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DESIGN REPORT

DETAILED ENGINEERING DESIGN THERMOELECTRIC ENVIRONMENTAL CONTROL UNIT

L-8028, Rev. 1

November 12, 1965

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AIRESEARCH MANUFACTURING DIVISION
Los Angeles, California

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SECTION 1

INTRODUCTION

This design report by AiResearch Manufacturing Company, A Division of The Garrett Corporation, Los Angeles, California, describes a detailed engineering design of the thermoelectric Environmental Control Unit (ECU). This design report is submitted in fulfillment of contract No. DA-44-009-AMC-1137(T), dated 15 May 1965, from the U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia. The performance, power consumption, and configuration of the ECU, and the report requirements are based on the requirements of Exhibit A to the RFQ, "Purchase Description for Detailed Engineering Design of Thermoelectric Environmental Control Unit," dated 9 April 1965. The basis of the design described in this detailed report is described in AiResearch Report L-3979 dated February 5, 1965 entitled "Technical Proposal Detailed Engineering Design Thermoelectric Environmental Control Unit" based on the requirements of Exhibit A to the RFQ, "Purchase Description for the Detailed Engineering Design of Thermoelectric Environmental Control Unit" dated 5 January 1965.

The ECU described in the following sections of this report satisfies all the requirements except the maximum volume limitation of the governing Exhibit A. Section 2 describes the ECU in detail, and Sections 3, 4, 5 describe the performance, control, and maintainability respectively of the ECU. Section 6 describes the manufacture of the ECU and Section 7 reflects the design consideration to arrive at the ECU described in this report. Section 8 describes the recommendations and conclusions of this report as well as indicating some of the areas in which development work could be of practical interest.

The design of the thermoelectric Environmental Control Unit (ECU), has been designed to implement the best combination of packaging, operating efficiency, and good engineering practice. The ECU is modular in nature, both physically, electrically and thermally. The ECU consists of three basic sections: the inside air fan chamber, the thermoelectric and heat exchanger section which includes the outside air fan inlet, and the power supply section which includes the inverter, outside air fan, and other power supply elements. The thermoelectric elements have been selected on the basis of operation at maximum COP and the structural integrity requirement consistent with the thermal expansions of the heat exchanger and thermoelectric module. A thermoelectric element has been chosen which has a cross sectional area of 1.0 cm^2 and a length of 0.4 cm. The total number of thermoelectric couples in the ECU is 5,472. The ECU operates with an overall net COP of 1.10. This high overall net COP is the result of careful optimization of thermoelectric operating efficiency, fan operating efficiency, cost and complementing heat exchanger design on both the hot and cold sides of the thermoelectric module.

SECTION 2

DESCRIPTION OF THERMOELECTRIC ECU

2.1 GENERAL

This overall configuration of the thermoelectric ECU, which AiResearch has designed and which is described in this report, is shown on Layout Drawing L-198116. The ECU has a volume of 21 cu ft which exceeds the allowable volume of 15 cu ft. However, the packaging of the ECU has not been designed in detail and an optimization should reduce the volume. Layout Drawing L-198116 presents an envelope which will house the complete ECU. A detailed design was not attempted at this time because the study considered the performance analysis as the primary objective and thus, some of the other considerations were limited to feasible concepts.

The ECU has been designed in three basic sections. The top section contains the inside air fan and appropriate ducting. The thermoelectric heat exchanger modules are in the center section. In addition, the inside air ducts, which are individually attached to the heat exchanger modules, and the outside air plenums are in the center section. The bottom section contains the power converter, frequency inverter, thermal controls, master control panel and outside air fan. Each section is accessible by removable panels on the outside face of the enclosure.

The ECU is made up of 12 thermoelectric heat exchanger modules that can be individually replaced as required. Each module consists of two heat transfer units. Each of the heat transfer units consists of 3 hot side fin sandwiches, 228 thermoelectric couples and 2-1/2 cold side fin sandwiches. The configuration of a module is shown on Layout Drawing L-198102.

Also shown on Layout Drawing L-198119 are the air paths, optional outlet duct air fan assembly for right and left handed operation. Table 2-1 lists the primary components of the ECU with their estimated weights. Descriptions of the individual components are discussed separately in subsequent paragraphs of this report.

2.2 ECU COMPONENT DESCRIPTION

2.2.1 Heat Exchanger Module

The heat exchanger module consists of two sets of hot side fins, three sandwiches in height and five cold side fin sandwiches constructed of aluminum and brazed and welded together. The aluminum fins are rectangular, off-set fins 0.008 in. thick and 0.153 in. high and 0.062 in. wide.

2.2.2 Thermoelectric Modules

For the design of the thermoelectric couple, it was necessary to obtain values for material properties of bismuth telluride such as the Seebeck coefficient, electrical resistivity and thermal conductivity. Because the

TABLE 2.1

LIST OF PRIMARY COMPONENTS AND THEIR ESTIMATED WEIGHTS

		Weight, lbs	
1.	Thermoelectric Heat Exchanger		290.60
a.	Heat Exchanger	133.17	
b.	Thermoelectrics	98.48	
c.	Ducts, insulation, flanges, etc.	58.96	
d.	Module	24.21	
2.	Cold Side Assembly		15.0
a.	Fan	12.0	
b.	Duct and diverter	3.0	
3.	Hot Side Assembly		27.0
a.	Fan	24.0	
b.	Mounts and brackets	3.0	
4.	Electronics		59.5
a.	ac - dc converter	24.3	
b.	Frequency inverter	5.3	
c.	Controls	14.3	
d.	Chassis and enclosure	12.6	
e.	Cable retractor	3.0	
5.	Control Panel		3.0
6.	Enclosure		59.5
a.	Frame	31.9	
b.	Panels	27.6	
7.	Miscellaneous		15.0
	Total Weight, Lb		469.6

information received from the manufacturers had some variance, average values were used in the design. The sources of information are discussed in paragraph 7.3. The ECU has a total of 5,472 couples, and each of the 12 ECU Modules contains 456 couples, 228 being in each heat transfer unit. The arrangement of the thermoelectric couples in each heat transfer unit is shown in Figure 2.1. As can be seen, there are 6 couples in the airflow direction, by 38 rows in the perpendicular direction. This arrangement of thermoelectric couples allows a practical and even segregation of thermoelectric couples for the series electrical arrangement. The couples themselves are constructed of rectangular thermoelectric material stock with a cross-sectional area of 1.0 cm^2 and a length of 0.4 cm.

2.2.3 Power Supply and Controls

In the power supply and controls section of the ECU, there are a number of individual systems for various functions. Categorically, the sub-systems are:

a. A power supply to convert a-c to d-c power;

b. A malfunction detection and module protection system;

c. An auxiliary 28 volt d-c power supply for the low current components in the control circuits;

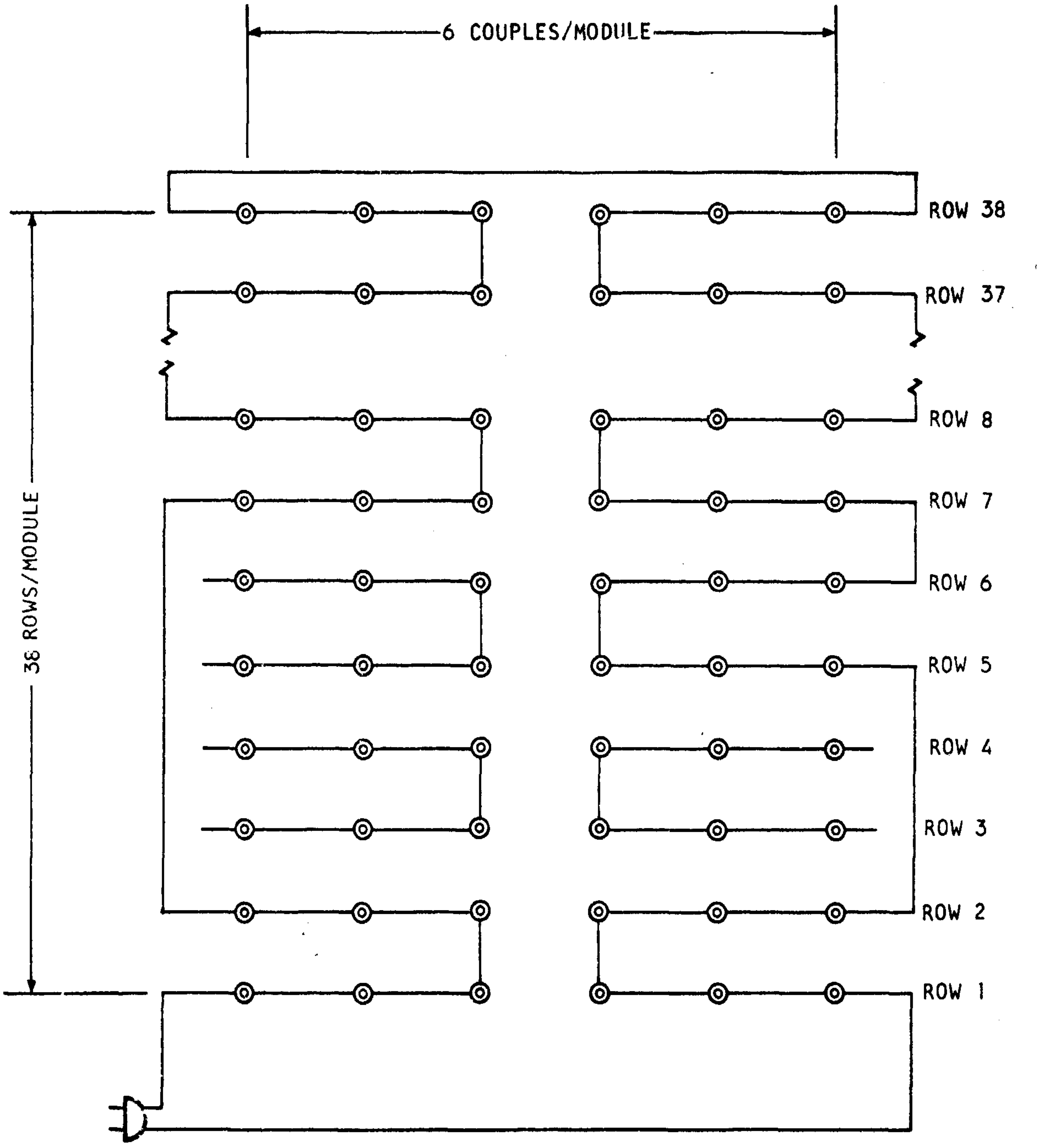
d. A frequency inverter to provide 400 cycle power to the fans when 60 cycle power is the input line power;

e. A thermal control system for regulation in both the cooling and heating modes of operation.

Descriptions of the individual sub-systems are discussed in subsequent sections of this report. The power supply and controls along with the outside air fan are installed in an enclosure in the bottom section of the ECU. The enclosure is mounted on sliding tracks and is removable from the outside fan of the ECU as a complete unit. Layout Drawings L-198120 and L-198117 show respectively the power supply and controls as part of the ECU and by itself.

2.2.4 Inside and Outside Fans

One of the most overlooked components in any system design is the air moving device or fan. In most applications, a system is designed around an available fan for cost and other reasons. In most applications, it is permissible to work with such a design philosophy. However for the ECU where the system COP was very critical, fans with optimum efficiencies and matched performances were required. For compactness, vaneaxial fans were used. Vaneaxial fans are normally noisier than some other types of fans but they are attractive because they are more compact and wholly contained in a housing and are readily adaptable for duct connections. They eliminate the necessity for shaft seals and are self-cooled.



SYMBOL ◎ REPRESENTS A COUPLE

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Figure 2.1 Thermoelectric Couples Matrix

Instead of using a sophisticated fan design such as a dual wound motor for both 60 and 400 cycle operation, AiResearch has elected to use only a 400 cycle motor fan with a frequency inverter for 60 cycle input power conditions. Selecting 400 cycle allowed a higher rotational speed and thus a smaller impeller for the desired airflows.

The engineering analysis resulted in a design that had the maximum COP when the hot side airflow was approximately twice the cold side airflow. This provided a very convenient system design where 2 cold side fans were used for the hot side. Beside being economically attractive, the use of 2 hot side fans also minimized the degree of maldistribution of airflow. A more detailed discussion of the fan is found in Section 3.3.4 of this report.

2.2.5 Frame and Enclosure

The enclosure for the ECU is basically a framework with panels. The material will be aluminum and the unit will be of welded, bolted and brazed construction. The framework shown on Layout Drawing L-198121 utilizes standard extruded sections and provides attachment points for the various components The framework is also the mechanical structure for the ECU that will withstand the external and internal loads imposed on the ECU. The framework is basically a rectangular box. Some of the flexibility of the design of the framework was lost because of the requirement of accessibility from only the outside face of the unit.

Besides just covering the ECU, the panels have many functional uses. Because the enclosure has many plenum sections, the panels become parts of these plenums. The connecting provisions are also on the panels. The center panel on the outside face has a full rectangular opening for the inlet air to the hot side of the heat exchanger and the opening has louvers and a protective screen for rain and foreign particle protection. Layout drawing L-198116 shows the six sides of the ECU. To achieve stiffness, the panels have stiffening member and dimpled grooves

SECTION 3

PERFORMANCE OF THERMOELECTRIC ECU

3.1 GENERAL

The thermoelectric ECU has been designed to meet the performance requirements of Table 3.1. The primary design point indicated on Table 3.1 is noted as the nominal cooling condition, and the net cooling load of 24,000 BTUs per hour has been achieved with an overall Net COP of 1.10. The thermoelectric modules operate with a current of 26.0 amp., and provide 1.49 watts per couple of cooling at the nominal cooling condition. Table 3.2 indicates performance of the ECU at various other conditions of interest as required by Exhibit A.

3.2 THERMAL PERFORMANCE CHARACTERISTICS

The thermal characteristics of the ECU are perfunctorily noted in Table 3.1. However, other points of interest regarding the thermal performance are the temperatures within the fin sandwiches themselves and also across the thermoelectric units. The temperature distribution from the outside of the hot fin surface, across the thermoelectric module, and to the midpoint of the cold side fin surface is shown in Figure 3.1. The Figure 3.1 is drawn to scale and the slopes indicated are representative of what is expected to occur within the thermoelectric ECU. The performance figures indicated in Figure 3.1 have been determined for the nominal cooling condition indicated in Table 3.1.

3.3 PERFORMANCE OF ELECTRICAL COMPONENTS

3.3.1 General

An electrical schematic of the ECU is shown on Figure 3.2. The various sections are discussed separately and are supplemented by other schematics, circuit diagrams and tables. The control panel on the inside face of the unit has all the controls for the ECU except the main power circuit breaker. The locations of these components are shown on Layout Drawings L-198116 and L-198117. The electrical schematic of the dc power supply and controls is shown on Figure 3.3.

The following paragraphs will briefly describe the general operation of the ECU. In order to energize the electrical circuits in the ECU, the main power circuit breaker must be in the "on" position. This is shown as switch K16 on Figure 3.2. When the circuit breaker is closed, the auxiliary (28 vdc) power supply is energized and the low current controllers can now operate. To start the ECU, the start switch, S2 in Figure 3.3 must be in the "on" position. The input power control relay is now energized and the ECU is now fully energized and is controlling to the appropriate temperature (sensor on the control panel) assuming that none of the manual switches have other components such as the fans turned off. The unit operates at manual cool, manual heat or automatic depending on the position of the selector switch.

TABLE 3.1

THERMOELECTRIC ECU DESIGN REQUIREMENTS

Inside Air	Parameter	Outside Air
Nominal Cooling Condition		
24,000	Net cooling capacity, Btu/hr	*
≥ 1.0	Net COP	*
120 to 126*	Inlet dry-bulb temperature, °F	120
66*	Inlet wet-bult temperature, °F	69
93	Outlet dry-bulb temperature, °F	140 to 160*
63	Outlet wet-bulb temperature, °F	69*
840 to 1000	Flow rate, cfm	1750 to 2100*
0.25	External static pressure losses, in. H_2O	*
14.7*	Inlet pressure, psia	14.7*
208 vac, 3ø 60 or 400 cps	Electrical power	208 vac, 3ø 60 or 400 cps
*	Internal static pressure losses, in. H_2O	*
Nominal Heating Condition		
*	Net heating capacity, Btu/hr	*
50	Inlet dry-bulb temperature, °F	-50
0	Inlet dew-point temperature, °F	-65
208 vac, 3ø 60 or 400 cps	Electrical power	208 vac, 3ø 60 or 400 cps

*Unspecified or assumed values.

TABLE 3.2

PERFORMANCE OF THERMOELECTRIC ECU

Points		1	2	3	4	5	6
Power frequency		Calculations valid for both frequencies indicated in specification					
Sensor temperature	°F	100	78	76	74	72	50
Supply air temperature							
(1) Dry bulb	°F	92	72	66	68	72	62.1
(2) Wet bulb	°F	63	60	58	54	50	0
Ambient air temperature							
(1) Dry bulb	°F	120	120	80	40	0	-50
(2) Wet bulb	°F	69	69	60	35	0	-65 (dew point)
Supply air flow rate	lb/hr	3800	4200	4200	3920	3650	4200
Return air temperature	°F	122.1	82.0	86.5	119	144	50
Outside air flow rate	lb/hr	7600	7640	8500	9500	10,120	0
Outside air temperature at the exit of heat exchanger	°F	143.	131.3	92.4	62.3	26.4	-50
Fan power heat gain to or from inside air (max)	watts	515	515	516	512	518	541
Duct heat conducted to inside air	watts	344	665	146	-529	-2160	-694
Inside longitudinal heat conduction loss	watts	154	53	109	262	338	117
Net total cooling or heating capacity	watts	7080	1767	5310	13,888	19,742	3610
Fan power							
(1) Inside air	watts	515	515	516	512	518	541
(2) Outside air	watts	990	986	974	964	952	0
Total power required	watts	6407	4951	3167	2764	1576	5382
Percent ripple in dc power		<10	<10	<10	<10	<10	<10
Net COP		1.10	0.358	1.68	5.02	12.5	0.675

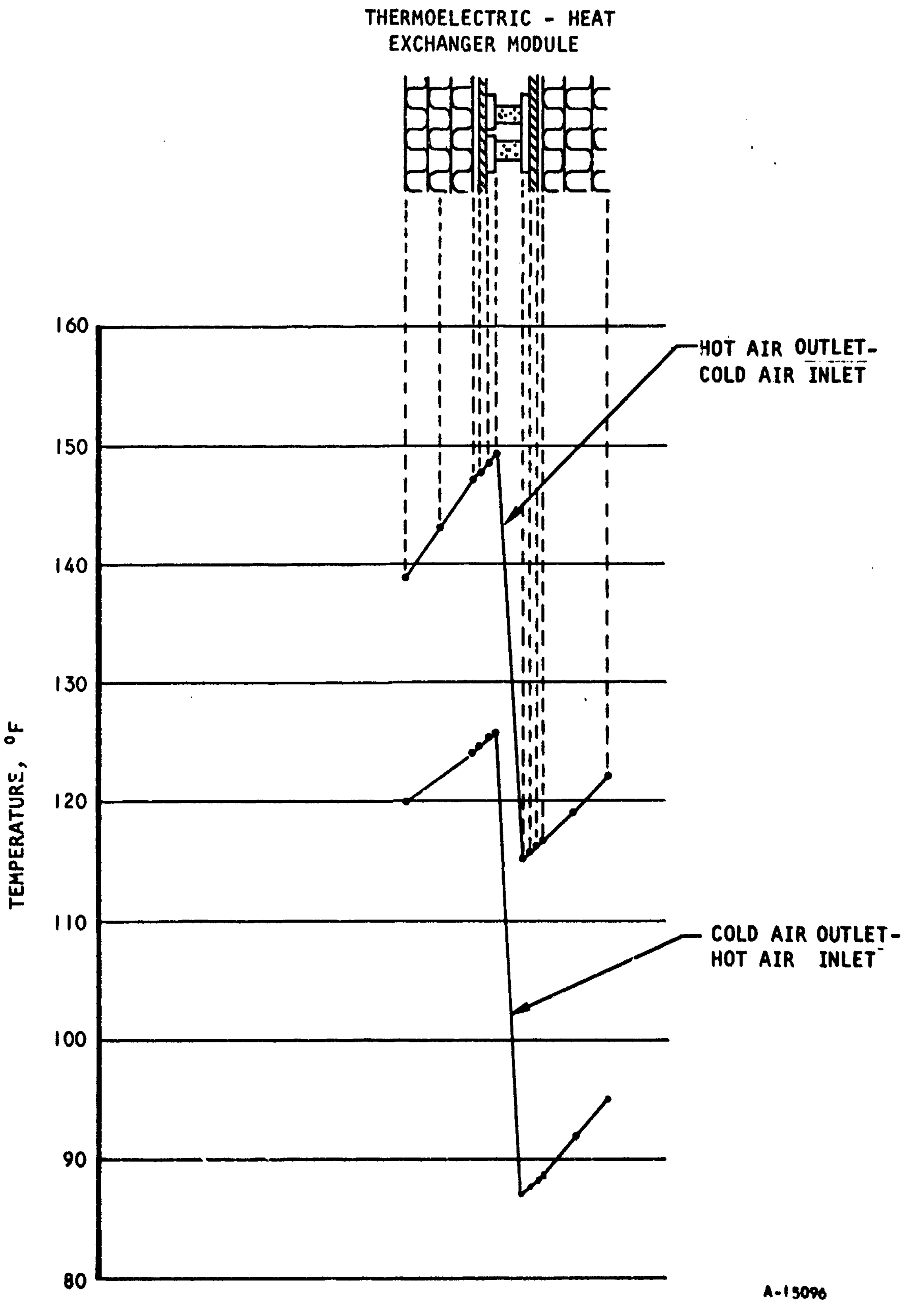


Figure 3.1 Temperature Gradient Across the Thermoelectric Module

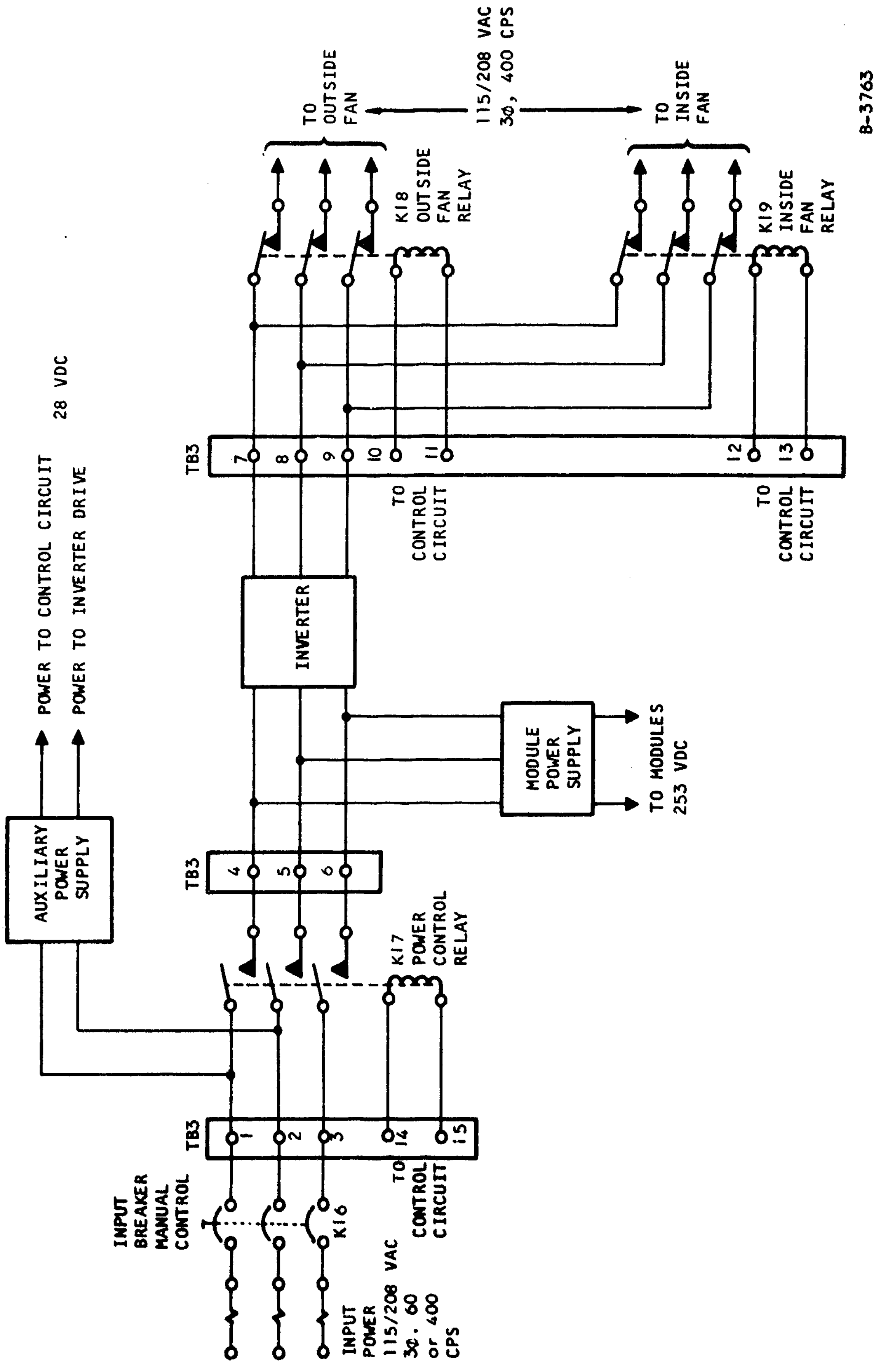
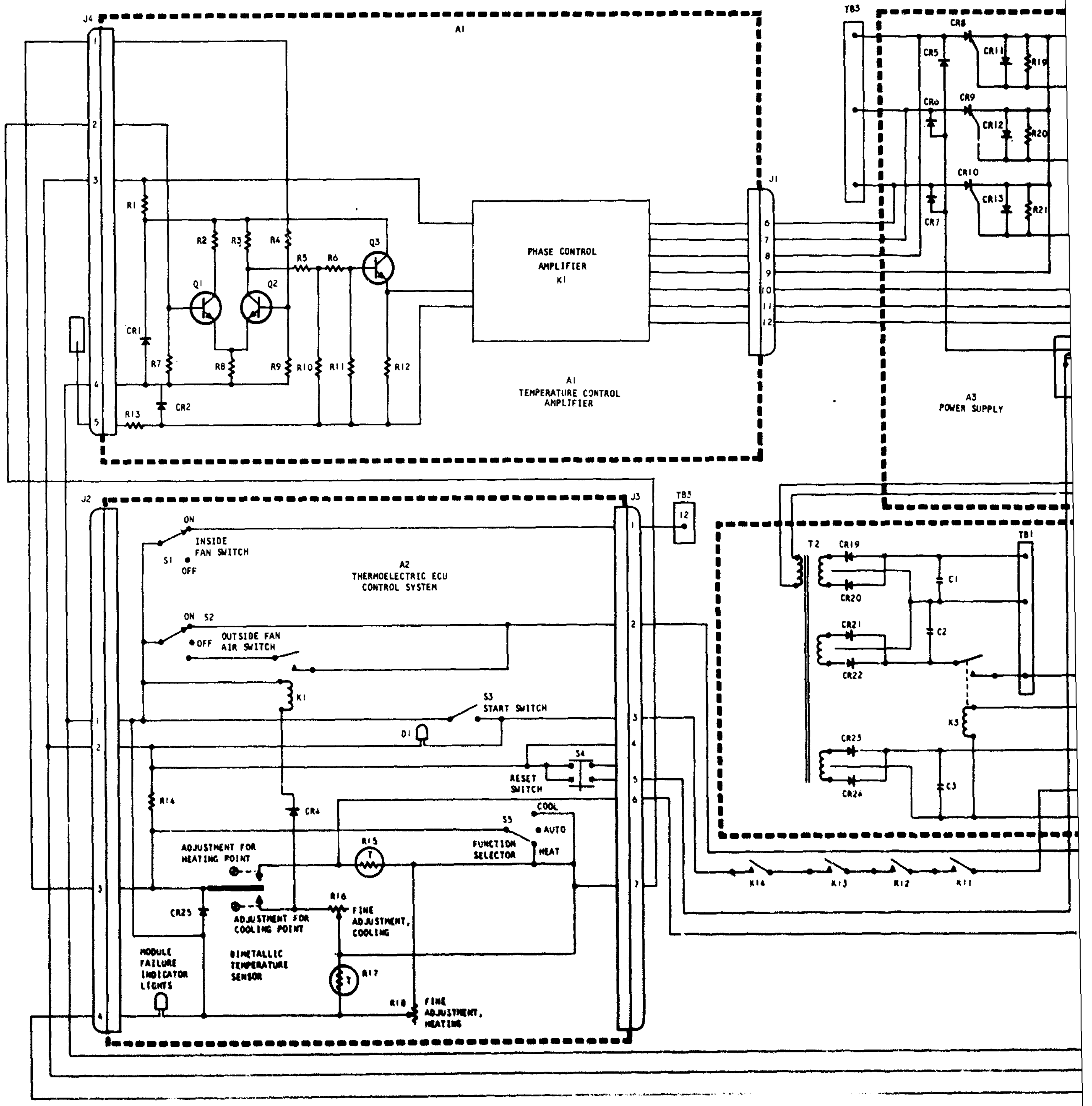


