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# EMERGENCY BREATHING AND SUIT PRESSURIZATION SYSTEM

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*GENERAL ELECTRIC CO.*

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# FOREWORD

This study was made by the Missile and Space Division of the General Electric Company, Philadelphia, Pa., under Contract No. AF 33(657)-11345 with the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The work was performed in support of Project No. 6373, "Equipment for Life Support in Aerospace," and Task No. 637305, "Analysis and Integration of Life Support Systems." The study, design, and fabrication on this project were initiated on May 31, 1963 and completed on March 31, 1964. The contract monitor for the Aerospace Medical Research Laboratories was Mr. Earl Sayre of the Requirements and Evaluation Branch, Biotechnology Division, Biomedical Laboratory.

This technical report has been reviewed and is approved.

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Technical Director
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# ABSTRACT

The design and fabrication of an Emergency Breathing and Suit Pressurization System (EBSPS), capable of sustaining three full-pressure suited crewmen within the Aerospace Medical Research Laboratories Life Support System Evaluator, has been investigated. Two operating modes are provided. One, when the Evaluator is pressurized, the Emergency Breathing and Suit Pressurization System operates as an open-loop system and ventilates the pressure suit with the ambient air. Two, when the Evaluator is depressurized, the Emergency Breathing and Suit Pressurization System operates as a closed environmental control system, and provides the crewmen with a habitable atmosphere. In this latter mode, the system regulates the suit pressure, the $CO_2$ partial pressure, relative humidity, composition (100% $O_2$), and temperature of the ventilating air, and supplies oxygen for breathing and leakage make up as required. In all modes, the Emergency Breathing and Suit Pressurization System regulates the flow of ventilating atmosphere through the pressure suits.

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# SECTION I

# INTRODUCTION

The Emergency Breathing and Suit Pressurization System (EBSPS) design that is presented herein was evolved to provide the capability for sustaining up to a maximum of three full pressure suited crewmen within the AMRL Life Support System Evaluator in either of two operating modes.

During the first mode, "normal condition," the EBSPS operates as an open-loop system and circulates the evaluator atmosphere through the crewmen's unpressurized suits. In the case of loss of evaluator total pressure, the system operates in the second, or "emergency mode." In this mode the EBSPS operates as a closed-loop system which maintains a habitable environment within the pressurized suits by continuously recirculating a ventilating flow via umbilicals between the suits and the various system conditioning devices.

The EBSPS equipment is packaged within a single modular envelope that is designed to fit into the evaluator nose section. The suit umbilical connections, individual suit manual flow adjustment valves, the monitoring instruments and control displays are located on a single face of the module where they are readily visible and accessible.

A fully operable prototype system has been fabricated, tested and delivered to AMRL for installation in the Life Support System Evaluator. The design of the system and components, results of the inhouse (GE) acceptance testing, and the checkout and operating procedures for the EBSPS are discussed.

# SECTION II

# SYSTEM DESIGN

## General

The performance capabilities presented herein have evolved as the result of satisfying technical requirements and also from the findings of this design study. This specification gives the performance capabilities and support equipment requirements for an Emergency Breathing and Suit Pressurization System (EBSPS) which is to be used within the AMRL Life Support Systems Evaluator. The system operates in two basic conditions, or modes: Normal Condition and Emergency Condition.

## Normal Condition Performance

During this mode the EBSPS operates as an open-loop system and circulates the evaluator atmosphere through the crewmen's unpressurized suits.

### Ambient Pressure Range

The EBSPS is capable of operating in Evaluator ambient total pressures of either 400 mm Hg or 740 mm Hg during this mode.

### Ventilating Flow Rate

The EBSPS is capable of providing between 2 and 8 cfm of ventilating flow to each of up to three crewmen in unpressurized suits against a back pressure of up to 16 in. $H_2O$ when the ambient pressure is 740 mm Hg. At 400 mm Hg, the EBSPS is capable of delivering the same ventilating volume rates of flow against a back pressure of approximately 8.7 in. $H_2O$. The ventilating flow rate of each of the suits is independently adjustable. Flow adjustments in any one of the suit circuits does not affect the ventilating flow rate to the remaining suits being supplied by the system.

