

Cargo Systems Manual: Heat Pipe Performance (HPP)

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STS-66

Operations Division
Payload Operations Branch

Basic
June 1994

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**Cargo Systems Manual:
Heat Pipe Performance (HPP)
STS-66**

Basic

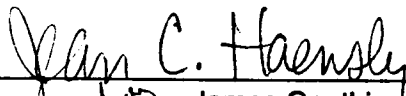
June 1994

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PREFACE

This document has been prepared by the Payload Operations Branch, Operations Division, Mission Operations Directorate (MOD), NASA, Lyndon B. Johnson Space Center, Houston, Texas, with editorial support from the Integrated Documentation Support Department, Hernandez Engineering, Inc., and technical support from the Space Shuttle Program, Cargo Engineering Office (TJ). The Cargo Engineering Office has reviewed the Cargo Systems Manual (CSM) to the level of detail contained herein and verified that all orbiter-to-payload avionics interfaces are accurately represented.

Comments concerning the general contents of this manual should be directed to DO65/Robert Napp, 713-244-0275.

PURPOSE

The purpose of the CSM is to provide a payload reference document for payload and shuttle flight operations personnel during shuttle mission planning, training, and flight operations. The CSM will include orbiter-to-payload interface information and payload system information (including operationally pertinent payload safety data) that is directly applicable to the MOD role in the payload mission. The CSM is an accurate source of this information for use by flight operations personnel.

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SECTION 1 INTRODUCTION

1.1 OBJECTIVES

The primary objectives of the Heat Pipe Performance (HPP) are to obtain quantitative data on the thermal performance of heat pipes in a microgravity environment. This information will increase understanding of the behavior of heat pipes in space and be useful for application to design improvements in heat pipes and associated systems.

The purpose of HPP-2 is to establish a complete one-g and zero-g database for axial groove heat pipes. This data will be used to update and correlate data generated from a heat pipe design computer program called Grooved Analysis Program (GAP). The program predicts maximum heat transport capacity vs. operating temperature for axially grooved heat pipes. The HPP-2 objectives are:

- Determine heat transport capacity and conductance for open/closed grooved heat pipes and different Freon volumes (nominal, under, and overcharged) using a uniform heat load
- Determine heat transport capacity and conductance for single/multiple evaporators using asymmetric heat loads
- Obtain precise static, spin, and rewicking data points for undercharged pipes
- Investigate heat flux limits (asymmetric heat loads)
- Determine effects of positive body force on thermal performance

1.2 HISTORY

Much of the HPP hardware design is an outgrowth of the Hughes Fluid Dynamics Experiment (FDE) developed before 1986. Experiments were conducted on the KC-135. The FDE underwent the space shuttle flight certification process in use at the time. The experience gained has been used to improve HPP, making the experiment safer and easier to perform. HPP flew for the first time on STS-52 in October 1992.

1.3 DESCRIPTION

The HPP hardware includes a control/motor module with attached safety shroud, 12 heat pipes filled with Freon 113, a shared payload general support computer (PGSC) and a PGSC interface unit (PIU). All of the hardware is stowed in three middeck lockers. Once unstowed and set up, the HPP apparatus is attached to two seat studs on the middeck floor. Two Brownline fittings secure HPP in place during the experiment runs. Four heat pipes can be mounted to the HPP apparatus. Only one heat pipe can be tested at a time. Typically, two heat pipes are mounted for a particular test run. The PGSC is used to collect HPP data (heat pipe temperatures, spin rate, power setting) during experiment operations. Total experiment time is about 22 hours. Figure 1-1 depicts the HPP apparatus.

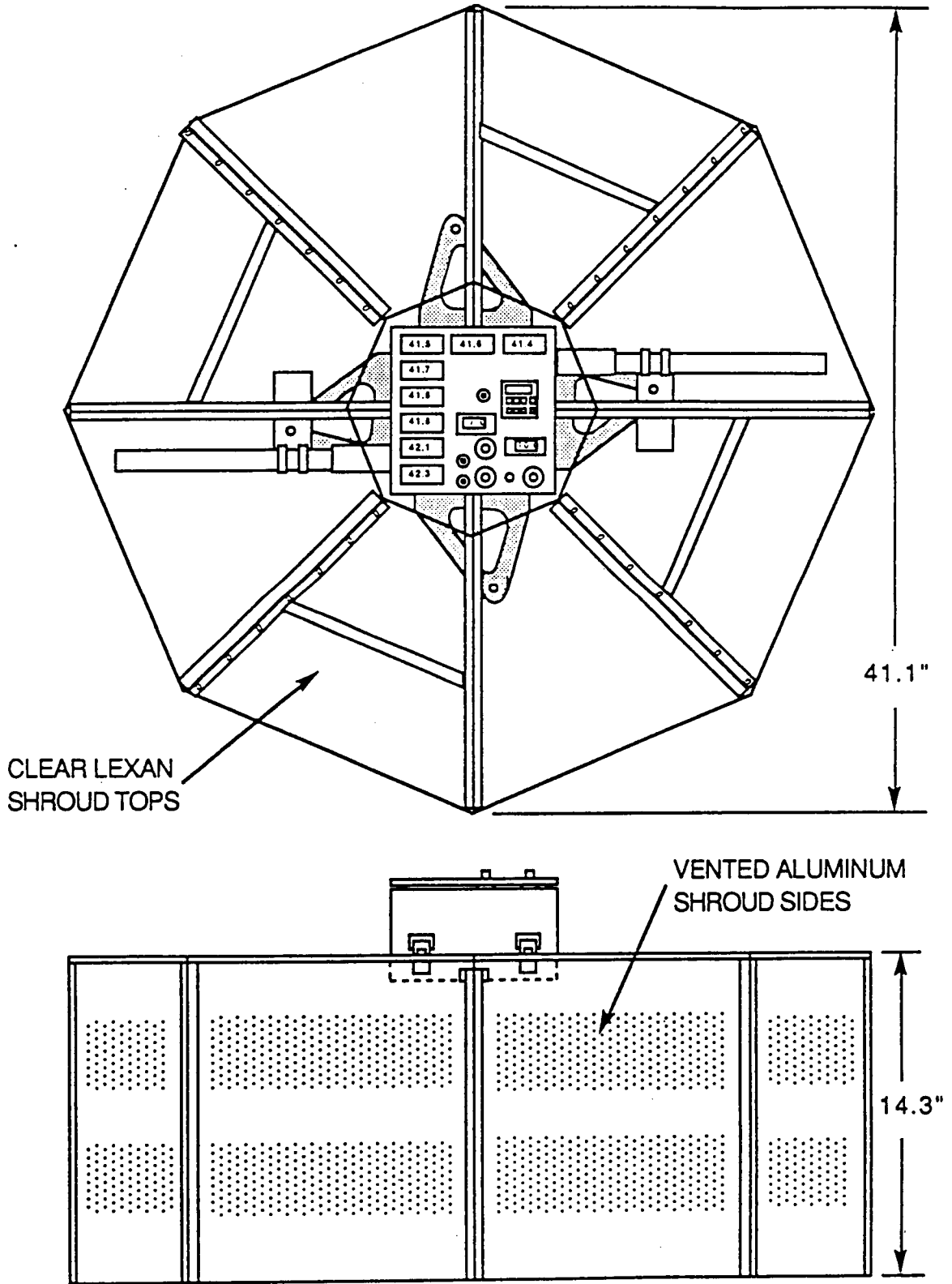


Figure 1-1. HPP apparatus

1.4 MISSION SCENARIO

There are three types of experiment tests: static, spin, and rewicking. The static test is performed with the heat pipes in a static (non-rotating) configuration. Eighteen tests are planned. Performance of the different heat pipe designs is tested with different heat loads on the evaporator end. Static tests require about 13.5 total hours to perform.

The spin tests are performed with the heat pipes in a rotating configuration. The heat pipes are attached in the same manner as in the static tests. Different spin rates are selected to cause the heat pipes to rotate similar to a merry-go-round. The Freon inside the pipe is forced out to the evaporator end. Performance of heat pipe designs using different heat loads and spin rates is measured. Fourteen spin tests are planned. Total test time is about 7 hours.

Rewicking tests begin by spinning the heat pipes. After about 10 minutes, the spin rate is reduced to zero. The time for the fluid to rewick under different heat loads is measured. Three rewicking tests are performed. Total testing time is about 1 hour.

SECTION 2 HEAT PIPE PERFORMANCE

2.1 INTRODUCTION

As spacecraft size and power requirements increase, the need for efficient waste heat rejection becomes greater. The design of effective thermal control systems requires an understanding of heat pipe behavior in the microgravity environment. This behavior cannot be adequately evaluated on Earth because of strong gravitational forces. During ground testing, gravity dominates the capillary forces acting in the wick and becomes a limiting factor. In the microgravity environment, however, surface tension forces dominate.

Characterization of rewicking times following a sustained acceleration parallel to the heat pipe axis, for example, is especially difficult in ground tests. In this case, the working fluid accumulates at one end of the pipe, which, upon cessation of the acceleration, does not function properly again until capillary action redistributes the fluid throughout the wicking system. Because of the dominance of gravitational forces over capillary, ground tests are not directly applicable for spacecraft heat pipes.

Additionally, excess fluid in the heat pipe, which is often included to compensate for fluid contraction at low temperature operation, can form slugs which affect the thermal transport capability of the pipe. In the presence of gravity, however, this excess fluid puddles along the bottom of the pipe and creates an enhancement to heat pipe performance. Microgravity experiments are therefore clearly necessary to evaluate these phenomena.

The experiment evaluates the sensitivity of state-of-the-art heat pipes to microaccelerations by obtaining quantitative data showing thermal profiles under operational, acceleration, and recovery conditions. Axial grooved heat pipes are investigated at various fill fractions.