Figure 3.2 Electrical Schematic of ECU

TABLE 3.3

COMPONENT PARTS LIST FOR FIGURE 3.2

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Main Power Breaker	K16	Mechanical Products Inc. MP713 Type	20 amps contacts thermal actuated
Power Relay, Input Power Control	K17	Rowen Controller Corp., FER Type	20 amps contacts 600 volts
Fan Control Relay	K18, K19	General Electric 208 EC Type	4 amps contacts 115 volts



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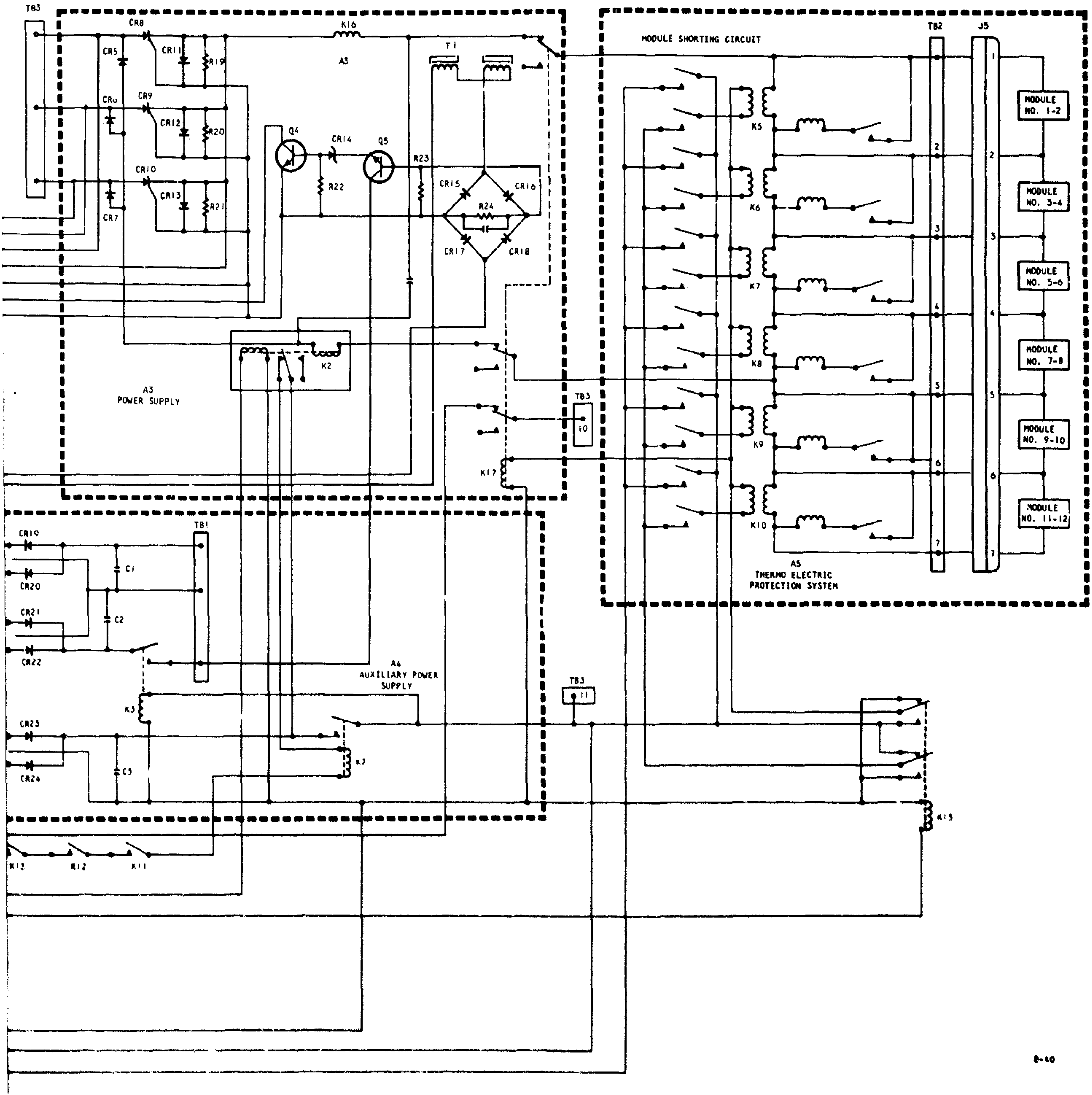

Figure 3.3 Electrical Schematic of DC Power Supply

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TABLE 3.4

COMPONENT PARTS LIST FOR FIGURE 3.3

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Resistor	R1, R13	Allen Bradley 2 watt RC-42	2 watt 500Ω carbon ±5%
Resistor	R2, R3	Allen Bradley R-C 20 Type	1/2 watt 6.8KΩ ±5% carbon
Resistor	R7	Allen Bradley R-C 20 Type	1/2 watt 33KΩ ±5% carbon
Resistor	R8	Allen Bradley R-C 20 Type	1/2 watt 330Ω ±5% carbon
Resistor	R4, R9	Dale RH Type	1 watt wire wound 100Ω ±1%
Resistor	R5	Allen Bradley R-C 20 Type	1KΩ±5% 1/2 watt carbon
Resistor	R10	Allen Bradley R-C 20 Type	3.3KΩ ±5% carbon
Resistor	R12	Allen Bradley R-C 20 Type	330Ω ±5% 1 watt carbon
Resistor	R19,R20,R21	Allen Bradley R-C 20 Type	47Ω ±5% 1/2 watt carbon
Resistor	R22	Allen Bradley R-C 20 Type	3.3KΩ ±5% 1/2 watt carbon
Resistor	R23,R24	Allen Bradley R-C 20 Type	1/2KΩ ±5% 1/2 watt carbon
Resistor	R14	Dale RH Type	200Ω ±1% 2 watt wire wound
Thermistor	R15, R17	Keystone Type 1	90Ω at 25°C 115 sec time constant 8.2%/F° temperature coefficient

TABLE 3.4 (Continued)

COMPONENT PARTS LIST FOR FIGURE 3.3

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Potentiometer	R16, R18	Bourns Trimpot Wire Wound Type	100Ω 1/2 watt screw adjustment
Transistor	Q1, Q2, Q5	Texas Instrument 2N697	100mw max β min = 60 signal transistor
Transistor	Q3, Q4	RCA 2N3053	500mw max β min = 40
Diode	CR1, CR2	Hoffman Zener Diode	5 watt 15 volt ±5%
Diode	CR25, CR14	Hoffman Zener Diode	1 watt 6.3 volt ±1%
Diode	CR4, CR11, CR12, CR13, CR19, CR20, CR21, CR22, CR15, CR16, CR17, CR18	IRC 1N457A	100ma,60 volt
Diode	CR23, CR24	Sarkes Tarzian H3-10	6 amps 100 volt
Diode	CR5, CR6, CR7	General Electric 1N 1344	6 amps 400 volt
Silicon Controlled Rectifier	CR11, CR12, CR13	General Electric C 15C	7 amps 400 volt
Amplifier	K1	Sprague Electric Amplifier (VS6732 EF-230/460Ω)	Gain factor 0.8ma/degree of φ shift
Inductor	L16	AiResearch	20 millihy 27 amp 300 volt

TABLE 3.4 (Continued)

COMPONENT PARTS LIST FOR FIGURE 3.3

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Magnetic	T1	AiResearch	27 amps 1 turn primary 27 ma secondary magnetic amplifier 1000 volt insulation
Relay	K1, K15	Potter Brumfield MDP Series	Contacts 2 amps, 11 volts Coil 1ma close, 1ma open
Relay	K7, K15	General Electric	110 volt, 3 amp Contact 28 volt coil
Reversory Relay	K17	Rowen Controller Corp., FER Type	10 amps break 40 amps no break 600 volt contacts
Relay	K2, K5, K6, K7, K8, K9, K10	Gordos Corp. MR 940, MR 050 Contacts Coils wound by AiResearch	3 amps contacts 500 amps contact
Transformer	T2	AiResearch	208 volt/28/28/50 all secondaries CT 100 watt transformer
Switch	S1, S3	Arrow, Hart and Hargman	DP/DT 3 amps contacts snap action toggle handle
Switch	S4	Arrow, Hart and Hargman	3 amps contacts DP/DT momentary contact
Switch	S2, S5	Centralab 20 Type Subminiature	0.5 amps 28 volt contacts 3 position rotary

The ECU has protection devices in the form of circuit breakers and fuses in many of the sub-circuits. A thermal type main power circuit breaker was selected so that the unit would not be frequency sensitive. In addition to this protection, the coil in the input power control relay cannot be energized if there is an overtemperature component in the unit or an overcurrent condition in the thermoelectric module power supply. Overtemperature protection is achieved by installing several normally closed thermal sensitive relays in series with the start switch. If any one of these relays is opened, the input power control relay cannot close. Overcurrent in the thermoelectric power supply also prevents the input power control relay to close. The auxiliary power supply is protected by line fuses and the frequency inverter is protected by magnetic circuit breakers and fuses. Fast action protection is necessary in the inverter to protect the SCR's in case of failure in the commutating circuit.

3.3.2 Power Conversion

Because the thermoelectric modules require d-c power for operation and because the only input line power available is a-c power, it was necessary to incorporate in the ECU, an a-c to d-c power converter. Incorporated in the design of the power supply is a malfunction detection circuit which automatically shorts two thermoelectric modules when its resistance or voltage drop increases to a limiting value. The limiting value was selected on the basis of a change in voltage that can be detectable and yet not detrimental to performance. The module shorting circuit is capable of by-passing all 6 modules. A more detailed discussion of the protection systems in the ECU is found in paragraph 4.2 of this report.

The thermoelectric power is taken directly from the converted input a-c power. Since only 180 volts are required and the output of a full wave bridge is approximately 279 volts, a voltage reduction is required. To obtain this voltage reduction, a full wave bridge with 3 control SCR's is used. The required output voltage is obtained by varying the input wave form at which the SCR's fire. For 180 volts, the SCR's are fired at a phase angle of 45 degrees.

The power supply has thus far supplied the proper voltage for the system at 26 amperes. Ripple control has increased from 4 percent to 40 percent of the output voltage. To reduce this ripple to less than 10 percent, an L-C filter is used. It is desirable to have continuous current flow through the inductors. For this system, an inductance of 6 mhy is required. For ripple reduction, the inductance value is increased to 12 mhy. A resultant reactance of 27 Ω is applied to the ripple frequency. This reactance is not sufficient to reduce the ripple below 10 percent. By adding a 1160 μfd shunt filter capacitor, reactance of 3.78 Ω is applied at the lowest fundamental ripple frequency. With these parameters the maximum ripple voltage will be 6.6 percent of the nominal operating voltage.

To supply heating power, relay X 17 is energized reversing the polarity of the voltage to the thermoelectric modules. Since the relay is reversed when the power supply current is zero, (the system is off at 72°F; polarity is reversed at 66°F; (system on for heating at 60°F), the relay contacts have mechanical wear only and should exceed the life of the ECU.

The power supply is protected from overcurrent by a current limiting relay K15 which opens the start circuit. This relay is set to operate at 35 amps. This condition of current will only occur if there is failure in the control circuit as the unit normally operates at a constant current of 26.5 amps maximum.

3.3.3 Frequency Inverter

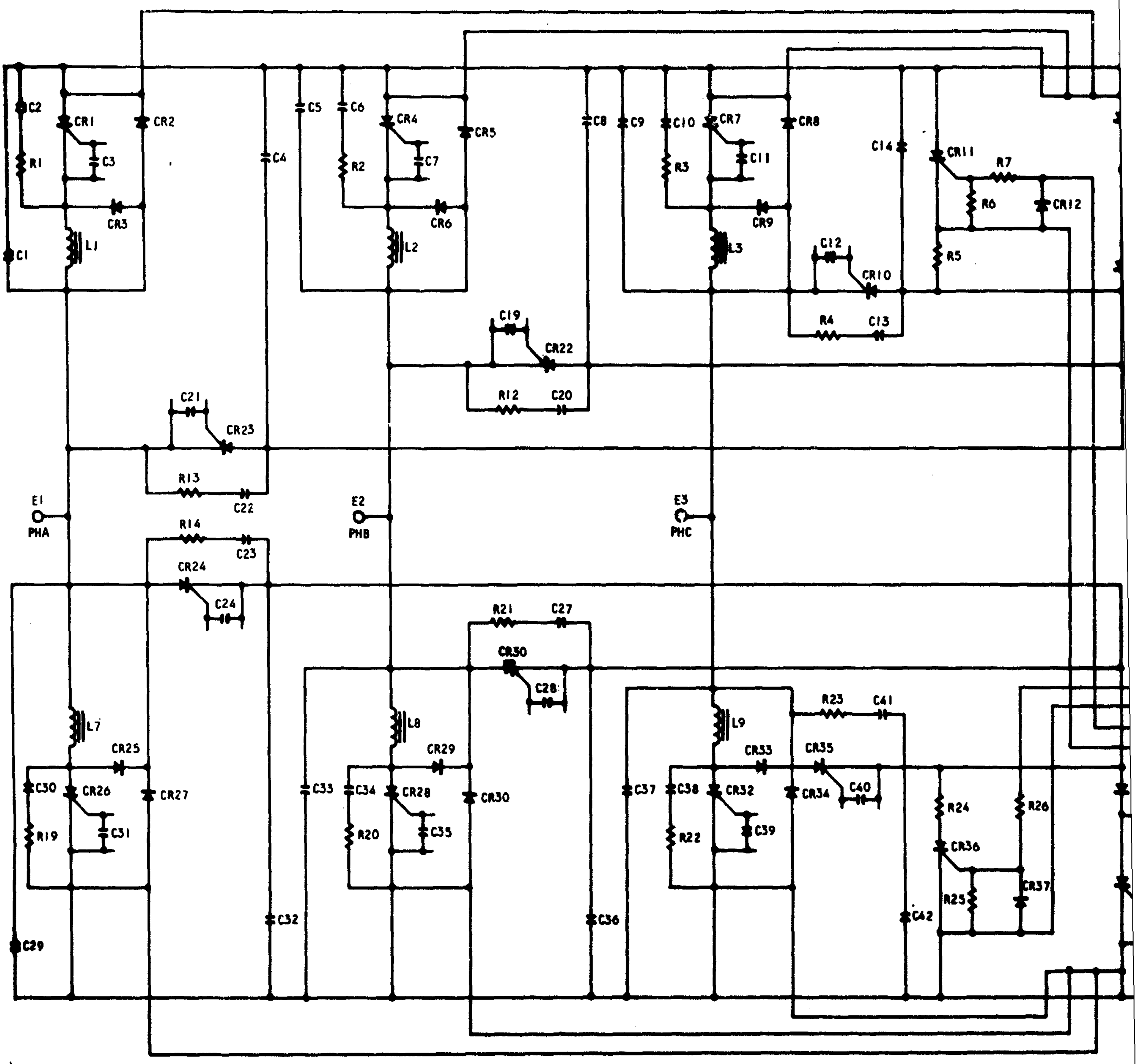
The decision to use only 400 cycle motor fans for the ECU was a critical decision because it required the addition of another component, namely, a 60 to 400 cycle inverter. However after considering the affects of size, efficiency, logistics and maintenance, it became more apparent that such a design had more advantages than disadvantages. Another alternative was considered and that was to use the rectified voltage and d-c motor driven fans. However, the maintenance requirements for the motor brushes and the increase fan size made this alternative very unattractive.

To avoid the possibility of operator error which could be very harmful to the fan motor, it was decided that a circuit to by-pass the 400 cycle inverter when 400 cycle power was available would not be used. Instead, the power passes through the inverter at all times. Although the inverter is slightly more sophisticated for this type of operation, the safety feature meritted its use. The power consumption is so low that the system COP was not greatly affected by its continuous operation. If only 400 cycle power is to be used, it would be a simple matter to modify the ECU to eliminate the frequency inverter.

The inverter circuit is shown on Figure 3.4. The unit is a three phase 400 cycle unit. SCR's CR1 and CR26 provide øA power, CR4 and CR28 provide øB power, CR7 and CR32 provide øC power. When an SCR is turned on it stays on until the current through it is reversed. To provide this reverse current for the positive half cycles CR13 charges capacitor C16. The energy stored on capacitor C16 is then discharged through either CR23, CR22, or CR10 depending on which phase is to be turned off. The commutating energy for the negative half cycle is supplied by capacitor C44 which is charged by CR39.

The order in which the gate signals are applied is shown in Figure 3.5. The gate signals are supplied by a logic circuit which is shown in the block diagram, Figure 3.6. This logic diagram uses integrated circuits throughout and was developed by AiResearch for use in a constant frequency airborne inverter of 40 kw power output. The power requirements to trigger SCR's is not a function of their current capability and therefore the logic which was developed can be used directly without any modification. This 40 kw inverter has been in operation under full power long enough to have established a mean time between failure (MTBF) of slightly over four years. In scaling down components for the 1 kw inverter for the ECU, a longer derating factor has been used which should extend the MTBF of this unit.

Figures 3.7 and 3.8 are circuit diagrams for the oscillator and time delay generator respectively. These subcircuits apply to the inverter logic diagram shown in Figure 3.6.



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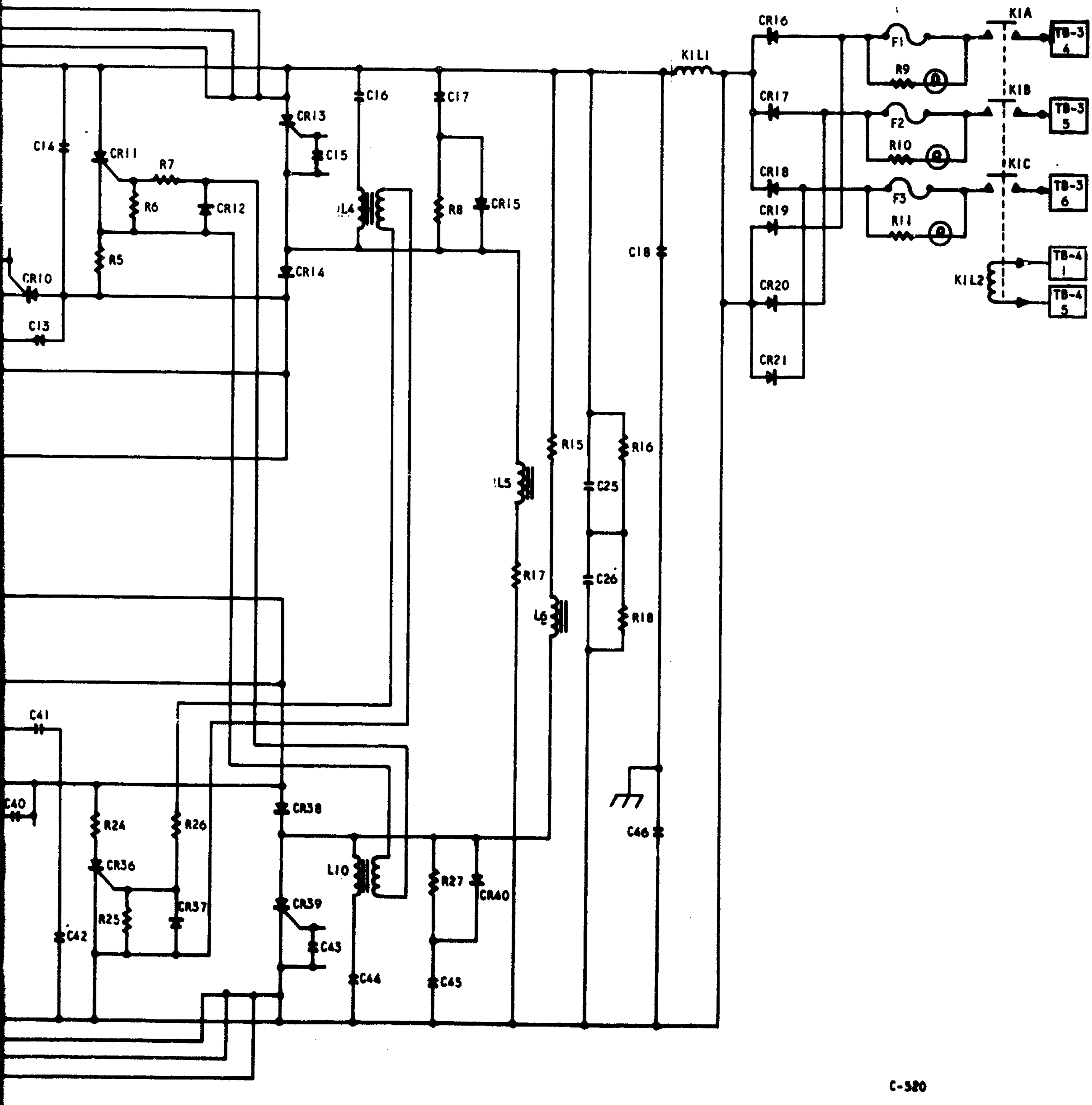

Figure 3.4 Frequency Inverter Circuit Diagram

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TABLE 3-5

COMPONENT PARTS LIST FOR FIGURE 3.4

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Main Power SCR	CR1, CR4, CR8, CR25, CR28, CR32	General Electric C12D	6 amps, 400 volt
Charging SCR	CR37, CR39	General Electric C12E	6 amps, 500 volt
Commutation SCR	CR25, CR22, CR10, CR24, CR30, CR35	General Electric C11E	6 amps, 500 volt
Coil Shorting Diodes	CR3, CR6, CR9 CR25, CR29, CR33	General Electric 1N1117	1 amp, 400 volt
Reactive Current Diodes	CR2, CR5, CR27, CR30, CR34	General Electric 1N1345	6 amps, 500 volt
Commutating SCR Isolation Diode	CR14, CR38	General Electric 1N1345	6 amps, 500 volt
Coils	L1, L2, L3 L7, L8, L9	AiResearch Mfg. Co.	5 µhy, 5 turns of No. 16 Wire
Commutating Coil	L4, L10	AiResearch Mfg. Co.	36 µhy, 18 turns of No. 16 Wire
Commutating Capacitor	C16, C44	Sprague Electric	5 µfd, 600 volt polycarbonate rated for 5 amps runs current
Capacitor	C1, C5, C9, C29, C33, C32, C37, C4, C8, C14, C36, C42	Sprague Electric	.1 µfd 300 volt
Filter Capacitor	C19, C46	Sprague Electric	500 µfd, 300 volt aluminum electrolytic computer grade

TABLE 3-5 (Continued)

COMPONENT PARTS LIST FOR FIGURE 3.4

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Resistor	R1, R2, R3, R19, R20, R22, R13, R12, R4, R14, R21, R23, R8, R27	Allen Bradley R-C 42 Type	10Ω 2 watt
Capacitor	C2, C6, C10, C17, C45, C30, C34, C38, C26, C22, C13, C23, C27, C41	Sprague Electric Ceramic Type	50μμfd 500 volt
Input Breaker	K1	Rowen Controller Corp., Type R	10 amps 600 volt contacts
Diodes	CR16, CR17, CR18, CR19, CR10, CR21	General Electric 1N1344	6 amps,400 volt
Fuses	F1, F2, F3	Bussman fuses with indicator lights Type FA	5 amps,300 volt

