}{m}$$

$$m = \sqrt{\frac{h_r w^2}{12Kt}}$$

w = Fin Width = 9.5 inches

k = Thermal Conductivity = 100 BTU/HR-FT-°R

t = Fin Thickness = (In inches)

On the basis of the above, the following fin efficiences were determined:

T_r °K	T_r °R	h_r $\frac{BTU}{HR-FT^2-°R}$	η t = .025"	η t = .05"	η t = .1"
150	270	.0285	.972	.987	.993
175	315	.0453	.958	.978	.989
200	360	.0677	.038	.967	.983
225	405	.0963	.914	.953	.977
250	450	.1321	.886	.938	.969

APPENDIX B. WEIGHT AND STRUCTURAL ANALYSIS

A weight and structural analysis was performed for the experiment configuration shown in BK005-1006. Results of the analysis are as follows:

B-1 Weight Analysis

Total estimated weight of the experiment is 13.62 Kg (30 pounds). A detailed weight breakdown is given in Table B-1.

B-2 Center of Gravity Determination

The estimated center of gravity for the experiment including the electronics module (See Figure B-1) is:

Xcg = +4.09 cm (1.61 inches)

Ycg = -2.41 cm (0.95 inches)

Xcg = +7.59 cm (2.99 inches)

For the structural analysis of the tubular experiment frame the center of gravity without the electronics module was used as follows:

Xcg = +2.21 cm (0.87 inches)

Xcg = +0.30 cm (0.12 inches)

Zcg = +7.42 xm (2.92 inches)

A log for the center of gravity is summarized in Table B-2.

B-3 Tubular Structure Load Distribution Analysis

A static stress analysis of the tubular structure was performed to determine the required size of the tubular elements. For this analysis, it was assumed that the "G" forces are as specified in Table 1-1 (Section 1.3), and that load amplification factors due to the resonance of the structure will be minimal.

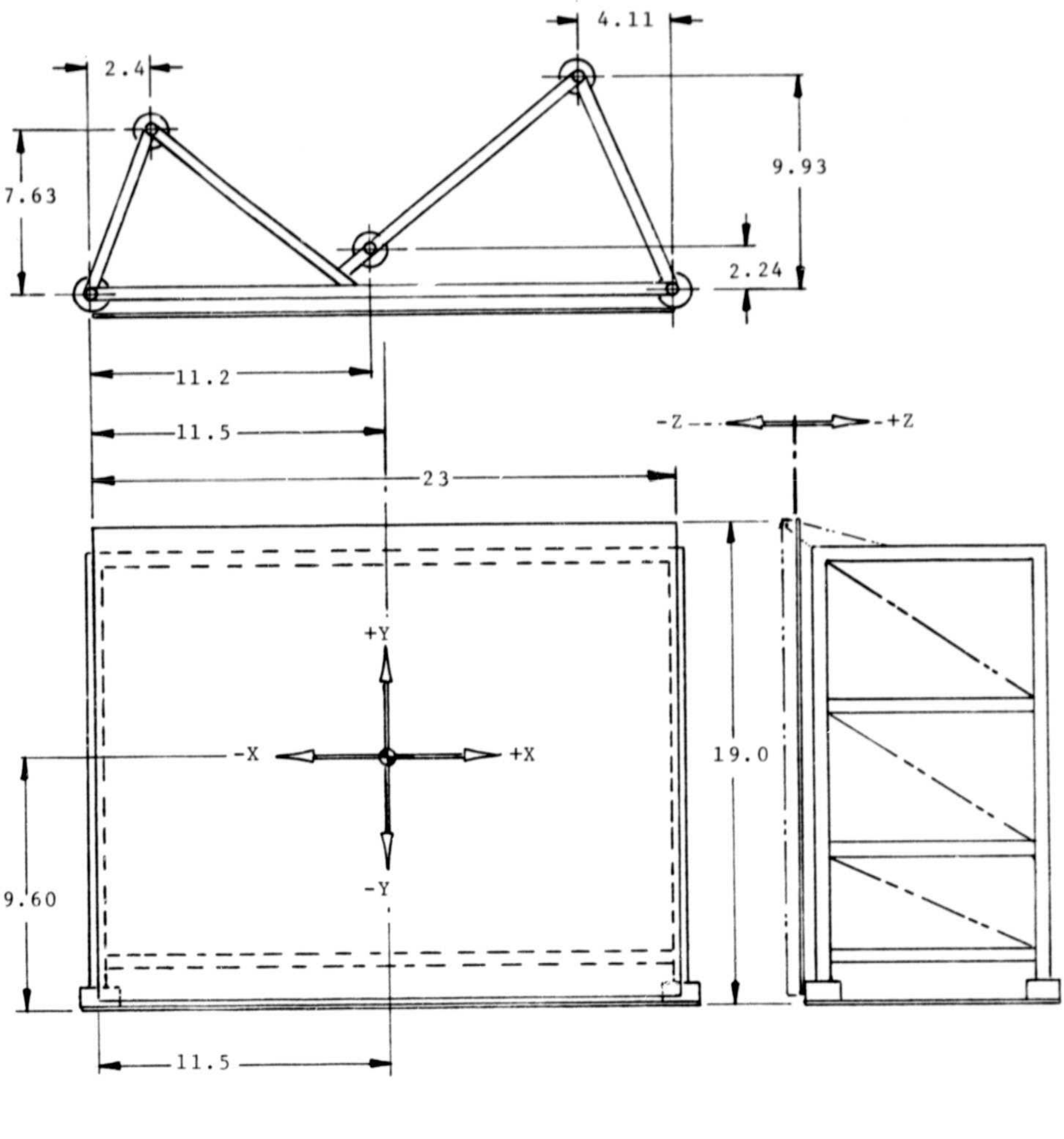
Table B-1 ERTS-C Cryogenic Heat Pipe Experiment
Weight Analysis Summary