The experiment consists of three modes. In the first mode, the test apparatus spins to simulate axial acceleration and force the working fluid to the outboard end of each pipe. The apparatus is then brought to rest, and the evaporator end of each pipe is warmed one at a time with low-wattage electric warmers. The time required to rewick the pipes is measured. The second mode is used to investigate static dryout and recovery by increasing power with no rotation until dryout is observed. In both cases, repriming rates for the deprimed heat pipe wicks and the effect of excess fluid are evaluated.

The last mode is used to measure heat transport capability and surface temperature distributions for axial grooved heat pipes subjected to various accelerations between zero g and one g. The power is set to a constant level and the spin speed varied between 4 and 7 rpm's. Thermal performance in all modes is evaluated using discrete temperature sensors.

The test apparatus is mounted to seat studs in the middeck during testing. The HPP is composed of several subsystems, the mechanical support and rotating assemblies, 12 heat pipes, a thermal control subsystem, and an instrument and control subsystem. The heat pipes are discussed in section 3.

2.2 MECHANICAL SUPPORT AND ROTATING ASSEMBLIES

The HPP apparatus consists of the motor and control module and the bearing support and cruciform assemblies. The motor and control modules do not rotate, but control the speed and

provide the structural support for the rotating structure. Figure 2-1 shows the HPP apparatus without the safety shroud.

The motor module is a 0.12-inch-thick aluminum box with detachable side panels within an electromagnetic compatibility (EMC) shield enclosure which contains the motor, motor electronics, and control electronics. The module mounts to the floor of the middeck via two seat studs. The nonrotating stainless steel shaft of the slip ring assembly is attached to the bottom of the motor module. A 0.25-inch aluminum plate covers the top of the module and supports the outer bearing and the rotating bearing support assembly that holds the main self-drive sprocket. Figure 2-2 shows the control/motor module.

The bearing support assembly also holds the two internal bearings which attach to the nonrotating shaft. Mounted atop this assembly is the 0.25-inch-thick cruciform assembly. The rotating cruciform assembly consists of the cruciform, four fans, and the slip ring outer housing. The cruciform has hinged arms that allow stowage in the middeck lockers.

The slip ring provides the electrical interface between the rotating and nonrotating structures. Power to the fans and heat pipe heaters passes through the slip ring as well as the telemetry from the platinum resistance thermometers (PRT's) back to the control module.

Heat pipes are attached to the cruciform arms via attach brackets using DZUS-type quick release, quarter-turn fasteners. The heat pipes are permanently mounted to the brackets using two single loop-style clamps. The clamps are covered with Nitrile insulation to thermally isolate the heat pipe from the bracket. The evaporator end of the heat pipe is also captured at the cruciform.

The control module is permanently mounted to the top of the nonrotating shaft and contains the control switches and displays. A clear Lexan shroud covers the glass-faced display meters.

To prevent inadvertent contact with the operating, rotating heat pipes by crewmembers, a safety shroud with a clear Lexan covering is installed around the motor module and spinning cruciform/pipe assembly. The shroud, which does not spin, is assembled with four quarter assemblies that are attached to the bottom of the motor module and with DZUS fasteners to the side of the control module. Four 1/8-inch-thick Lexan quarter-panel plates, which are hinged for locker storage, are hinged to the aluminum framework. Velcro is used to secure the panels into position. Figure 2-3 shows the safety shroud in position on the HPP.

2.3 INSTRUMENTATION AND CONTROL

The HPP instrumentation consists of temperature sensors bonded to the heat pipes, liquid crystal display (LCD) readouts to display the temperature, power, spin rate, settings, and a PGSC to record the data. The displays and control switches are all located in the control module. Drawing 2.1 shows the electrical block diagram of the HPP.

The various control and selection switches necessary to operate the experiment are contained on the face of the control module. These include a five-place indexed rotary switch to select the heat pipe to which power is applied and from which instrumentation is read; three 10-turn potentiometers to adjust the warmer power, spin rate, and fan flow rate; and two pushbutton power switches, one to turn power on and one to turn power off. Separate momentary on/off switches are used so that power is held on through a relay. This prevents the device from being connected to orbiter power in the ON position. The display board also contains a timer that is preset by the crew to automatically cut off power to the heaters after a specified period of time.

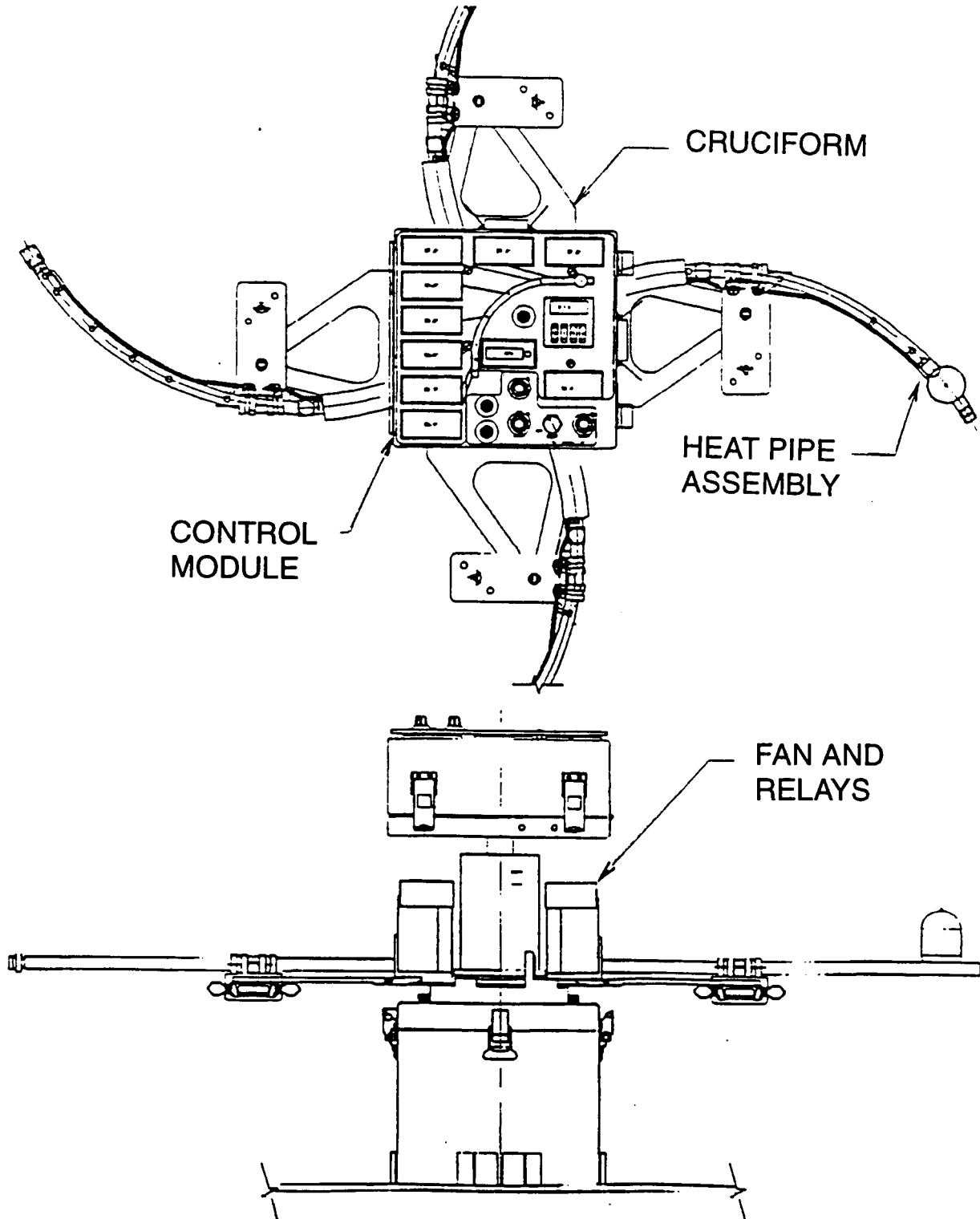


Figure 2-1. HPP apparatus (without safety shroud)

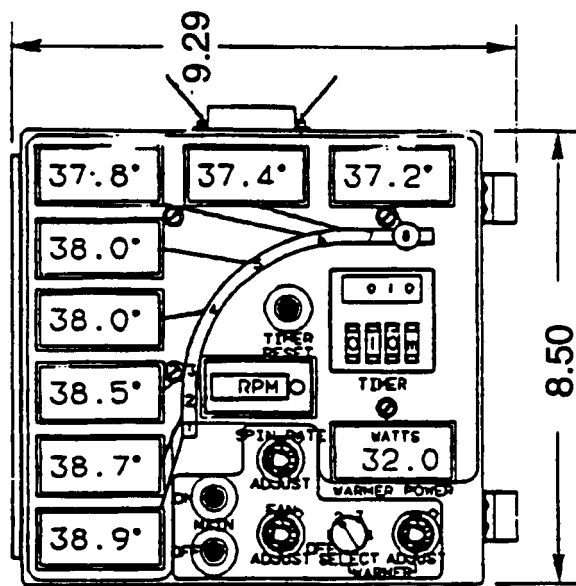
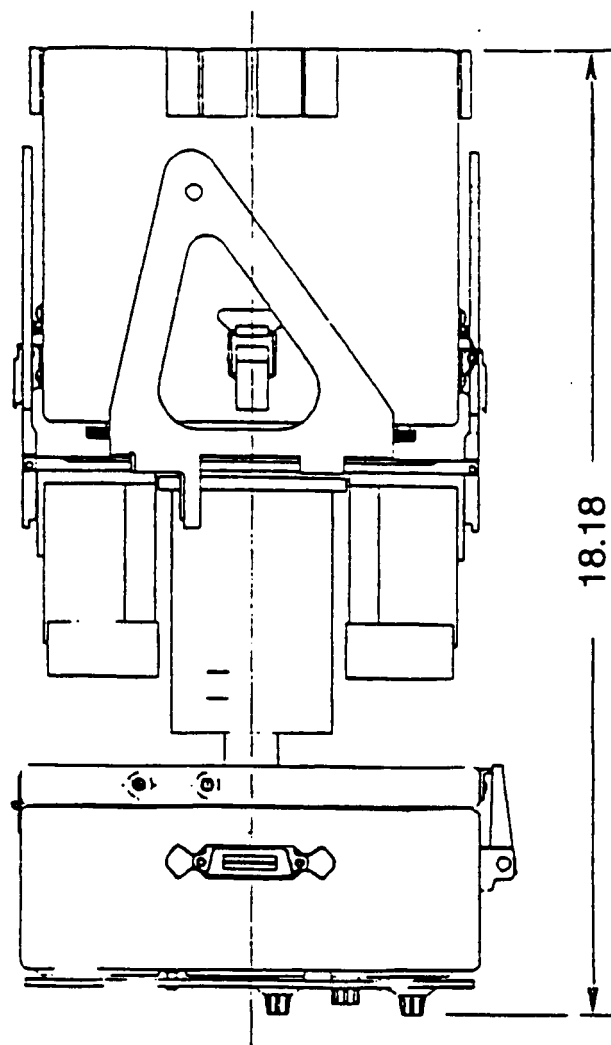