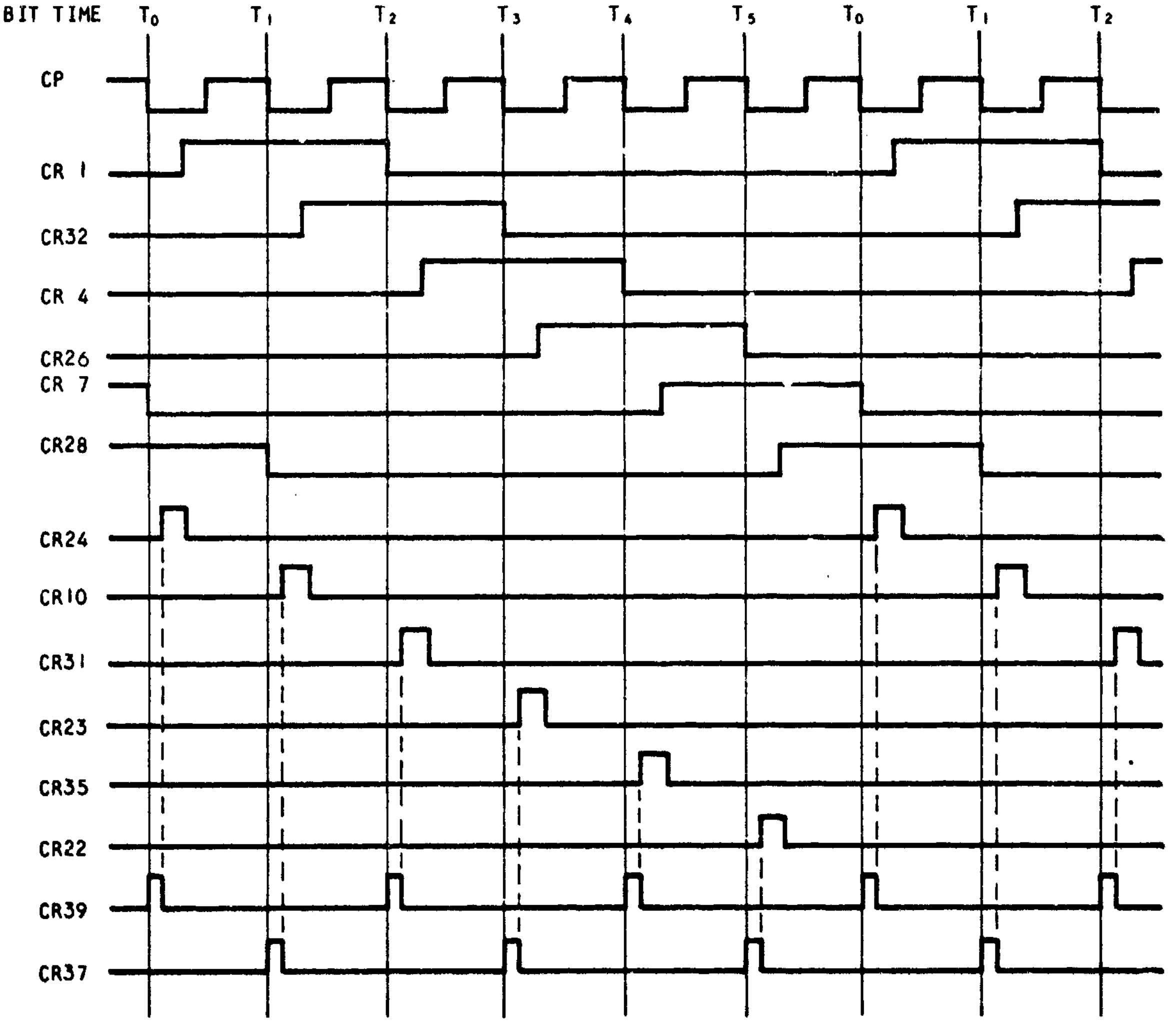
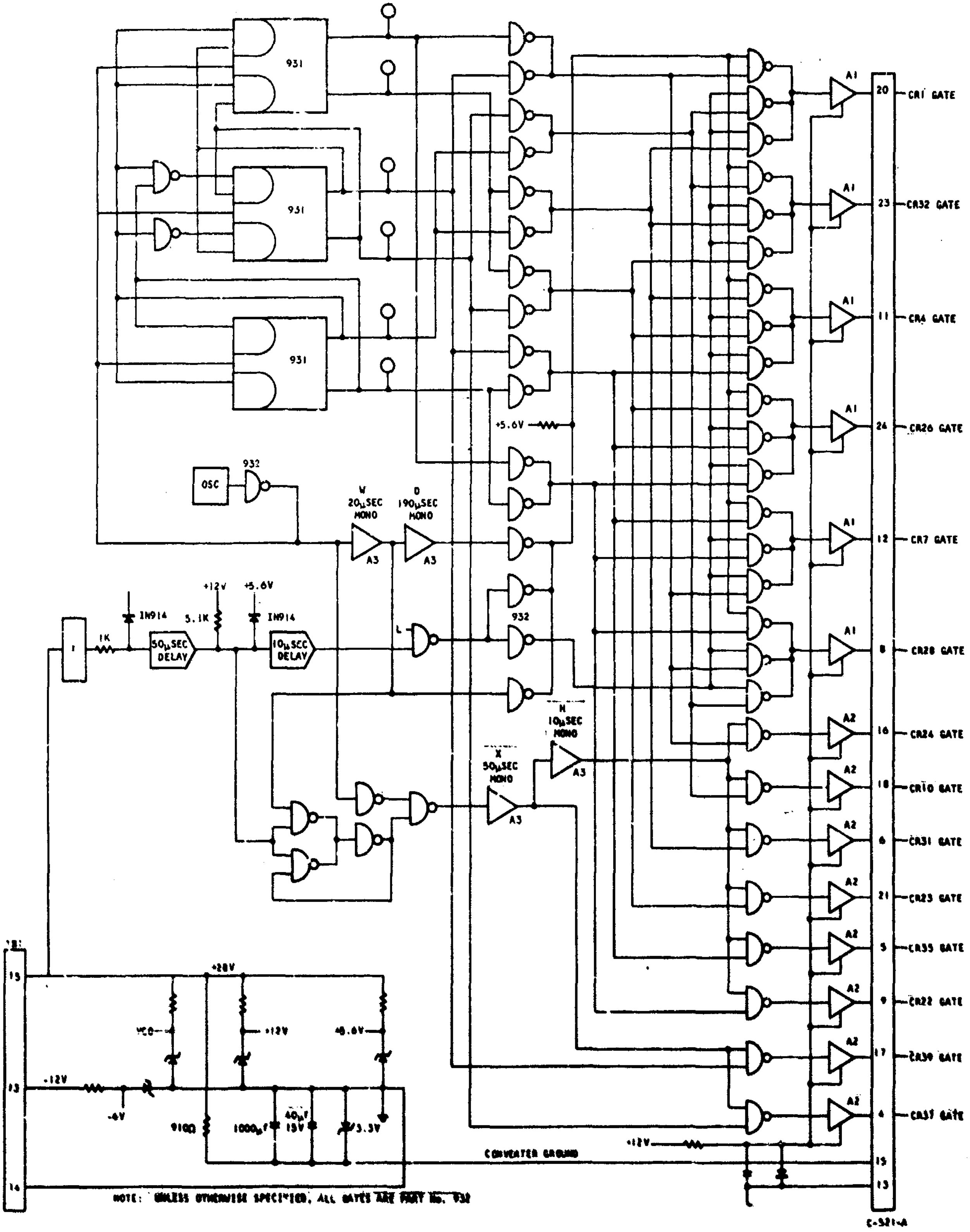


Figure 3.5 Inverter Timing Chart



NOTE: UNLESS OTHERWISE SPECIFIED, ALL GATES ARE PART No. 932

Figure 3.6 Inverter Logic Diagram

TABLE 3.6

COMPONENT PARTS LIST FOR FIGURE 3.6

Description and Designation	Manufacturer's Name and Part Number	Performance Rating	Number Required
Pulse Amplifiers (A1)	AiResearch Part No. 543661	SCR long duration driver 2 amps peak pulse 1 millisec duration	6
Pulse Amplifiers (A2)	AiResearch Part No. 543659	SCR Short Duration Driver, 2 amps peak pulse 10μsec duration	8
Oscillator	See Figure 3.7		1
Time Delay Generator	See Figure 3.8		4
All Gates NOR	Fairchild Part No. 932		48
Logic Amplifiers	Fairchild No. 931		3
All Resistors	Allen Bradley R-C 20 Type	1/2 watt ±4%	7
All Capacitors	Sprague Electrolytic 601D Type	15 volt	2
All Zener Diodes	Hoffman 500 milliwatt Type Voltage as noted	500 milliwatt	5
All Diodes	Hoffman 1N914	50ma High speed	2

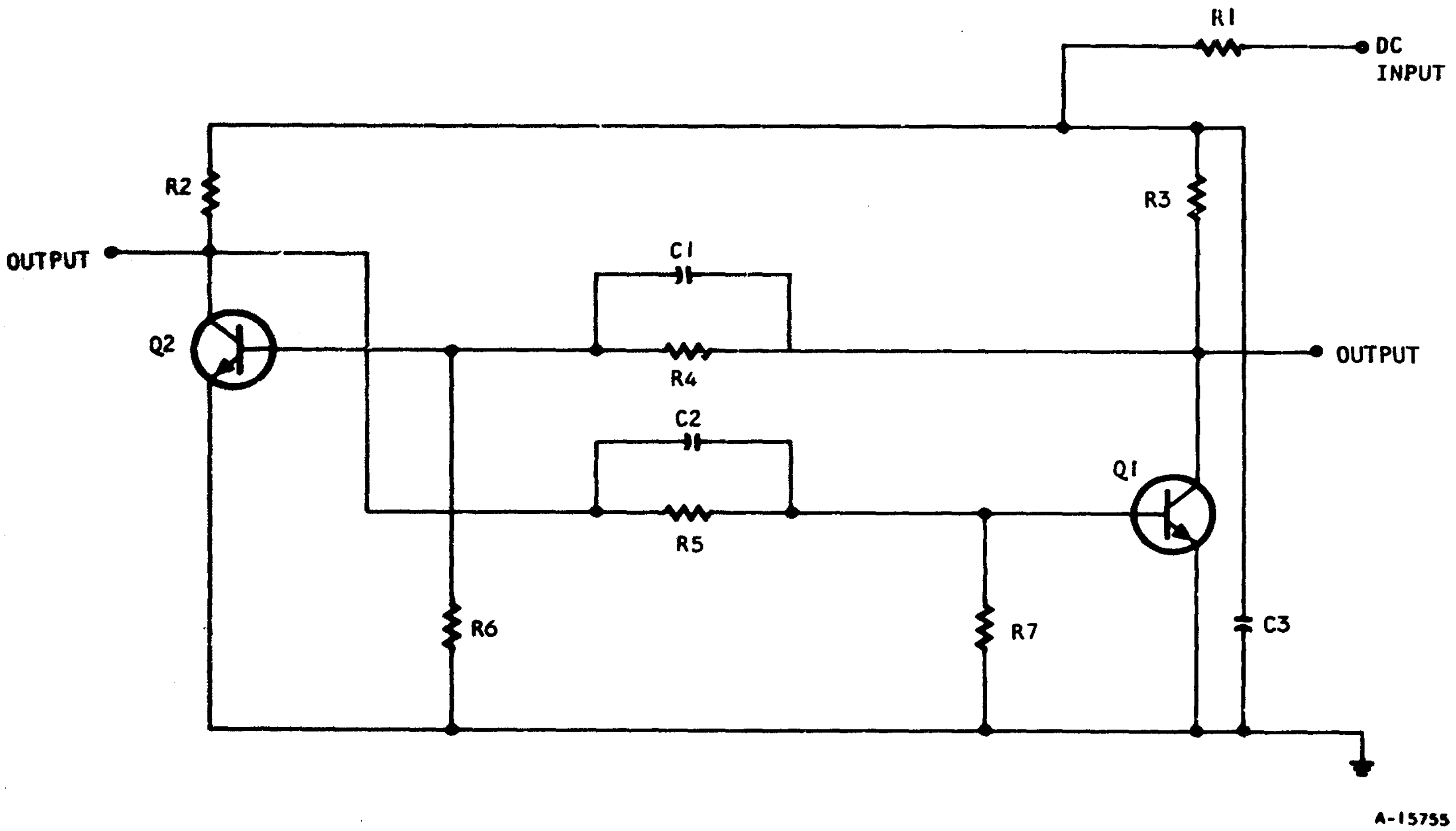


Figure 3.7 Oscillator Circuit Diagram

TABLE 3.7

COMPONENT PARTS LIST FOR FIGURE 3.7

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Transistor	Q1, Q2	Texas Instrument 2N697	100mw β = 40
Resistor	R2, R3	Allen Bradley R-C 20 Type	6.8KΩ±5% 1/2 watt carbon
Resistor	R4, R5, R6, R7	Allen Bradley R-C 20 Type	3.3KΩ±5% 1/2 watt carbon
Capacitor	C1, C2	Sprague Electric Polycarbonate	300 volt selected for 400 cycle operating frequency
Resistor	R1	Allen Bradley R-C 20 Type	9.7KΩ±5%, 1/2 watt
Capacitor	C3	Sprague Electric Aluminum Electrolytic	10μfd 20 volt

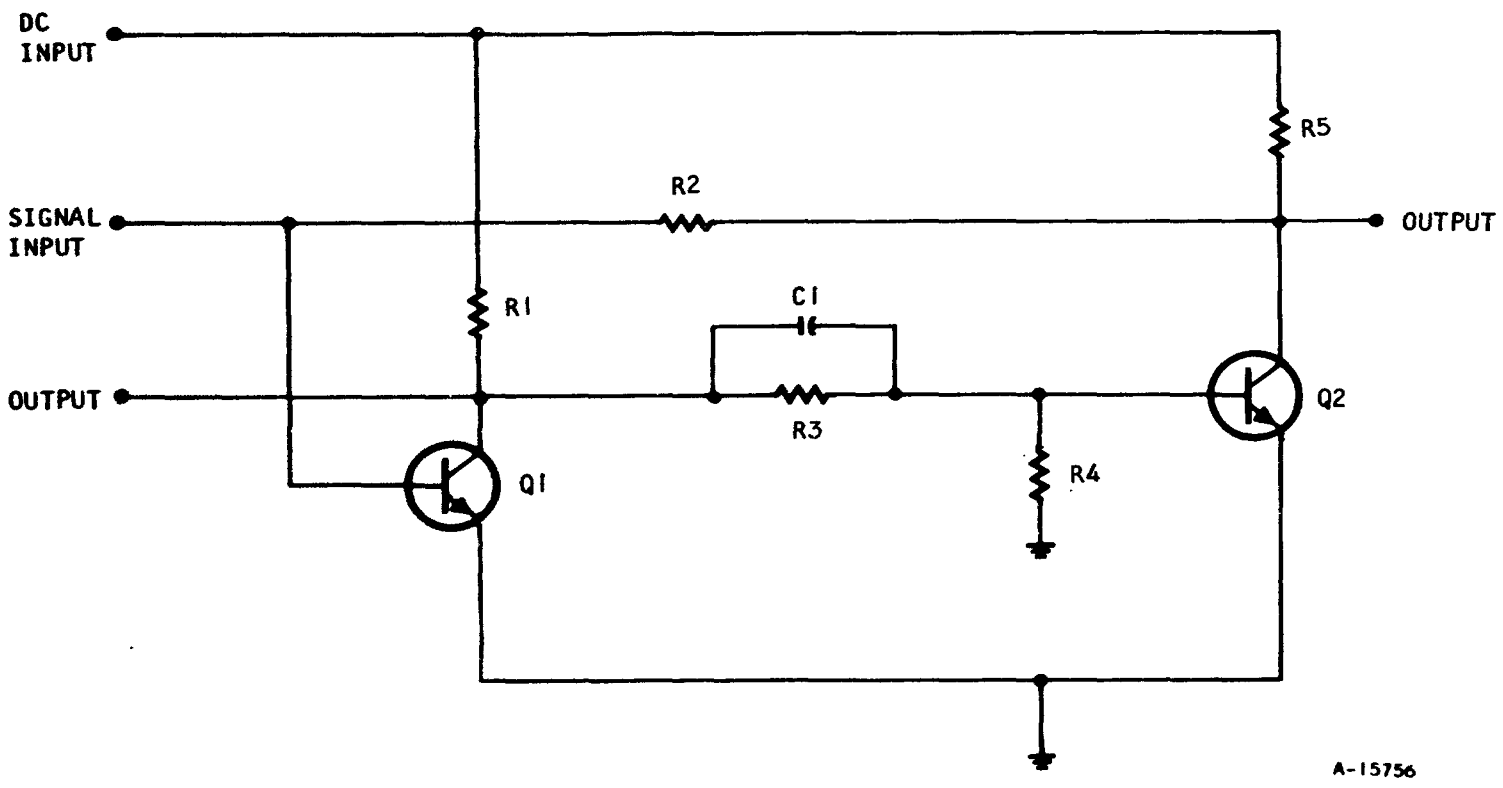


Figure 3.8 Time Delay Generator Circuit Diagram

TABLE 3.8

COMPONENT PARTS LIST FOR FIGURE 3.8

Description	Designation	Manufacturer's Name and Part Number	Performance Rating
Transistor	Q1, Q2	Texas Instrument 2N697	Transistor 100mw $\beta = 40$
Resistor	R1, R5	Allen Bradley R-C 20 Type	6.8KΩ±5% 1/2 watt carbon
Resistor	R2	Allen Bradley R-C 20 Type	33KΩ±5% 1/2 watt carbon
Resistor	R3, R4	Allen Bradley R-C 20 Type	6.8KΩ±5% 1/2 watt carbon
Capacitor	C1	Sprague Electric Polycarbonate	Selected for time delay required

3.3.4 Fans

The motor driven fan designed for the ECU is aerodynamically identical to an existing AiResearch fan Part Number 207335. Hundreds of these fans have been used for various military ground applications such as the environmental ground cooling cart for the Hawk missile. The fan has been qualified to military specifications and has required minimum field service. The performance of the fan for the ECU can be predicted with great confidence since the required performance is within the limits of proportionality that are governed by the fan laws of dynamic similarity. In other words, the flow is directly proportional to the speed and the pressure rise is directly proportional to the square of the speed. Aerodynamic and motor efficiencies will remain relatively unchanged since the Reynolds Number effect, and the windage and bearing frictional losses are very small in this specific speed and power range. Figure 3-9 shows performance curves for the 207335 fan based on actual test data.

The fan for the ECU has been designed to provide 900 cfm of flow with a total pressure rise ($\Delta P/\sigma$) of 2.65 in. H_2O. The fan is a single stage vane-axial type with 16 high efficiency, aerodynamic shaped airfoil blades, twisted from hub to tip to provide uniform aerodynamic loading in the radial direction. All of the aerodynamic components such as the impeller, de-swirl vanes, and housing are of aluminum construction.

The motor selected is a 8 pole, 3 phase, 115/208 volt, 400 cycle, squirrel cage induction motor operating at 5700 rpm. The motor stator is constructed of high quality steel laminations wound with copper wire having high temperature insulation and vacuum impregnated for maximum dielectric resistance. The electrical rotor is constructed of high quality steel laminations plus an integral cast aluminum cage, mounted on a steel shaft. Motor cooling is provided by heat conduction through the motor housing and aerodynamic stator vanes, and subsequent connection to the main air stream. In addition, cooling airflow is provided by internal circulation through the motor.

The bearings selected for this machine are high quality ball bearings, sized for high load capacity, using high temperature resistant grease as a lubricant, plus grease seals. The bearings are lubricated for the overhaul life of the machine. Normal spring type pre-loading will also be applied in the installation. Thermal protection networks are built into the motor windings to prevent damage by overheating.

The estimated performance is presented in Figure 3.10 A description and operational characteristics of the fan are summarized in Table 3.9.

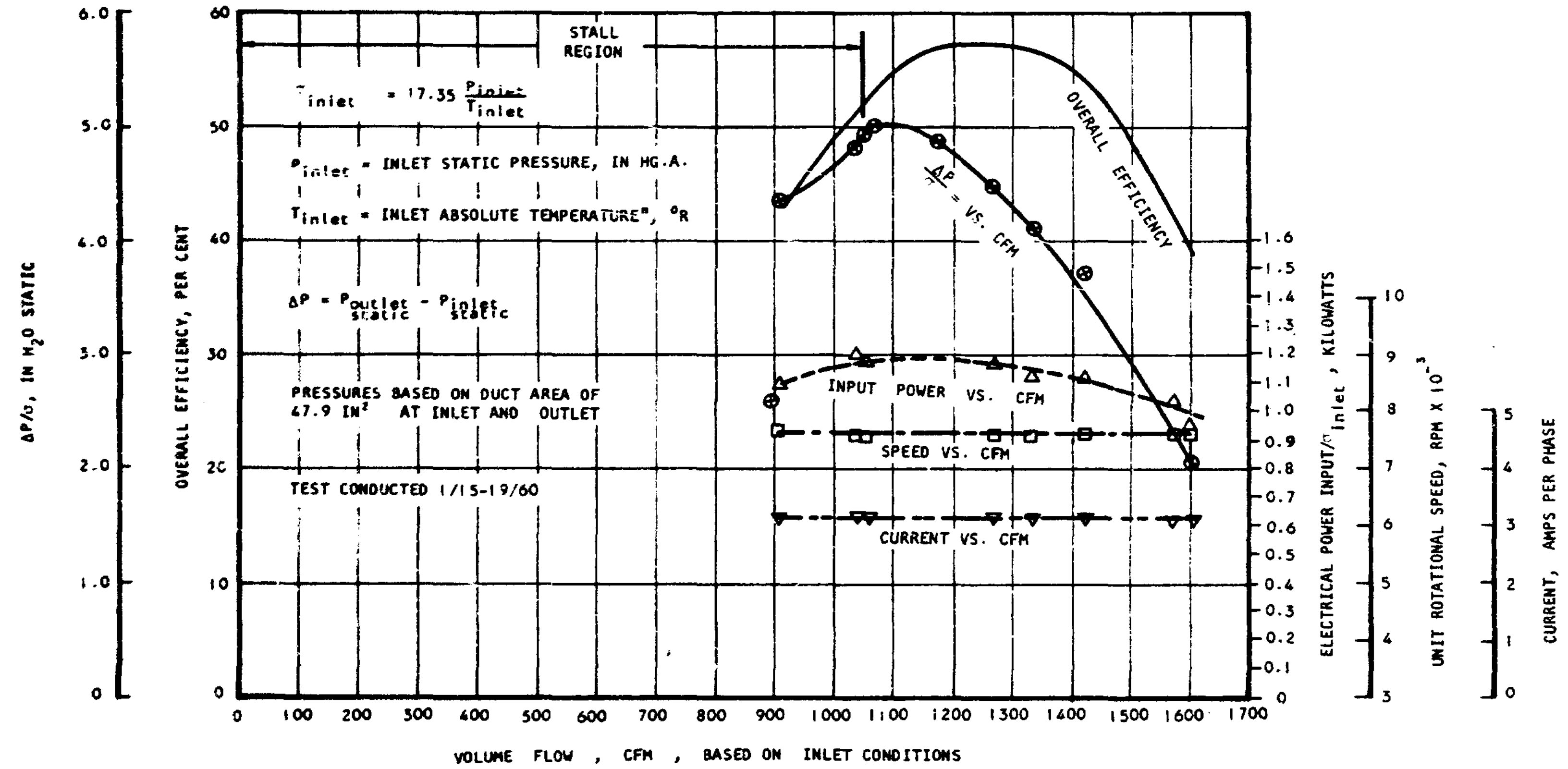


Figure 3-9. Performance Curves for 207335 Fan

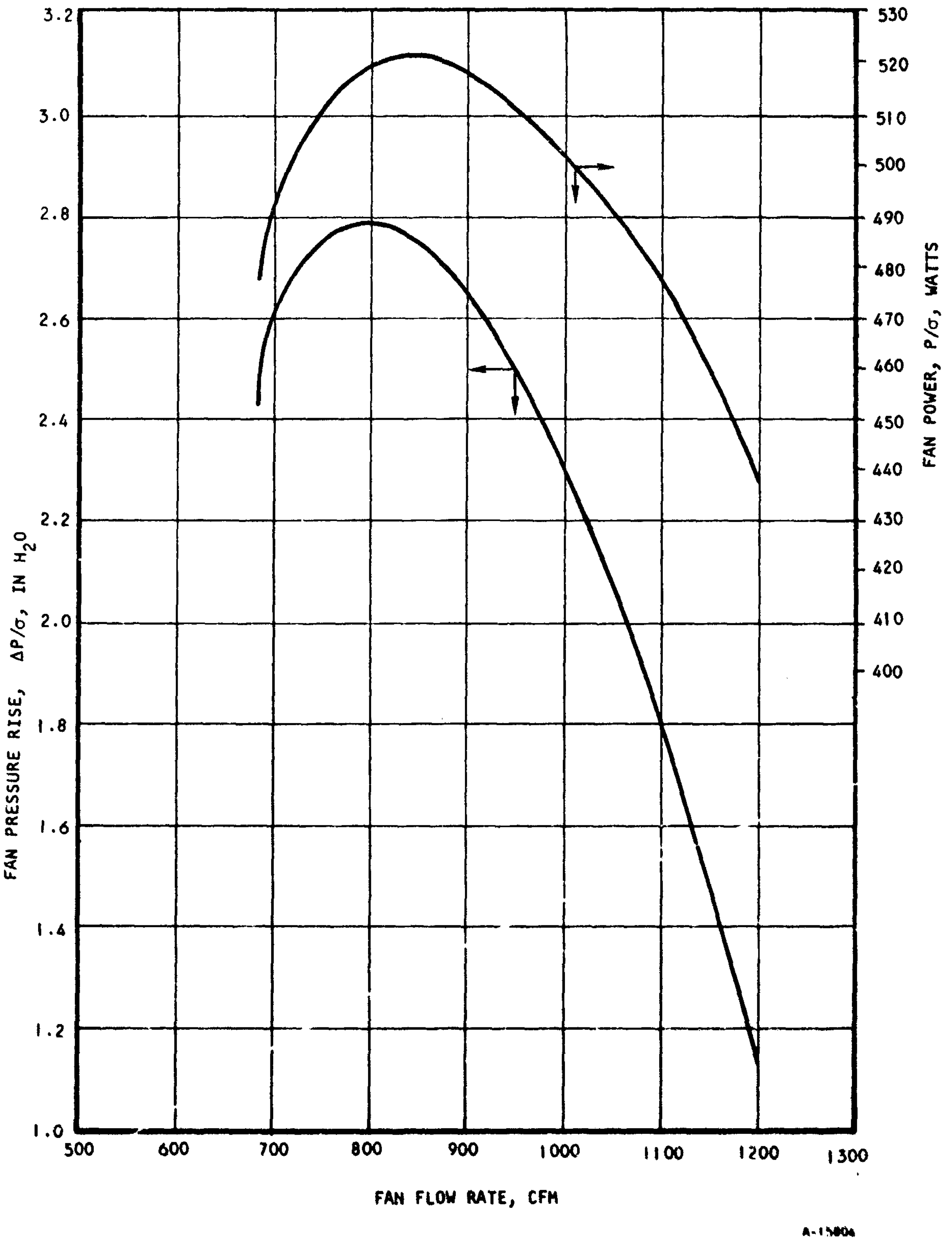


Figure 3-10. Performance Curve for ECU Fan

TABLE 3.9

FAN PERFORMANCE TABLE

Parameter	Performance at Nominal Cooling Load
Fan inlet pressure; in. Hg A	29.92
Fan inlet temperature; ^{0}F	117
Fan total pressure rise; in. H_2O	2.4
Fan volumetric flow; cfm	900
Rotational speed; rpm	5700
Electrical power	3 phase ac
Frequency; cps	400
Motor input voltage; volts	115/200
Motor input power; watts	460
Motor power factor;	.70
Fan Weight; lbs	12.00
Housing diameter; in.	8.15
Motor diameter; in.	4.06
Blade diameter; in.	7.75
Housing length; in.	6.4
Motor protrusion; in.	1.25

SECTION 4

TEMPERATURE CONTROL AND MALFUNCTION DETECTION

4.1 TEMPERATURE CONTROL

Temperature control is achieved by varying the current supplied to the thermoelectrics. The signal generated by a thermistor sensor is compared to the output current from the power supply by a differential amplifier. When the sensor temperature is greater than 72°F, the bimetallic switch controlling the ECU operation is in the position for cooling and a constant voltage is applied to the thermistor network. The control is designed for full cooling when the sensor temperature is at 78°F or greater.