### Cooling Capability

During normal operation the Evaluator atmosphere is circulated through the suits without any cooling or processing by the EBSPS. If desired, during the normal condition, the EBSPS is capable of supplying the ventilating flow to the suits at a temperature of 60° F with a specific humidity of 5-15 mm Hg, provided the Evaluator ambient temperature is no higher than 80° F at 50% RH and the coolant from the external heat sink (see 1.4 below) is supplied to the EBSPS at 50° F or less.

## Emergency Condition Performance

An emergency condition is defined as that which occurs when Evaluator total pressure is lost. During the Emergency Condition the EBSPS operates as a closed-loop system by continuously recirculating a ventilating flow of essentially 100% $O_2$ between the suits and its various conditioning devices where it is cooled and contaminants are removed. The EBSPS also maintains suit pressure at controlled levels and provides oxygen for breathing and leakage makeup. The system is capable of operating continuously for 90 minutes while it is supporting three crewmen without any maintenance or adjustment other than flow adjustments which are made at the option of the individual crewmen.

### Operating Pressure Level

Upon loss of Evaluator pressure the EBSPS pressure lags the decline in Evaluator pressure by 3.0 or 4.5 psi (level is preselected to conform with the suit requirements). Then the EBSPS maintains the suit 100% oxygen atmosphere at the set operating pressure level of 3.5 or 5.0 psia by means of demand-type regulation. Purging of the EBSPS suit circuits with 100% oxygen is accomplished during the pressure level transition period for a time interval and at a purge flow rate sufficient to assure that the suit $pO_2$ does not drop below 120 mm Hg at any time. During Evaluator repressurization, the EBSPS is capable of maintaining suit pressures 2.5 psi above the Evaluator pressure until normal Evaluator pressure is reached (either 400 or 740 mm Hg). Upon reaching this pressure, the suits are bled down to normal evaluator pressure, and the EBSPS can then operate in its normal mode.

### Ventilating Flow Rate

Ventilating volume flow rates to each of the suits during the emergency condition are the same as those specified during normal conditions. As in the case of normal mode operation, flow regulation prevents one crewman from increasing his ventilating flow beyond a value which would result in a decrease in the ventilating flow to the remaining crewman.

### Cooling and Moisture Removal Capabilities

During an Emergency Condition the EBSPS is capable of providing ventilating oxygen at its outlet ports at a temperature of 60 ± 5° F and a specific humidity of 5 -15 mm Hg.

### $CO_2$ Removal

The EBSPS is equipped with a rechargeable chemical absorbent canister assembly which is capable of removing the $CO_2$ exhaled by the three crewmen at a rate sufficient to maintain the $CO_2$ pressure at the EBSPS outlet port below 2 mm Hg for 90 minutes of continuous operation.

### Makeup Oxygen Supply

The EBSPS has an integral high pressure (1800 psig) gas storage cylinder with sufficient capacity to provide breathing, leakage and makeup oxygen for 90 minutes of continuous operation while supporting three crewmen. The cylinder has sufficient storage volume to provide for a single oxygen purge cycle as well.

## Support Facility Performance Requirements

### External Heat Sink

The EBSPS must be supplied with an ethylene glycol-water coolant from a heat sink external to the evaluator. The heat sink should have the capacity to provide flows of up to 2 gal/minute at a temperature of 50° F or less. The coolant circulating pump is provided separate from the EBSPS module for mounting external to the Evaluator.

### Electrical Power Requirements

The EBSPS requires 110 VAC 60 cps single phase and 110 VAC 400 cps single phase.