	Lbs.	Kg
1.0 STRUCTURE		
1.1 Tubular Stainless Steel Structural Members	4.79	2.17
1.2 Radiator Isolators and Hardware	1.20	0.55
1.3 Spacecraft Isolators and Hardware	.40	0.18
1.4 Mounting Hardware For Heat Pipes	.35	0.16
1.5 Electronics Mounting Plate	.45	0.21
Sub-Total	7.20	3.27
2.0 RADIATOR ASSEMBLY		
2.1 Radiator Plate	2.16	.08
2.2 Radiator PCM Box	2.00	0.91
2.3 Radiator PCM	2.00	0.91
Sub-Total	6.16	2.80
3.0 TRANSPORTER HEAT PIPE EXPERIMENT		
3.1 Primary Transporter Heat Pipe	0.95	0.43
3.2 Back-up Transporter Heat Pipe	0.95	0.43
Sub-Total	1.90	0.86
4.0 DIODE HEAT PIPE EXPERIMENT		
4.1 Diode Heat Pipe	.80	0.36
4.2 PCM Heat Pipe	.30	0.14
4.3 PCM Container	1.50	0.68
4.4 PCM	2.00	0.91
Sub-Total	4.60	2.09

Weight Analysis Summary (Continued)

	LB.	Kg
5.0 ELECTRICAL		
5.1 Electronics Module	4.50	2.04
5.2 Instrumentation and Harness	1.30	0.59
5.3 Heaters	.20	0.09
Sub-Total	6.00	2.72
6.0 MLI INSULATION	1.50	0.68
7.0 EARTH SHIELD & DEPLOYING MECHANISM	2.64	1.20
TOTAL WEIGHT	30.00	13.62

FIGURE B-1. CENTER OF GRAVITY COORDINATES



NOTE: All Dimensions ir Inches

Table B-2. Log For Center of Gravity

ITEM	WT (LB)	X (IN)	WTXX (INLB)	Y (IN)	WTXY (INLB)	Z (IN)	WTXZ (INLB)	DESCRIPTION
1	7.2	1.0	7.2	0	0	5.0	36.0	Structure
2	2.16	0	0	0	0	0.03	0.07	Radiator
3	0.95	-0.5	-0.48	1.0	.95	1.0	0.95	Trans. H.P.#1
4	0.95	-0.5	-0.48	4.2	3.99	1.0	0.95	Transp. H.P.#2
5	0.80	-1.5	-1.2	-1.75	-1.4	0.5	0.40	Diode H.P.
6	3.80	4.0	15.2	-1.75	-6.65	4.0	15.2	Diode-PCM
7	1.5	0	0	-2.6	-3.9	7.0	10.5	Elec. Instal.
8	1.5	0	0	0	0	4.0	6.0	Insulation
9	4.0	.5	2.0	2.5	10.0	1.1	4.4	Radiator PCM
10	4.5	5.8	26.1	-7.0	-31.5	3.4	15.3	Electronics Mod.
11	2.64	0	0	0	0	0	0	Shade & Mechanism
	30.00		48.34		-28.51		89.76	

Case #1	x_{cg} = 1.611	Y_{cg} = -0.95	Z_{cg} = 2.99	Complete Experiment
Case #2	X_{cg} = 0.872	Y_{cg} = 0.117	Z_{cg} = 2.92	Exp.W/O Elec. Module
Case #3	X_{cg} = 0.872	Y_{cg} = -0.32	Z_{cg} = 2.67	Complete Experiment Shield Open ACS mode

In addition the mass of the electronics module was excluded from this analysis since its load will be applied directly to the spacecraft.