Figure 2-2. Control/motor module

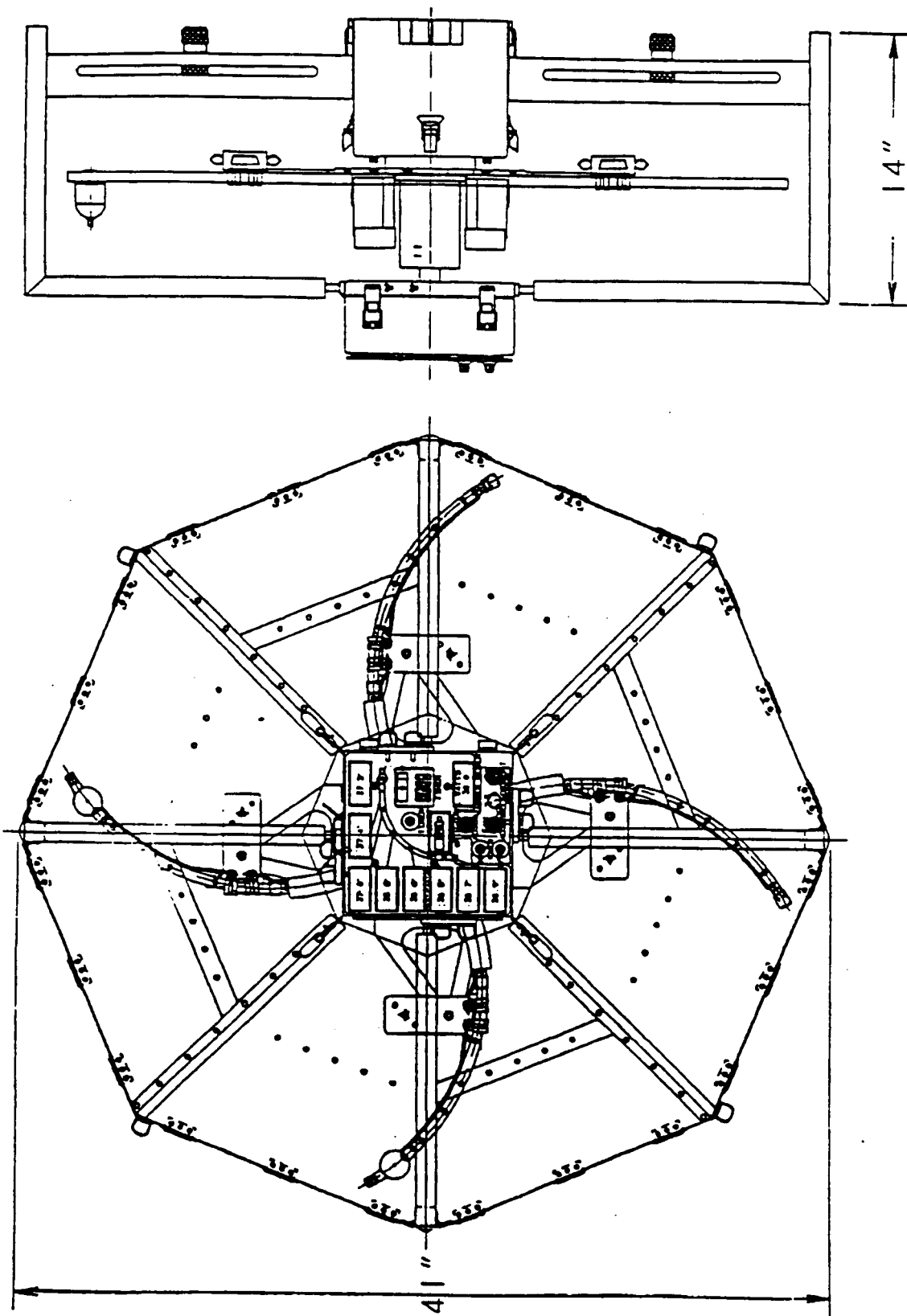


Figure 2-3. Safety shroud envelope

A 10-meter LCD display is also part of the control module. Eight of the meters read out the temperature indicated by the PRT's on the selected pipe. The two other meters output a reading of the amount of power being input into the heat pipe warmer and the spin rate of the heat pipe assembly. Because the LCD meters have glass faces, a clear Lexan shield covers the entire display portion of the control module. Figure 2-4 shows the LCD's and controls on the control module.

A PIU is connected via an RS-232C interface to the side of the control module. The PIU connects to a PGSC through an RS-232C, which records the outputs of the PRT's, the spin, and power settings at a rate of TBD seconds.

2.4 POWER

The HPP receives 28 V dc power from the orbiter middeck utility power. The PGSC is plugged into any free dc middeck utility power outlet. Average power during experiment operations is 60 watts. Maximum (peak) power is 115 watts. Table 2-1 lists the power requirements of the HPP equipment.

Table 2-1. Power requirements of HPP equipment

Component	Location	Maximum power (watts)
Warmers	Heat pipes	60
Fans	Cruciform arm	6
Motor	Motor module	23
Control module electronics	Control module	3
PGSC	TBD	TBD

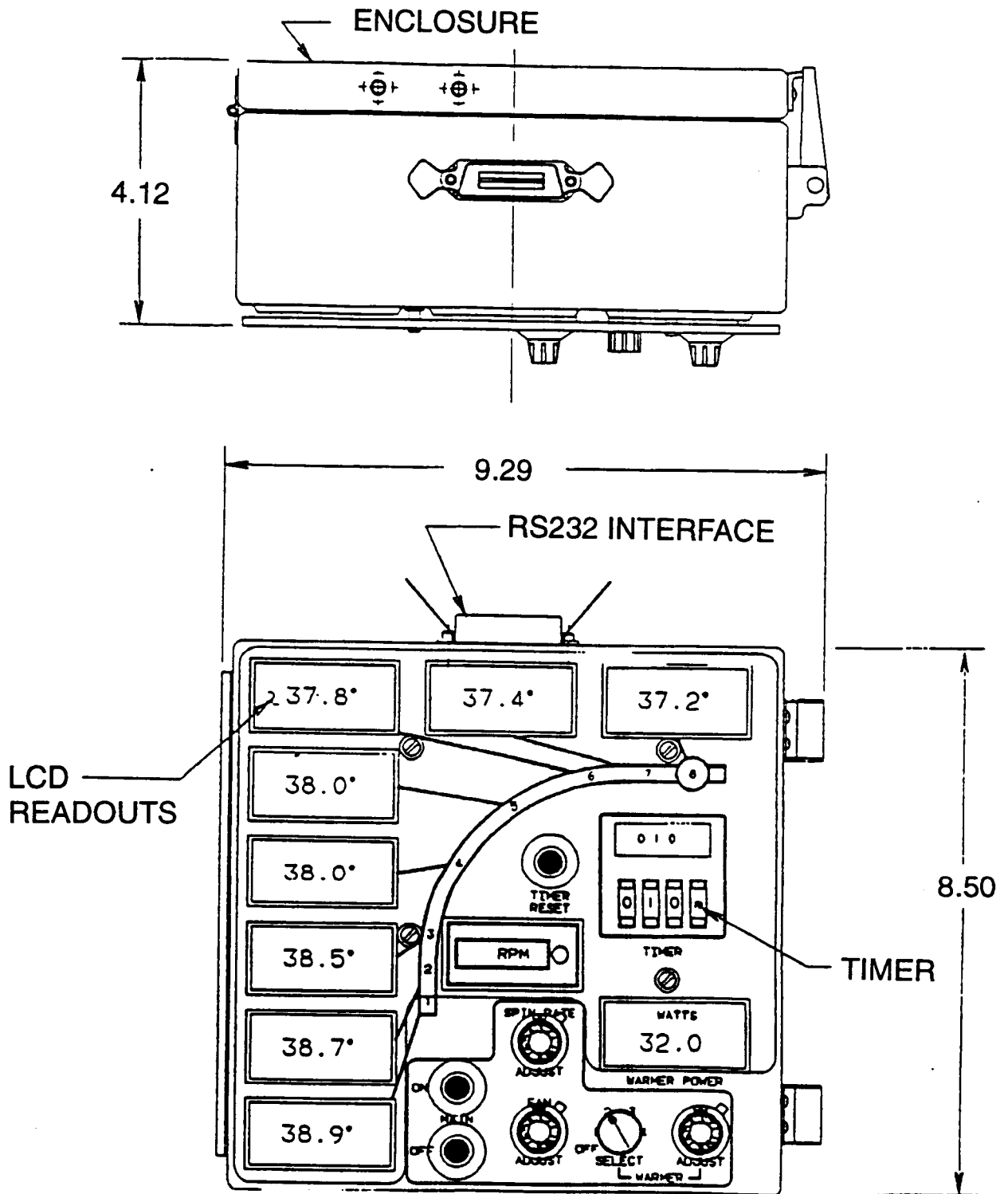


Figure 2-4. HPP control module

SECTION 3 HEAT PIPES

Twelve axial grooved constant conductance heat pipes are flown with the HPP apparatus. Ten of the twelve are to be used during experiment operations. The remaining two pipes are flight spares. Freon 113 is used as the working fluid (approximately 8.5 grams). Each pipe is 16 in. long with a 0.5 in. by 0.5 in. cross section. The heat pipes are made from type 6063-T6 aluminum. See figure 3-1.