## System Design Concepts

The EBSPS major environmental control functions may be categorized as follows:

a. Ventilating Flow Circulation and Filtering
b. Pressure Regulation
c. Makeup Oxygen Supply
d. Temperature Control
e. Humidity Control
f. $CO_2$ Removal
g. Odor Removal

Certain of the design concept approaches which have been employed to perform the above functions were specified by the AMRL, thus in these cases it was not necessary to perform concept optimization comparison studies. Instead discussions are presented in these system areas which amplify the approach which was specified. In all other design areas the various possible concepts were compared in order to determine the optimum system. The concepts which are employed and the results of the studies which were performed to establish them are presented below. It should be emphasized that concepts were compared with regard to establishing an optimum laboratory system and not an optimum flight operable system.

### Temperature and Humidity Control

Thermal control of the suit ventilating flow stream is best accomplished by rejecting the heat load to a liquid coolant that is continuously circulating through a cooling coil mounted within the ventilating flow circuit. The liquid coolant is pumped through a commercial condensing unit heat sink which is located outside of the Evaluator. The cooling coil simultaneously accomplishes cooling and dehumidification. Excess moisture from the ventilating stream condenses on the coils and at the same time the atmosphere temperature is reduced.

The condensate from the coil is collected by gravity feed within a reservoir located beneath the cooling coil plenum. In this application, the above approach proves to be the most workable since the external heat sink already exists as a portion of the overall Evaluator habitable atmosphere control system, and no zero gravity condensate collection complications are required.

Also considered as possible thermal control design approaches were concepts which would be integral with the Emergency Breathing and Suit Pressurization System. An expendable refrigerant such as water can be evaporated at reduced pressure within the heat exchanger cooling coils to remove approximately 1,000 BTU per pound of water evaporated. For a 90-minute period, using the anticipated pressure suited man's heat load, blower and $CO_2$ absorbent heat of reaction; less than two pounds of water need be evaporated per man. For a space application where space vacuum is available, an expendable water refrigerant would be the best system. The shortcomings of this system in the laboratory are that a large size, specially adapted, high cost vacuum pumping system is required to handle the resulting large quantity of water vapor and at the same time maintain pressures low enough to produce water boiling at approximately 40°F. (A cryogenic pumping system could be designed but its operation would be inconvenient, requiring large surface areas, and a liquid nitrogen circulation system.)

The sublimation of ice at low pressure is capable of removing approximately 1,200 BTU per pound of ice sublimed, but this system has the same shortcomings of the expendable liquid refrigerant approach for a laboratory application, i.e. lack of space vacuum, plus a logistics problem of furnishing ice in space when needed.

The melting of ice will remove 144 BTU/pound of ice melted and will require approximately 10 pounds of ice per man. This system is presently used for the Mercury suit ground support cooling. In addition to a considerable weight penalty, the logistics of furnishing ice within the Evaluator and problems associated with preventing the ice from melting prior to activation of the system emergency condition are its biggest drawbacks.

Thermoelectric cooling and the conventional vapor-compression cycle are two other approaches. However, with the Evaluator evacuated there is no medium, i.e. air, to cool the hot thermoelectric junctions or to cool the condenser of the vapor compression unit. Rejecting their heat by radiation or by direct conduction into the Evaluator walls is impractical. Therefore a direct cooling medium is required, i.e., the liquid coolant from the Evaluator thermal control system. To date, thermoelectric cooling has proven to be inefficient for large size space or ground applications. Power consumption and heat dissipation needs will be many magnitudes greater than those of a vapor compression unit for the same cooling effect. Therefore, the recommended approach to thermal control (assuming the high vacuum system required for expendable liquid refrigerants is not available) is a vapor compression unit with liquid cooled condenser.

This liquid coolant would come from the Evaluator system or from an external source piped through the Evaluator walls. The cold refrigerant from the vapor compression system would circulate through a finned tube evaporator as described previously, and would provide cooling and dehumidification.

## $CO_2$ Removal

The relatively short "Emergency Mode" mission duration does not warrant the use of regenerable absorbents such as molecular sieves nor the reduction of the carbon dioxide to recover its retained oxygen. For this application expendable absorbents result in minimum weight, volume and complexity.