Since the CG for the experiment (minus the electronics) is nearly in the center of the radiator, a symmetrical distribution of the loads was assumed as shown in Figure B-2. The resulting load distribution in the frame is shown in Figure B-3.

This load distribution determination was made on the following assumptions:

(a) Maximum "G" load from Table 1-1, Sec. 1.3 is in the transverse direction and is 18-g.

(b) Weight of experiment without electronics Module is 25.5 lbs. Therefore, 459 lbs. are applied in the transverse direction at the C.G. (i.e. perpendicular to the radiator).

(c) The radiator is attached to the frame at 20 points near the circumference.

(d) Radiator can be considered stiff and resonance effects are assumed to be minimal since 3 heat pipes and 1 PCM box are bolted to the radiator.

(e) The load against the radiator frame is reacted at 10 points as shown in Figure B-2.

(f) 50% of load is reacted at points B & E, 25% at points A, G, H, D and 25% at points C, J, K, F. 50% of load reacted at "B" and "E" was assumed to create the most severe buckling load in the longest diagonals in Sections C-C and D-D in Figure B-3.

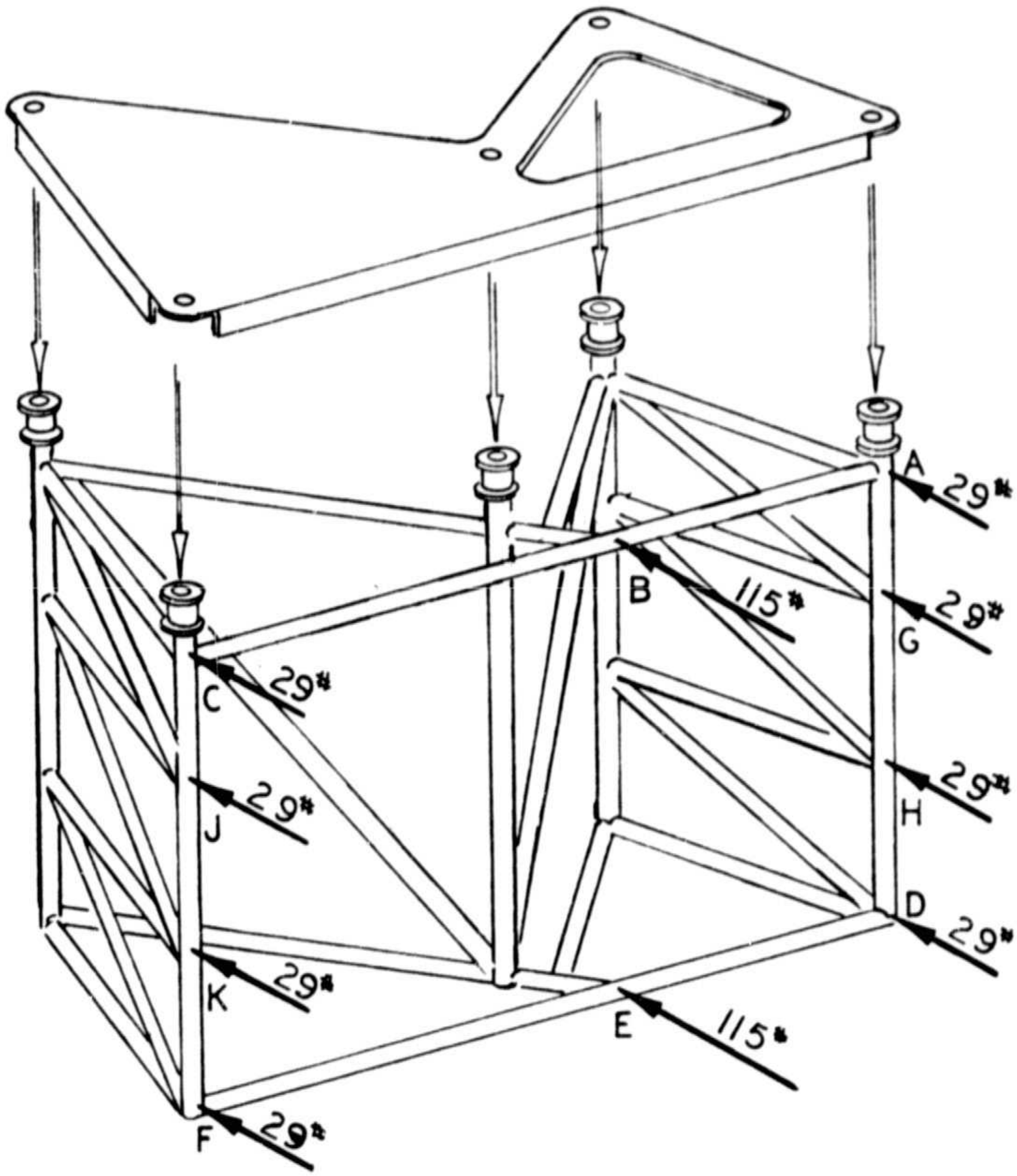


FIGURE B-2. APPLIED LOAD DISTRIBUTION

B-4 Tubular Structure Stress Analysis

Figure B-3 shows that the most severely loaded members are the diagonals in Sections C-C and D-D. Both see a maximum compression load of approximately 150 lbs. and have a length of about 19 inches. The diagonal in Section DOD is removable to allow installation of the Electronics Module. Since this diagonal is pinned at both ends, the ultimate strength required in buckling is (Ref. 5):

$$f_c = \frac{\pi^2 E}{\left[\frac{KL}{r}\right]^2}$$

where: f_c = Ultimate strength

E = Modulus of elasticity

K = Column End Condition Factor

(K = 1 for column pinned at both ends)

L = Column length (19 inches)

r = Radius of Gyration

For 1/2" dia. x .035" wall stainless steel tube structural members:

$E = 28 \times 10^6$ psi

r = 0.165 inches

and

f_c = 20,800 psi

The ultimate allowable compressive load is:

P_a = fc x Area

Area = 0.0511 in^2

P_a = 1060 lbs.