Heaters are located on each pipe to apply different heat loads. There are three primary heat pipe heater configurations. Each heater is a dual-element, Kapton-insulated, thin-foil Minco heater. There are three heater configurations. See figure 3-2. Each pipe has one of the three heater configurations attached to it. In addition, each heater configuration can have up to three heater circuit arrangements. See figures 3-3, 3-4, and 3-5. The different heater circuits can be selected with a rotary switch located on each heat pipe. See figure 3-6. Using the warmer circuit select knob, different heat loads can be applied. Heat can be applied uniformly around the pipe or from one side. The amount of power applied to the heaters can be varied from a knob on the control module. Input power ranges from 0 to 60 W.

For safety, six storage containers house the heat pipes when they are not attached to the HPP apparatus. Each storage container holds two heat pipes. The storage boxes are doubly contained to protect against the inadvertent leakage of Freon. Nominally, only two heat pipes will be out at any one time. The six storage containers are contained in a single middeck locker. See figures 3-7 and 3-8.

A fan mounted to each arm of the rotating cruciform support provides cooling airflow to the operating heat pipe. The fans increase the convective heat transfer between the pipe and the middeck air to allow the experiment to operate at safe temperatures. Temperature range for a heat pipe will vary between 40° and 85° C. Each fan has a dual-position baffle design used to regulate the amount of air flow over the heat pipe. A knob on the control module adjusts the speed of the fan.

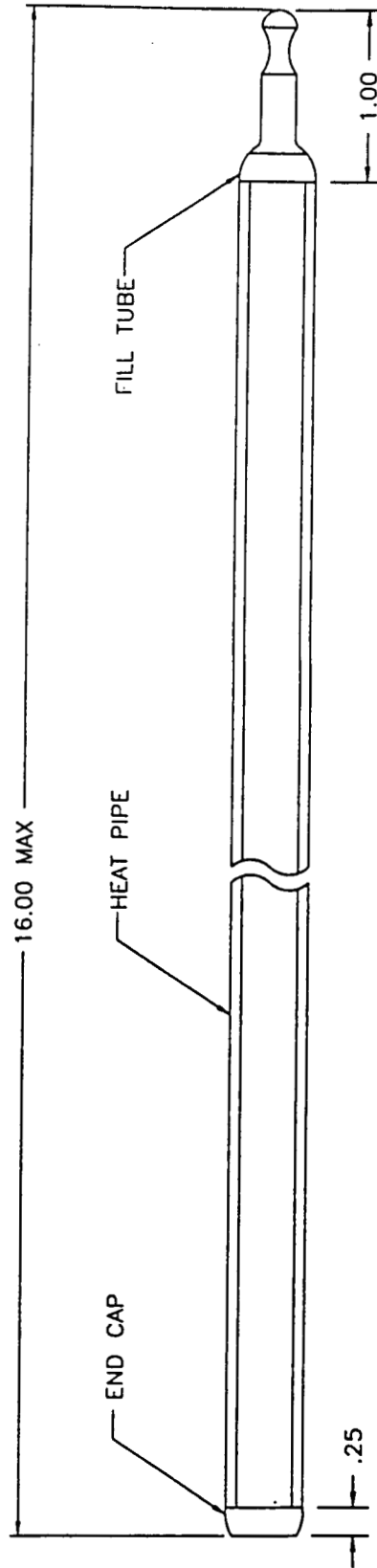
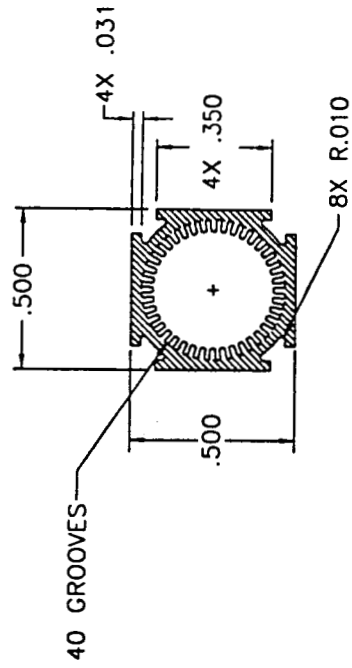


