DEVELOPMENT OF THERMOELECTRIC HEATING AND VENTILATING SYSTEM

April 15, 1965

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DEVELOPMENT OF THERMOELECTRIC HEATING AND VENTILATING SYSTEM

Final Report, Phase III, Step I

Report No. WAED 65.26E

by

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U.S. ARMY

HEADQUARTERS QUARTERMASTER RESEARCH AND ENGINEERING COMMAND

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Natick, Massachusetts

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Contract DA 19-129-QM-1981 (OI 6069)
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WESTINGHOUSE ELECTRIC CORPORATION
AEROSPACE ELECTRICAL DIVISION
LIMA, OHIO

REPORT NO. WAED 65.26E

April 1965

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FOREWARD

This report covers the work done under Phase III, Step I of contract DA19-129-QM-1981 (OI 6069) by the Aerospace Electrical Division of Westinghouse Electric Corporation, Lima, Ohio, funded by the U.S. Army Headquarters Quartermaster Research and Engineering Command, Natick, Massachusetts. The work was done over the period from June 29, 1963 to April 15, 1965. Mr. Leo A. Spano of the U.S. Army Natick Laboratories was the technical director for the program. Mr. Andrew M. Bernard was the project engineer for Westinghouse Electric Corporation.

ABSTRACT

Three thermoelectric heating and ventilating systems for environmental control of troops when exposed to extreme environments or enemy imposed hazards were delivered under Phase III, Step I, of contract DA19-129-QM-1981 (OI6069). Modifications of a battery start, easy fill fuel tank and a package cover were requested after delivery of the first unit and were then made to all three units. The modifications increased the package weight but were considered necessary for the success of the program. In general, the units performed well in laboratory evaluation delivering the required 18 cfm of air at 4 in. static water pressure or 28 watts of electrical power to an external load.

Additional areas of improvement became evident during the fabrication and laboratory evluation of the three units. The weight of the unit could be reduced to a maximum of eleven pounds from the present 15.7 lbs., including all present specifications and modifications.

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INTRODUCTION

Background

Contract DA 19-129-QM-1981 (OI 6069) called for a three-phase program of design, development, and delivery of a thermoelectric heating and ventilating system. The prime purpose of such a unit is to provide a flow of air to be used in heating or ventilating a combat-clothing ensemble to keep troops in thermal balance when operating in extreme environments or when exposed to enemy-imposed hazards. Phase I and Phase II were completed June, 1963, by Westinghouse Research and Development Center. Phase III, Step I, is the subject of this report and was completed April, 1965.

Phase I fabricated an engineering model which provided a flow of air by means of a centrifugal blower driven by a d-c motor. The electric power for the motor was obtained from a thermoelectric generator which was heated by the combustion of propane fuel. Heating of the air for the unit, when desired, was obtained by utilizing the waste heat from the thermoelectric generator.

Phase II consisted of limited life and operation testing of the unit fabricated in Phase I and of conceptual redesign and planning for the test models of Phase III.

Object of Phase III, Step I (the subject of this report)

Phase III, Step I, consisted of the design, development, fabrication, and delivery of three self-powered heating-ventilating systems for integration into thermalibrium clothing.

Characteristics:

fuel	gasoline or kerosene
Rated Output	
gross	33 watts at 12 volts
net	25 watts at 12 volts

volumetric flow to suit	18cfm at 4 in. H_2O STP*
Operational Limits	
elevation	sea level to 7500 ft
temperature	-40°F to +110°F
weather	driving rain, sand, or snow
Weight	13 lb (including 8½ hours fuel supply)
Thermoelectric life	1500 hours to 10% degradation

Summary of Phase III, Step I

The three units delivered under Phase III contained modifications consisting of an easy-fill fuel tank, a rechargeable battery start system, and a cover. The increased package weight of slightly less than 16lbs.was considered acceptable since additional tasks had been requested. In general, the units performed exceptionally well in laboratory evaluation.

Additional areas of improvement became evident during the fabrication and laboratory evaluation of the three units for Phase III, Step I. The weight of the unit could be reduced to a maximum of eleven pounds with a target goal of ten pounds. This unit would include all of the specifications of the present contract and all modifications to Phase III, would operate with logistically available fuels, and would have self-start and self-charging capabilities.

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*STP - Standard Temperature and Pressure

SECTION II

TECHNICAL DESCRIPTION AND OPERATION

A plan-view layout of the thermoelectric heating and ventilating system is shown in Figure 1. Combustion air and cooling air for the generator enter the vane-axial blower. From the blower, air flows into a plenum. All but about 1-1/2 cfm of this air flows through the thermoelectric generator cold-side heat exchanger. The heated air is either exhausted or is partially deflected by a grid valve into a duct leading to the inlet of the suit centrifugal blower. Figure 2 shows a layout of the vane-axial blower, combustion core, cold-side heat exchangers, thermoelectric modules, and inlet and exit plenums of the generator assembly. The assembled configuration of the generator and its components is shown in Figure 3, a view looking at the air grid valve and duct opening to the suit blower. Under room temperature conditions, the air leaving the cold-side heat exchanger is about 105°C. The mixture of the heated air and ambient air is controlled by a flipper valve acting in unison with the grid-by-pass valve. The two valves are turned by means of a control knob adjacent to the flipper valve. The heated air and the ambient air mix as they are drawn into the suit centrifugal blower prior to entrance into the suit.

As previously mentioned, about 1-1/2 cfm of air is supplied to the multipass burner system for combustion. This air enters the burner at the end of the thermoelectric generator opposite the entrance of the cold-side heat exchanger air. The air enters a cavity where it helps the fuel vaporize, mixes with the fuel, and then burns. The combustion products are then circulated through the multipass burner system over the generator core (the opposite side of which is the hot surface of the thermoelectric modules) and expelled from a collector duct to the atmosphere. A capillary tube in the fuel line to the burner meters the fuel flow. Pressure to the metering tube is maintained constant by two stages of regulation. Fuel to the regulators is supplied from a bladder within the fuel tank which is pressurized by means of a hand pump and works similar to a hydraulic accumulator system. Thus the fuel and the pressurized air do not come in physical contact.