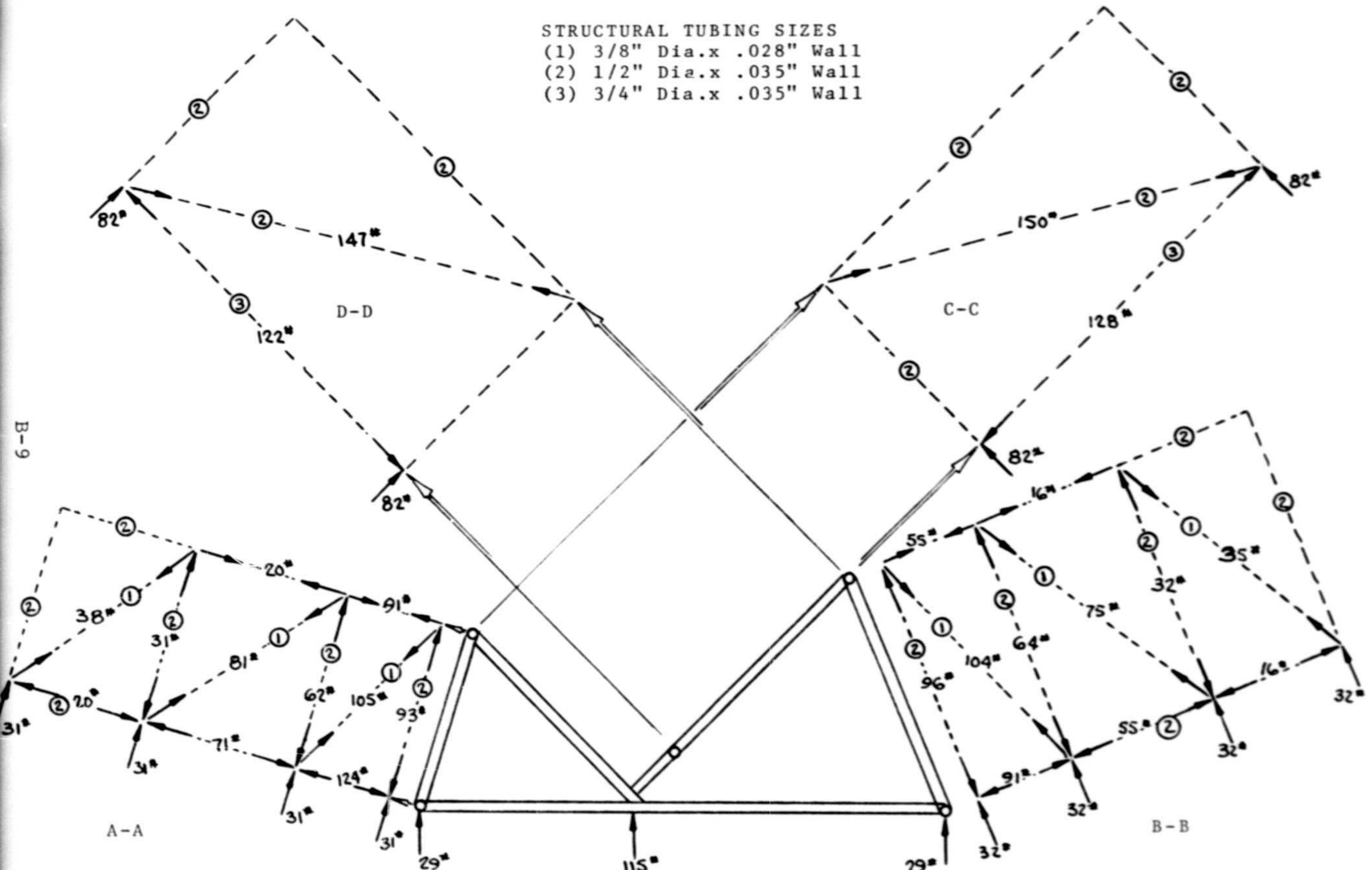


FIGURE B-3. LOAD DISTRIBUTION IN THE STRUCTURAL FRAME

The maximum actual load for the diagonal is 150 lbs. and allowing a factor of 2 for ultimate design load, the margin of safety in compression (MS_c) is:

$$f_c = \frac{P_a}{P} - 1 = \frac{1060}{300} - 1 = 2.5$$

A stress analysis for the diagonal in tension was also made as follows:

$$P_a = F_{ty} \times \text{Weld Factor} \times \text{Area}$$

where: F_{ty} = 35,000 psi (Type 304 Stainless Steel)

Weldfactor = 0.84

Area = 0.051 in^2 (1/2" dia. x .035" wall)

P_a = 1500 lbs.

The margin of safety in tension (MS_t) therefore is:

$$MS_t = \frac{P_a}{P} - 1 = \frac{1500}{300} - 1 = 4$$

Since similar loads are applied to the vertical and horizontal members of the tubular frame, the same size structural tubing is used for each of these members with the exception of the center column of the experiment. This column will be subjected to bending and twisting forces caused by the loads of the diode PCM, the transporter heat pipe and the diode heat pipes. A bending stress analysis was performed for this column and its size was increased to 3/4" dia. x .035" wall to account for the bending stresses.

An analysis of the diagonals in Section A-A and B-B of Figure B-3 was also performed. Since these members see a smaller load, their size was reduced to 3/8" dia. x .028" wall. For the most severe load of 105 lbs., with stainless steel tubing the following were determined:

$$f_c = 11{,}600 \text{ psi}$$

where: $E = 28 \times 10^6$ psi

$K = 0.5$ (Column fixed at both ends)

$L = 12$ in.

$r = .123$ in.

Based on this ultimate strength, and an ultimate design load of 210 lbs. (2 x 105 lbs.) the allowable load for this tubing is

$$P_a = fc \times \text{Area} = 11{,}600 \text{ psi} \times .0306 \text{ in.}^2 = 3550 \text{ lbs.}$$