Figure 3-1. Heat pipe

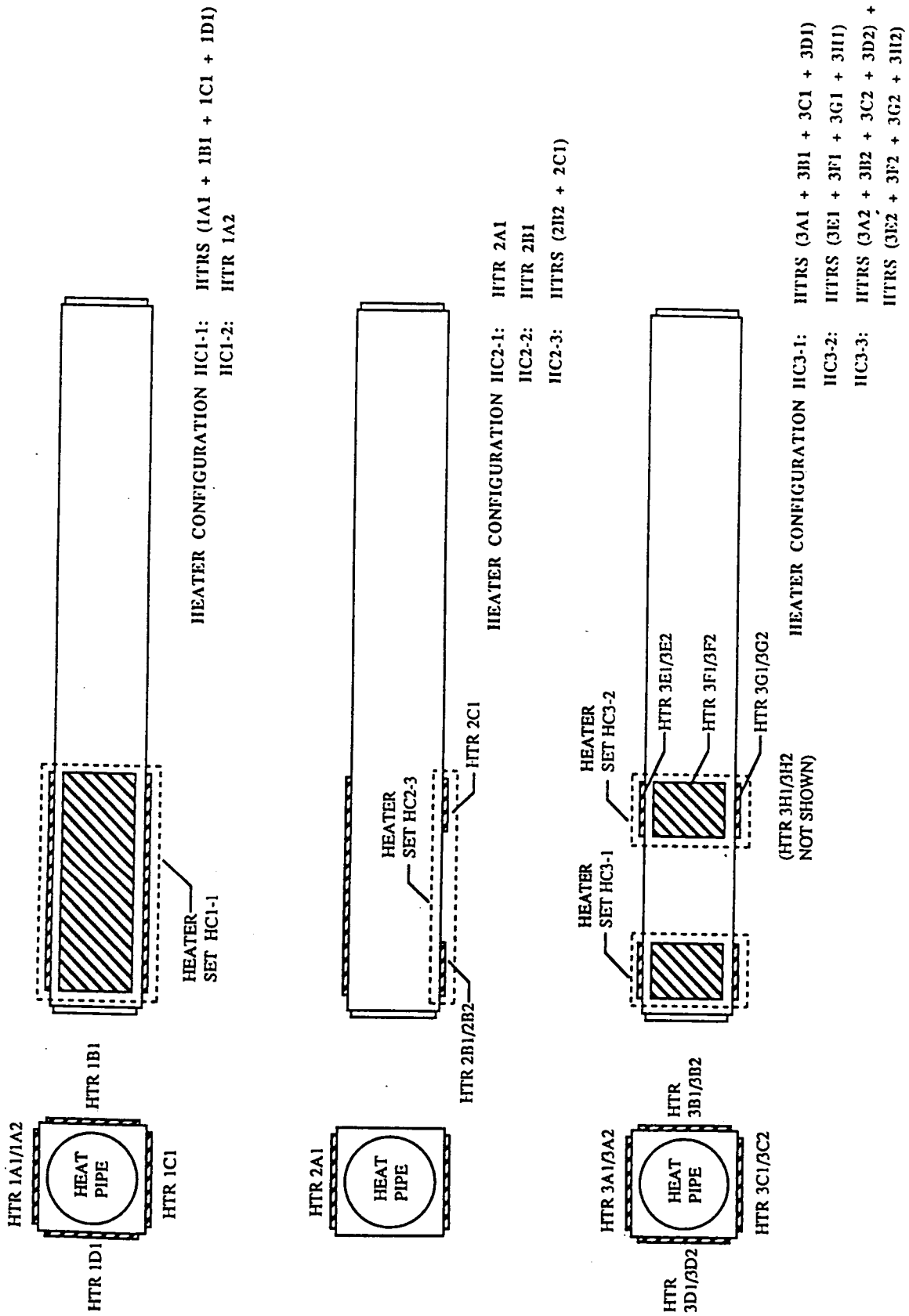


Figure 3-2. Heat pipe heater configuration

HEATER CONFIGURATION HC1-1: CRTS (1A1 + 1B1 + 1C1 + 1D1) = 12Ω
 HC1-2: CRT 1A1 = 12Ω

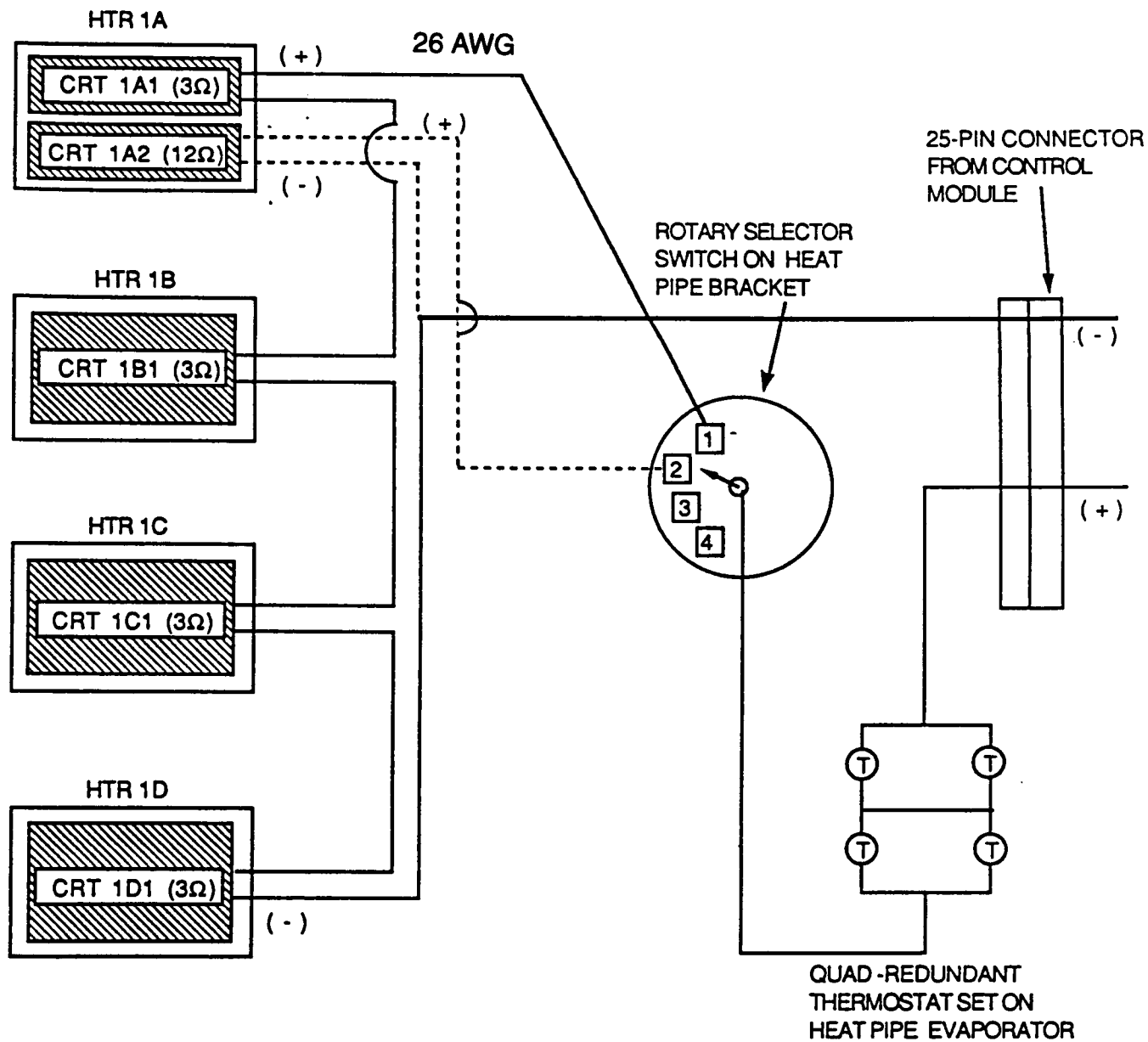


Figure 3-3. HC1 heater configuration

HEATER CONFIGURATION HC2-1: CRT 2A1 = 12Ω
HC2-2: CRT 2B1 = 12Ω
HC2-3: CRTS (2B2 + 2C1) = 12Ω

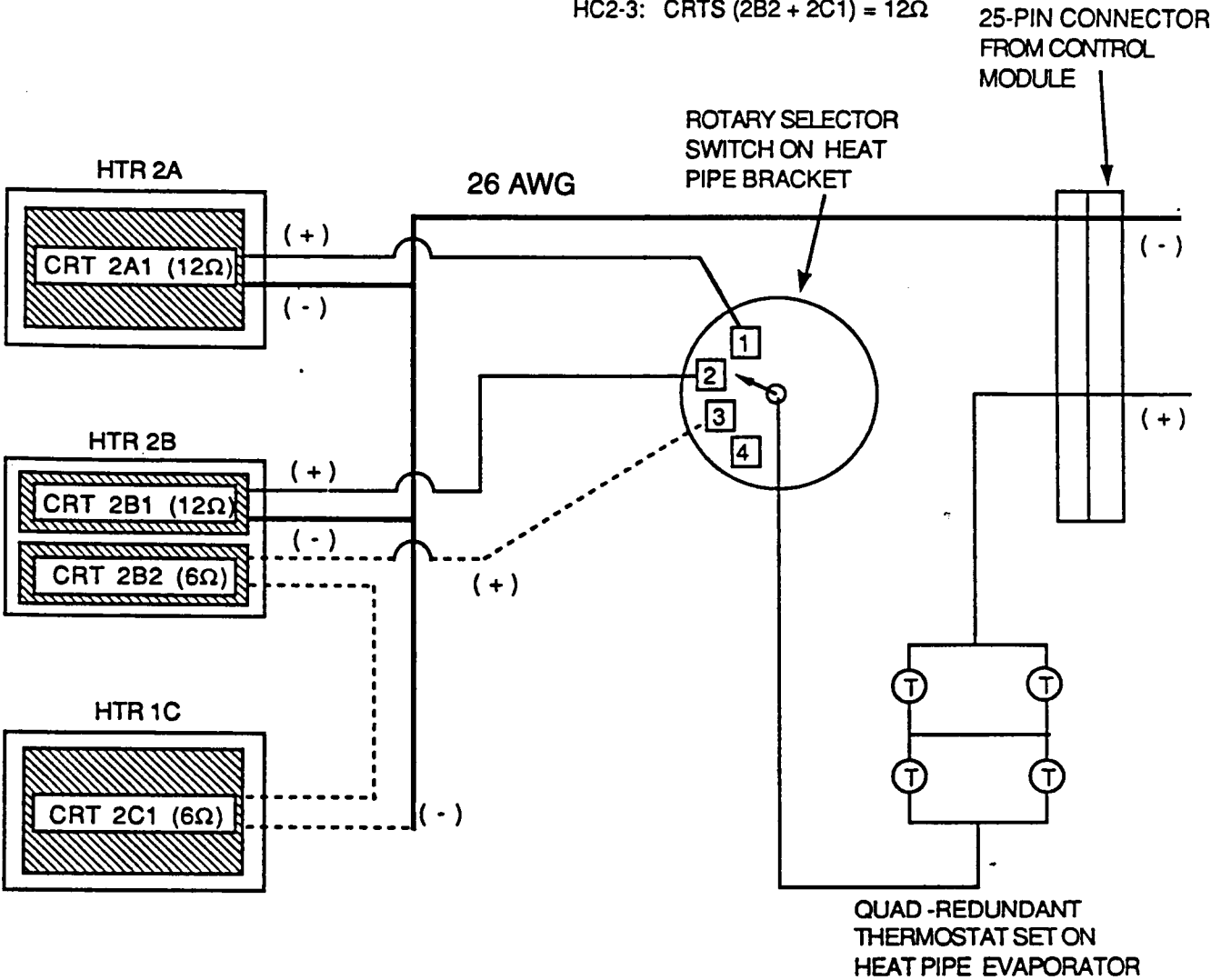


Figure 3-4. HC2 heater configuration

HEATER CONFIGURATION HC3-1: CRTS (3A1 + 3B1 + 3C1 + 3D1) = 12Ω
HC3-2: CRTS (3E1 + 3F1 + 3G1 + 3H1) = 12Ω
HC3-3: CRTS (3A2 + 3B2 + 3C2 + 3D2) +
CRTS (3E2 + 3F2 + 3G2 + 3H2) = 12Ω