The thermistor has a rated output of 65 millivolts per degree F. The signal generated by the thermistor is amplified and transmitted to an SCR bridge firing circuit. The SCR bridge circuit is the type manufactured by Sprague Manufacturing Company (Part No. VS6732FF). The bridge circuit turns on the SCR's in the power supply and allows current to flow to the thermoelectrics. The power supply current is sensed and fed back to another set of control windings in the bridge firing circuit. This feedback control transforms the power supply from a constant voltage device to a constant current device. In other words, the power supply is a current regulated device instead of a voltage regulated device. The feedback ratio is set so that the power supply output current is approximately 1000 times the control winding current. For a thermistor output of approximately 0.5 milliamp °F, the amplifier current gain required is 6.5. A current gain of 40 per stage is the minimum amount expected from the transistors used. The excess gain will be reduced to the required amount by increasing the local feedback. This amount of feedback will make the gain of the amplifier accurate to approximately ±10 percent for the expected component variations.

As the current out of the power supply approaches 27 amps the temperature control amplifier is saturated, limiting the power supply current to 27 amps. As the temperature drops from 78°F to 72°F the power supply current decreases to zero. The power supply current follows the curve shown in Figure 4.1. At 72°F the bimetallic switch opens. Power to the outside fan is removed and the power supply reversing relay is energized to reverse the polarity of the output current.

When the sensor temperature reaches 60°F the bimetallic switch closes in the heating mode. The power supply operation is now identical to operation in the cooling mode.

4.2 THERMOELECTRIC MODULE MALFUNCTION DETECTION

An indication that the thermoelectric module is malfunctioning is when the electrical resistance of the semiconductor increases, thus increasing the voltage drop across the module. The cause of the increased resistance is normally due to microscopic fractures in the material reducing the effective

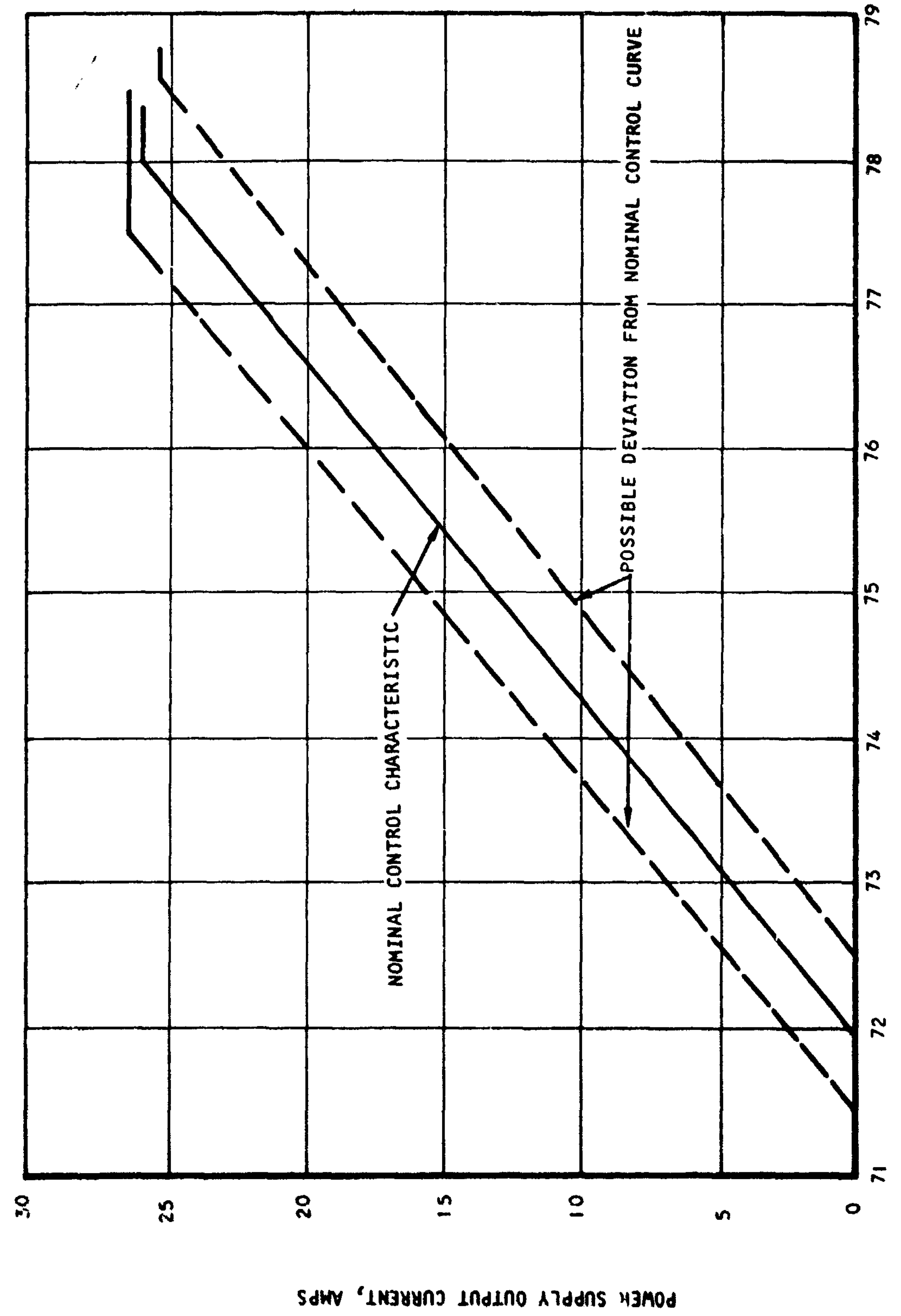


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Figure 4-1. Power Supply Output Current During Temperature Control Phase cross-sectional area of the conductor. If the unit is not properly designed, both thermal and mechanical stresses can create these microscopic fractures. When the voltage drop across a module increases by a factor of two the current in a coil shunting the module increases from 40 ma to approximately 80 ma. The increased electromotive force due to the increase in current through coil in the malfunction bypass circuit causes a reed relay to close, shorting out two modules. The relay is held closed by a heavy current coil in series with its contacts. This coil shorts out the faulty module and closes a second reed relay which supplies a signal to the remote indicator panel.

Since the power supplied to the thermoelectric module is continuous the reed relays would open only when the thermoelectric module power supply voltage is removed. To keep the contacts across the faulty modules closed, a holding coil in series with the contacts used for the remote indicator light holds both the remote indicator and the module shorting contacts closed.

A reset button is provided on the indicator panel for the purpose of breaking the holding circuit to check for actual module failure or an intermittent fault condition. This is accomplished by setting the unit on manual control, turning the manual control selector switch to either heat or cool and pressing the remote indicator light reset switch. If the light continues to burn there is a module failure.

SECTION 5

MAINTAINABILITY

5.1 GENERAL

One of the prime considerations in the design of the ECU was ease of maintenance. A requirement in the design was to provide accessibility for maintenance through one face of the unit only. The specification requirement was that this face be the outside face of the unit. Although this requirement does not seem to be very stringent it created some design problems. Packaging design flexibility was limited and the structural design of the frame had to be compromised. To satisfy this design requirement, the outside face has removable panels for the three sections of the ECU. All removable sections are attached with quick disconnect captive fasteners. The maintenance of each section is discussed separately below.

5.2 TOP SECTION

The removal of the access panel completely exposes the internal fan and duct assembly. The removal of this assembly is independent of the outlet conditions of the conditioned air (right-handed or left-handed operation). This assembly is mounted in position by two split bands at the ends of the assembly. To remove the assembly, the electrical connector must first be disconnected. Removing the loose halves of the split band by the removal of the mounting bolts permits the assembly to be removed from this section. The remaining halves of the band are permanently attached to the unit.

Because the assembly has identical ends, the reversal of air flow is accomplished by inverting the complete fan and duct assembly. This is shown on Layout Drawing L-198119.

5.3 CENTER SECTION

After the louvered panel is removed, the twelve thermoelectric heat exchanger modules become accessible. Each of the twelve modules may be removed individually. The control system has a malfunction detection lamp which indicates that the thermoelectric modules are malfunctioning. The operation of the control circuit is described in detail in another section of this report. As shown in Figure 3.3 the dc output is circuited through a bank of terminals before reaching the modules. To isolate the bad module, a resistance check can be made across these terminals located in the electronics enclosure in the bottom section of the ECU. Accessibility to this section is discussed in the next section of this report.

Once the bad module has been located, it is removed by following the procedure outlined below. Layout Drawing L-198102 should be used to assist in following the outlined procedure.

1. Remove the electrical connector.

2. Remove the bolt at the cold air outlet duct flange.

3. Remove the bolt at the mounting bracket at the mounting ~~bracket~~ at the bottom of the heat exchanger module.

4. Pull backward to remove the module. The seal at the top of the module will break immediately since the module is sliding along the inclined shelf.

5. Since each module weighs approximately 25 pounds, the module should be properly supported after the retaining bolts are removed and during the removal of the module.

6. The above procedure is reversed for installation.

After the module has been removed it is possible to isolate defective couples within the module. The circuit for the couples is designed so that the minimum number of couples that can be isolated is six. The schematic shown on Figure 2.1 shows the couple circuit with single and double row bypass conditions. To locate the defective rows, a resistance check across the rows must be made. The terminals at the ends of each row are exposed by removing the connecting clips. Figure 2.1 shows that both ends of the rows are accessible for resistance checks. Bypassing is achieved by using longer connecting clips. The defective rows should be capped to prevent short circuits.

5.4 BOTTOM SECTION

The panel for this section is the back face of the electronics enclosure. The enclosure is mounted on sliding tracks and can be removed after the panel fasteners are disengaged. When the enclosure is fully retracted but still engaged in the tracks, all connecting cables must be disengaged if the enclosure is to be removed from the ECU. With the enclosure in the retracted position, minor maintenance can be performed because the enclosure access panel is removable in this position. The removal of this panel provides accessibility to the control system, power converter, frequency inverter and outside fan. The tracks have a captive feature and the enclosure must be lifted to be released from the tracks.

The only section in the ECU which is removable from the front is the control panel. Because the thermal control sensor is mounted in this panel and must have provisions for remote placement, its removeability from the front panel was mandatory. For remote operation, the control panel is first removed from the ECU. Sufficient length of cable is provided for the control panel to clear the ECU. The cable must then be removed and an extension added for remote sensing.

SECTION 6

FABRICATION OF THERMOELECTRIC ECU

6.1 GENERAL

The fabrication of the ECU is based upon standard manufacturing processes. The only areas that may be considered as advanced state of art are in the fabrication of the thermoelectric couples and the associated joining techniques. Many manufacturers of thermoelectrics consider the joining techniques highly proprietary and will not release information in these areas. The fabrication of the various components are discussed in subsequent paragraphs. Discussions on components that are described in detail in other sections of this report are only briefly discussed in this section.

6.2 HEAT EXCHANGER

The heat exchanger is a brazed assembly with aluminum plate fins. The sheets of fins are stacked and dip brazed into individual cores. The base plates are machined and prepared for joining to the thermoelectrics. A relatively flat surface is required to insure a high percent of surface contact with the thermoelectrics for maximum heat transfer. For joining by soldering, this surface is plated and cut into smaller sections to minimize the thermal stresses across the thermoelectrics created by the contraction and expansion due to the differential temperature across the thermoelectrics.

6.3 THERMOELECTRICS

AiResearch does not fabricate thermoelectric modules and thus must procure them from manufacturers of same. However, the manufacturing procedures are understood and therefore realistic approaches to the design of thermoelectric couple and modules are used. In the procurement of the thermoelectrics, AiResearch will specify parametric requirements such as those listed below.

1. Seebeck Coefficient, S
2. Electrical Resistivity, ρ
3. Thermal Conductivity, k
4. Element size, A, L
5. Couple density, A_C/A_T
6. Operating Current

The design used for the ECU is based upon realistic parameters furnished by a number of manufacturers of thermoelectrics. Confirmation has been obtained that the couple design can be manufactured.

6.3.1 Joining of Thermoelectrics to Heat Exchanger

One of the most important considerations of the design of a thermoelectric cooling unit is the selection of the proper joint between the thermoelectrics and the heat transfer surfaces. There are several methods used such as the use of thermal greases and epoxies, and by soldering. If a dielectric interface is required, interfaces such as Mylar Film, dielectric thermal greases and oxidized surfaces (hard anodize for aluminum, aluminum or beryllium oxide ceramics) are used. The primary requirements are that this joint has high thermal conductivity and high dielectric strength. It is inherent that a material with high dielectric strength has relatively low thermal conductivity. After investigating the various methods of joining, the conclusions is that the optimum design is the use of a metalized ceramic interface with a soldered joint. There are many ways of achieving this interface. The actual method must be thoroughly discussed with the manufacturer of the thermoelectric material because it is related to the module design discussed above.

6.4 POWER CONVERTER, FREQUENCY INVERTER, CONTROLS

These components are thoroughly discussed in other sections of this report. The fabrication of these components is not involved. Standard techniques are used to assemble the components which are basically comprised of SCR's, rectifiers, capacitors, relays, etc. These components are basically solid state devices which AiResearch has designed and fabricated for many other applications.

6.5 FANS

The fans are discussed in detail in Section 3.3.4.

6.6 ECU ASSEMBLY

The discussion of the ECU assembly will be limited to areas not previously discussed and which are not obviously presented on the layout drawings which supplement this report.

The cold side air ducts which are attached to the thermoelectric heat exchanger will be made of fiberglass for thermal insulation. The ducts can be either molded or assembled from individual sections or a combination of both methods. The ducts will be attached to the heat exchanger by epoxy.

The electrical wiring will be assembled into individual harnesses with standard connectors for termination. Electrical conduits will be used only in areas where either protection is required or the installation is permanent.

The ECU enclosure will be thermally insulated with sheets of rigid polyurethane foam approximately 3/8 in. thick. The insulation will be attached to the panel with an adhesive compatible to both surfaces. The insulation will be coated with a clear sealer to prevent flaking.

SECTION 7

DESIGN CONSIDERATIONS OF THERMOELECTRIC ECU

7.1 GENERAL CONSIDERATIONS

The design of the ECU has been centered about the following major considerations: (a) nominal net cooling load of 24,000 Btu per hr at a net COP of 1.0 or greater; (b) maximum dimensions of 66 in. high, 18 in. depth, and 44 in. wide; (c) a modular type construction with a minimum of six separate modules within the heat transfer section of the ECU; (d) maintenance to be accomplished from the front face of the ECU only, (e) maximum volume of 15 cu ft.

These considerations guided the design of the ECU, and while some of the design requirements may have dictated less than optimum performance of some of the components, the overall result is a well integrated, high performance ECU.

7.2 NET COEFFICIENT OF PERFORMANCE OPTIMIZATION STUDY

In designing the thermoelectric unit a systematic study was made to determine what flow conditions and heat exchanger size would yield the optimum system or net coefficient of performance (COP). The study was made by first deriving an expression relating the net COP to the various parameters which influence the net COP.

The derivation of the net COP expression was based on a constant flow rate on the cold side since the design requirements have essentially established the cold side flow rate. Certain parameters which do not vary appreciably and whose variation does not have a significant effect on the net coefficient of performance were held constant in order to minimize the complexity of the expression. The expression, therefore, does not yield exact values of the net COP but yields a very good approximation of where the optimum net COP occurs. Once having established where the approximate optimum point is, the optimization study can then be concentrated around this point. The actual optimum net coefficient of performance can be determined by a detailed study of net coefficient of performance around this point.

The net COP can be expressed as follows:

$$E_N = \frac{Q_N}{\frac{K\ Q_R}{\epsilon} + Q_{Fi} + Q_{FO}} \qquad (1)$$

where E_N = net COP

Q_N = net heat rejection = constant

Q_R = total heat rejection

Q_{Fi} = inside or cold side fan power

Q_{FO} = outside of hot side fan power

ϵ = thermoelectrical COP

$K = \frac{1}{\text{Inverter Efficiency}}$

Q_R, Q_{Fi}, Q_{FO} and ϵ can be further expressed as follows:

$$Q_R = Q_N + Q_D + Q_K + Q_{Fi} \qquad (2)$$

where Q_D = duct losses which will be assumed as constant

Q_K = axial conduction load, which can be expressed as

$Q_K = \frac{C_1}{L}$, where L is the heat exchanger length
C_1 = constant

$Q_{Fi} = C_2 L + C_3$, where L is the Heat Exchanger Length
C_2 and C_3 = constant

therefore

$$Q_R = Q_N + Q_D + C_1/L + C_2 L + C_3 \qquad (3)$$

$Q_{FO} = C_4 W_H^3 + C_5 W_L^3$, where
L = Heat Exchanger Length
W_H = hot side flow rate
C_4 and C_5 = constant

$$\epsilon = \frac{T_c}{\Delta T}\left[\frac{\gamma - 1 - \frac{\Delta T}{T_c}}{\gamma + 1}\right] \qquad (4)$$

where ΔT = thermoelectric temperature lift

T_c = cold side thermoelectric absolute temperature

$\gamma = \sqrt{1 + Z\left(\frac{T_c + T_H}{2}\right)}$ where Z = thermoelectric figure of merit

T_H = hot side thermoelectric temperature, °K

Note in this application T_c and γ are approximately constant for all conditions

Let $D_1 = T_c$; $D_2 = \gamma - 1$

therefore

$$\epsilon = \frac{D_1}{\Delta T}\left[\frac{D_2 - \frac{\Delta T}{D_1}}{D_2 + 2}\right] = \frac{D_1 D_2 - \Delta T}{\Delta T(D_2 + 2)} \qquad (5)$$

Substituting for Q_R, Q_{Fi}, Q_{FO} and ϵ into Eq 1, we get

$$E_N = \frac{Q_N}{\dfrac{K\left[Q_N + Q_D + C_1/L + C_2 L + C_3\right]}{\dfrac{D_1 D_2 - \Delta T}{\Delta T(D_2 + 2)}} + C_2 L + C_3 + C_4 W_H^3 + C_5 W_H^3 L}$$

Simplifying, we get

$$E_N = \frac{Q_N(D_1 D_2 - \Delta T)}{K\,\Delta T(D_2+2)(Q_N+Q_D+C_1/L+C_2 L+C_3)+(C_2 L+C_3)(D_1 D_2-\Delta T)+C_4 W_H^3(D_1 D_2-\Delta T)+C_5 W_H^3 L(D_1 D_2-\Delta T)} \qquad (6)$$

The net COP expression is applied by generating plots of net COP vs heat exchanger length (which represents the heat exchanger size) for various thermoelectric temperature lifts (ΔT_{TE}) and hot side flow rates.

The plots of Figures 7-1 through 7-3 are based on a cold side flow rate of 3800 pounds per hour. These plots are shown in Figures 7-1 through 7-3. Note that all the points shown in Figures 7-1 through 7-3 do not represent possible solutions. The possible solutions for each case lie along the

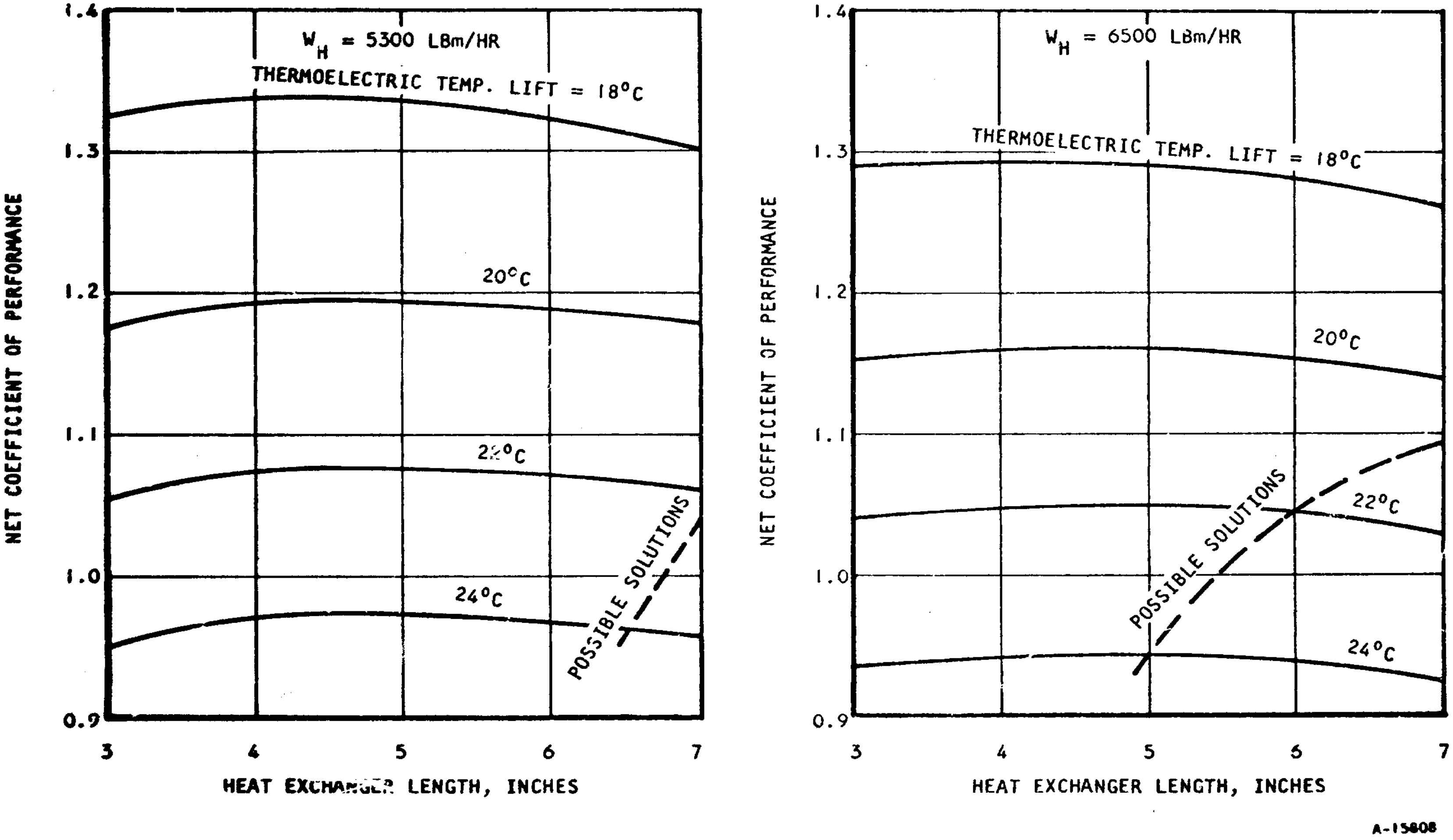

Figure 7-1. Net Coefficient of Performance Versus Heat Exchanger Length for Hot Side Flow Rates of 5300 LBm/HR and 6500 LBm/HR