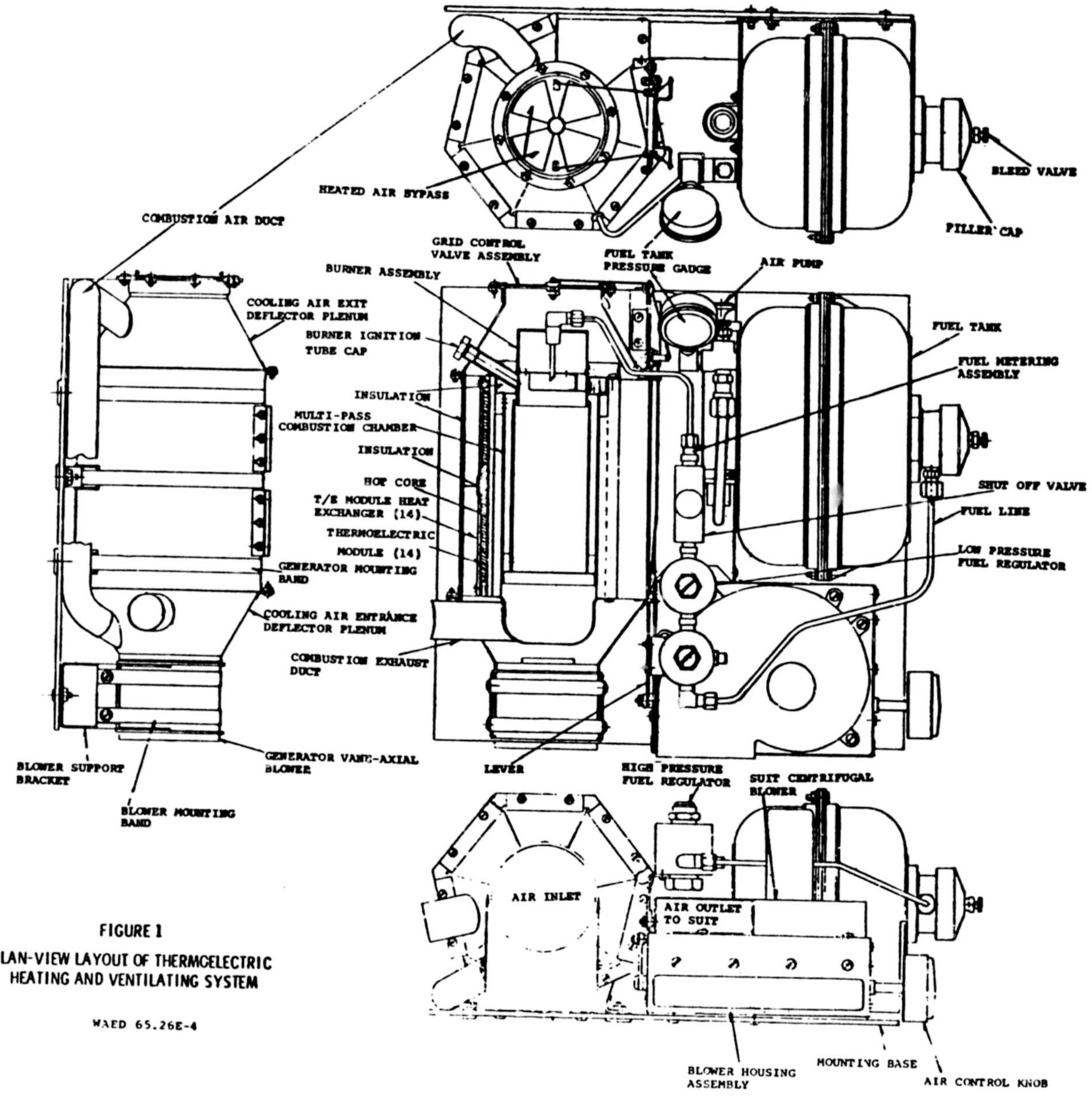

FIGURE 1

PLAN-VIEW LAYOUT OF THERMOELECTRIC HEATING AND VENTILATING SYSTEM

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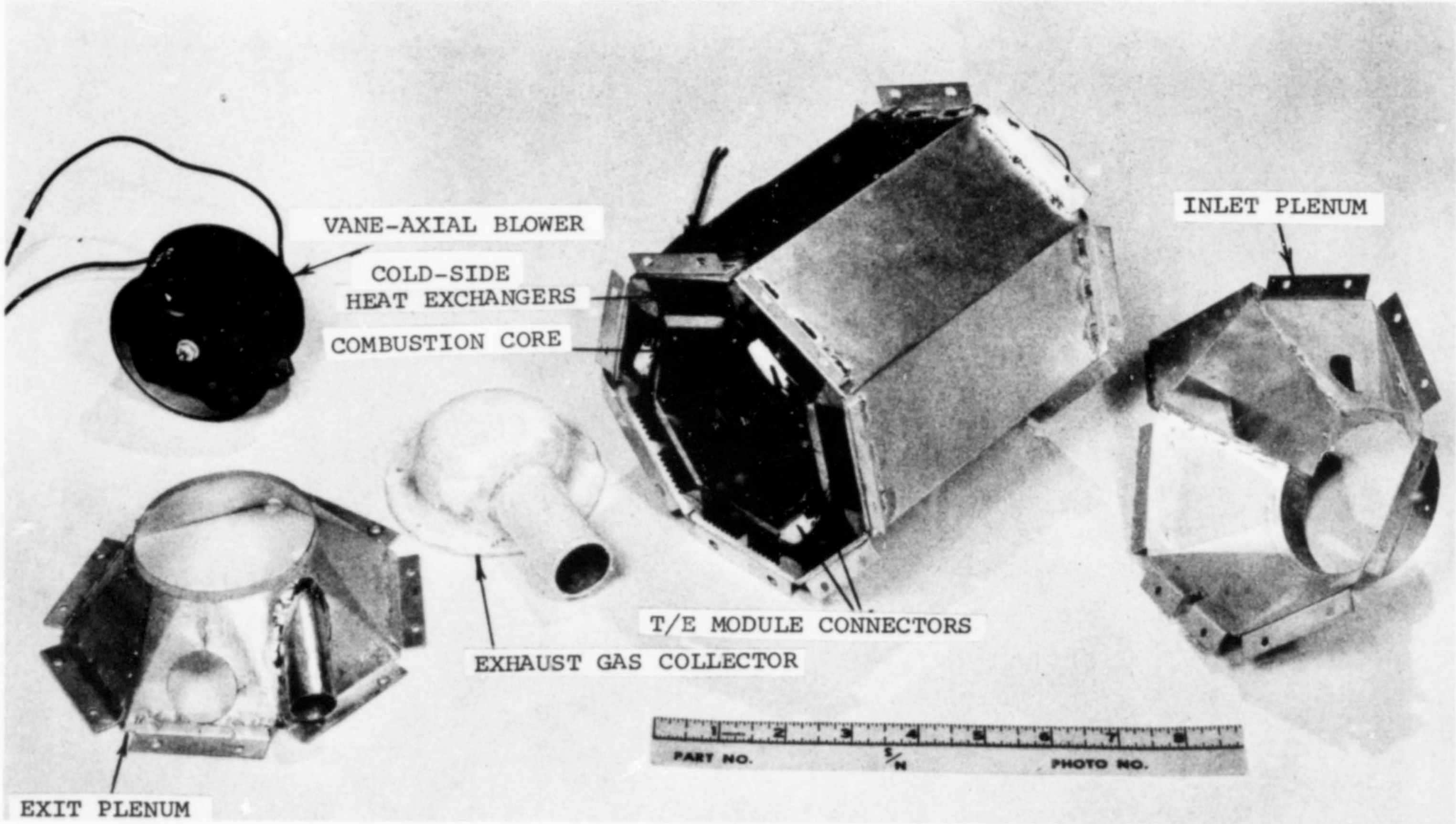