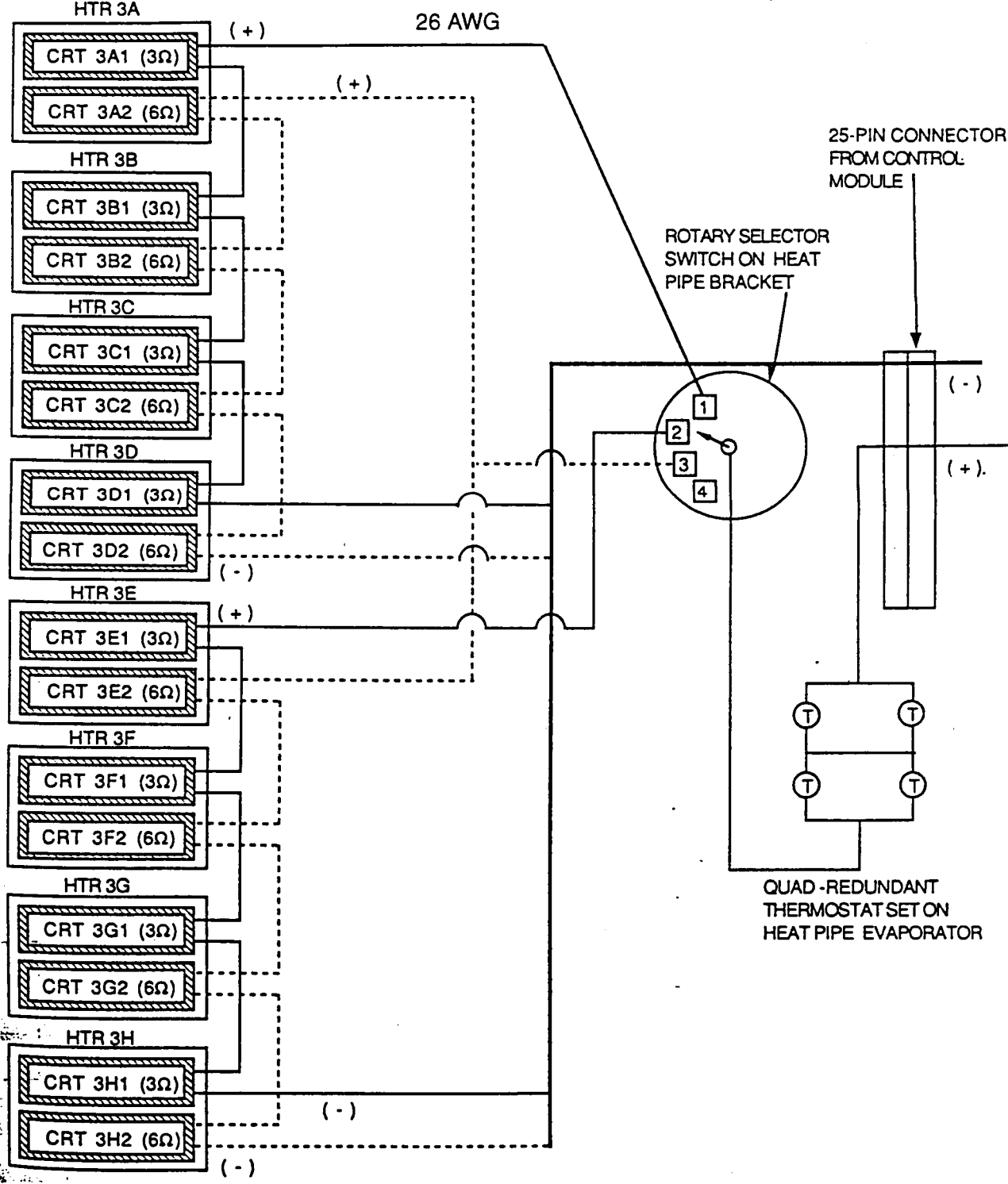


Figure 3-5. HC3 heater configuration

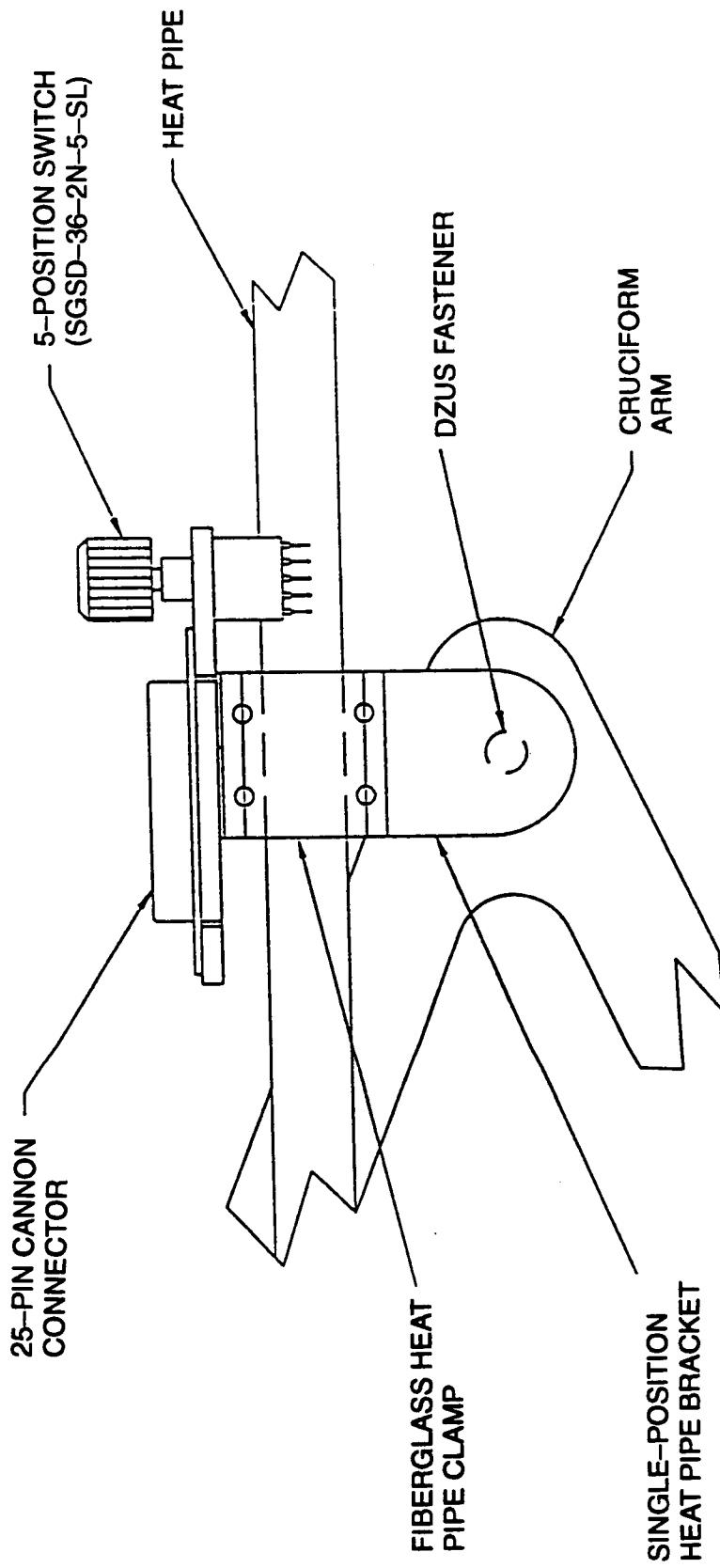


Figure 3-6. Heater circuit select switch

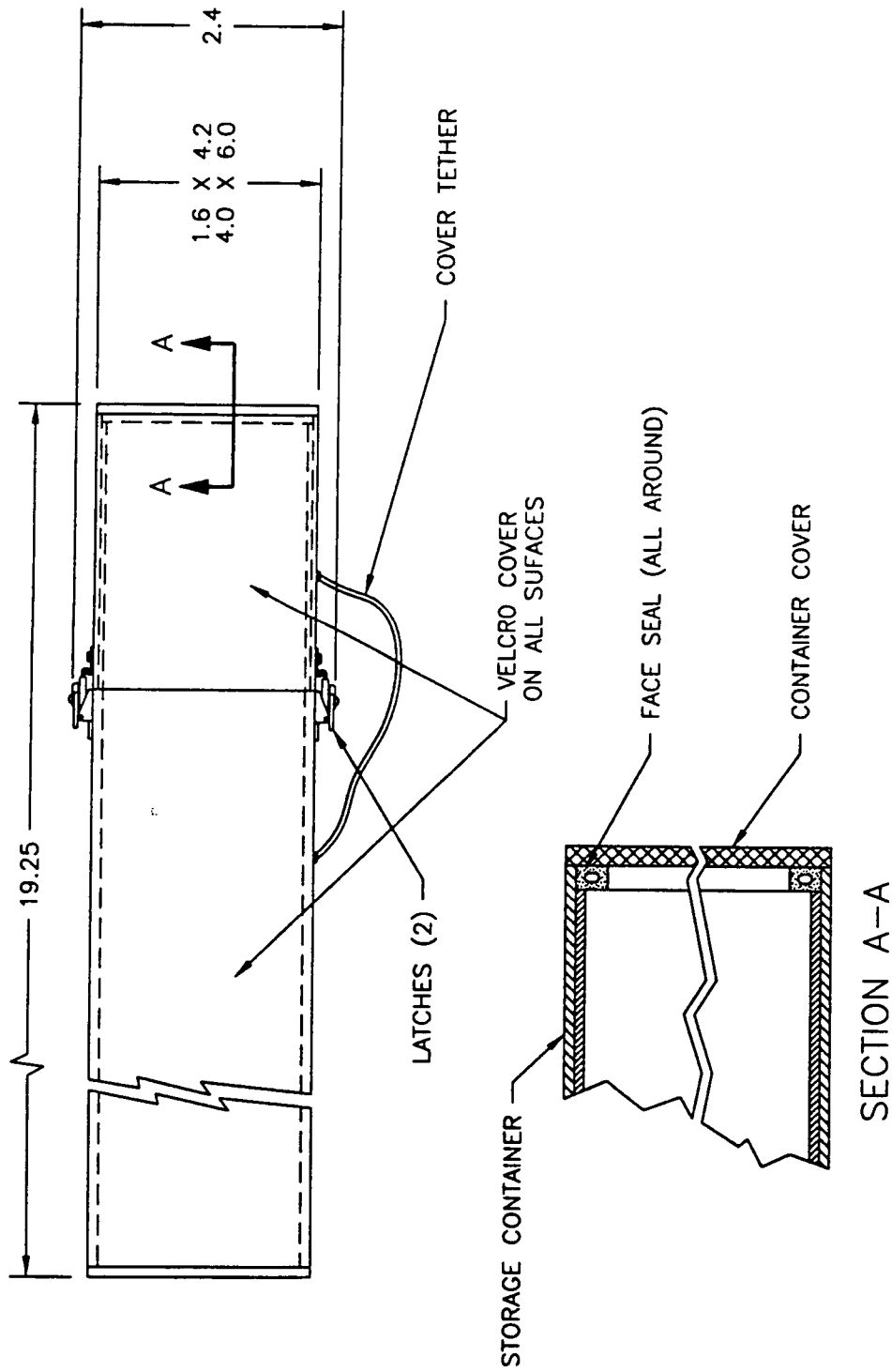


Figure 3-7. Heat pipe storage container

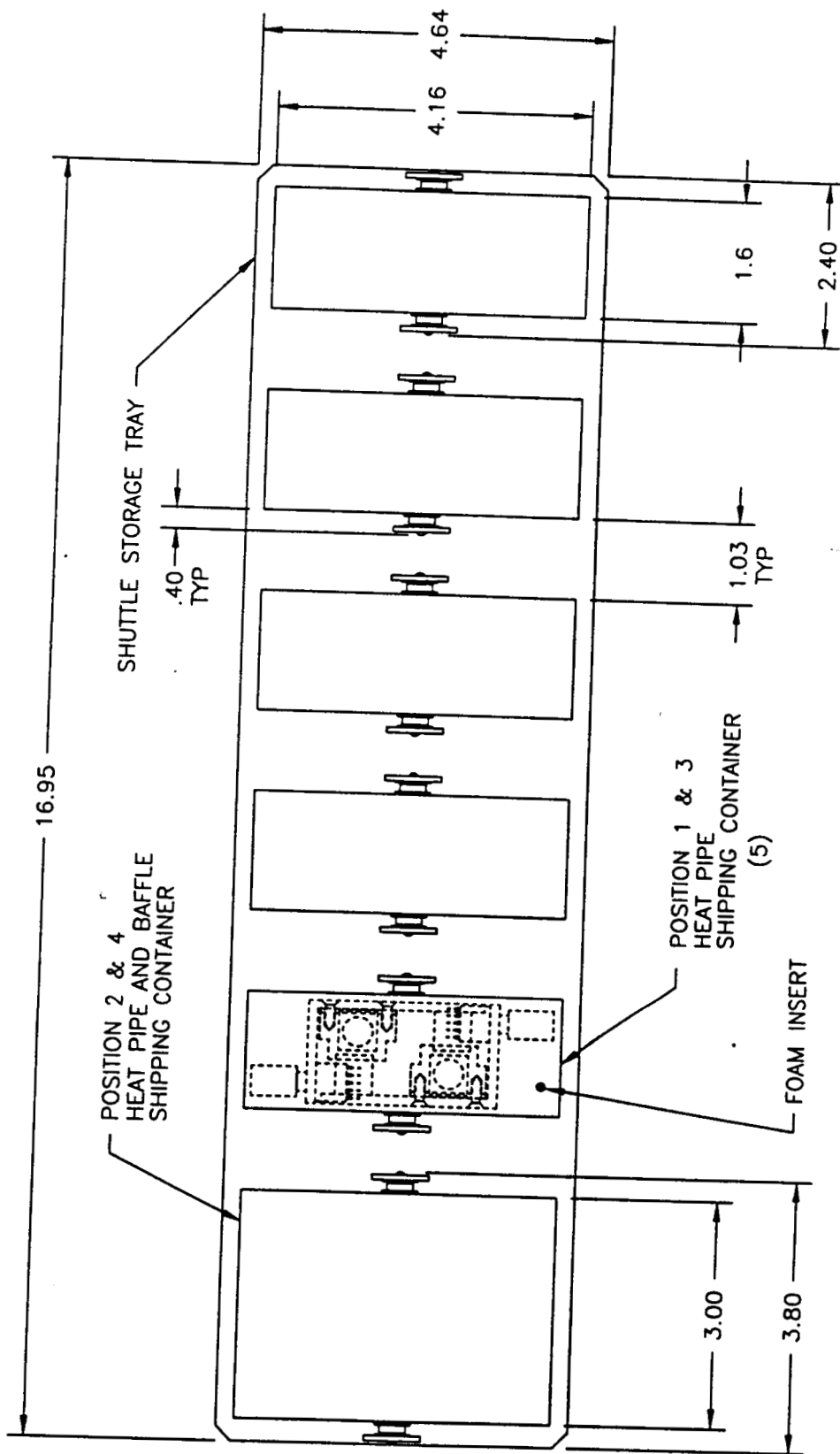


Figure 3-8. Heat pipe storage container tray

SECTION 4 DISPLAYS AND CONTROLS

4.1 CONTROL MODULE

4.1.1 Display

The HPP uses 10 LCD displays on the control module to display the temperatures on a selected heat pipe, the rpm of the rotating heat pipes, and the heater input power.

Switch/Indicator	Function
Temperature displays	Eight displays that indicate the temperatures along the powered heat pipe
RPM	Displays the rpm of the rotating heat pipe structure
WATTS	Displays the power input to the selected heater on the heat pipe
TIMER	Displays the time remaining before automatic shutdown of the timer

4.1.2 Control

The HPP controls are located on the control module and consist of several switches, adjustable potentiometers, and a settable timer.

Switch/Indicator	Function
MAIN ON pb	Enables power to the HPP electronics
MAIN OFF pb	Disables power to the HPP electronics
WARMER SELECT rot sw	Enables power and telemetry readouts to the selected heat pipe (1-4). The OFF position disables power and telemetry
WARMER ADJUST knob	Adjusts input power to the heaters on the selected heat pipe. Power input ranges from 0 to 60 W
FAN ADJUST knob	Adjusts the fan speed to regulate the amount of airflow over the heat pipe
SPIN RATE ADJUST knob	Adjusts the rpm of the rotating heat pipes. The range is from 0 to 147 rpm
TIMER pbs	Settable countdown timer. Left three buttons set digits (000-999). Rightmost button selects seconds, minutes, hours
TIMER RESET pb	Resets timer to last value selected

4.2 PGSC

An orbiter shared PGSC is used to acquire, display, and store HPP data. A PIU is connected between the HPP control module and the PGSC. Heat pipe temperatures, spin rate, and heater power are displayed on a customer-generated computer program. The menu driven data acquisition software retrieves data from PIU at fixed intervals through RS-232 serial port. There are no control functions associated with the software, only display capabilities.

Prior to experiment operations, the software must be loaded from floppy disks. At the completion of experiment operations, the data files are transferred from the PGSC hard drive to floppy disks.

Daily portable audio data modem (PADM) data dumps are performed of the most recent experiment data to allow ground personnel to track heat pipe test results and anomalies.

APPENDIX A ACRONYMS AND ABBREVIATIONS