The actual load is

$$P = 2 \times 105 \text{ lbs.} = 210 \text{ lbs.}$$

And the margin of safety in compression:

$$MS_c = \frac{3550}{210} - 1 = 15.9$$

In tension, the allowable load is:

$$Pa = F_{ty} \times \text{Weld Factor} \times \text{Area}$$

$$Pa = 35{,}000 \text{ psi} \times .84 \times .0306 \text{ in.}^2$$

$$Pa = 900 \text{ lbs.}$$

And the margin of safety in tension is

$$MS_t = \frac{900}{210} - 1 = 3.3$$

B-5 Mounting Bolt Stress Analysis

A stress analysis of the five (5) bolts connecting the experiment to the spacecraft was made and bolt sizes were determined.

The following assumptions were made:

(a) The maximum lateral force perpendicular to the radiator at 18 g's is 540 lbs.

(b) The moment arm between the CG of the experiment and the attachment face is 8.65 inches (See Figure B-1). The shortest moment arm in the attachment face is 7.63 inches. Therefore, the maximum tension load in the bolts is 306 lbs.

(c) It was assumed 540 lbs. in shear is going to 2 of the 5 bolts.

Strength data (Ref. 6) for #AN-4 (1/4-in) bolts indicates that a margin of safety of 10 for the combined tension and shear stresses that apply. Smaller bolts would provide adequate margin but are not as practical.

APPENDIX C

DIODE HEAT PIPE DESIGN REQUIREMENTS

NASA/GSFC ERTS-C CRYOGENIC HEAT PIPE EXPERIMENT

ARC CRYOGENIC DIODE HEAT PIPE DESIGN SPECIFICATION

SPECIFICATION NUMBER BK005-1008

February, 1975

Prepared by

B & K ENGINEERING, INC.
Towson, Maryland 21204

CONTENTS

1.0 SCOPE

This document defines the objectives and operational modes of the Ames Cryogenic Heat Pipe Diode to be incorporated within the ERTS-C Cryogenic Heat Pipe Experiment. The environments to which the diode will be subjected as part of the Experiment are also defined.