FIGURE 2

PARTS LAYOUT OF THERMOELECTRIC GENERATOR COMPONENTS

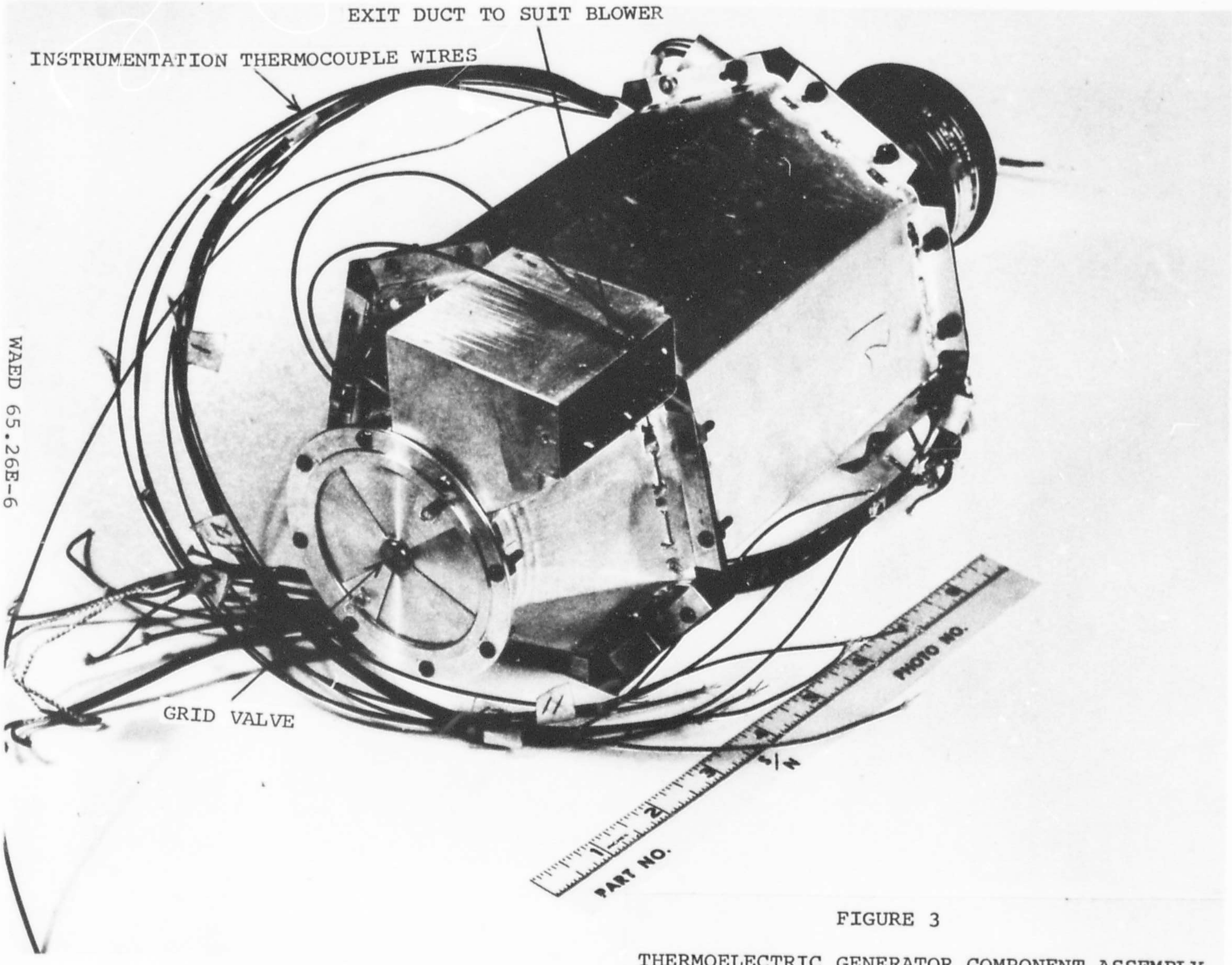


FIGURE 3

THERMOELECTRIC GENERATOR COMPONENT ASSEMBLY

In the two protographs of the overall assembled package of the thermoelectric heating and ventilating system, Figure 4 shows the air temperature control knob, fuel tank filler cap and bleed valve, inlet to the vane-axial blower, the switches for staring, external load terminals, and fresh air inlet and outlet of the suit blower while Figure 5 shows the igniter tube and cap, fuel tank air pump and combustion exhaust tube.