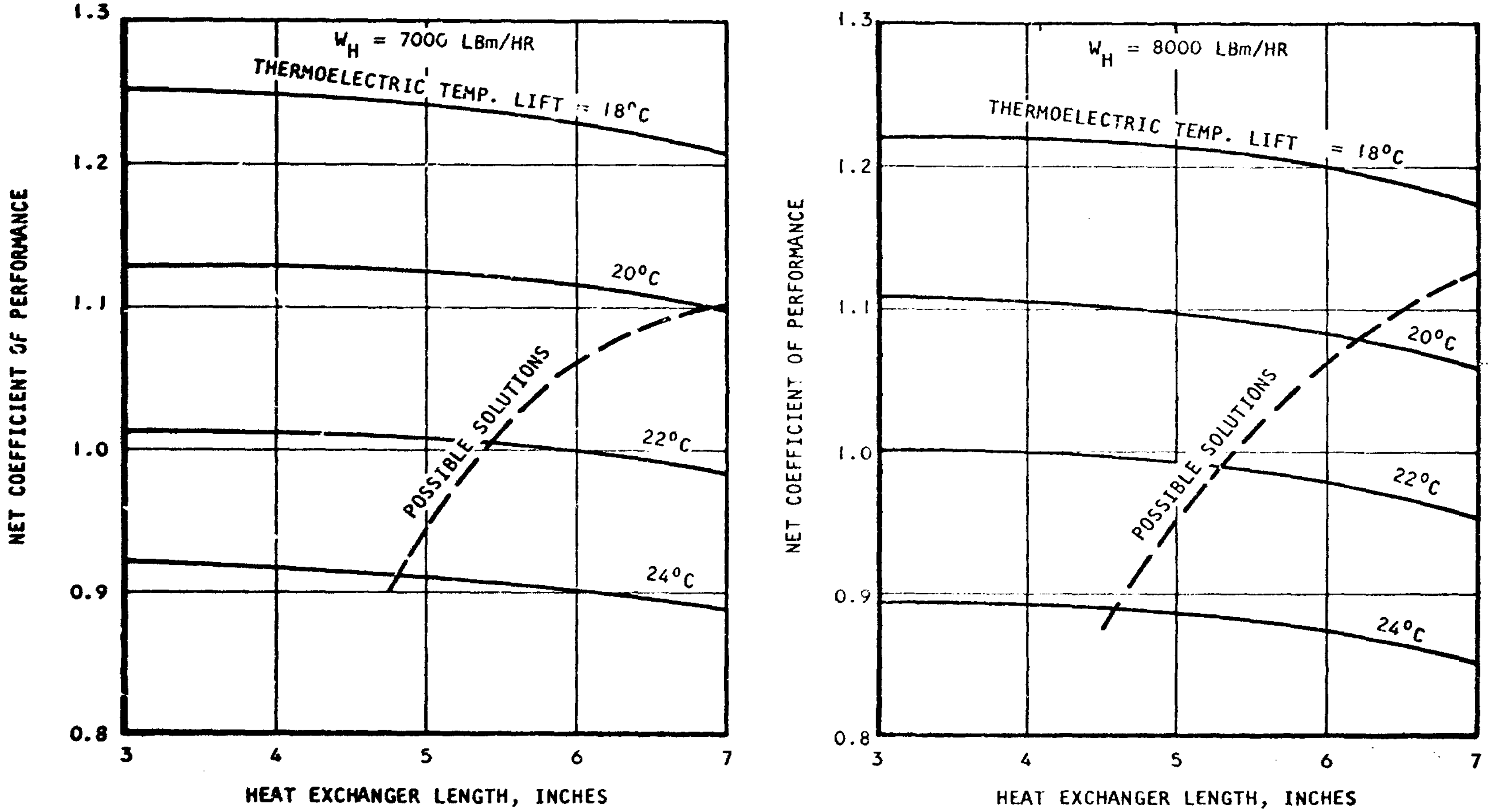

Figure 7-2. Net Coefficient of Performance Versus Heat Exchanger Length for Hot Side Flow Rates of 7000 LBm/HR and 8000 LBm/HR

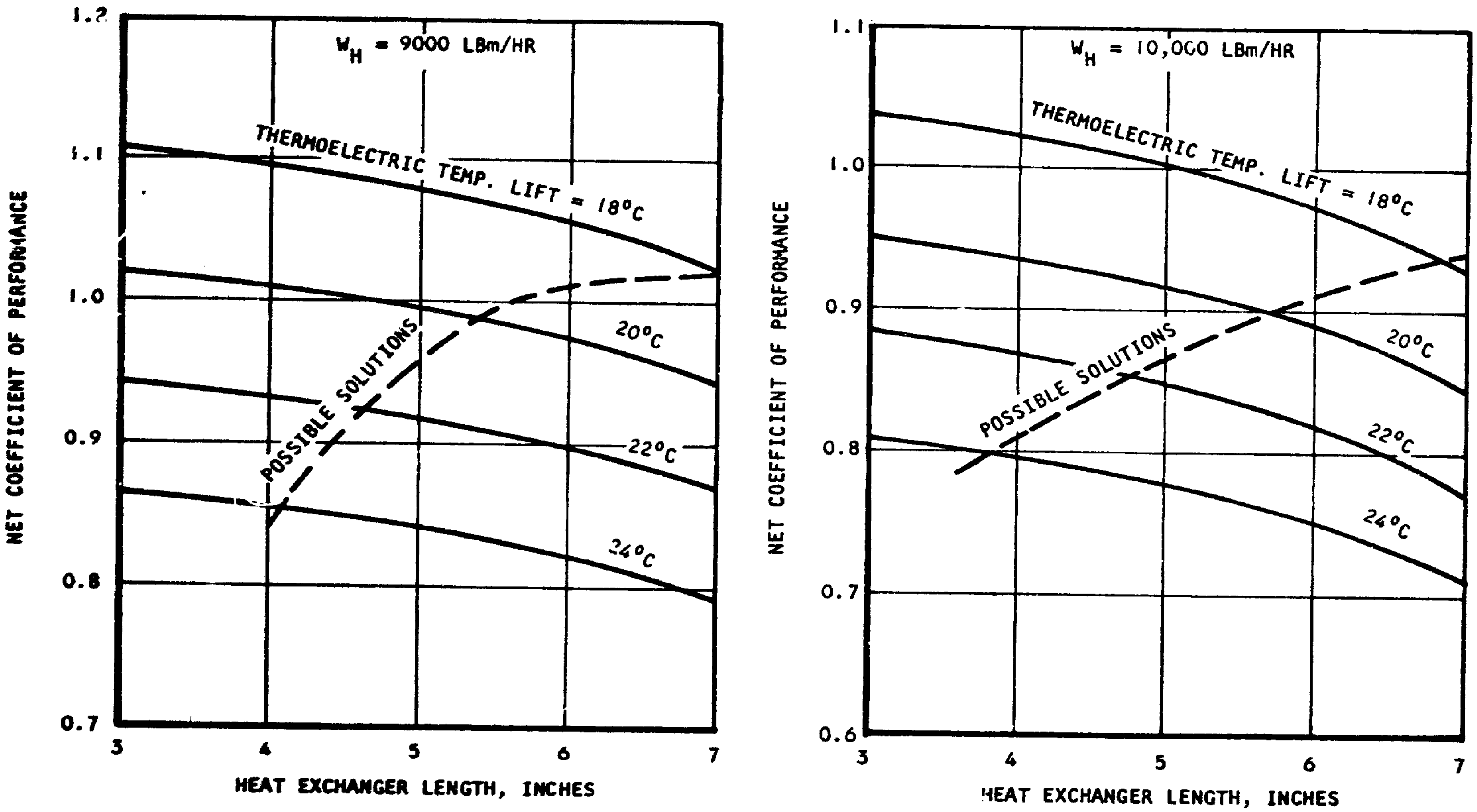

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Figure 7-3. Net Coefficient of Performance Versus Heat Exchanger Length for Hot Side Flow Rates of 9000 LBm/HR and 10,000 LBm/HR dashed lines on the plot. It can be easily seen why some of the points do not represent possible solutions. By citing an example: For instance, in the case, where the hot side flow rate is 5300 pounds per hour the thermoelectric temperature lift due to the temperature difference between the hot and the cold air and due to the junction thermal resistances alone is approximately 19°C. This does not include the thermoelectric temperature lift due to the air side film resistances. Obviously it is not possible to attain a thermoelectric temperature lift equal to or less than 19°C. In order to attain a temperature lift of 20°C, the temperature lift due to the air side film resistances should be 1°C. This would require a very large heat exchanger which could not be accommodated in the available envelope. Points which do not represent possible solutions were nevertheless plotted in order to apply the net COP expression more extensively and thereby to provide a broader basis for arriving at an optimum net COP.

The optimum point for each hot side flow rate was determined. These optimum points are those which require heat exchanger sizes which are well within the available envelope. Figure 7-4 shows a plot of the net COP vs hot side flow rate. It can be seen from Figure 7-4 that the maximum net COP occurs at a hot side flow rate of 8120 pounds per hour. For flow rates below 8120 pounds per hour, the effect of the fan power is not very pronounced. The effect of increasing the hot side flow rate is to decrease the thermoelectric temperature lift, which increases the thermoelectric COP. This effect prevails over the effect of increasing the fan power and therefore tends to increase the net COP. Beyond a hot side flow rate of 8120 pounds per hour the effect of increasing the fan power prevails over the effect of decreasing the thermoelectric temperature lift. The net COP drops very sharply as can be seen from Figure 7-4.

7.3 HEAT EXCHANGER CONSIDERATIONS

No difficulties were encountered in designing the plate fin heat exchangers to match the optimum thermoelectric design. The number of modules and the module dimensions were determined by an investigation that took into account the ECU package requirements and the pressure drop-power considerations that determined the net COP. There are obvious tradeoffs that can be made beyond what has already been done. However, the design presented will be adversely affected in some manner by such changes. For instance a smaller unit could be achieved by increasing the heat exchanger pressure drop but a lower net COP would result. Additionally, a lower fin sandwich would result in high fin efficiencies, lower weight but a greatly increase number of modules and surface area.

The heat exchanger must also be compatible with the thermal expansion requirements of the thermoelectric modules. At this time it appears that a development program will be required to determine which method of joining is the most feasible. These several methods are discussed in Paragraph 7.5. The ducts that guide the inside and outside air in and out of the thermoelectric heat exchanger module are of great importance in assuring uniform air flow distribution across the face of the heat exchanger. Without uniform flow distribution the desired heat rejection cannot take place.

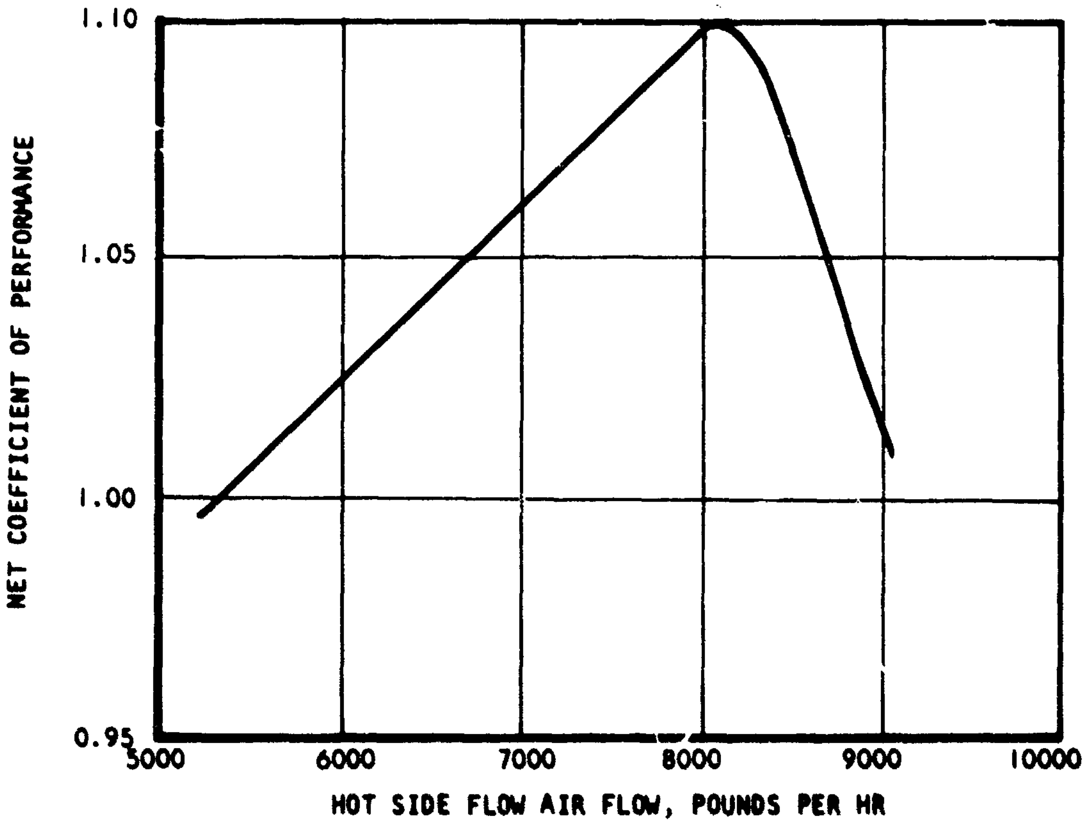

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Figure 7-4. Net Coefficient of Performance for Various Hot Side Flow Rates (Note: The Cold Side Flow Rate is Constant at 3800 Pounds Per Hr.)

Several works in heat exchanger ducts, References 1, 2, 3 and 4 have shown that for a counter flow path the minimum end-to-end pressure drop for uniform flow distribution occurs with rectangular ducts that allow an inlet velocity equal to $\sqrt{2}$ times the outlet velocity. When this situation occurs the duct pressure loss is 0.5 times the inlet velocity head. Additionally the flow distribution in both air flows must be such that the thermal performance of the heat exchanger can be achieved. The need for proper flow distribution necessitated an increase in the outside air exit plenum. The flow distribution that resulted is shown in Figure 7-5. It can be seen that the flow distribution is not completely uniform, but the maximum deviation from inside to outside flow distribution is only 9.1 percent at the bottom of the heat exchanger module. It should be noted that a 10 percent deviation from uniform flow will have a small adverse affect on the overall heat transfer of the ECU, but larger deviations are to be avoided as the loss in heat transfer performance increases rapidly with increasing deviation.

The pressure drop associated with the nominal cooling condition is shown in Table 7-1.

7.4 THERMOELECTRIC MODULE CONSIDERATIONS

AiResearch wishes to acknowledge the following manufacturers for their assistance and information regarding thermoelectric materials and properties:

a. Asarco Intermetallic Corporation, 120 Broadway, New York, New York, 10005

b. Cambridge Thermionic Corporation (CAMBION), 445 Concord Avenue, Cambridge, Massachusetts, 02138

c. Cominco Products Inc, 933 West Third Avenue, Spokane 4, Washington

d. Energy Conversion, Inc, 336 Main Street, Cambridge, Massachusetts, 02142

e. Frigistors, Ltd, 5770 Andover Avenue, Montreal 9, Quebec, Canada

f. International Energy Conversion, Inc, 430 Kirby Stree, Garland, Texas

g. Materials Electronic Product Corporation MELCOR), 990 Spruce Street, Trenton, New Jersey, 08638

The information received from these manufacturers is shown in Table 7-2. AiResearch chose representative property values for design purposes and these values are shown on Figure 7-6.

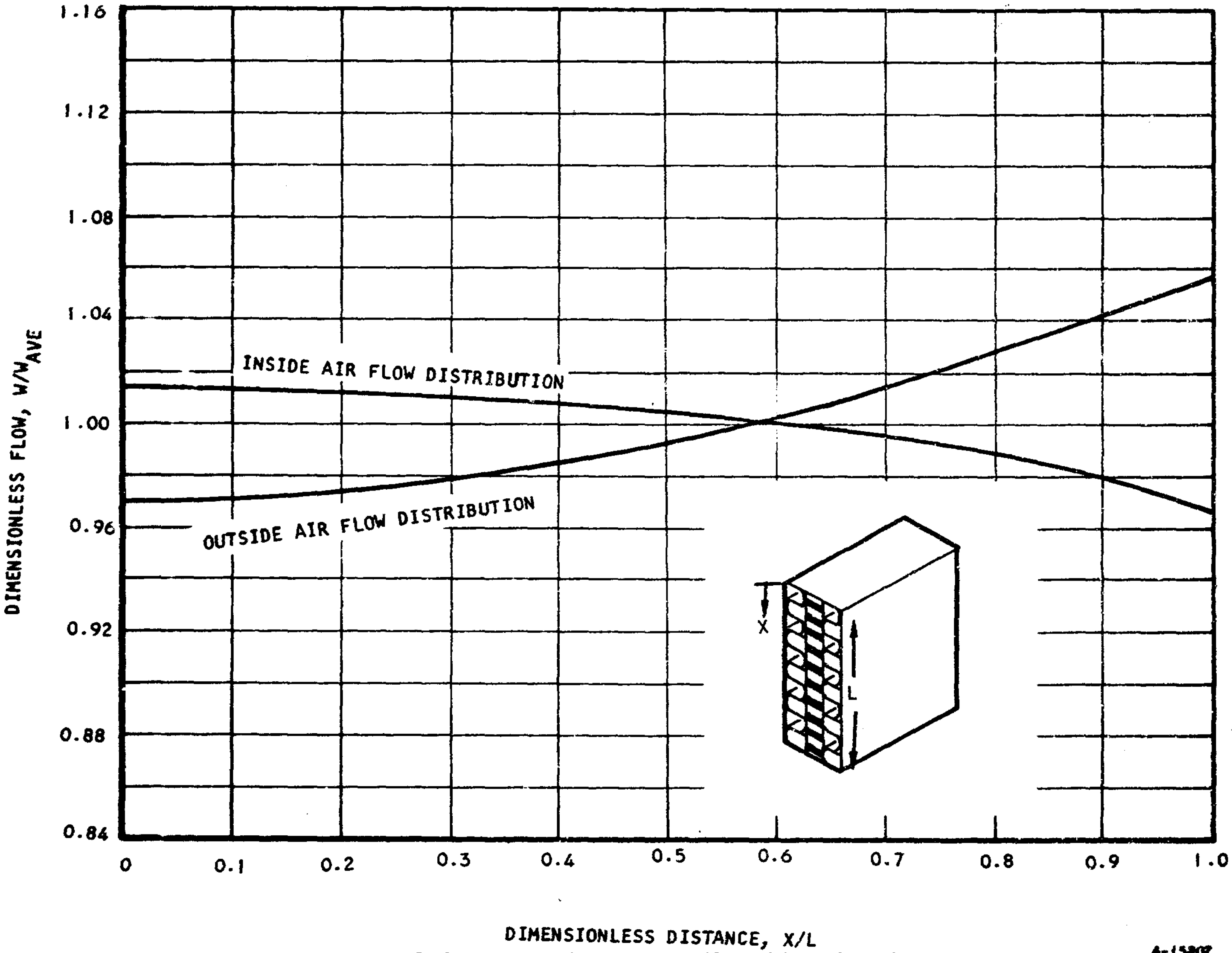


Figure 7-5. Heat Exchanger Flow Distribution

TABLE 7-1

PRESSURE LOSS SUMMARY THERMOELECTRIC ECU
NOMINAL COOLING CONDITION

Location	Flow Area (in.^{2})	Loss Coefficient	Pressure Loss (in. H_2O)
INSIDE AIR			
Inlet screen (10 mech, 0.010 in. round wire)	37.9	0.330	0.228
Fan outlet (exit loss)	40.0	0.800	0.490
Duct entrance (inlet header to ECU modules)	35.8	0.100	0.082
Inlet header	35.8	0.178	0.145
Heat exchanger core loss	--	--	0.700
Outlet header	51.1	0.645	0.210
Exit screen (10 mech, 0.010 inch round wire)	112.0	0.33	0.027
	Total Pressure Loss		1.998
	Fan Rise		2.300
OUTSIDE AIR			
Inlet screen (10 mesh, 0.010 in. round wire)	430.0	0.378	0.0161
Heat exchanger core loss	--	--	1.488
Outlet header	196.3	0.740	0.0908
Transition to bottom section	127.5	0.744	0.0161
Exit screen (10 mesh, 0.010 in. round wire)	80.0	0.378	0.246
	Total Pressure Loss		1.867
	Fan Rise		1.910

TABLE 7-2

THERMAL AND ELECTRICAL PARAMETERS OF THERMOELECTRIC MATERIALS AT 300°C

	Frigistor	Melcor	Energy Conversion	Cambion	Cominco	International Energy Conversion	ASARCO Intermetallics Corporation
P-Type Materials (300°K)							
Resistivity, ohm-cm	0.0015	0.0010	0.001525	0.00125	0.00115- 0.00135	0.00095	0.001335- 0.000952
Seebeck coefficient, µV/°C	2000	195	224	200	210-225	198	185-215
Thermal conductivity, watts/cm-°C	0.011	0.0135	0.0155	0.0130	0.0125 0.0135	0.016	0.0144- 0.0133
Density, gm/cm³	---	--	--	7.4	7.4	--	6.76
N-Type Material (300°K)							
Resistivity, ohm-cm	0.0011	0.0010	0.00095	0.0011	0.0008- 0.0014	0.00095	0.001335- 0.000909
Seebeck coefficient, µV/°C	195	211	203	200	200-250	198	170-200
Thermal conductivity, watts/cm-°C	0.0131	0.0154	0.0163	0.0155	0.0145- 0.0165	0.016	0.0135- 0.0151
Density, gm/cm³	--	--	--	7.8	7.8	--	7.7

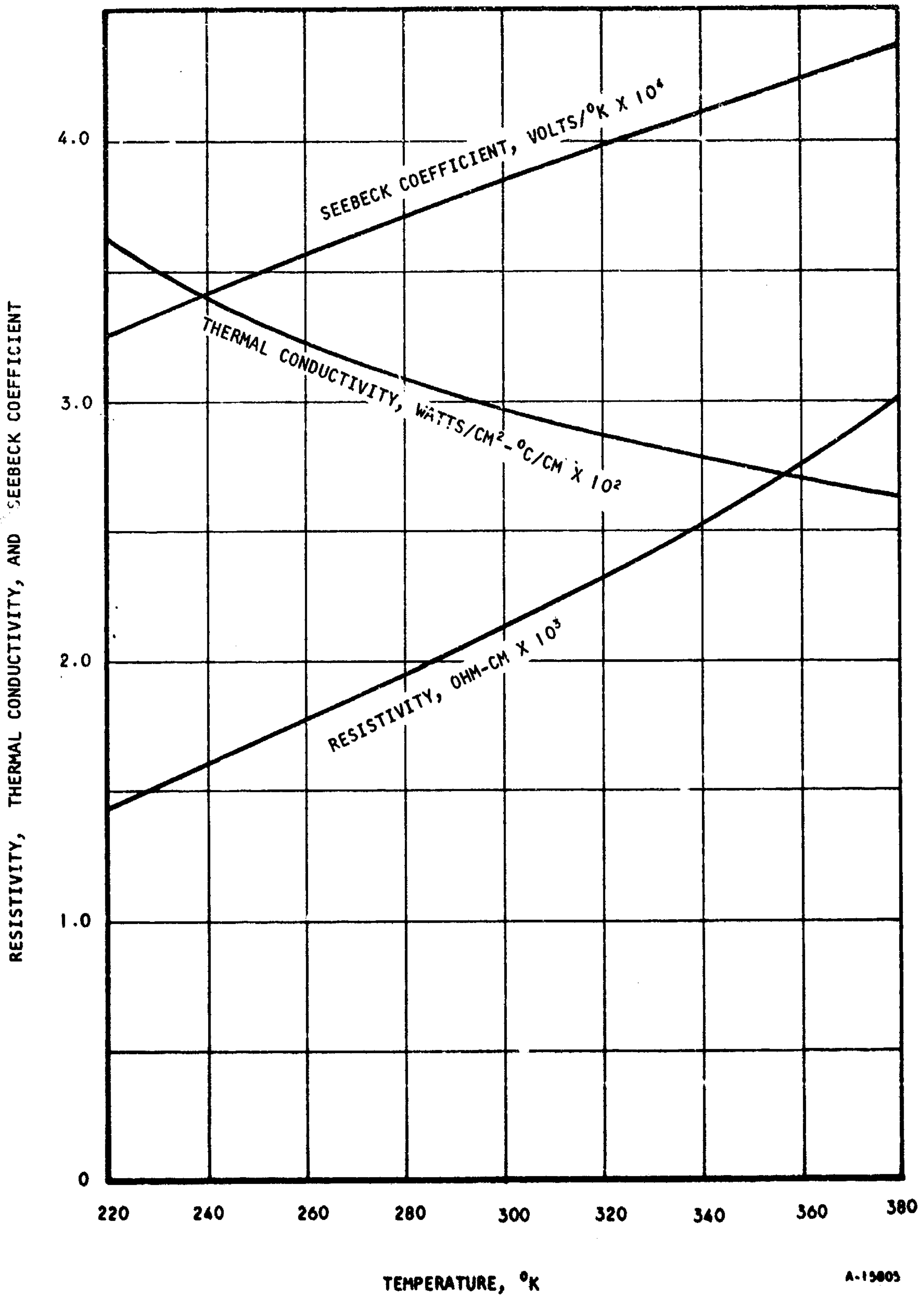


Figure 7-6. Properties of Thermoelectric Material Versus Temperature

In conjunction with these numbers the following equations for finding the effective conductance and resistance were employed:

$$R = \frac{L}{A_C} \left[\rho_c + \frac{4R_j}{L} \right]$$

$$K = \frac{A_c}{L} \left[R + R_P \left(\frac{A_T}{A_c} - 2 \right) \right]$$

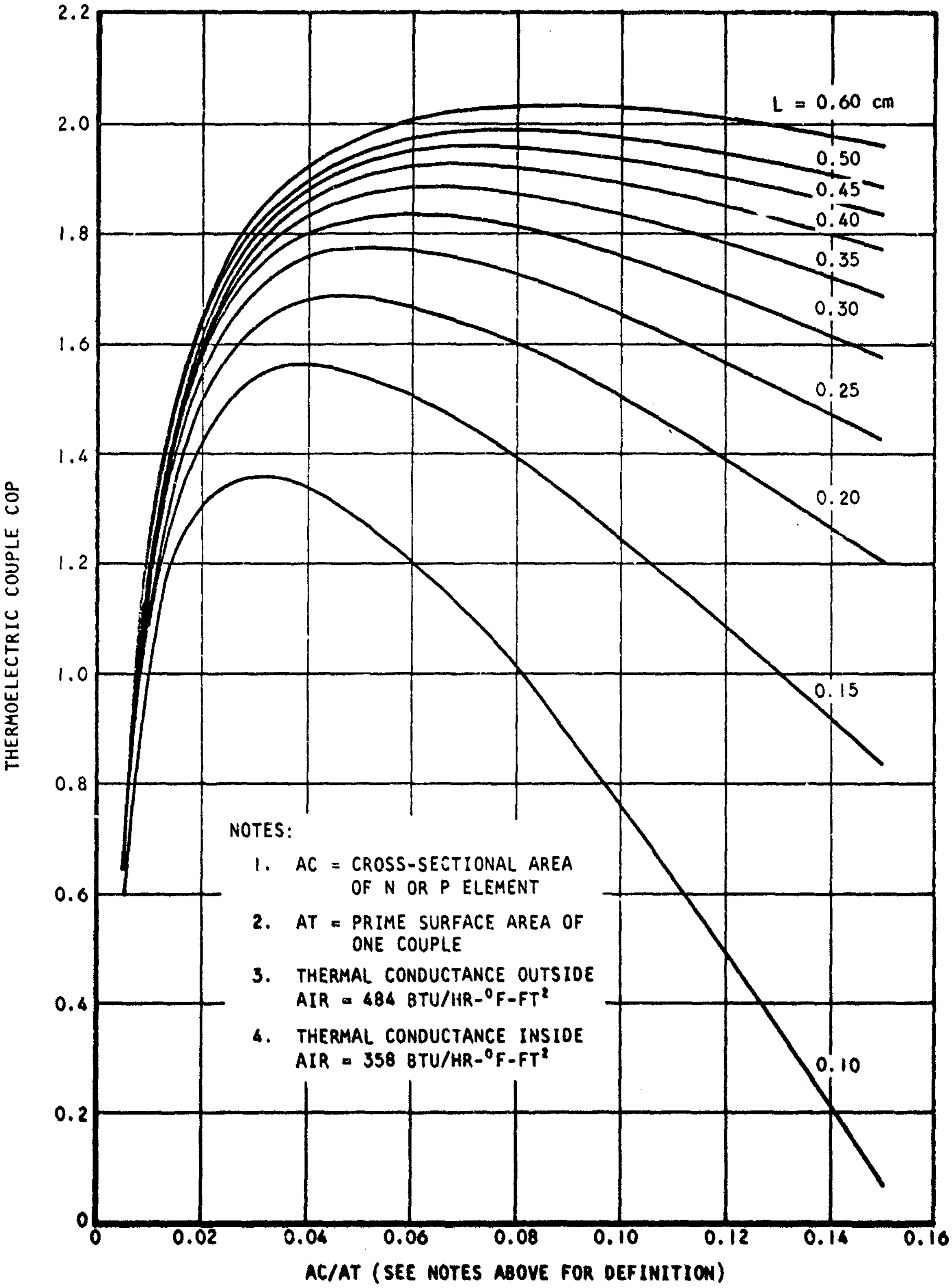
For the design chosen by AiResearch of a 1.0 cm^2 area element 0.4 cm long, at 322°K,

$$R = 0.00096 \text{ ohm } (R_j = 5 \times 10^{-6} \text{ ohm}) \text{ and}$$

$$K = 0.0736 \text{ watts}/^0\text{C } (K_F = 2.65 \times 10^{-4} \text{ watts/cm-}^0\text{C}).$$

Using these thermoelectric material properties, several designs were considered. Figure 7-7 is a parametric plot of thermoelectic couple COP as a function of couple length and area ratio. Area ratio, A_C / A_T, is defined as the ratio of the thermoelectric element cross-sectional area to the plate heat transfer area for one thermoelectric couple. This curve has been used to obtain ECU module designs shown in Table 7-3. The tradeoff between Figure 7-7 and Table 7-3 is primarily econimic considerations associated with the number of couples. The ECU net COP varies from 1.242 to 1.090 in Table 7-3, but a realistic estimate of the value of an increase COP vs number of couples has not been made. Therefore the solution which offered the most advantageous from the several desirable considerations was a couple length of 0.20 cm. However, before a final couple size can be chosen a stress analysis must be made to determine what stresses will be imposed. Section 7-5 will discuss the stresses involved in the joining process and the limitations of these stresses.