2.0 APPLICABLE DOCUMENTS

The following documents and drawings of the issue in effect on the date of release of this document apply to the extent stated herein:

S-320-EN-1	Environmental Test Specification for the ERTS (A&B) and Nimbus (E&F) Observatory Systems, Subsystems, and Experiments.
GSFC-430-60-200	Nimbus G Sensor Interface Requirements.
BK005-1007	Diode Heat Pipe Specification Drawing for ERTS-C Cryogenic Heat Pipe Experiment.

3.0 REQUIREMENTS

3.1 General

The Ames Cryogenic Thermal Diode Heat Pipe is part of the NASA/GSFC Heat Pipe Experiment designed for flight onboard the ERTS-C spacecraft. The orbit will be a 500 nautical miles, 9:30 orbit.

The experiment will consist of a transporter heat pipe, diode heat pipe, PCM, radiator, structure, insulation; instrumentation, electrical heaters and an electronics module. The electrical heaters will provide the heat loads required to test the heat pipes. Individual heaters with separate commands will be used to effect a number of different operational modes. These modes have been designed to accomplish experiment objectives for the various thermal control components within the ERTS-C experiment. The operations have been defined so that individual experimental subsystems will operate independently and will not compromise objectives of other heat pipe experiments.

Experiment package electrical and parasitic heat inputs will be dissipated to space by a passive radiator which is thermally isolated from the spacecraft. The radiator is mounted perpendicular to the plane of the spacecraft sensory ring in the earth pointing direction and is normal to the earth. Its surface views deep space at all times. A deployable shield blocks earth heat inputs.

3.2 Objectives

The objective of the Ames Cryogenic Diode Heat Pipe will be to demonstrate "reverse mode" shutdown and "forward mode" heat transport capabilities of a heat pipe diode operating at cryogenic temperatures. The technology derived from this experiment will be applied to detector cooling applications where radiator coolers are periodically exposed to high temperatures resulting from intermittent energy inputs such as solar radiation.

3.3 Design Definition Requirements

A definition of the ARC Cryogenic Diode Heat Pipe is required to finalize the ERTS-C Cryogenic Heat Pipe Experiment design, performance, operating modes and the requirements for power, command and telemetry. Definition of the diode heat pipe should include the following:

(a) Design configuration including:

Geometry

- Heat pipe diameter
- Bend configuration
- Reservoir Size and configuration
- Reservoir radiator size and configuration

(b) Performance characteristics including:

- Forward mode transport capacity as a function of operating temperature.
- "One-g" performance test requirements as a function of operating temperature.
- Forward mode conductance
- Turndown ratio or "Off" - conductance
- Shutdown energy including transient shutdown losses, if any.
- Reservoir heater power for active shutdown.

*(c) Interfacing Requirements:

- Condenser saddle geometry and dimensions
- Evaporator saddle geometry and dimensions
- Support point attachment details

* Details to be defined by Experiment Integrator, however, these are items which the diode fabricator should address.

- Reservoir radiator mounting and isolation requirements.
- Heat pipe thermal isolation requirements.
- Installation constraints.
- Insulation requirements.

(d) Test and operating mode constraints.

- Test objectives and suggested test mode profile.
- "One-G" leveling requirements.
- Wick priming considerations, if any.
- Power, command and telemetry requirements.

The design of the diode heat pipe shall be within the ERTS-C Experiment limitations as defined in this specification.

4.0 DESIGN DESCRIPTION

4.1 Baseline Design

A baseline Cryogenic Diode Heat Pipe design configured to fit within the allowable ERTS-C envelope dimensions is shown in Dwg. No. BK005-1007. The design consists of a thermal diode heat pipe, a PCM container and a PCM heat pipe. The PCM heat pipe and the PCM container form an integral package with the PCM heat pipe extending out of both ends of the container. The PCM heat pipe is a conventional heat pipe. It has a heater attached at one end to simulate detector heat load and is interfaced with the thermal diode heat pipe at the other end.

In the forward operating mode of the diode, heat dissipated by the simulated detector heater will be transported via the PCM heat pipe to the thermal diode heat pipe which in turn will transfer the heat to the radiator where it will be dissipated to space. Heat of fusion released from the PCM during freezing will also be transported to the radiator this way.

Reverse mode operation (shutdown) will be simulated, in the ERTS-C Experiment, by applying heat to the radiator with an electrical heater. During this period of time, the diode heat pipe will be required to isolate the simulated detector and the PCM from the hot radiator. Also during this period of time, heat from the simulated detector will be transported to the PCM via the PCM heat pipe. Temperature of the simulated detector will be maintained by the melting of the PCM.