CSM	Cargo Systems Manual
EMC	electromagnetic compatibility
FDE	Fluid Dynamics Experiment
GAP	Grooved Analysis Program
HPP	Heat Pipe Performance
JSC	Johnson Space Center
LCD	liquid crystal display
MOD	Mission Operations Directorate
PADM	portable audio data modem
pb	pushbutton
PGSC	payload general support computer
PIU	PGSC interface unit
PRT	platinum resistance thermometer
rot sw	rotary switch
rpm	revolutions per minute

APPENDIX B CONFIGURATION CONTROL

B.1 INTRODUCTION

B.1.1 Purpose

The purpose of this appendix is to delineate configuration control procedures for the Cargo Systems Manual (CSM). This will ensure the proper coordination of changes and provide a record of proposed changes, rationale, and disposition.

B.2 CONFIGURATION CONTROL PROCEDURE

B.2.1 Submission of Changes

Proposed changes are solicited from any individual or any organization having a valid input. Changes should be submitted to the CSM book manager at mail code DO6, NASA/Johnson Space Center, Houston, Texas 77058.

Individuals desiring to submit a change should complete all applicable items on the Change Request Form (fig. B-1). This form should be typed or neatly printed. Additional pages may be used if the space provided is not adequate. The original completed form should then be forwarded to the CSM book manager.

B.2.2 Disposition of Changes

The CSM book manager will obtain formal concurrence and comments from the necessary personnel, including customer representatives. All proposed modifications to the CR will be coordinated with all necessary personnel prior to disposition.

Upon obtaining the required concurrences, the CSM book manager will present the proposed change to the appropriate section head for final disposition.

A copy of all dispositioned CR's will be retained by the CSM book manager for future reference. A courtesy copy of all approved CR's will be sent to ZC01/J. Woodall, ZC01/S. Snipes, and TJ4/M. Hollman.

B.3 CSM REVISIONS/PCN'S

B.3.1 Development

The CSM book manager will compile all approved changes and any typographical errors and incorporate them into a revision or PCN to the document.

Pen and ink changes may be used to correct typographical errors if there are no other changes on the page concerned.

B.3.2 Approval

Any revisions/PCN's to the document will be approved by the appropriate section head. Revisions/PCN's to the final versions will also be approved by the chief of the Cargo Engineering Office.

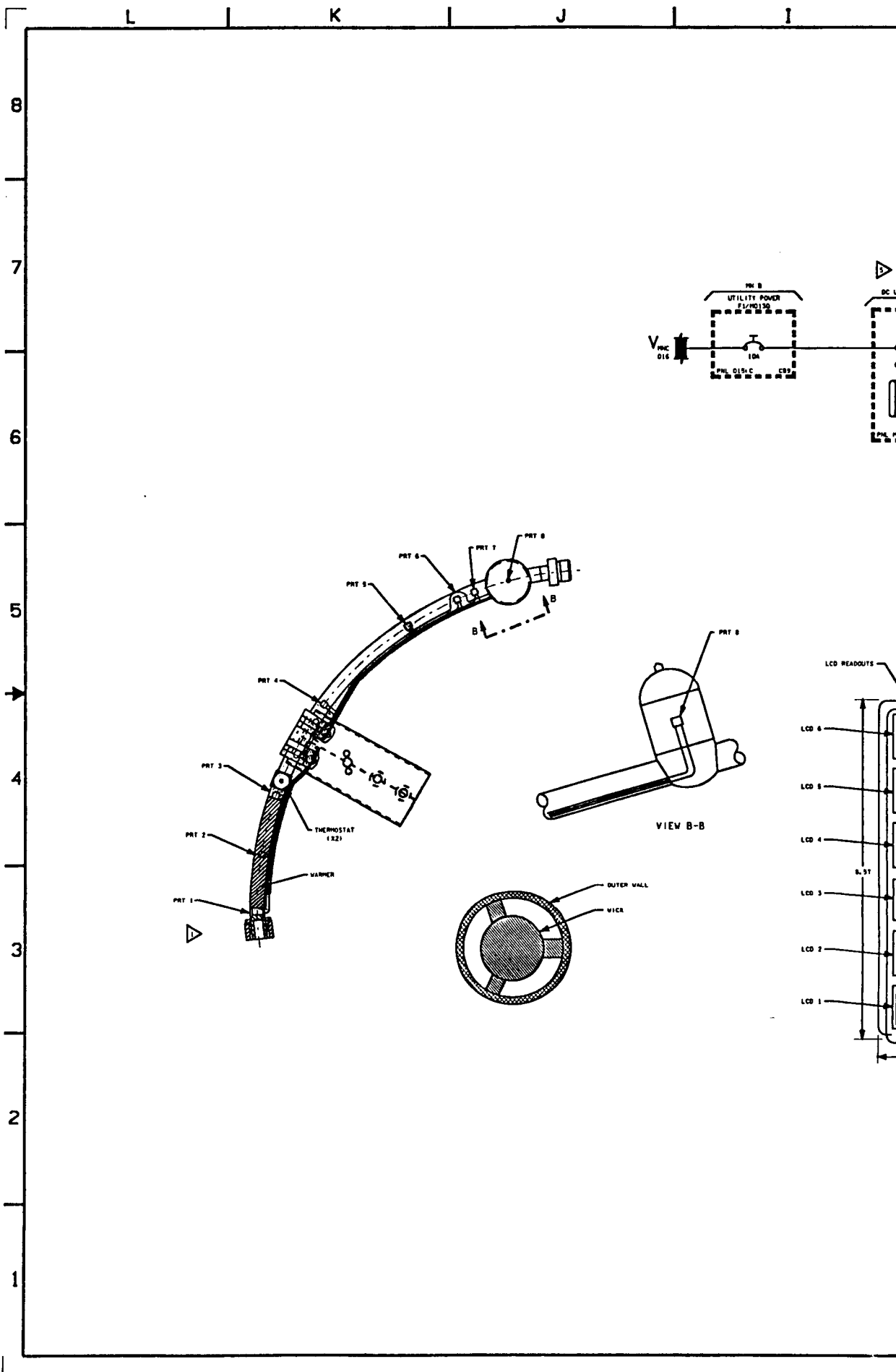
B.3.3 Publication

Revisions/PCN's will be made on an as-required basis. Revisions/PCN's will be printed and distributed to the standard distribution list.