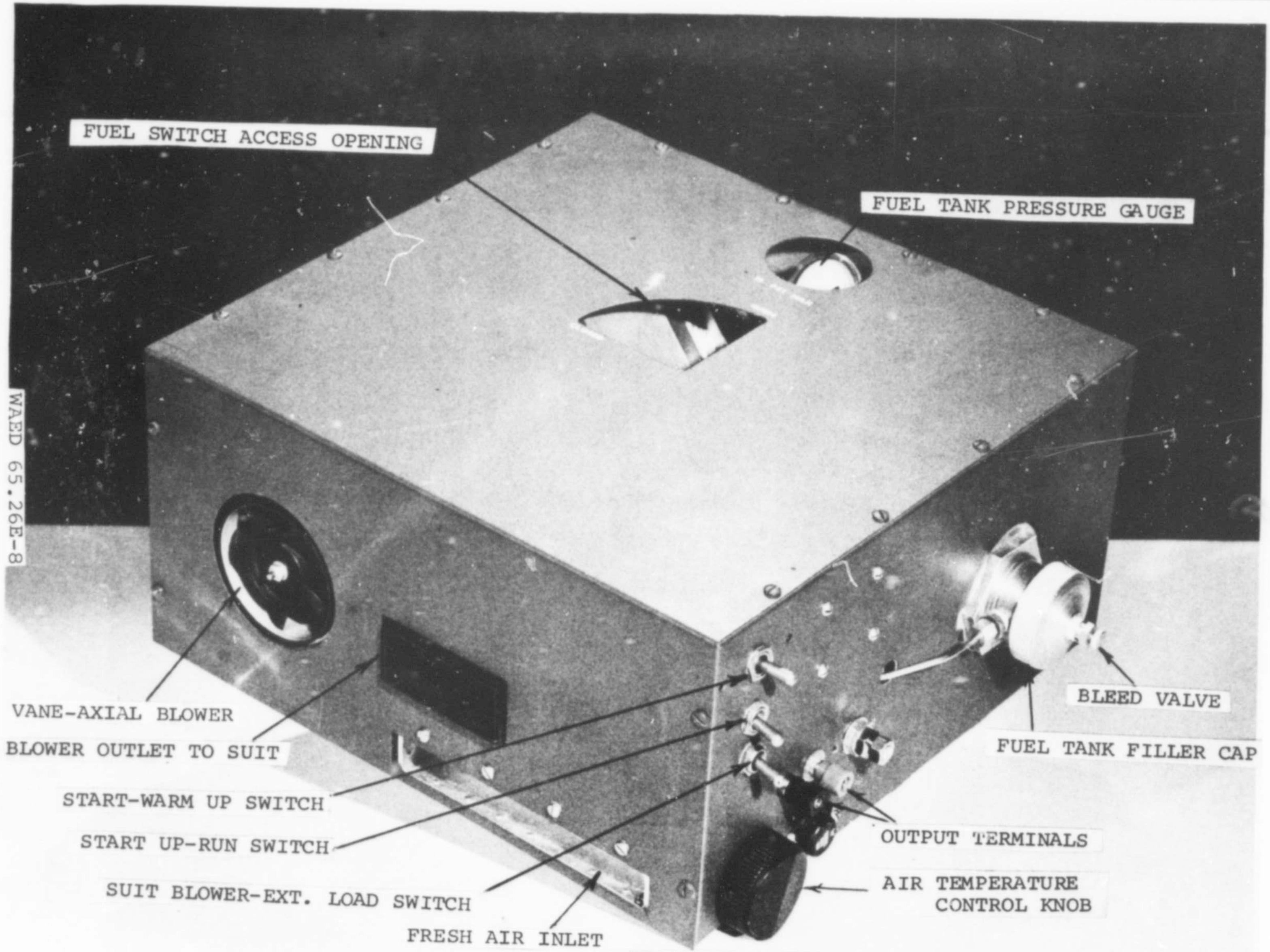


FIGURE 4

PACKAGED CONFIGURATION OF T/E HEATING & VENTILATING SYSTEM

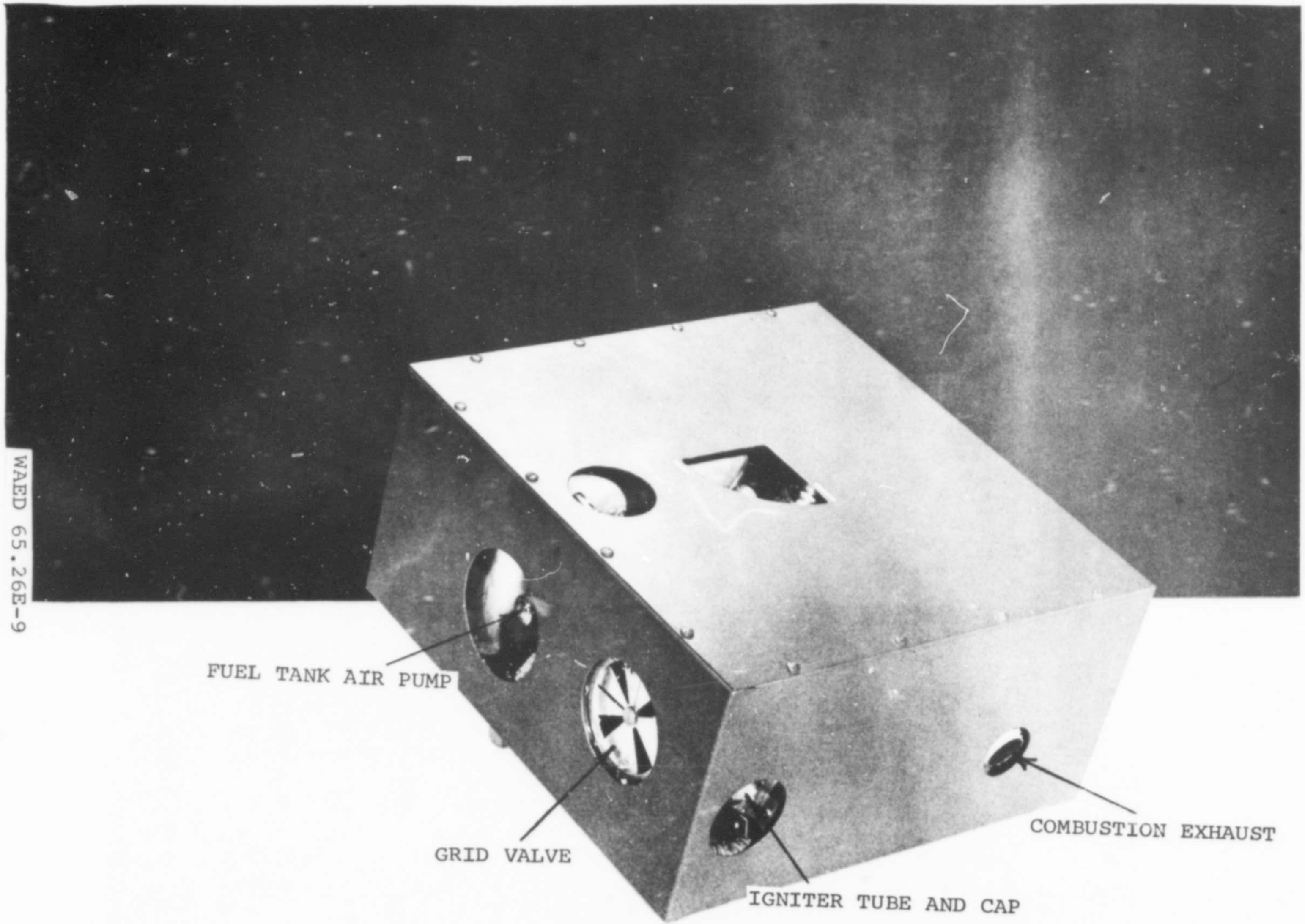


FIGURE 5

PACKAGED CONFIGURATION OF T/E
HEATING & VENTILATING SYSTEM

SECTION III

COMPONENT DEVELOPMENT

(1) Burner

Westinghouse, realizing that available fuel burners were not adequate for thermoelectric generator needs, initiated a development program. The resultant newly developed burner was modified in size and adapted to this design. The prime modification was in minimizing the operating pressure yet allowing for considerable variations in excess air. The initial test burner which incorporated these changes produced excess smoke, but subsequent modifications remedied the problem. The present system does smoke slightly at light-off and during warm up but is not visible during operation.

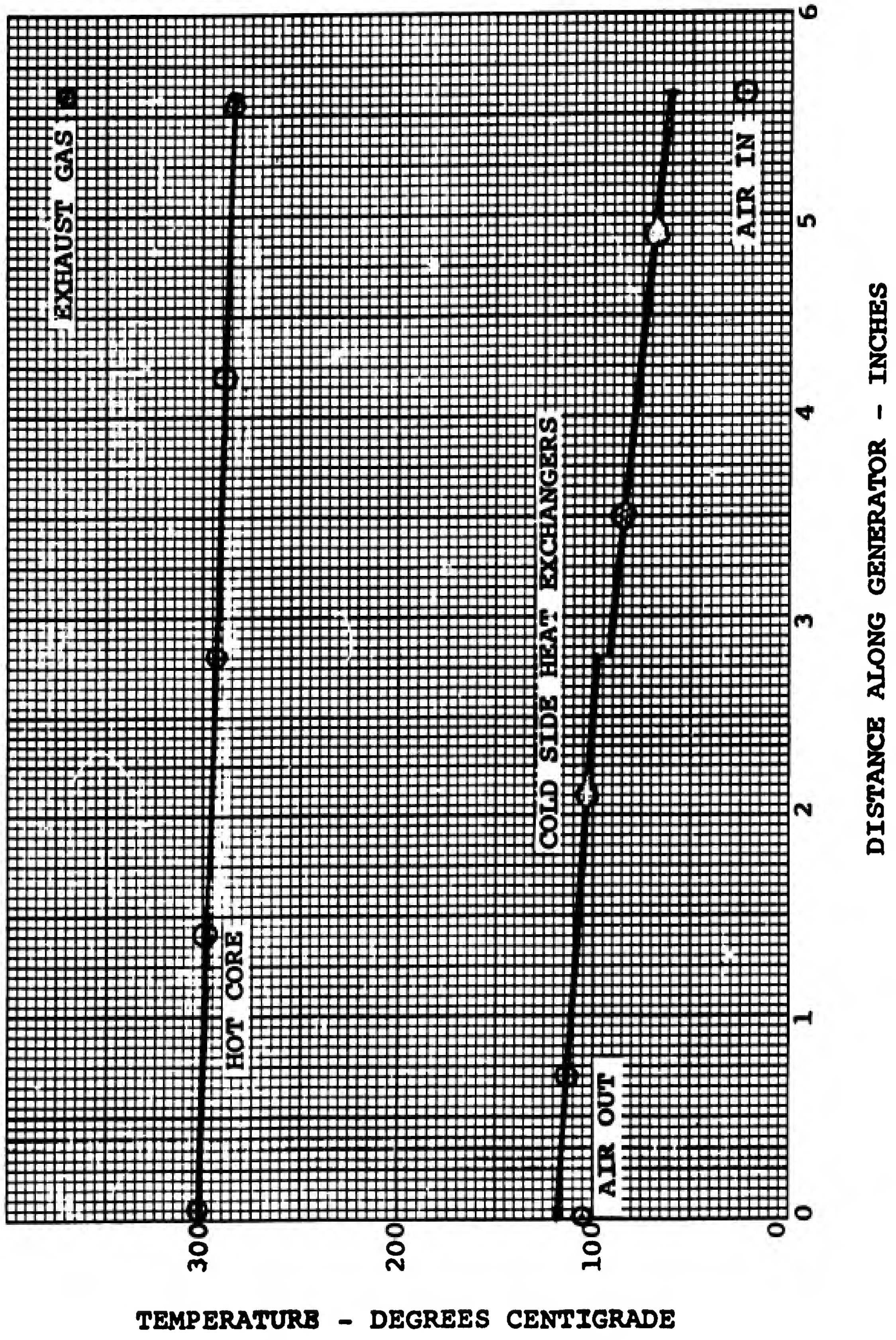
(2) Combustion Chamber

A multi-pass combustion system was selected to minimize the temperature gradient on the hot core. In spite of having three-passes for the combustion products, considerable effort was necessary to increase the quantity of heat transferred to the hot core. The best results were obtained with a counter flow arrangement of gases. i.e., the lowest temperature cooling air entered at the end where the lowest temperature products of combustion exhausted; and the hottest combustion products impinged on the hot core at the end where the hottest cooling gases exhausted. This gave a constant temperature differential on all thermoelectric elements. The temperature profile in Figure 6 represents the results obtained in the delivered generators.

(3) Fuel Metering and Regulation

For this application the minimum accurate metering pressure appeared to be 1.5 psig. At this pressure the metering orifice would be only 4 mils in diameter. Obviously, this would plague the operator with cleaning problems. Therefore, to avoid this difficulty, a 10 mil capillary was used. With only reasonable care and sensible placement of strainer screens, the operator encountered no cleaning problems.