In determining the performance of the thermoelectric modules at the off design conditions of Table 3-2, a trial and error procedure was used. The cooling points are straight forward calculations because both the inside and outside fans are operating. During the heating mode, however, a different situation arises. The heat transfer to the outside air is governed by natural connection, conduction and radiation since the outside fan is turned off during a heating mode. In the situations where the temperature difference across the thermoelectric couples is low enough at the inside air inlet to allow the couples to pump a small quantity of heat from the outside air to the to the inside air there are relatively small uncertainties in the heat transfer calculations. If the return air temperature is near the outside ambient air then, of course, the couples will provide a temperature difference sufficient to pump a small amount of heat from the outside air to the inside air. As the inside air is recirculated, its temperature will rise to some steady state value dependent upon the heat loss with time. If, however, the return air temperature is 50°F then the thermoelectric couple will act as a double heat pump. Essentially what has happened is that the sum of the Joule



NOTES:

1. AC = CROSS-SECTIONAL AREA OF N OR P ELEMENT
2. AT = PRIME SURFACE AREA OF ONE COUPLE
3. THERMAL CONDUCTANCE OUTSIDE AIR = 484 BTU/HR-°F-FT^2
4. THERMAL CONDUCTANCE INSIDE AIR = 358 BTU/HR-°F-FT^2

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Figure 7-7. Thermoelectric Couple Dimensions Effect on Thermoelectric Couple COP

TABLE 7-3

THERMOELECTRIC MODULE DESIGNS

$A_C = 0.36\ \text{cm}^2$

Length, L (cm)	Couple COP	Net COP	Couple Current (amps)	Weight of Couples (lb)
0.40	1.537	1.242	10.3	64.1
0.30	1.475	1.200	14.2	35.4
0.25	1.452	1.182	17.2	25.4
0.20	1.395	1.134	21.7	15.5
0.15	1.323	1.090	30.2	8.4

heating and back conduction exceed the Peltier effect and heat is transferred outwardly from both ends of the couple. Thus the cold air will be heated locally and natural convection will cause some air flow. The extent to which this occurs is difficult to estimate, but it appears that at the inside air inlet to the heat exchanger-thermoelectric module heat may be transferred out in both directions while the center of the heat exchanger-thermoelectric module, because of air stagnation heating, may pump heat in only one direction. Thus the average heating may change somewhat, depending upon how much stagnation and air flow does occur. The magnitude of change could be as much as 10 percent or roughly 500 watts more of inside air heating. The heat rejected by the outside heat exchanger has been estimated using the recommendation of Kreith, Ref 5. Basically Kreith recommends the use of $\frac{Ub}{K} = 1$ for a value of the Grashof Number less than 8000 for vertical enclosures. For Condition 6 the Grashof Number is 982, thus pure conduction is the appropriate mode of heat transfer. The overall heat Transfer coefficient can be estimated by assuming conduction through the metal and air. Based upon an air conductivity of 0.014 Btu/Hr-Ft^2-^{0}F/Ft and a metal conductivity of 100 Btu/Hr-Ft^2-^{0}F/Ft the overall heat transfer coefficient is 0.08 Btu/Hr-Ft^2-^{0}F. This coefficient will vary considerably however if any air flow through the outside heat exchanger occurs.

7.5 JOINING THERMOELECTRIC MODULES AND HEAT EXCHANGERS

In addition to the joints within the module, it is also necessary to join the module to the heat exchangers. In this case, electrical resistance is not the controlling parameter, but the thermal conductivity of the material is of prime importance.

There are two types of thermoelectric module available. The first of these utilizes metallic plates to form the complete module. Where this is the case, the material used to form the joint between the module and the heat exchanger has high dielectric characteristics to provide the necessary electrical isolation of the module. Where a ceramic plate module construction is used, a metallic joint between module and heat transfer surface is permissible, as no further electrical insulation is required. In either case, the joining method must be a low-temperature procedure. This is necessary as the thermoelectric couples are joined to the plates using a low-temperature solder process. This limitation in temperature level eliminates metallic joining processes such as brazing or welding.

Where metallic modules are used, it is necessary to utilize a joining material that has both high dielectric strength and high thermal conductivity. This requirement for high dielectric strength and high thermal conductivity can be achieved either with a single material or with a dual material. Where aluminum heat exchangers are used, it appears impossible to hard anodize the aluminum surface to provide a dielectric insulating layer. AiResearch has performed some preliminary tests which indicate that the anodized layer is almost completely destroyed during the soldering process. For this reason hard anodizing of aluminum has been discarded for use as a dielectric interface.

Another method of joining metallic modules is to use an epoxy-based glue. The loss due to the joint resistance and low thermal conductivity is higher than that of a soldered unit, but a glue with a thermal conductivity of 0.8 Btu/hr-ft^2-^{0}F/ft will be acceptable with the heat transfer surfaces used. Such an epoxy is Epoxylite III with silica bulking material. AiResearch has no experience with this glue but it may be of great importance if the conductivity quoted is realistic.

AiResearch has talked with many thermoelectric module and material manufacturers, as noted in Paragraph 7.4, and the general consensus seems to be that the use of a viscous thermal joint compound such as a thermal grease is undesirable because of a low reliability and loss of good contact with time. AiResearch has had short duration testing experience with thermal joint compounds on thermoelectric test units, but has not seen what effect a long period of operation has on the compounds. Unless long operating period reliability can be obtained there appears to be no need to consider these types of compounds.

AiResearch is of the opinion that a metallized ceramic material soldered to the heat exchanger plate is the primary candidate method of joining heat exchangers and thermoelectric modules. Metallizing ceramic is not an AiResearch process, but flame spraying appears to be a feasible method. AiResearch has procured ceramic material metallized and tinned along with the thermoelectric modules. The major consideration remaining is that of the thermal stresses set up in the thermoelectric module. Figure 7.8 indicates the possible joining technique.

The stress analysis performed made a preliminary estimate of the stress limitations on the thermoelectric heat exchanger. The areas investigated were the thermoelectric elements themselves and the ceramic plates attaching to the heat exchanger on one side and the thermoelectric elements on the opposite side. The stresses considered in the analysis are those produced by the temperature gradient through the heat exchanger and the differences in the thermal expansion coefficients of the various materials.

The stress analysis treats the thermoelectric element both as a beam and a flat plate depending upon whether the width to length ratio is less than or greater than one.

The governing shear equation is:

$$\tau_{MAX} = \frac{2.12\ (28.5 - 4.28 \times 10^{6}\ E_e\ L\ \frac{a}{d})\ m\ \Delta T}{2a^2 + \frac{7.48 \times 10^{6}}{E_e}\ a\ (\frac{L}{a})^3\ [1 + 4\ (\frac{a}{L})^2]}$$

The shear stress, τ_{MAX}, must not exceed the maximum element allowable shear stress which is approximately 3600 psi based upon manufacturers information. Figures 7-9 and 7-10 are the result of applying this equation for various

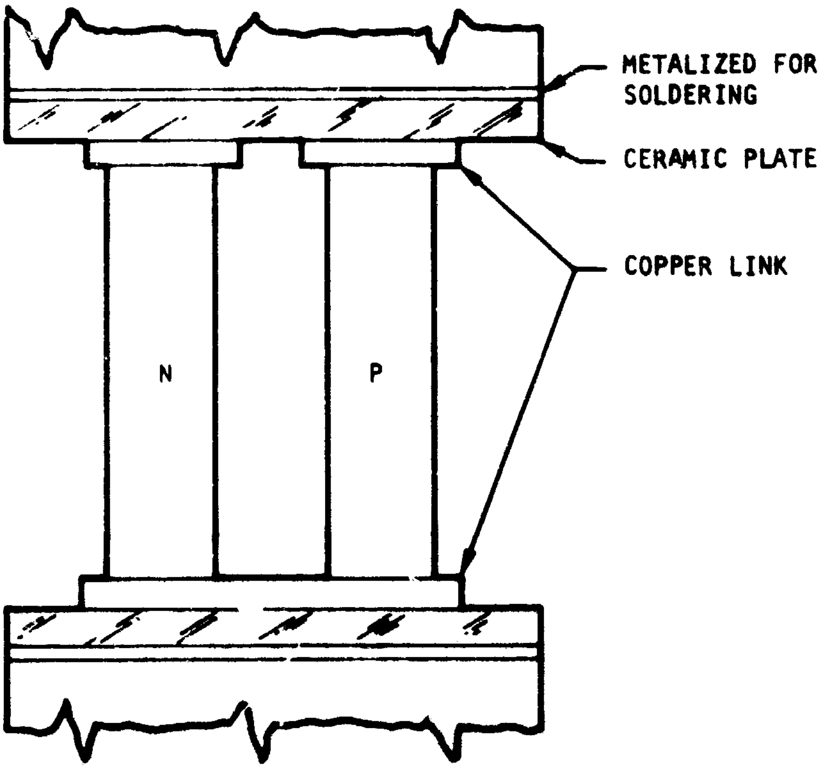

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Figure 7-8. Metallized Ceramic Plate Joining Sketch

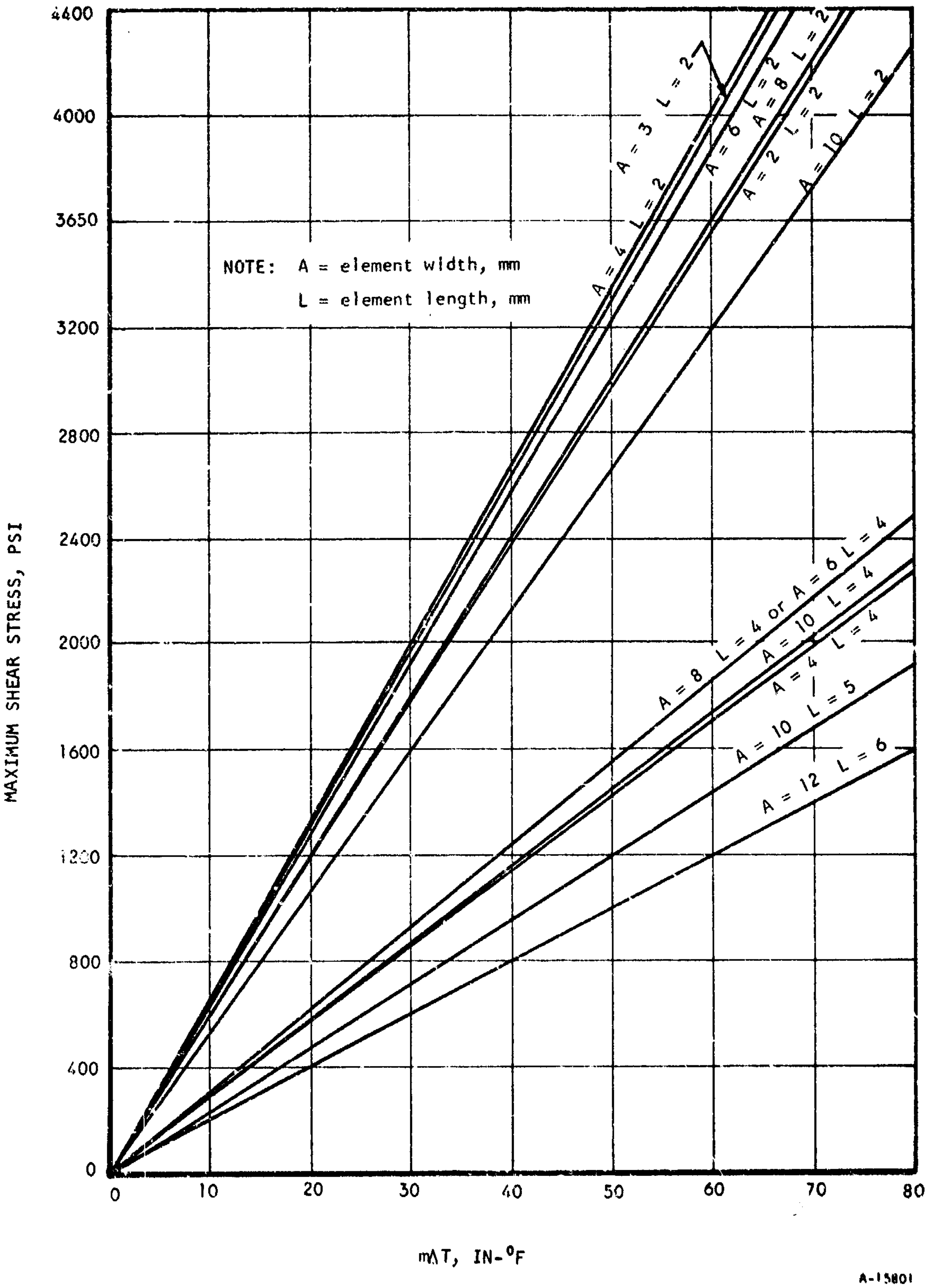


Figure 7-9. Maximum Shear Stress Vs. the Product of the Width of Square Couple Module and Temperature Differences

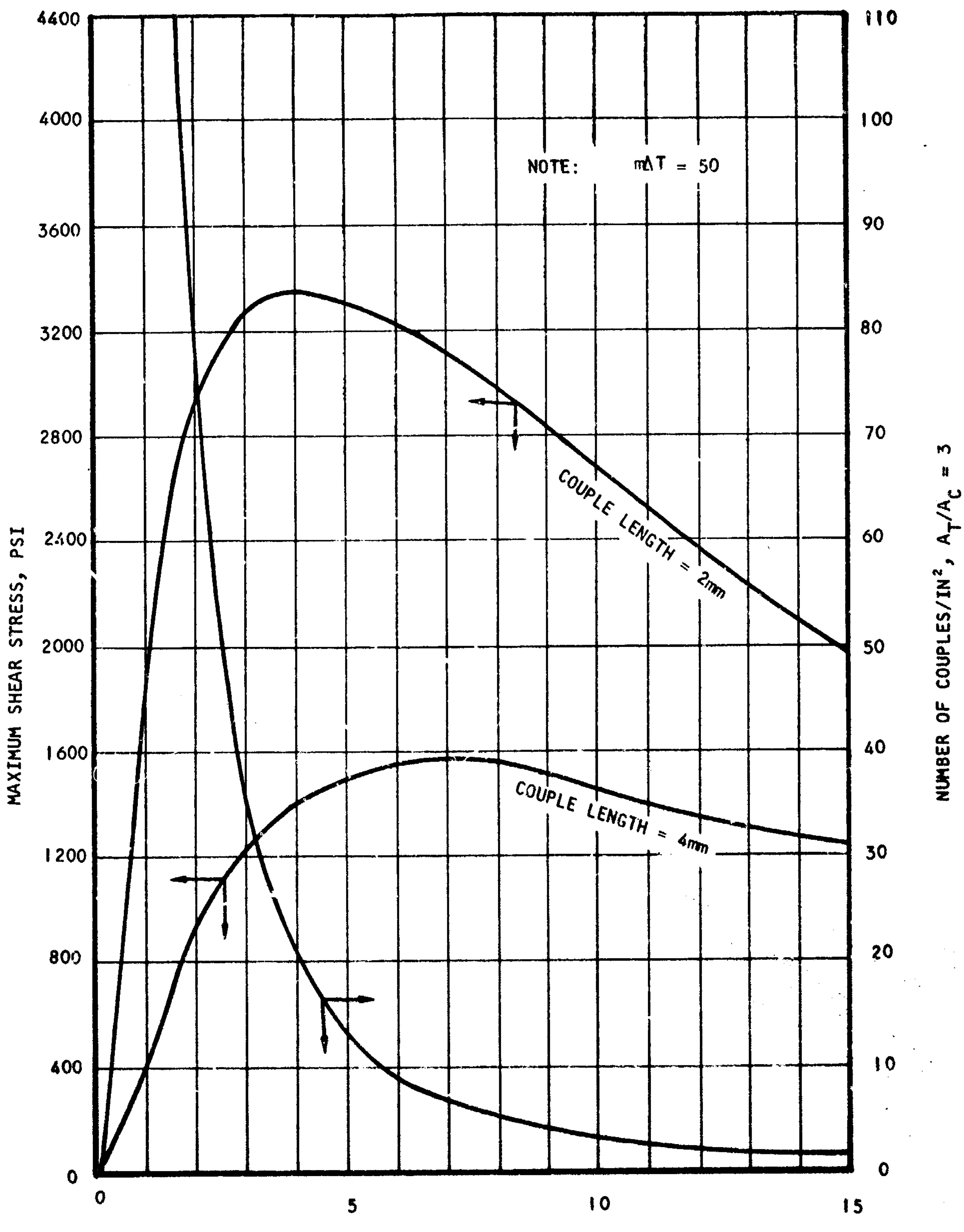


Figure 7-10. Maximum Shear Stress Versus Element Width

element sizes. It can be seen that the larger face area, longer length elements result in lower stresses. In view of this an element size of 10 mm wide by 4 mm long was selected. This is a relatively large element, but a low number of couples and a convenient packaging arrangement result from its use.

7.6 DESIGN CONSIDERATIONS FOR THE ELECTRONICS

The power supply, frequency inverter, controls and protection system were designed with prime consideration given to performance maintainability and simplicity. Because of the high system COP requirement, the efficiency of the electronics was critical. Solid state electronics are highly reliable when designed properly. AiResearch has been required to produce many highly efficient systems for various missile and space applications and has vast experience in this type of design.

Although the economic considerations were secondary, the latest design techniques and circuitry design were used. The circuit approach was based on a 10 year continuous operation with minimum maintenance. Relays and other mechanical components were used only where the estimated number of operations over a 10 year period did not exceed 50 percent of the minimum rated life of the component.

A major problem with electronic power components is self generated heat. This problem is compounded when the power components are enclosed. Most electronic power components are rated on the assumption that free convection cooling is available. To avoid this problem of overheating, the components are mounted exposed to the ambient air. The moisture problem will be avoided by spraying the components and terminations with a protective coating such as Dow Corning compound No. 630. This is a silicon coating resin which due to the thinness of the layer does not prevent good heat transfer to the air and yet gives adequate protection to moisture and dirt.

7.7 FAN DESIGN CONSIDERATIONS

The prime requirement of an optimum for design from the standpoint of power consumption for the required air flow and pressure rise is achieved by matching fan blade configuration, motor speed, size and capacity, and blade tip clearance. These design procedures are standard and have been followed carefully by AiResearch to achieve the optimum fans described in Section 3.3.4. One of the more important design considerations required by Exhibit A is that of fan noise and AiResearch has considered this requirement carefully.

Noise from motor driven fans result from three sources: mechanical, electrical and aerodynamic. In a vane axial type fan, much of the noise is aerodynamic due to the relatively high tip speed and high pressure differential across the blades. By proper design, the fan noise can be minimized.

By the use of precision bearings, spring preloads and resilient mounts, the mechanical noise can be greatly reduced. Mechanical noise is also reduced by precision dynamic balancing of the rotating members. Electrical noise can be minimized by a properly designed motor (use of proper stator slot count for number of poles and squirrel cage bar count).

As previously mentioned, the aerodynamic noise is a great percent of the total noise in a fan. Aerodynamic noise results from the blades intercepting filaments of air resulting in a pressure buildup on the face of the blade and a rarefaction on the other side. This pressure pulsation is known as blade passage frequency. Eddy losses at the tip of the fan blades and from the wake coming off the trailing edges of the fan blades intercepting stationary support struts or deswirl vanes of the fan assembly also create aerodynamic.

Tip clearance noise can be minimized by running very close clearances between the blade and housing. Wake effect noise level can be minimized by correct axial location and number of stationary struts or vanes and by proper design of the airfoil sections to minimize boundary layer buildup. Also the intensity at which the aerodynamic noise transmitted through a fan is a function of the annulus axial velocity which should be kept to as low a value as practical to meet the aerodynamic performance and envelop requirements.

Based on experience with geometrically similar fans, it is estimated that the overall noise level measured to NAFM Bulletin 110 for the fan will be 81 db.

7.8 FRAMEWORK

The twofold purpose of the basic framework for the ECU is to provide attach points for mounting the components of the system and to provide a mechanical structure that will enable the unit to withstand external loads. Mechanical loads can be induced on the structure internally by the attached components and externally by the environment surrounding the unit. More often than not, the dynamic loads govern the design of the structure rather than the static loads. The analytical design of a structure for this type of system becomes very difficult due to the complexity of the structural network and the dynamic characteristics which attenuate or amplify the environmental loading. The design of any structure must consider the following:

a. The type and magnitude of the loading, static, dynamic or thermal, induced upon the unit.

b. The mounting provisions for the unit.

c. The weight and mass distribution within the unit.

d. The determination of load paths.

e. Structure flexibility and dynamic load transmittability.

The design shown on Layout Drawing L-198121 has attempted to incorporate all the considerations above. The top section supports about 4 percent of the total system weight within approximately 20 percent of the total volume. The only concentrated weight within this section is the fan which is about 80 percent of the weight in this section and is at one end of the section. This can be seen on Layout Drawing L-198116. The center section is the largest and heaviest (approximately 58 percent of the total volume and 74 percent of the total weight). The weight distribution is relatively uniform throughout this section. The bottom section carries approximately 22 percent of the total volume. The weight distribution is fairly uniform within this section. From the above description, it can be seen that the unit center of gravity is located close to the volumetric center of the unit. The unit does not have any exceptionally concentrated load remotely located from the center of gravity. This is a very attractive feature of the design and simplifies the structural design of the framework.

The outside panels will provide the unit with added rigidity. Surface skins are excellent in tension but have a tendency to "oil can" during vibration. Therefore, during the development of the unit, careful selection of additional attach points may become necessary to shift the resonant points of the panels.

The development of the cooling unit, should include vibration and shock testing to determine system response and to provide data for final design with considerations to the actual resonances, transmittance and reactions.