A liquid blockage diode heat pipe was assumed for the baseline design. For this purpose a reservoir equipped with a small radiator has been included as part of the design.

4.2 Dimensional Constraints

The basic design of the diode heat pipe including diameter and bend configuration is optional. Reservoir design, reservoir radiator design and optical coating are also optional. Final design dimensions shall be within the limits shown in Dwg. No. BK005-1007.

4.3 Interface Requirements

For the baseline design, interfacing requirements shall be in accordance to Dwg. No. BK005-1007 including the following:

(a) An integral mounting saddle shall be provided as part of the diode heat pipe condenser for bolting to the radiator.

(b) An integral mounting saddle shall be provided as part of the diode heat pipe evaporator for bolting to the PCM heat pipe.

(c) A pick-up point shall be provided as part of the diode heat pipe near the bend (See BK005-1007) for support from the structure.

(d) The reservoir radiator shall be integral with the reservoir and will be attached to the main radiator as shown in BK005-1007.

4.4 DESIGN LIMITATIONS

The diode heat pipe shall be designed to meet the following requirements:

4.4.1. Weight

The maximum weight of the diode heat pipe experiment including the diode heat pipe, the PCM and the PCM heat pipe shall be a 2.25 Kg (5 -lbs.). Estimated baseline design PCM and PCM heat pipe weight is 1.75 Kg (3.85 pounds).

4.4.2 Pressure Retention

The diode heat pipe design shall allow a 5 to 1 pressure safety factor at 315°K service temperature.

4.4.3 Power, Command and Telemetry

Temperature sensors, signal conditioning, electrical heaters and commands will be provided by the experiment integrator. Twelve (12) temperature sensors have been allocated to the diode heat pipe experiment. Maximum power available for transport testing will be 25- watts. Four (4) "On-Off" command channels will be available for the diode heat pipe experiment.

4.5 Design Options

The use of PCM material on the ERTS-C experiment may be excluded because of potential contamination of the MSS. As an alternative, the diode heat pipe supplier shall conside the effects of a solid aluminum thermal mass of equal weight 1.75 kg (3.8 pounds) on the performance of the diode.

Other design alternatives which may be considered by ARC include:

(a) Simulatneous forward mode and diode operation with a single heat pipe. The combination of two heat pipes in series was selected for the baseline design because a continuous single heat pipe does not appear to be within current "state-of-the-art" for the liquid blockage diode technology. However, it would be desirable to interface the detector/PCM/radiator with a single heat pipe which would provide continuous transport from the detector to the PCM and simultaneously "block" the PCM from the hot radiator. Gas-controlled pipes offer this feature as a potential alternative.

(b) Liquid trap Diode: The liquid blockage design was selected because of previous experience and because it presumably has better shutdown characteristics. The liquid trap diode, however, may be considered as an alternative.

5.0 OPERATING MODES

The operating modes of the diode heat pipe are summarized in Table 5-1. Operating modes of the diode heat pipe will be as follows:

5.1 Transient Forward Mode

This mode will occur during cooldown from reverse mode operation. The purpose of this test mode will be to characterize the diode forward mode transient performance. The operating temperature in this mode will be determined by the 190°K nominal melting temperature of the diode PCM (ethyl acetate). The heat loads during this mode of operation will include the heat dissipated from the simulated detector, parasitic heat loads to the PCM and heat pipes and the heat of fusion of the PCM.

TABLE 5-1 ERTS-C/AMES Cryogenic Diode Test Modes

Test Mode	Heat Pipe Heater Power (Watts)	PCM (Watts)	Total to Heat Pipe (Watts)	Radiator Heat (Watts)	Nominal[(1)] Temp. °K	Approximate Duration	Frequency
Transient	3	3 watts	6 watts	0	190	8 hrs.	Once/30 da
Reverse	3	--	0	25	190	8 hrs.	Once/30 da
Long Term Forward	3	0	3 watts	0	180	Cont.[(3)]	Cont.[(3)]
Low Temperature Transport	25[(4)]	0	25	0	180	2 hrs.	Once/30 da
High Temperature Transport	25 [(4)]	0	25	0	225	4 hrs.	Once/30 da

(1) Approximate diode heat pipe evaporator temperature. Actual temperature will be dependent on forward conductance and turn down ratio.

(2) Radiator temperature during this mode will be approximately 225°K.

(3) Long term forward mode will be continuous except when other test modes are being exercised.

(4) Derived from present 30-w power budget. Additional power will be requested to accomplish burn-out if required.

Combined simulated detector and parasitics will be approximately 3.0 watts. Estimated duration of this mode is 8 hours based on a 24 watt-hours PCM capacity. Beyond this time period the PCM will become sub-cooled and steady state operating temperature will be reached at approximately 180°K.