To maintain reasonably constant electrical power output, it was necessary to maintain accurate pressure at the metering capillary. To maintain reasonably constant electrical power output, it is necessary to accurately meter the fuel to the burner. This is accomplished by maintaining a fixed pressure



TEMPERATURE PROFILE OF T/E HOT CORE AND HEAT EXCHANGERS

FIGURE 6

drop across a 10 mil capillary tube in the fuel line. Clogging of this restriction is prevented by sensible placement of strainers and with only reasonable care the operator should encounter no cleaning problems. To minimize the power output variation, a fuel pressure of 42 ± 0.5 inches of H_2O is required. A small, lightweight pressure regulator was developed, but unfortunately, the inlet pressure range established (from 60 psig down to 1.5 psig) was too great for close pressure regulation. To obtain regulation of ± 0.5 inches water column, it was necessary to go to two stages of pressure regulation. The first stage was designed for a range of 60 psig pressure to 6 psig, and the second state was designed for a range of 6 psig to 1.5 psig outlet pressure. The fuel pressure regulators were supplied by Generant Inc. Variation in power output resulting from variations in fuel inlet was virtually undetectable.

(4) Fuel Tank and Pressurization System

Because of size limitations, a compromise was made between the capacity of the air pressurization chamber and the pressure of operation. The fuel tank is designed so that the flexible fuel bladder is surrounded by an air chamber formed by the walls of the tank. Pressurized by a simple manual pump, the compressed air forces the fuel from the bladder. Initial designs called for pressurization of 40 psig to obtain 8½ hours operation from single manual pressurization. Further examination of the system showed that the materials required would increase the weight to 2½ times the design specification (or to an excess system weight of 1½ lb). To keep the weight of the fuel tank and pressurization system within specifications, a lighter weight material was used, and the tank pressurization was reduced to 20 psig maximum. The change put a further restriction on the system, now requiring that two manual pressurizations would be needed for 8½ hours of operation. After delivery of the initial unit it became evident that a larger opening was required on the fuel tank for easier filling. The fuel tank inlet was increased from ¼ inch to 1¼ inches, and a knurled cap with an air bleed valve was added. The cap is easily removed and no special tools are needed for refilling.

(5) Thermoelectric Modules

Each generator contains fourteen bismuth-telluride thermoelectric modules connected electrically in series. Each module is made up of twenty couples, making a total of 280 series-connected couples in the generator. Developed on Westinghouse Independent Research and Development funds, these thermoelectric modules produce 34 watts of electrical power at 7.7 volts d-c when an average temperature differential of 150°C is maintained across the thermoelectric modules. The overall efficiency of the thermoelectric generator (including shunt thermal losses and mechanical fasteners) is a minimum of 2.7% computed from the ratio of electrical power generated to the thermal energy entering the combustion core. The module design of Westinghouse was chosen so that the entire weight of the fourteen modules and all electrical connectors within the generator would not exceed 1.0 lb.

(6) Heat Exchangers

Getting an adequate correlation between an analytical design and a laboratory model of the heat exchangers for this program was difficult. Design parameters of low flow rates (32 cfm total for seven sides) and low pressure drops (0.34 inches of water column static pressure) are unique to this application. The analytical approach plus a laboratory test program was used to develop the individual components.

The final configuration consists of fourteen individual heat exchangers around a seven-sided core with a thermoelectric module mounted beneath each heat exchanger. Each heat exchanger consists of 18 fins 0.55 in. high and .024 in. thick with seventeen spaces. The base plate of the heat exchanger is .060 in. thick. The heat exchangers are made of magnesium thick anodic coated by Brooks and Perkins Inc. for electrical insulation of the thermoelectric module junctions. Because of the optimized design and material selection, the weight of the heat exchangers was kept to a minimum of 0.85 lb.

(7) Blowers

A specific contractual requirement was the engineering of a special high-performance blower subsystem. A design study was conducted on the basis of the peak performance attainable according to published design literature and manufacturers' specifications. Of the more than thirty manufacturers of similar devices who were contacted to bid on supplying the generator blower and suit blower according to the stringent size, weight, power-input, and air-power specifications, only Torrington Manufacturing Company felt confident of meeting the specifications. Awarded the subcontract, Torrington attained exceptional performance by their special impeller design. However, some improvements can be expected in the performance of the motors, which were procured from a separate commercial and military supplier.

(8) Air Control System

To supply the temperature - controlled air to the suit, a grid valve to reject the unused heated air from the generator operates in unison with a butterfly valve to mix the heated air from the generator with ambient air. Varying the proportions of the heated and the ambient air gives the desired temperature. The balancing of the static pressure drop across the grid control valve with the static pressure drop through the duct leading to the suit blower over the controlled temperature range was achieved by adjustment during initial testing.

(9) Self-Start

The method of starting---that is, the method used to supply combustion air---was not finalized until after delivery of the first system. Start-up of the units at Westinghouse was accomplished with a variable voltage d-c supply which powered the generator vane-axial blower. After this first unit was delivered, the capability of self-starting was requested. To accomplish this with a minimum amount of space and weight, four (size AA) nickel-cadmium rechargeable batteries were series connected with a switching arrangement and a resistor, as shown in the Wiring Diagram, Figure 7. With the #1 switch in the "Light" position and the #2 switch at "Start" a very low air flow is supplied to the combustion chamber. When the burner is lighted, the #1 switch is positioned in the "Warm Up" position thus increasing the air flow. After approximately 90 seconds the number 2 switch is flipped to "Run" and the batteries are thus disconnected. Included in the system is a Zener diode for voltage control and two external load terminals which enable using the power for other than driving the suit blower. To choose between the external load or the suit blower is just a matter of positioning switch number 3. A possible refinement to this system would be the development of a trickle charge arrangement to maintain a full charge on the batteries.