SECTION 8

RECOMMENDATIONS AND CONCLUSIONS

8.1 GENERAL

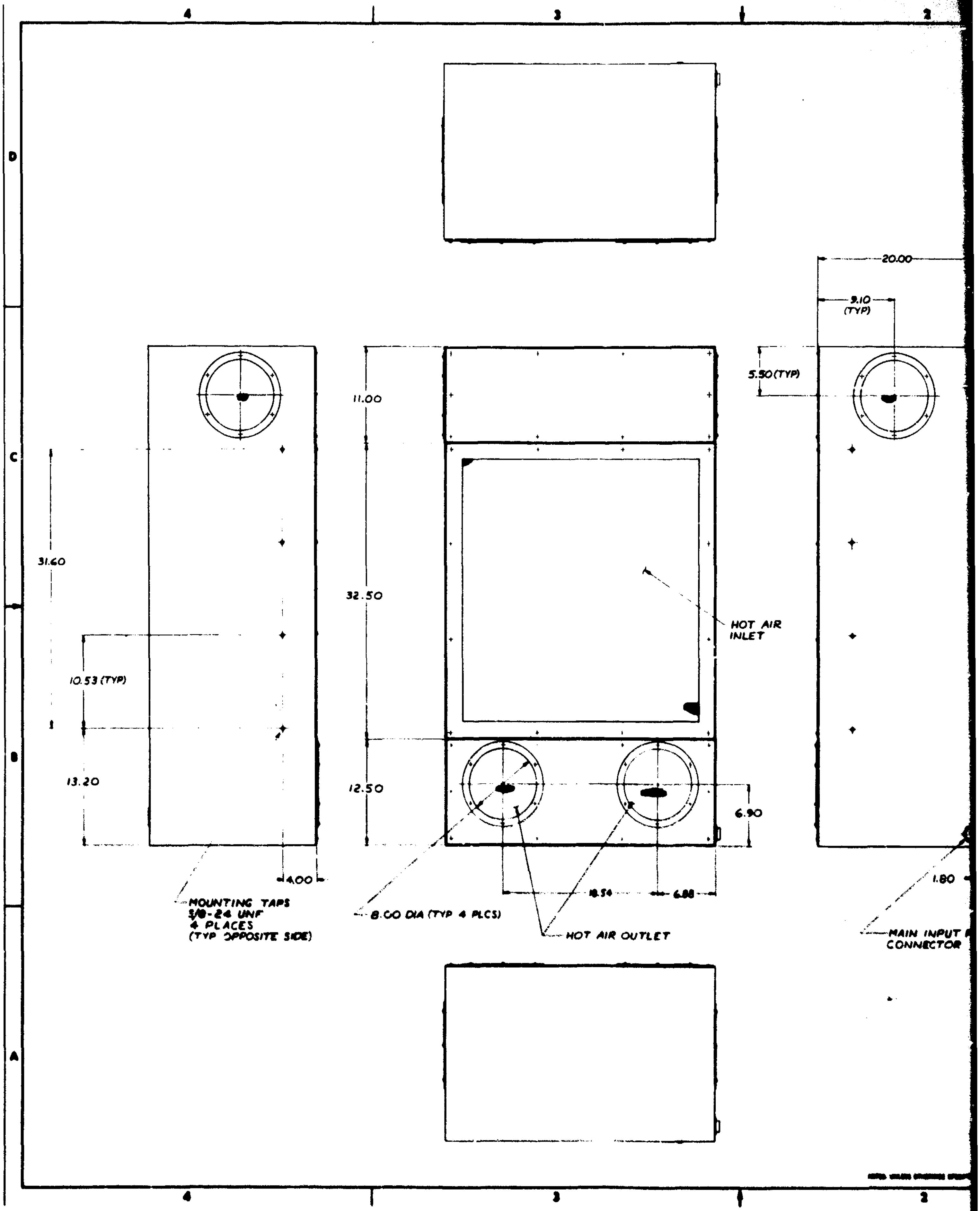
This design contract resulted in a well integrated, high performance thermoelectric ECU design. The integration of the power supply, fans, heat exchanger, thermoelectric couples, and controls required a maximum of engineering effort and ingenuity. Each component or component area had to be optimized with respect to weight, volume, cost and performance so that the design goals could be achieved.

The joining of the thermoelectric couples to the heat exchanger has been found to be an area in which development work would appear to be needed the most. Additionally the variation of thermoelectric material physical and electrical properties with temperature does not appear to be well known.

The design goal of a net COP ≥ at the nominal cooling condition was met, but not within the desired overall volume, despite having remained well within the limiting dimensions.

8.2 DEVELOPMENT AREAS

In recent years there have been virtually no improvements in the figures of merit of thermoelectric materials for use at ordinary temperatures. For development of thermoelectric materials studies are needed over a wide range of temperatures of the physical properties and conduction mechanisms, of the chemical stability and of the effects of pressure. Insufficient data is available regarding the mechanical properties of thermoelectric modules. It is well known that bismuth telluride alloys, while being the best for cooling applications, possess poor mechanical properties. Hence, it is important that the tolerances of thermoelectric modules to vibration, compression, shear and shock be determined. Contact resistance between a metal and semiconductor is one of the important problems in the field of thermoelectric devices. Stable, low resistance contacts are of prime importance for the making of thermoelectric couples. Information must be acquired concerning compatibility of thermoelectric materials with contact materials. Finally there remains the need for continued improvement of fabrication methods with the ultimate aim of obtaining the best performance of a cooling unit. In fact, this appears to be the most important area in which development is needed and can be readily initiated. Methods of joining heat exchanger modules to thermoelectric couples such as by direct attachment of the couples to the fins or sectioning the heat exchanger plate area so as to allow movement under thermal stresses, can possibly provide the answer to the joining problem.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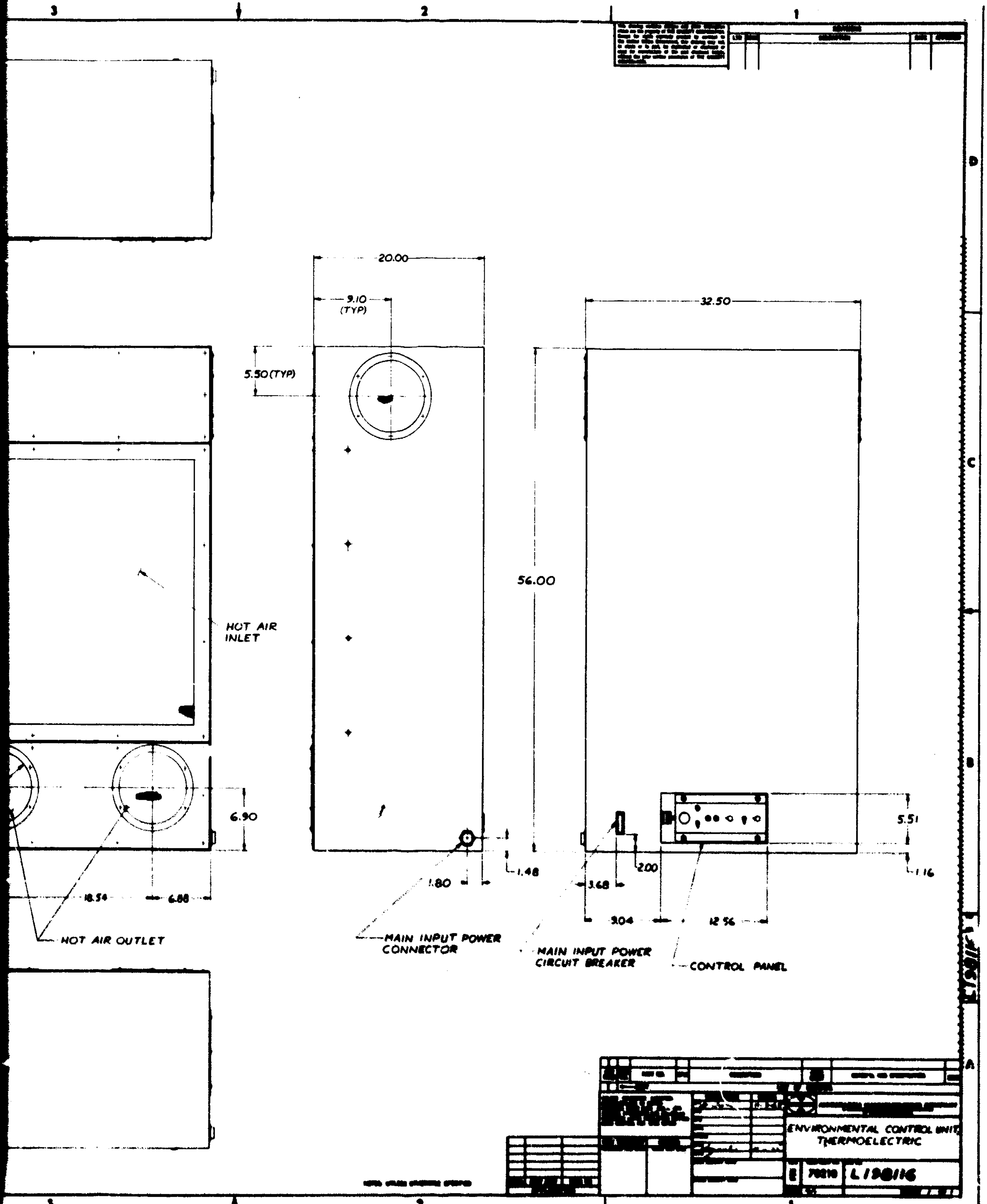
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MAIN INPUT POWER CIRCUIT BREAKER
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ENVIRONMENTAL CONTROL UNIT, THERMOELECTRIC
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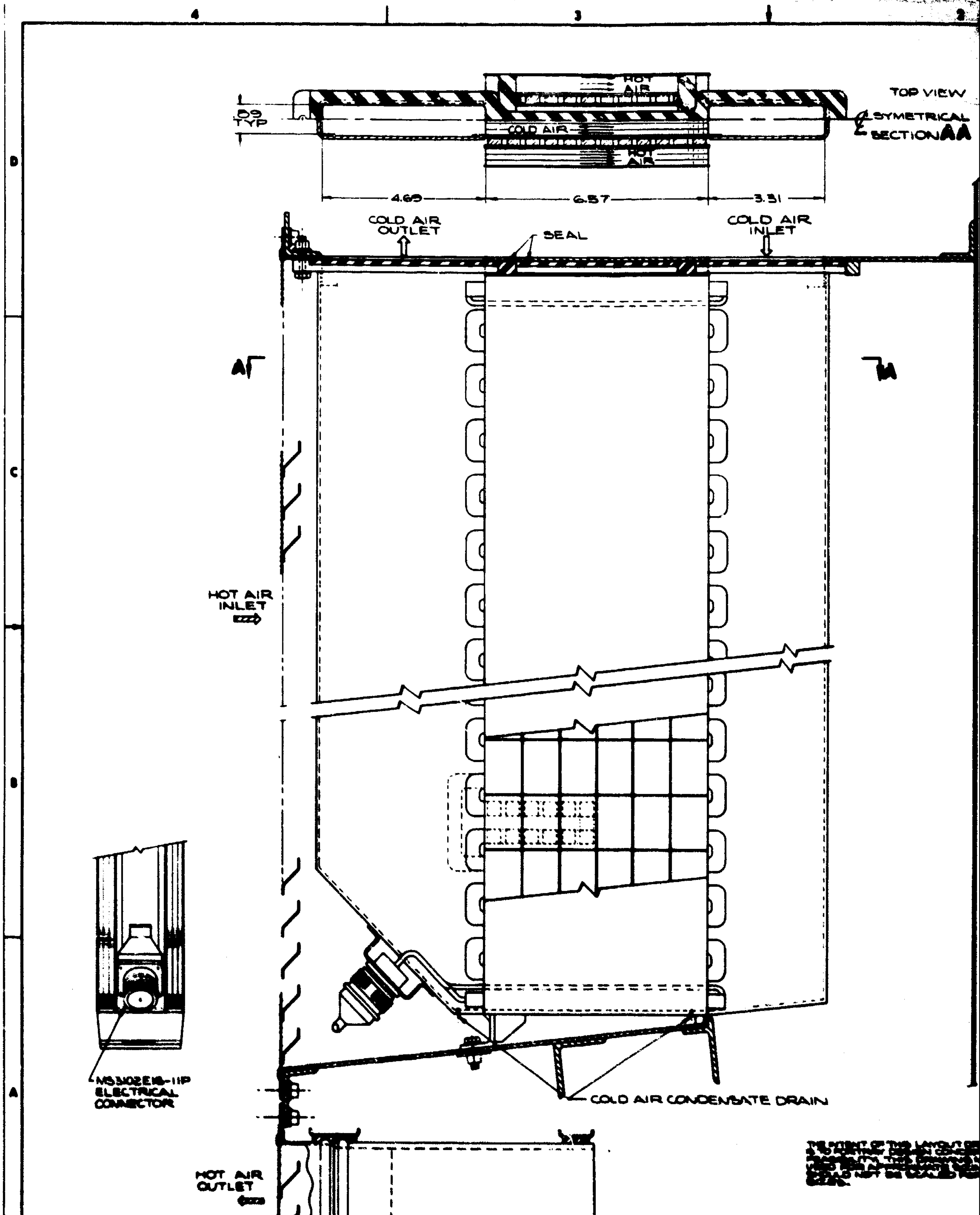
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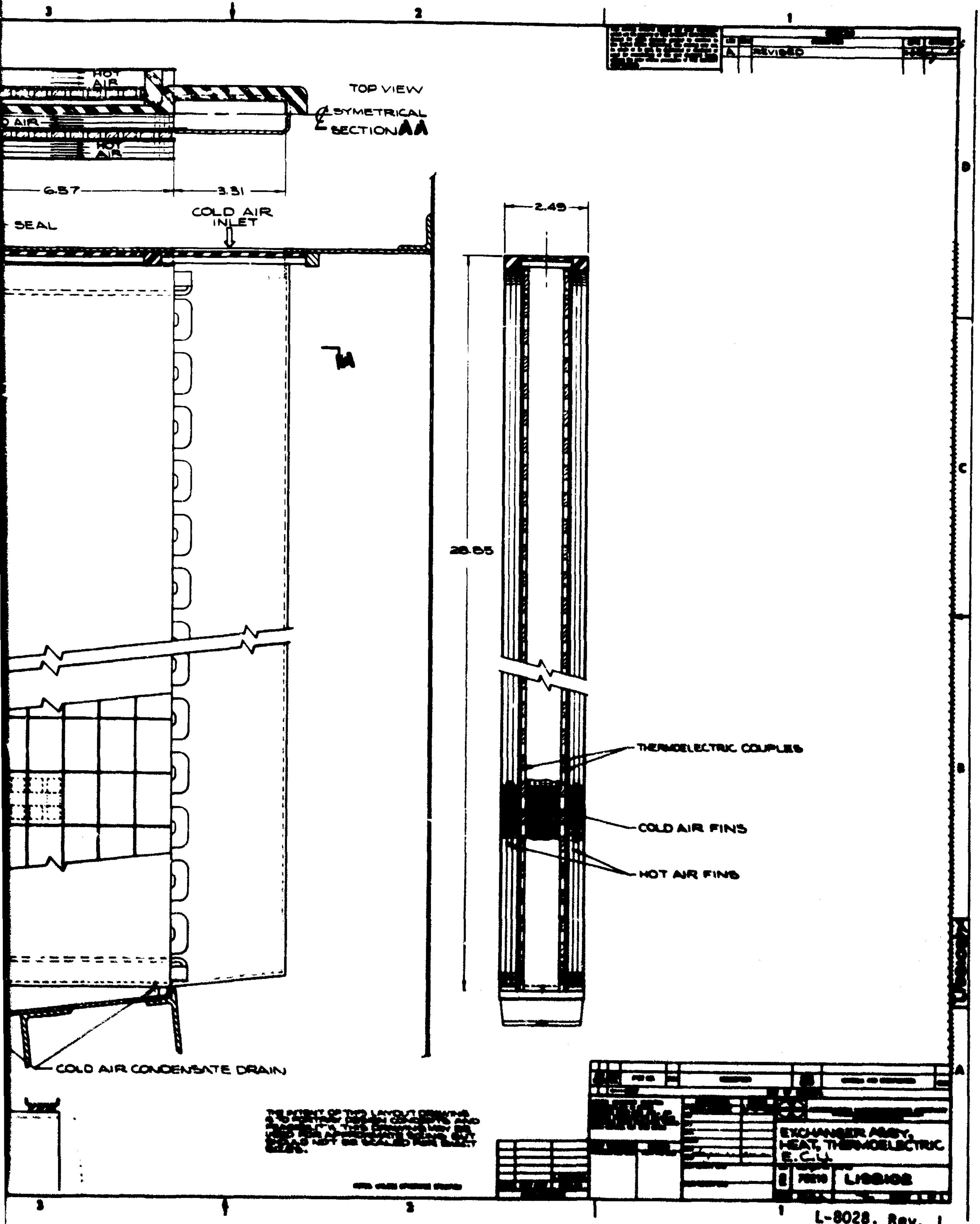
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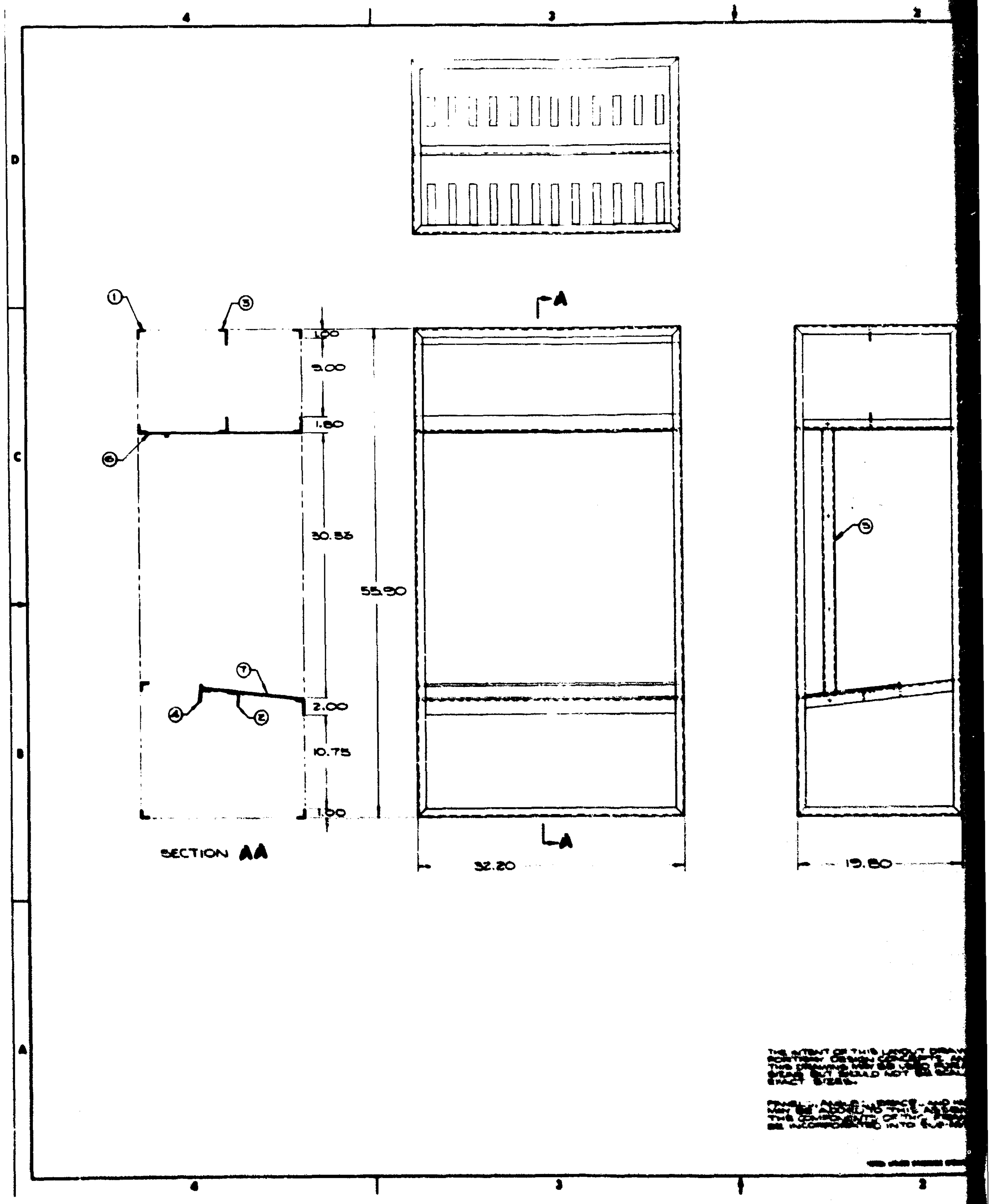

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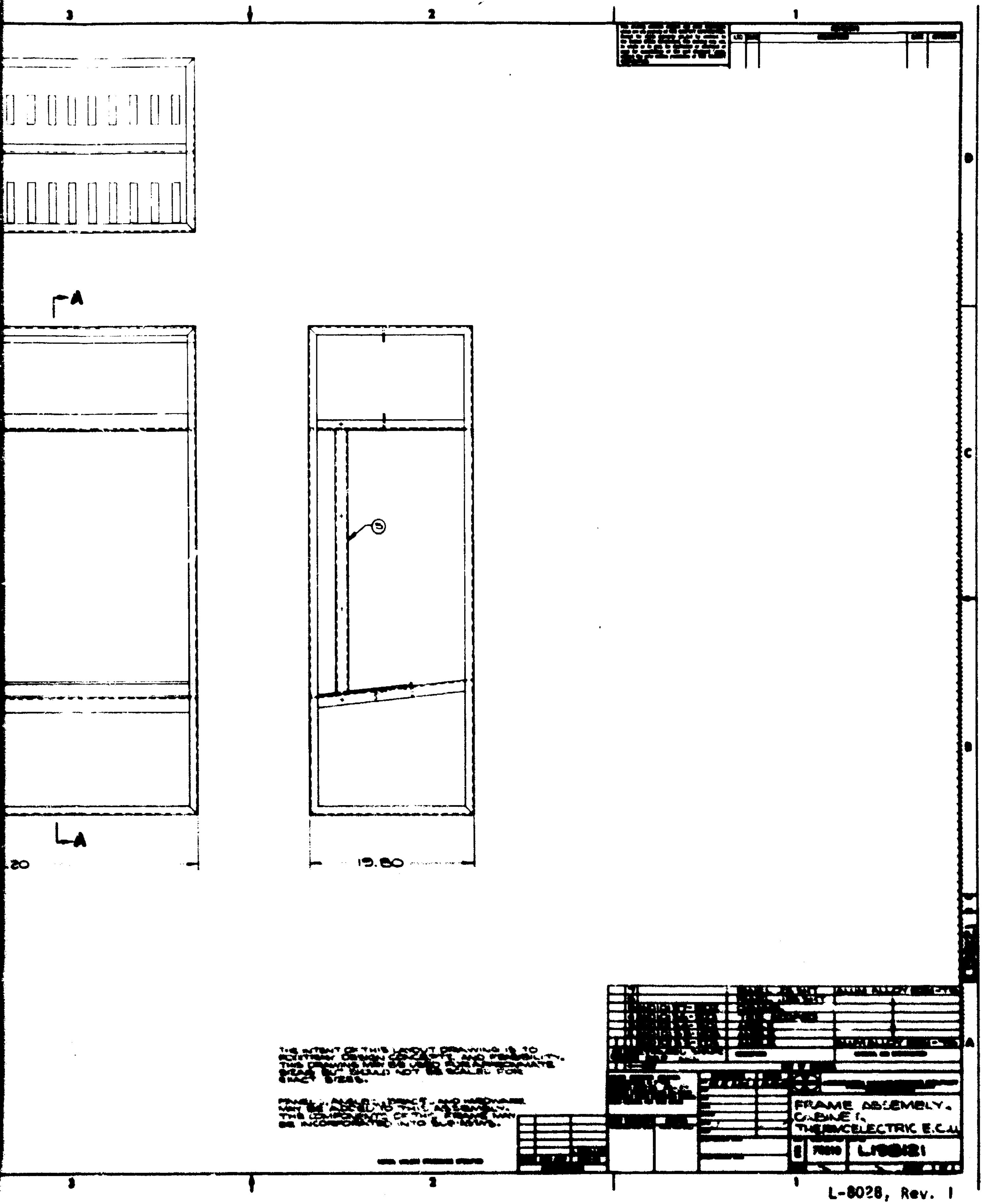

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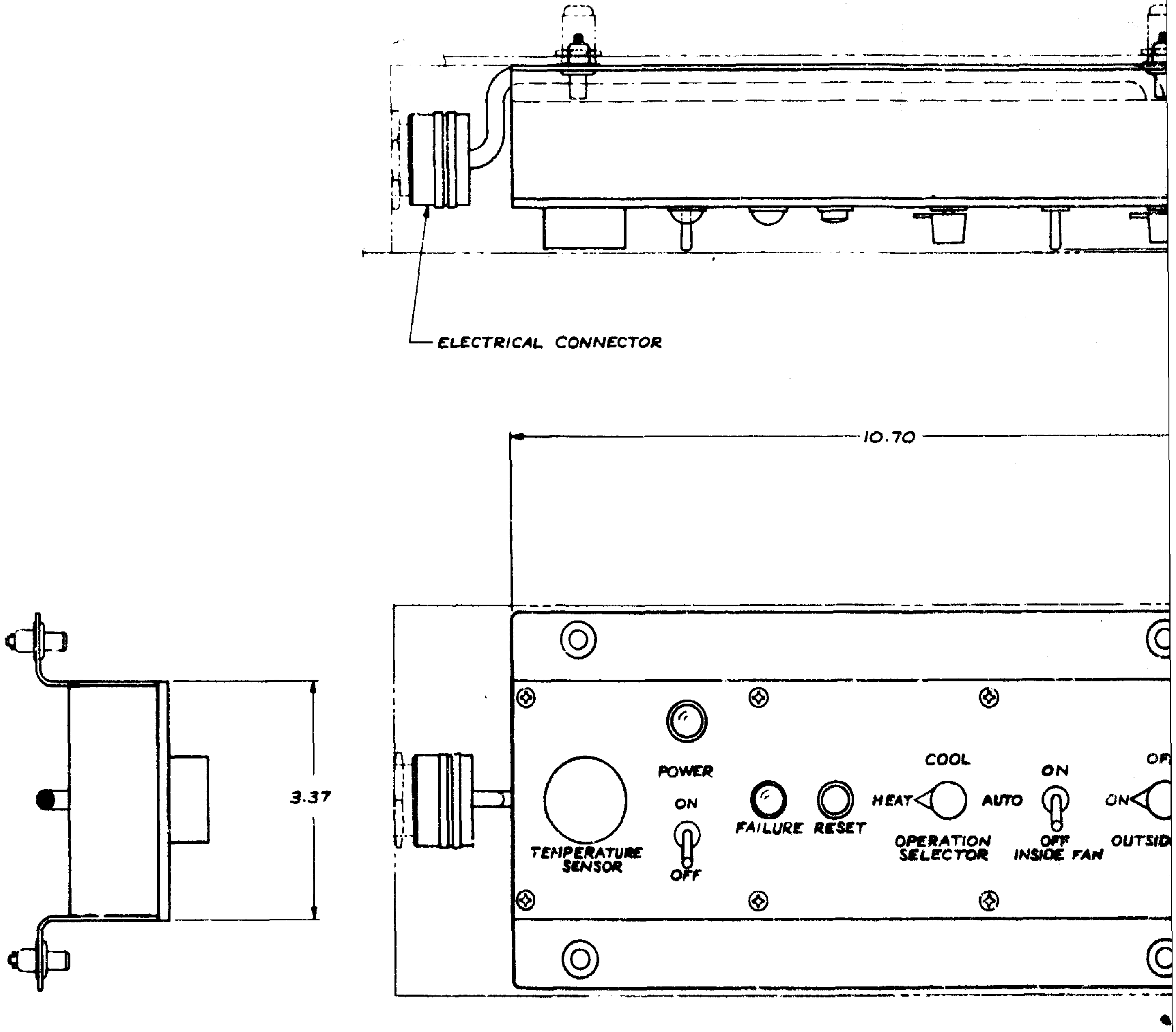