5.2 Reverse Mode

The objective of this test mode will be to characterize the diode shutdown properties including turn-down ratio and shutdown energy. This test will be initiated with the diode PCM in a frozen state. Twenty-five watts of power will be applied to the radiator with an electrical heater attached to the inboard side of the radiator. This power will raise the temperature of the radiator to a steady state temperature of approximately 225°K. During this mode, heat from the simulated detector, parasitic heat leaks and diode reverse mode heat leaks will be absorbed by the PCM. Duration of the mode of operation will last up to 8 hours and will be dependent on shutdown energy, transient shutdown losses, if any, and diode reverse conductance (shutdown ratio).

5.3 Long Term Forward Mode

The diode heat pipe will be tested in the Forward Mode over an extended period of time to establish long term operating characteristics. Tests in this mode will be performed continuously except when other short term test modes are being exercised. Approximately 3.0 watts of power, including parasitics, will be applied to the diode heat pipe during this time. Operating temperature will be approximately 180°K.

5.4 Low Temperature Transport Test

The diode heat pipe will be exercised to verify maximum capacity at low temperatures. The high power required to perform this test will be accomodated by the PCM package attached to the radiator. Heat pipe operating temperature will be in the 170°K to 180°K range. The radiator PCM capacity will be approximately 40 watt-hours which will allow up to 2 hours of test time at heater power inputs of 25 watts.

5.5 High Temperature Transport Test

Maximum capacity at high temperatures will be verified during this test mode. This will be performed by applying a heat load which will increase the operating temperature to a point where the heat pipe will burn out under the applied load.

6.0 ENVIRONMENTAL CONDITIONS

The diode heat pipe shall be designed to operate under the following environmental conditions:

6.1 Thermal

6.1.1. Operating Temperature Range

The diode heat pipe shall be designed to operate in the range of 160 to 250°K. Within this range the diode heat pipe will be tested at the following temperatures:

(a) Long term steady state forward mode- - 180-185°K

(b) Temperature control characterization (Reverse Mode/Forward Mode Cycling Tests) - - - - - - - - - - - - - 190°K

(c) Low Temperature High Power Test - - - - 170-180°K

(d) High Temperature High Power Test - - - 225°K

During reverse mode tests the radiator temperature will be approximately 225°K.

6.1.2 Thermal Environment

The diode heat pipe shall be subjected to a thermal environment derived from the thermal inputs from the earth and spacecraft. The net radiator capacity as well as other applicable thermal parameters that apply to the Preliminary Experiment design are as follows:

a. The net radiator heat rejection capacity, accounting for parasitic heat leaks and earth input are given as a function of radiator temperature as:

$$Q_{net} = C_1 T_r^4 + C_2 T_r - C_3$$

Where: $C_1 = 1.36 \times 10^{-8}$ watts/°K^4

$C_2 = 8.25 \times 10^{-3}$ watts/°K

$C_3 = 12.83$ watts

b. The total thermal mass of the radiator, as it will affect the transient operation between the various test modes, is 1.47 watt-hours/°C.

c. The diode heat pipe PCM shall have a capacity of 24 watt-hours. The freezing point of the PCM shall be 190° ± 2°K.

d. The experiment will be designed to minimize parasitic heat leaks to the diode heat pipe and PCM. For diode design purposes, total parasitic input to the diode experiment can be assumed to be less than 0.5 watts.

6.1.3 Maximum Temperature Range

The diode heat pipe shall be designed to withstand handling, shipment, storage and flight temperatures ranging from 150°K to 325°K.

6.2 Mechanical

6.2.1 Dynamic

The diode heat pipe experiment shall be designed to withstand the dynamic loads as defined in Table 6.1.

6.2.2 Leveling Requirements

The diode heat pipe shall be capable of operating in "One-g" with a 0.2 inches adverse tilt.

Table 6.1 ERTS Dynamic Test Requirements-Qualification Level

(Below the torus on long mounts)

SINUSOIDAL

Frequency Range (Hz)	Amplitude - "g" 0-to-Peak Thrust	Transverse
5-40	8.0*	-
40-200	10.0	-
200-2000	5.0	-
5-60	-	6.0*
60-200	-	18.0
200-2000	-	5.0

* Exposure limited to .5" double amplitude.

Sweep rate: 1 octave/minute

RANDOM*

Frequency Range (Hz)	Power Spectral Density (g^2Hz)	g-RMS	Duration
20-2000	0.09	13.4	4 Min/axis

* These levels apply to all three axes.

Reference: "Environmental Test Specification For The ERTS (A and B) and Nimbus (E and F) Observatory Systems, Subsystems and Experimencs" S320-EN-1, November 1971