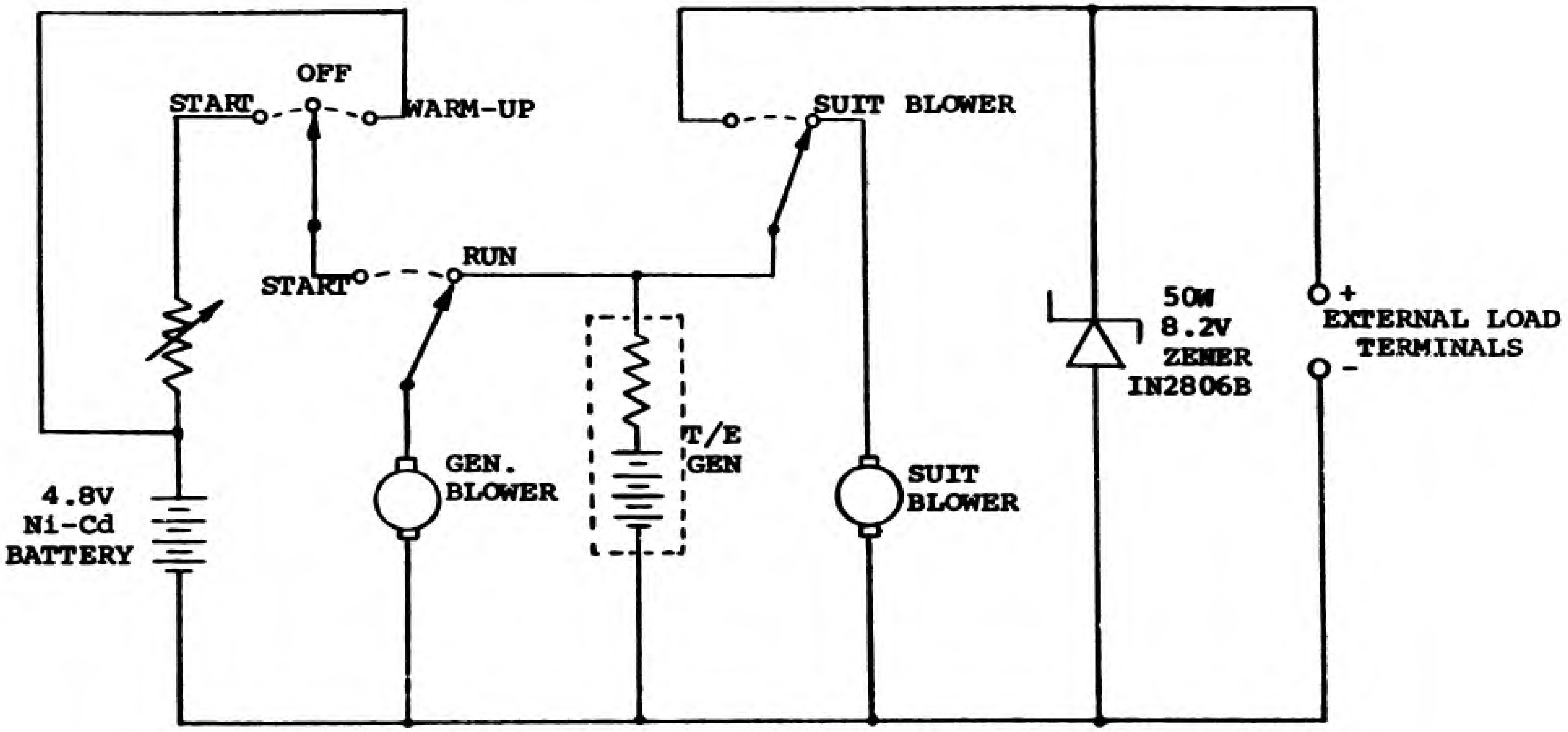


FIGURE 7

T/E HEATING AND VENTILATING SYSTEM
WIRING DIAGRAM

(10) Packaging

All components are located in the final package for the best functional relationship. The packaging minimum size criterion influenced the design of some components. For example, the fuel tank was limited to a rectangular shape rather than a more desirable cylindrical configuration. In general, very little can be done to improve the package with the components as they are at present.

A cover was added to the overall unit. Functional holes for operation were included in the cover, and component identification was added. A schematic diagram of the electrical system was placed inside the cover.

(11) Operation

All components used in starting are identified by name and position. To go through a start and a shutdown procedure, merely follow the abbreviated instructions below.

To Start

1 - Pump fuel to 20 psi and BLEED AIR from tank. (BE SURE FUEL VALVE IS CLOSED)

2 - Set HEAT-COOL knob to HEAT and set switches to OFF, START, and EXTERNAL LOAD.

3 - Remove BURNER CAP, Open FUEL VALVE - Wait 1½ minutes.

4 - Turn LIGHT-WARM UP switch to WARM UP then to LIGHT - Wait 1½ minutes.

5 - Light gases at burner. (CHECK VISUALLY)

6 - After 15 seconds turn switch to WARM UP.

7 - Replace BURNER CAP - Wait 1½ minutes.

8 - Turn switch to RUN.

9 - After 7 minutes unit is up to temperature.

   (a) Set HEAT-COOL knob to COOL and connect a power load to external load terminals or

   (b) Turn switch to SUIT BLOWER and connect unit to a suit. Adjust HEAT-COOL knob for desired air temperature in suit.

To Shut-Down

1 - Turn switch to EXTERNAL LOAD.

2 - Turn knob to COOL.

3 - Turn fuel valve to CLOSED.

4 - After 5 minutes turn switch to OFF.

SECTION IV

SYSTEM PERFORMANCE

The thermoelectric heating and ventilating system for combat clothing was designed and developed to the following specific objectives.

1. Duration of continuous operation at maximum output without refueling: not less than eight (8) hours with a sufficient fuel capacity for 8½ hours of operation.
2. Weight limitation for complete unit, fueled: not more than thirteen (13) pounds.
3. Usable output to the combat clothing: not less than 18 cfm air at STP and 4 in. H_2O positive static pressure. The temperature of the air delivered to the clothing is to be controllable over the ambient temperature range of -40°F to +110°F so that it can be delivered at temperatures ranging from +150°F to +5°F above the ambient temperature.
4. Service Life (cyclic operation)
    a. 500 hour minor overhaul
    b. 1500 hours major overhaul
    c. 3000 hours total service life
5. The units must be capable of using liquid fuels, i.e., gasoline or kerosene.
6. Rated Output Power
    a. Gross......33 watts at 12 volts
    b. Net........25 watts at 12 volts
7. Operational Limits
    a. Elevation.....sea level to 7500 ft
    b. Temperature...-40°F to +110°F

    c. Weather......driving rain, sand, or snow

8. Thermoelectric life...1500 hours to 10% of degradation

The three units delivered are to be tested by the Quartermaster Research and Engineering Command in their climatic chambers. Each unit was given a laboratory evaluation as an indication of performance prior to delivery. The typical system performance under laboratory conditions is tabulated below.

1. Thermoelectric Generator

a.	Thermoelectric generator efficiency	2.7%
	(Ratio of gross electrical power output to heat into hot core)	
b.	Fuel rate	0.31 lb/hr
c.	Gross power output @ 7.7 volts*	34 watts
d.	Net usable power output @ 7.7 volts	28 watts
e.	Load voltage	7.7 V d-c
f.	Hot core surface temperature (avg)	295°C
g.	Thermoelectric hot junction temperature (avg)	260°C
h.	Thermoelectric cold junction temperature (avg)	105°C

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*To keep the elements and modules to a reasonable geometry for manufacture and to optimize the power to weight ratio, it was necessary to reduce the operating voltage to 7.7 volts from the original 12.0 volts. This change had no adverse effect on the system.

	i.	Cold side heat exchanger base temperature (avg)	$90^{\circ}C$
	j.	Air temperature into cold side heat exchanger	$24^{\circ}C$ ($75^{\circ}F$)
	k.	Air temperature at exit from cold side heat exchanger	$110^{\circ}C$ ($230^{\circ}F$)
	l.	Cooling air flow rate (at STP)	32 cfm
2.	Generator Motor-Blower		
	a.	Total air flow (at STP)	33½ cfm
	b.	Static pressure head	0.5 in. H_2O
	c.	Power input to blower motor (7.7 V d-c)	6 watts
	d.	Motor efficiency	~ 49%
	e.	Impeller efficiency (based on static pressure)	64%
3.	Suit Motor-Blower		
	a.	Total air flow (at STP)	18 cfm
	b.	Static pressure head	4.0 in. H_2O
	c.	Power input to blower motor (7.7 V d-c)	28 watts
	d.	Motor efficiency	47%
	e.	Impeller efficiency (based on static pressure)	64%
	f.	Suit air temperature from blower (no recirculation-ambient air into system)	2° to $65^{\circ}C$ above ambient

4. Fuel System

a. Fuel tank capacity (leaded gasoline)	2.33 lb
b. Fuel tank pressure	20 psig max.
c. Fuel inlet pressure to burner	42 in. H_2O
d. Fuel regulation (2 stages)	± 0.5 in. H_2O

A weight breakdown of the present thermoelectric heating and ventilating system is as follows.

1. Fuel System

Fuel	2.33 lb	
Pump and Tank	1.50 lb	
Valve	.30 lb	
Pressure Regulator	.40 lb	
Fuel Lines	.10 lb	
		4.63 lb

2. Thermoelectric Generator

Hot Core	.80 lb	
Thermoelectric Modules	1.10 lb	
Fasteners	.12 lb	
Heat Exchangers & Shroud	1.00 lb	
Burner	1.30 lb	
Miscellaneous	.50 lb	
		4.82 lb

3. Air System

Generator Motor & Blower	.50 lb	
Suit Motor & Blower	.65 lb	
Inlet and Exit Plenums	.20 lb	
Air Temperature Adjustment and Blower Housing	1.00 lb	
		2.35 lb

4. Support Structure

Packboard	.75 lb	
Switches	.24 lb	
Wiring	.20 lb	
		1.19 lb

5. Modifications

External Cover	1.30 lb	
Easy Fill Fuel Inlet	.40 lb	
Battery Self-Start	1.00 lb	
		2.70 lb
TOTAL		15.69 lb

Included in the total weight are the modifications which add 2.70 lb to the design concept but are considered necessary for the success of the overall program.

A separate requirement was the engineering of a high performance blower subsystem. A special development effort for the blowers was subcontracted according to the specifications of the system design study. The exceptional performance of the generator vane-axial blower and of the suit centrifugal blower is shown in Figures 8 and 9.