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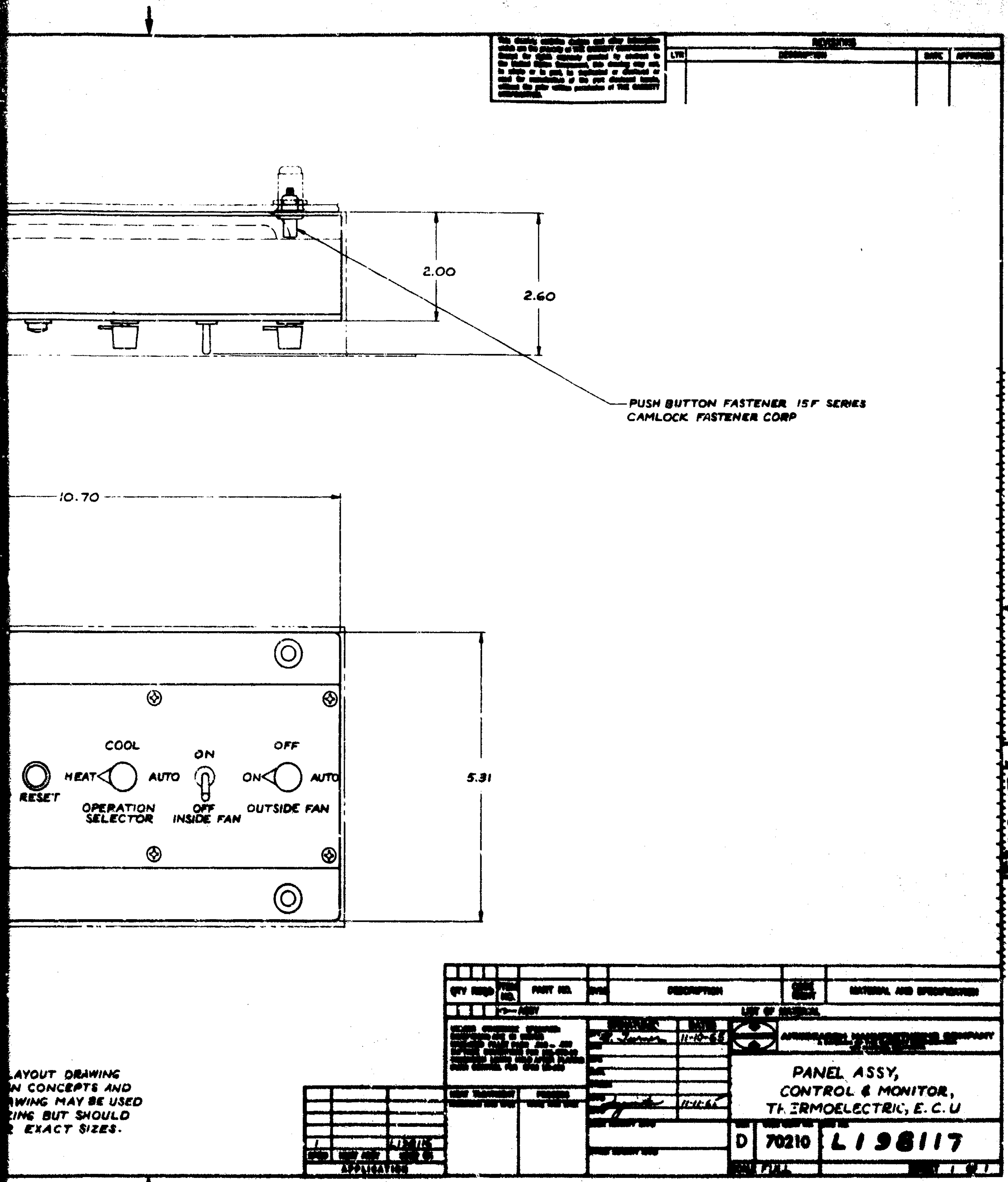

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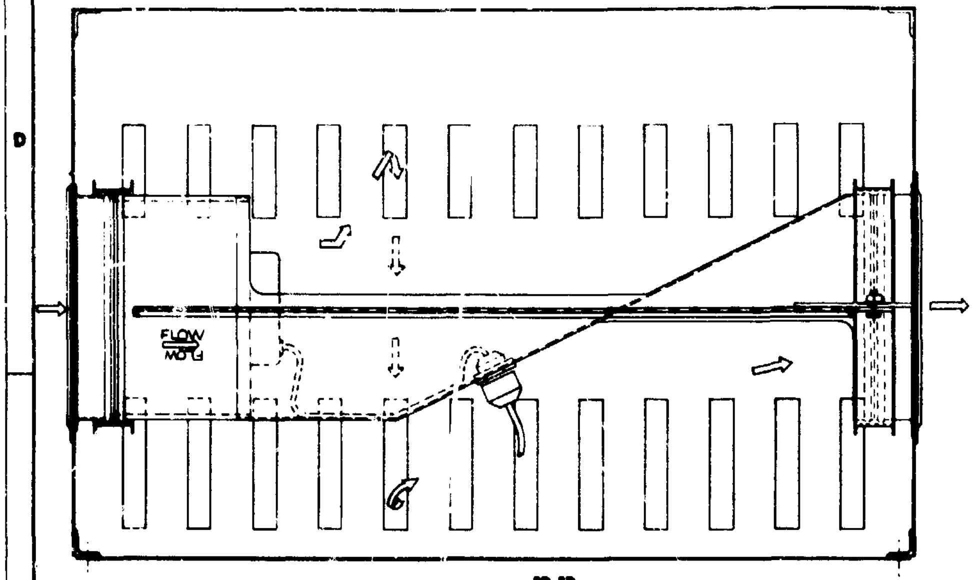

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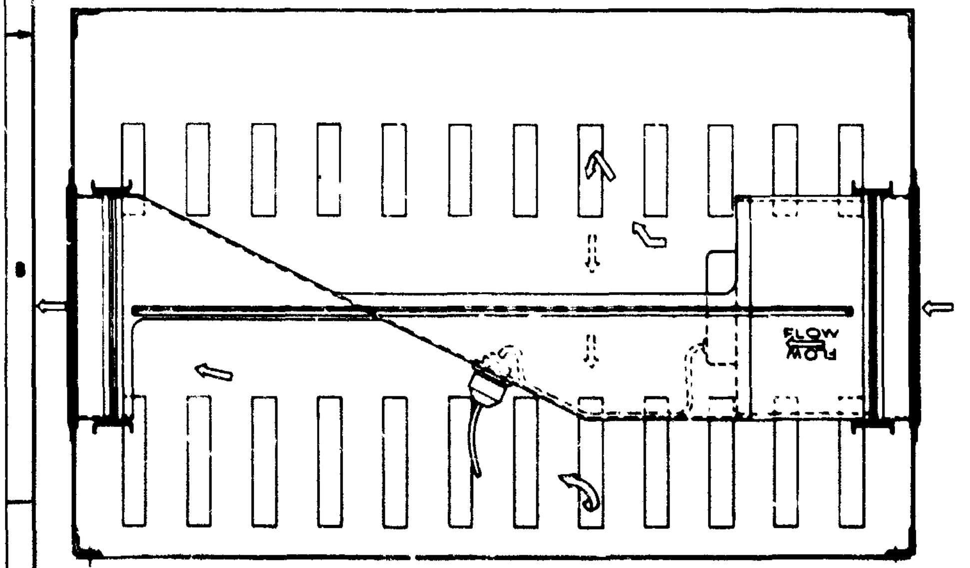
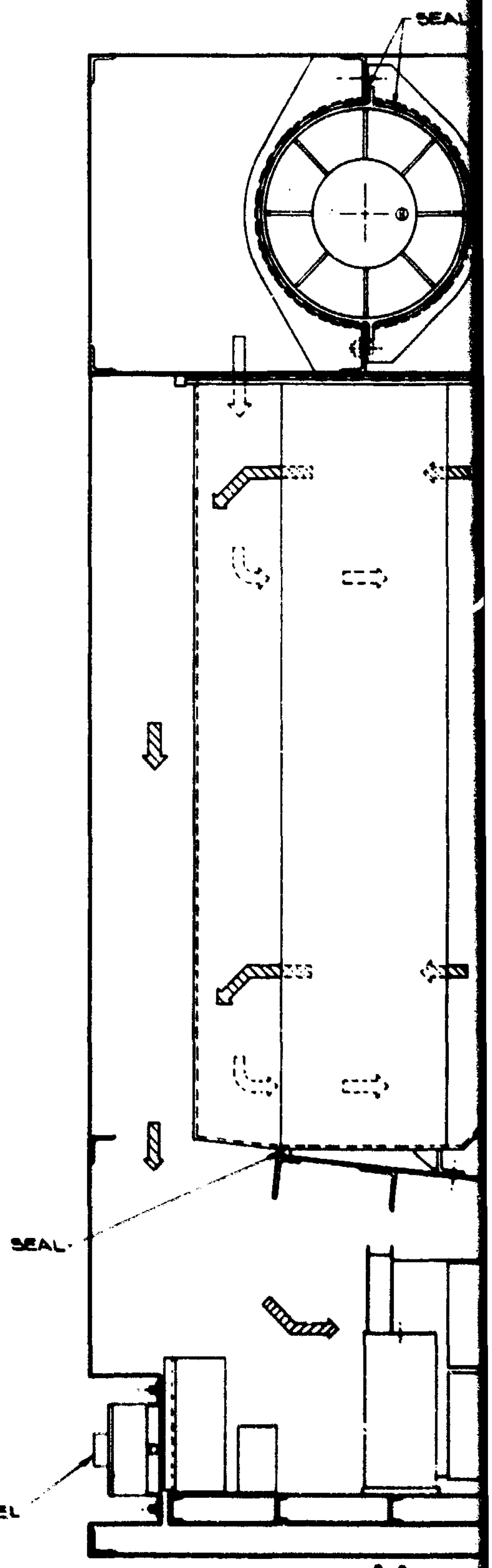


SECTION BB
AIR FLOW RIGHT TO LEFT



SECTION AA

THE INTENT OF THIS LAYOUT DRAW
IS TO PORTRAY DESIGN CONCEPTS
FEASIBILITY. THIS DRAWING MAY
USED FOR APPROXIMATE SIZING
SHOULD NOT BE SCALED FOR SI

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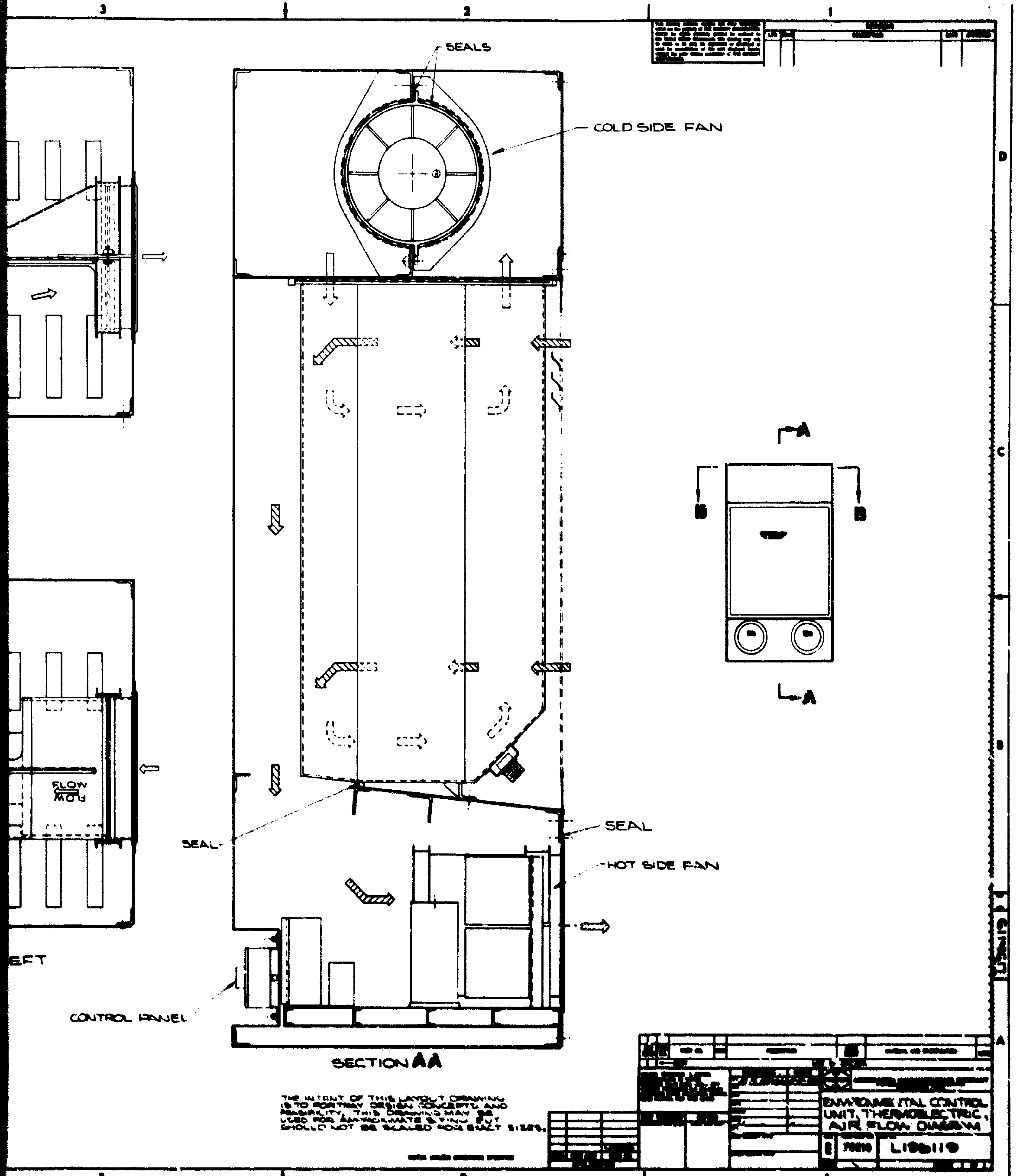
SEALS
COLD SIDE FAN
FLOW
SEAL
SEAL
HOT SIDE FAN
CONTROL PANEL
EFT
SECTION AA
A
A
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3
2
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D
C
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A
THE INTENT OF THIS LAYOUT DRAWING IS TO PORTRAY DESIGN CONCEPTS AND FEASIBILITY. THIS DRAWING MAY BE USED FOR APPROXIMATE SIZING BUT SHOULD NOT BE SCALED FOR EXACT SIZES.
ENVIRONMENTAL CONTROL UNIT, THERMOELECTRIC, AIR FLOW DIAGRAM
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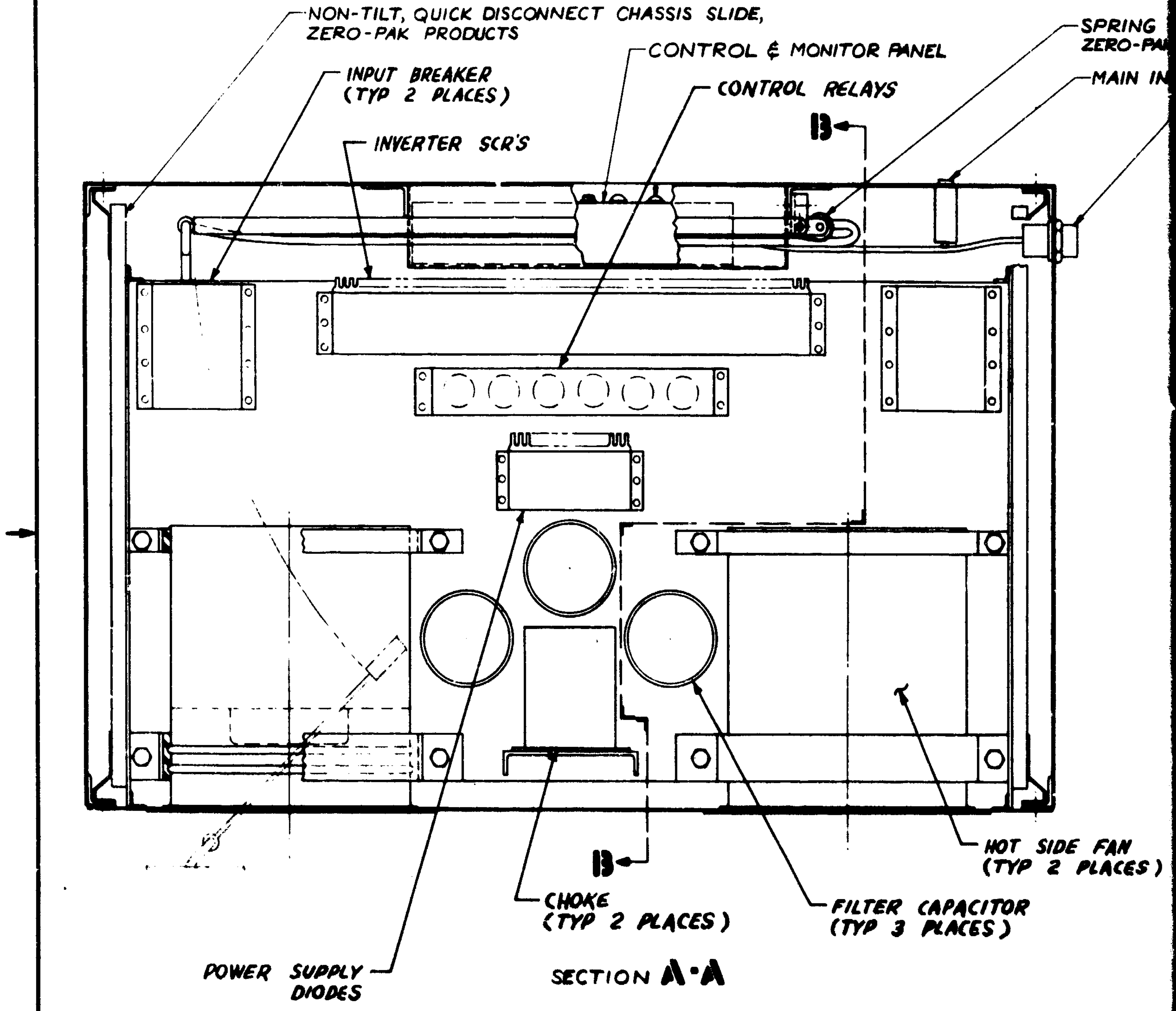
2



SECTION A-A

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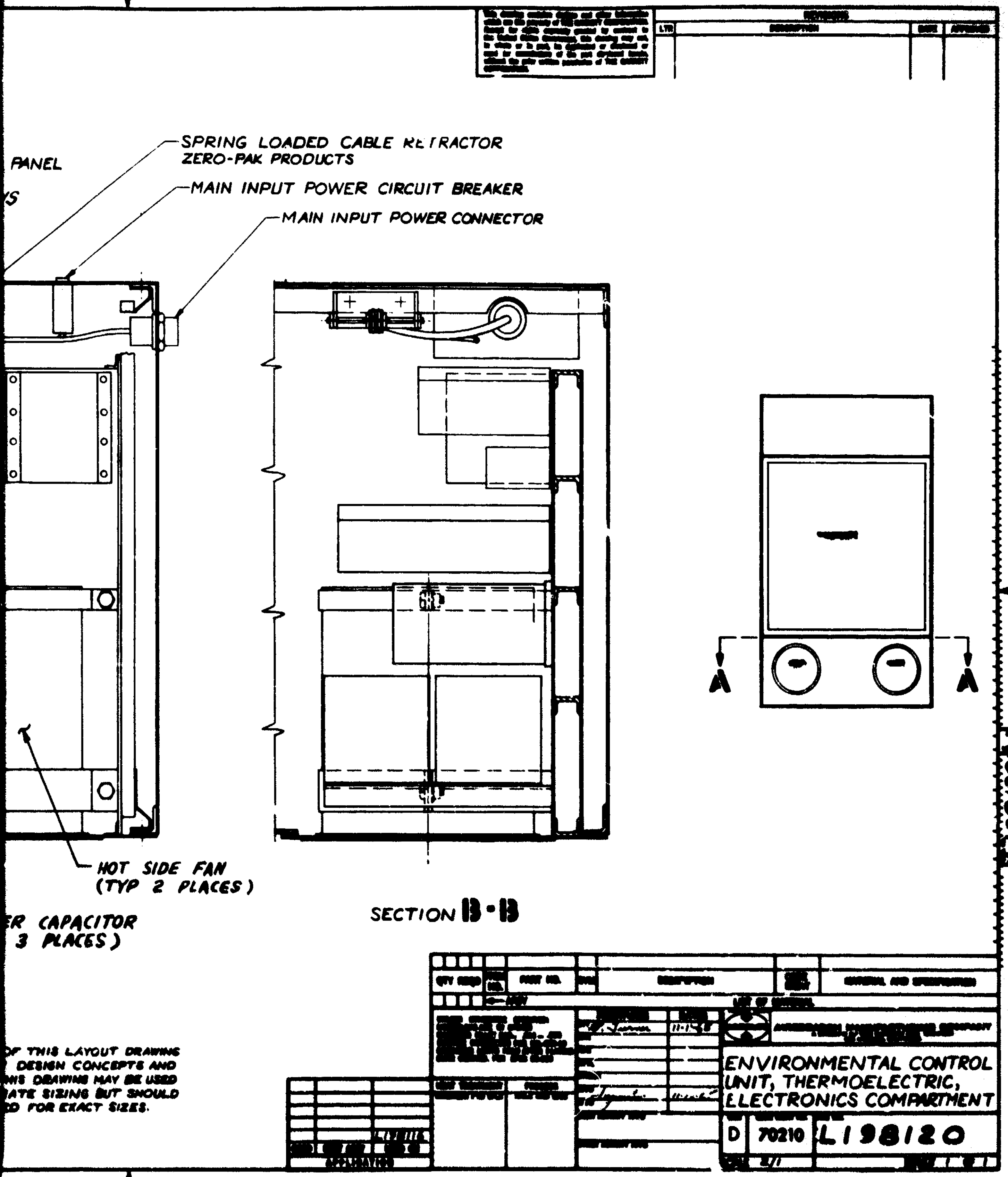PANEL
S
SPRING LOADED CABLE RETRACTOR
ZERO-PAK PRODUCTS
MAIN INPUT POWER CIRCUIT BREAKER
MAIN INPUT POWER CONNECTOR
HOT SIDE FAN
(TYP 2 PLACES)
ER CAPACITOR
3 PLACES)
SECTION B-B
A
A
OF THIS LAYOUT DRAWING
DESIGN CONCEPTS AND
HIS DRAWING MAY BE USED
ATE SIZING BUT SHOULD
D FOR EXACT SIZES.
11-15-68
ENVIRONMENTAL CONTROL
UNIT, THERMOELECTRIC,
ELECTRONICS COMPARTMENT
D
70210
L198120
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2

REFERENCES

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NOMENCLATURE

L = characteristic length, ft, or element length

g = acceleration due to gravity, 32.2 ft/sec^2

β = coefficient of cubical expansion, in^3/in^3 - ^{0}F

ρ = density, lb/ft^3

μ = viscosity, lb/sec-ft

ΔT = temperature difference

c_p = specific heat, Btu/lb-^{0}F

h = heat transfer coefficient, Btu/hr-ft^2-^{0}F

h = average heat transfer coefficient, Btu/hr-^{0}F-ft^2

S = Seebeck coefficient, μv/^{0}C

ρ = resistivity, ohm-cm

K = conductivity, watts/cm^2 - ^{0}C/cm or
Btu/hr-ft^2-^{0}F/ft

σ = density ratio = $\dfrac{17.35P}{T}$

where P = static pressure, in. Hg A

T = temperature, ^{0}R

A_C = area of N or P element, cm^2

A_T = plate area for heat transfer of one couple, cm^2

P = pressure, in. Hg or in. H_2O

T = temperature, ^{0}R or ^{0}K

a = element width in

d = element spacing

E_e = Young's modules

m = element module width

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13. ABSTRACT

This report describes a detailed engineering design of a thermoelectric environmental control unit (ECU). The ECU is a complete self-supporting unit that requires only a 115 vac, 3 phase, 60 or 400 cycle electrical power input. Besides the thermoelectric heat exchanger, the ECU has an ac to dc power converter, a 60 to 400 cycle frequency inverter, a thermal control system, a malfunction detection and protection system, 3 fans and a master control panel that can be removed for remote operation. At design point, the ECU has a cooling capacity of two refrigeration tons (24,000 Btu/hr). A requirement was to design a unit with an overall operational system coefficient of performance (COP) of one or greater at design point. The report describes an ECU with a system COP of 1.10. The ECU is an air to air unit designed for ground operation (U).

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14. KEY WORDS	LINK A		LINK B		LINK C	
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THERMOELECTRICS ENVIRONMENTAL CONTROL UNIT						

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