NASA - JOHNSON SPACE CENTER CHANGE REQUEST FORM		NUMBER: _____
SECTION(S) AFFECTED:		
WAS:		
IS:		
RATIONALE FOR CHANGE:		
ORIGINATOR NAME _____ ORGANIZATION _____ TELEPHONE _____	CONCURRENCE _____ LEAD PAYLOAD OFFICER DATE _____ CUSTOMER REPRESENTATIVE DATE	
BOOK MANAGER NAME _____ RECOMMENDATION: _____ _____ INCORPORATED: _____ _____ DATE	<input type="checkbox"/> APPROVED <input type="checkbox"/> DISAPPROVED <input type="checkbox"/> APPROVE WITH CHANGES INDICATED _____ SECTION HEAD DATE	

Figure B-1. CSM Change Request Form

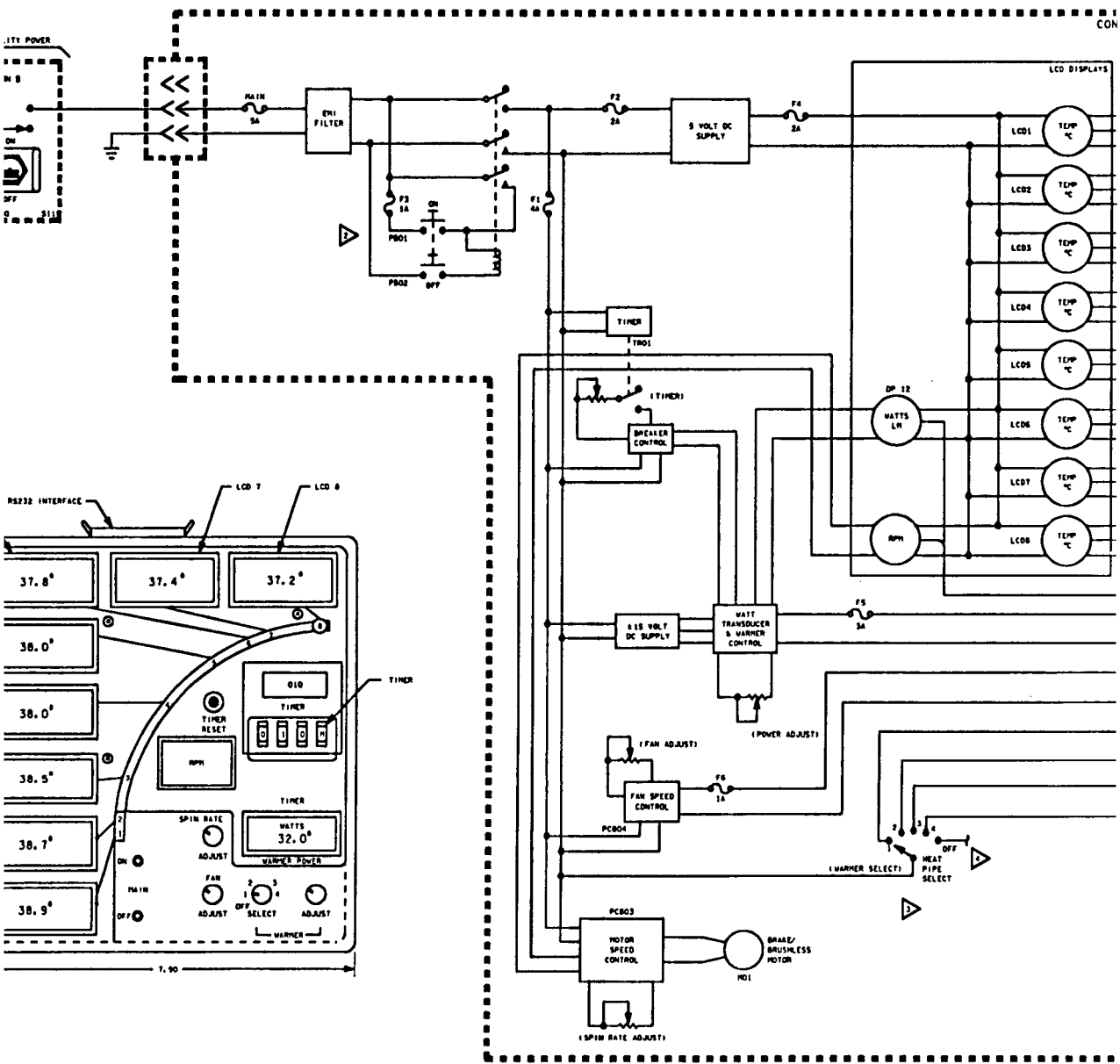
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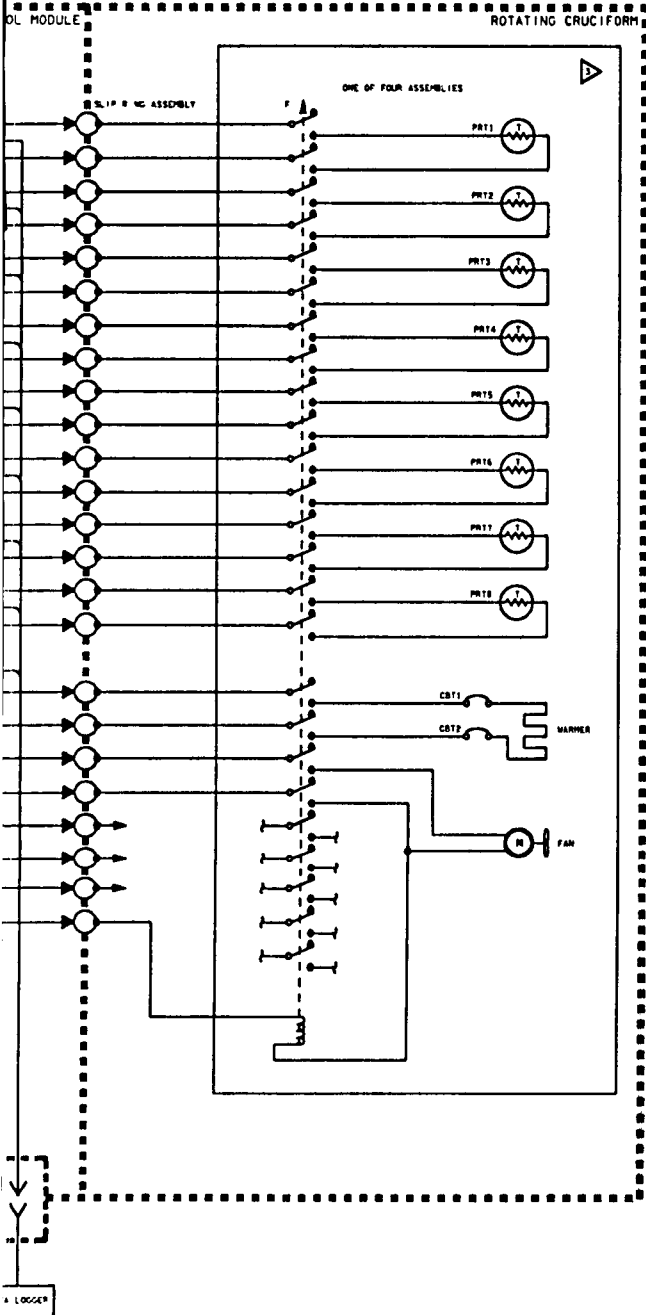
FOLDOUT FRAME

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DATE: 05/24/92	NAME: PSD	VERSION: 100+1
DATE: 05/25/92	NAME: MDU	VERSION: 100+2
DATE: 05/27/94	NAME: BJB	VERSION: 100+3



- ▽ DATA LOGGER IS CONNECTED VIA A RS-232C TYPE PORT
 - ▽ THE HPP CAN BE CONNECTED TO THE HPP PANEL, IF DESIRED
 - ▽ POSITION "OFF" INHIBITS ALL FOUR HEAT PIPES
 - ▽ ONLY ONE ASSEMBLY IS ACTIVE AT A TIME. THE HEAT PIPE SELECT SWITCH IS USED TO SELECT THE DESIRED HEATPIPE
 - ▽ THE ON/OFF SWITCH USES TWO PUSH BUTTONS TO PROVIDE ON/OFF OPERATIONS
- NOTES: ▽ PRT 1 IS THE TEMPERATURE SENSOR USED IN CONJUNCTION WITH LCD 1. PRT 2 IS USED WITH LCD 2 AND 30 ON

HPP ELECT BLK DIAG

SIGNATURE	DATE	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION L. THOMAS B. JENNINGS SPACE CENTER HOUSTON, TEXAS	
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DR			
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ENGR: Robert Happ 5/10/92			
APP: J. HANCOCK 5/10/94		DWG NO	
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D04/R. Nute
D045/Attitude & Pointing
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