FIGURE 8

PRESSURE PERFORMANCE OF GENERATOR VANE-AXIAL BLOWER AT 7.7 VOLTS D-C

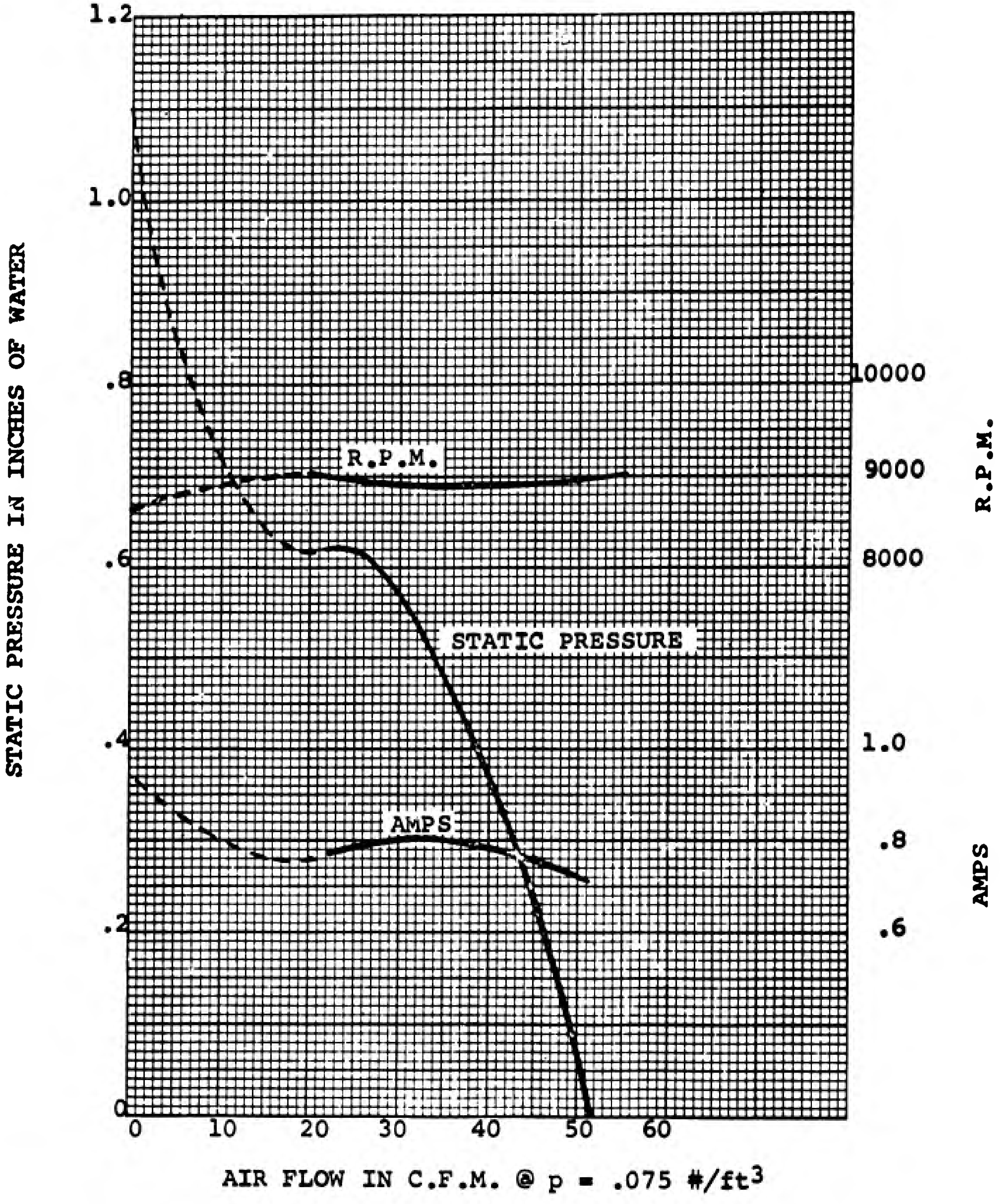
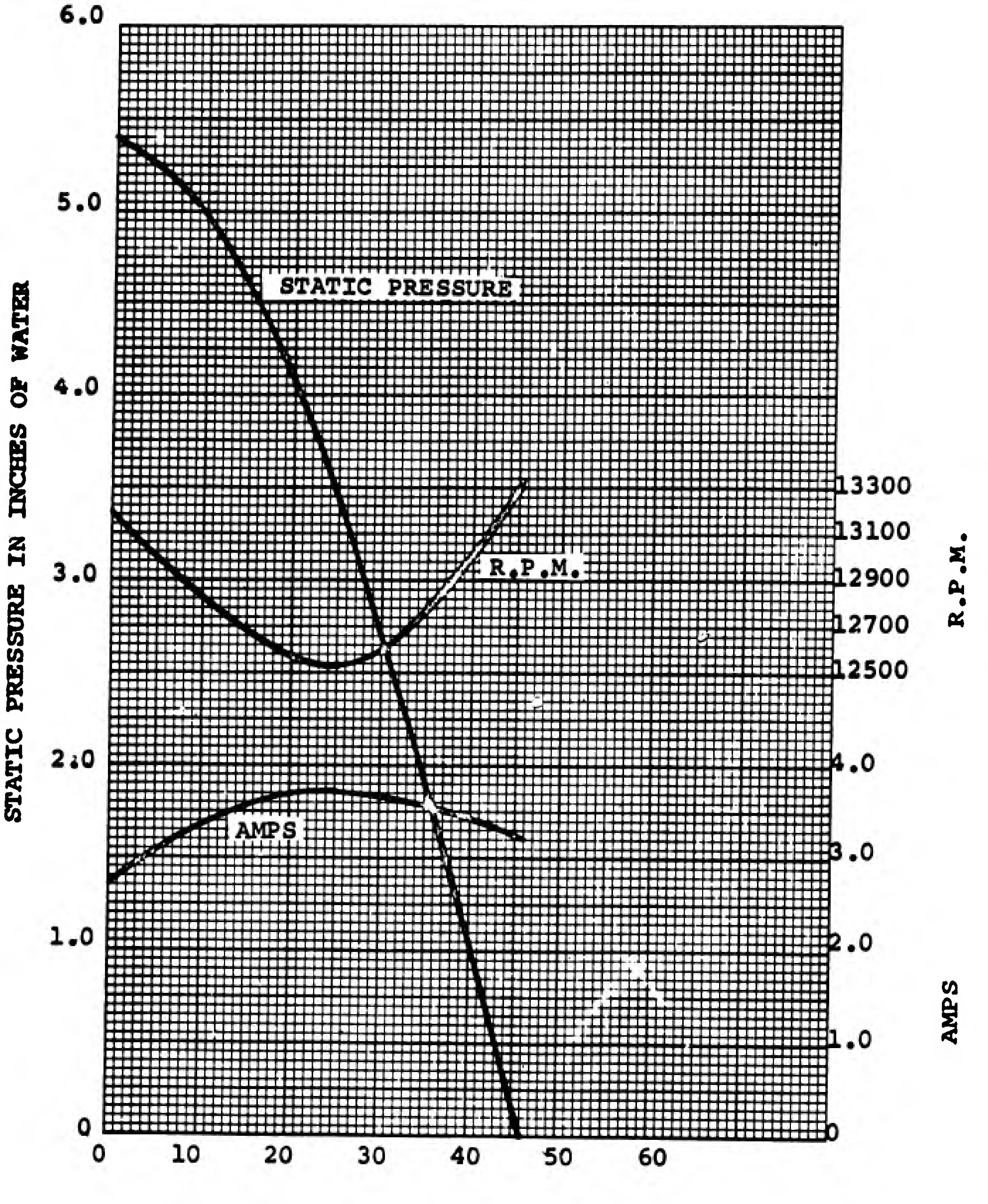


FIGURE 9

PRESSURE PERFORMANCE OF SUIT
CENTRIFUGAL BLOWER AT 7.7 VOLTS D-C



AIR FLOW IN C.F.M. @ $p=.075$ #/ft^3

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Although the units produced in Phase III, Step I, performed very well, areas of improvement became evident during the construction and laboratory evaluation of the devices. The areas of improvement not only increase the performance capabilities of the unit but also decrease the weight and size of the overall system. The particular areas which can be improved most are as follows.

(1) Improved Thermoelectric Energy Conversion System

The thermoelectric modules used in Phase III were composed of P and N type bismuth telluride. The modules were operating with a temperature differential of 150°C and a conversion efficiency of slightly under 3%. Westinghouse Independent Research and Development Programs have shown that the bismuth telluride is capable of operation at a higher temperature. To utilize the allowable increase in temperature, an improvement in the material-joining procedure is required and is now being developed. The efficiency of conversion is expected to improve to almost 4%. This higher conversion efficiency enables construction of the thermopile from fewer (or smaller) thermoelectric modules. It permits reduction of the cold-side heat exchanger, reduces the burner core size, and for less fuel will produce the same power output as in Phase III. To accommodate this will require a redesign of the entire thermoelectric generator along with the inlet and exit air plenums and the fuel storage system.

Only a slight change is anticipated in the performance of the combustion system. The increase in efficiency of operation of the thermoelectric modules will result in an overall weight reduction of at least two pounds from the present system weight.

(2) Improved Suit Blower-Motor Sub-Assembly

A more efficient, lighter-weight suit blower-motor subsystem could be integrated into the overall thermoelectric heating and ventilating package. The fan of the suit blower of Phase III operates at about 64% efficiency and might be indirectly improved. Previous experience with fans has shown that an improvement in finish and tolerances of the impellers and the impeller housings may result from casting rather than sheet metal fabrication techniques. Such improvements would result in better fan efficiencies and reduced motor speeds. The motor performance would improve because of the reduced speed (friction, windage and brush drop reduced). A weight reduction would be possible since lighter materials (e.g., magnesium or phenolics) for castings could then be employed. At this time the d-c motor operates at about 47% efficiency and may be improved to 52%. This would result in a 2 watt reduction of load power and 0.5 lb weight reduction for the overall system.

Brushless d-c motors with solid state commutation have a present published efficiency of 60% and a predicted performance as high as 80%. The integration of a static commutation brushless d-c system with increased performance to 60% efficiency would reduce the power requirement about 5 watts and the weight about 1.5 lb because the reduction of the thermoelectric modules, heat exchangers, combustion core, and fuel tank. A volume reduction would also be expected because of the decrease of the bulk of the components. Periodic maintenance of motors for brush changes, bearing replacement, and commutator turning would be eliminated since the expected life to maintenance of static commutating burshless d-c motors is in excess of 3,000 hours. There is no advantage in using brushless d-c motors based on an a-c chopper system or a-c motors operating from an inverter. In fact, for this particular application the last two approaches mentioned are heavier than the d-c motor system.

(3) Improvement of Fuel System

The areas of the fuel system which can be improved most are the fuel pressurization mechanism and the fuel container. The pressurization system can be improved to give 8 hours continuous operation (as well as start-up) from an initial manual pressurization. The geometry of the container can be improved so that higher pressures can be tolerated with negligible container wall deflection at reduced weight. The fuel bladder can be reduced to a diaphragm separating the air pressurization chamber from the fuel container, both within a common cell. The reduced fuel requirements as a result of the higher efficiency and reduced power output would mean a substantial volume reduction of the fuel supply and pressurization system in addition to the overall package weight reduction previously noted.

(4) Self-Start System

In Step I of Phase III a self-start mechanism was incorporated into the overall package of the heating and ventilating system after the overall system had been completed. The self-start system consisted of four AA nickel-cadmium batteries series connected with a two-position switch to give a reduced air flow from the generator blower for lighting purposes. The start system is maintained by removing the batteries from the units and recharging from a regulated d-c current source. The system could be improved substantially by incorporation of a charging circuit from the thermoelectric generator and integration of the charging-start system into the overall design. In addition, the weight of the starting system could be reduced by the use of special batteries.

In Phase III the incorporated start system weight was approximately one lb. The weight could be reduced by about one-half.

(5) Cold Start on Liquid Fuels

The burner of the units delivered in Step 1 of Phase III will operate on fuels heavier than gasoline. In particular, the burner is intended to operate on JP-3, JP-4 (MIL-J-5624E), CIE fuel (MIL-F-46005), kerosene(VV-K-211C), and gasoline(MIL-G-3056B). The higher volatility of gasoline at room temperature is now relied on for ease of lighting. A considerable amount of effort must be expended to provide lighting capabilities of fuels at all ambient conditions. The basic problem areas are (a) to light the fuel initially, (b) to select the best method of providing combustion air, and (c) to provide adequate combustion and release sufficient heat to warm up.

(6) Fuel Metering to Compensate for Varying Ambient Conditions

Means of metering the fuel must be provided to assure a constant fuel input to the burner over the varying ambient conditions. Large variations in fuel input result from the large change in fuel viscosity, particularly at low temperatures. The areas to be investigated are manual metering and automatic metering of fuel with respect to the varying ambient.

A system designed to such specifications including the improvements indicated would have a maximum weight of 11.0 lb as given in the following weight breakdown. However, if the improvements as stated could be fully realized, it is conceivable that the overall system weight would be reduced to a maximum of 10.0 lb.

(7) Anticipated Weight Breakdown

1. Fuel System		
Fuel	1.80 lb	
Pump and Tank	1.00 lb	
Valve	.15 lb	
Pressure Regulator	.40 lb	
Fuel Lines	.07 lb	
		3.42 lb
2. Thermoelectric Generator		
Hot Core	.65 lb	
Thermoelectric Modules	1.00 lb	
Fasteners	.05 lb	
Heat Exchangers	.80 lb	
Burner	1.00 lb	
Miscellaneous	.20 lb	
		3.70 ln
3. Air System		
Generator Motor & Blower	.44 lb	
Suit Motor & Blower	.56 lb	
Inlet & Exit Plenums	.20 lb	
Air Temperature Adjustment and Blower Housing	.68 lb	
		1.88 lb
4. Support Structure		
Packboard	.55 lb	
Switches	.15 lb	
Wiring	.15 lb	
		0.85 lb
5. Miscellaneous		
External Cover	.50 lb	
Easy Fill Fuel Inlet	.15 lb	
Battery Self-Start	.50 lb	
		1.15 lb
TOTAL		11.00 lb

(8) Improved System Specification

1. Weight limitation for the completely self-powered, self-starting unit fully fueled for 8 hours of continuous operation will be less than 11.0 lb with a primary goal of 10.0 lb.

2. The system will be capable of operation using commonly available military fuels, i.e., gasoline (MIL-G-3056B), JP-4 (MIL-J-5624E), and kerosene (VV-K-211C).

3. The net power output from the thermoelectric generator will be sufficient to provide the suit blower and motor sub-system with a minimum output of 18 cfm of air at STP with a 4" H_2O positive static pressure and at the same time provide sufficient power for recharging the starting batteries during the eight-hour operating period. With improvement in the suit blower and motor efficiency as a result of predicted development this power requirement may be lower than the 25 watts specified.

4. The system shall have start-up and performance capabilities under the following operational limits:

   (a) elevation..............sea level to 7500 ft

   (b) ambient temperature....-40°F to +110°F

   (c) weather................driving rain, sand, and snow

5. The unit shall be capable of operation in any position.

6. The fuel tank shall be fillable from standard fuel containers.

7. Usable output from the suit blower to the combat clothing is to be a minimum of 18 cfm of air at STP with a 4 in. H_2O positive static pressure. The temperature of the air delivered to the clothing will be controllable over a temperature range of from +150°F to +5°F above ambient. The air supplied will be free of any contamination as a result of being delivered by the thermoelectric system.

8. Service Life (cyclic operation)

   (a) 500 hours before a minor overhaul

   (b) 1500 hours before a major overhaul

   (c) 3000 hours total