Among the available absorbents, lithium hydroxide and "Baralyme" were compared in detail because of their comparatively high absorption capacity and the availability of prior use experience for these materials. Lithium Hydroxide absorbs $CO_2$ according to the following reaction:

$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + HEAT$$

This exothermic reaction produces 875 BTU/lb of $CO_2$ absorbed. The theoretical absorption capacity of LiOH is approximately 0.90 lb $CO_2$ per lb. of LiOH. Lithium Hydroxide's principal disadvantage is that canister design complexities and handling difficulties arise as a result of its tendency to give off a fine powdery toxic dust.

"Baralyme" is a mixture of barium hydrate, calcium hydroxide, potassium hydroxide and a wetting agent. It has about one-half the theoretical absorption capacity of lithium hydroxide. Its reaction with $CO_2$ is also exothermic. Baralyme's principal advantages are the handling ease and simplified canister design made possible by its dustless stability. Table I illustrates the quantities of each of the above absorbents which are required for 90 minutes of operation for both one and three man systems.

Table I

Absorbent Comparison

| System | Absorbent | Quantity required @ 90% absorption efficiency |
|---|---|---|
| One man | LiOH | 0.3 lb |
| | Baralyme | 0.6 lb |
| Three man | LiOH | 0.9 lb |
| | Baralyme | 1.8 lb |

From the table it can be seen that the absorbent requirement for both compounds is small. Therefore, Baralyme has been selected for use because of its ease of handling characteristic and to permit a simplified canister design.

## Oxygen Storage Cylinder Capacity Determination

During the Emergency mode the oxygen storage cylinder must provide oxygen to make up for suit leakage and metabolic consumption. Sufficient gas must also be provided to assure a complete 100% oxygen purge cycle upon initiation of the Emergency Condition. Oxygen is supplied from an 1800 psig gaseous storage cylinder as specified.

For purposes of sizing the oxygen supply cylinder, it was assumed that suit leakage is 5.0 torr liters per second (obtained from NASA-MSC as a typical value for Apollo suit leakage.) Man's metabolic consumption was assumed to be an average of 0.94 ATM. $ft^3$/hr. The total requirement for makeup per man on the basis of the above figures comes to 1.78 ATM. $ft^3$/man-hr. or 8.0 ATM. $ft^3$ for a three man-ninety minute mission. A storage cylinder which has a capacity of 22 ATM $ft^3$ has been selected which allows some 14 ATM $ft^3$ for purging. The EBSPS internal free volume has been estimated to be 1 $ft^3$ and individual suit free volumes can be assumed as an average of 2 $ft^3$. This gives a total volume for purging of 7 $ft^3$. Fourteen $ft^3$ will give two complete oxygen changes throughout the suit circuits which should be sufficient to effectively purge the system of diluent gases.

A second back-up storage cylinder of the same size may be manifolded into the oxygen supply circuit to supply additional makeup capability for suit configurations which have higher leakage rates than that which has been assumed.

## Ventilating Flow Circulation

### Ventilating Flow Rate Range

The specific ventilating flow range and delivery pressure levels for the two system operating conditions were called out in the design requirements of the study. Past General Electric experience with suit environmental control systems substantiates that the flow rates which have been specified are adequate since the suit heat load in this application will not include any heat load from external heat sources (solar heat, etc.). Furthermore, the activity levels of the suited crewmen within the restricted confines of the Evaluator nose section are anticipated to be comparatively low and metabolic heat generation rates are assumed not to exceed 500 BTU/HR/ crewman, sensible and latent combined.

It might be pointed out that the flow rates specified do not have significant sensible heat removal capacity, particularly for the lower operating pressures occurring during the Emergency mode and therefore the crewmens' heat output is removed mainly as a latent load. At the present, this is of no consequence because most existing suits, the Apollo suit included, are essentially "sweat suits" which due to their restricted flow characteristics do not allow flow rates that have a significant sensible capacity.

The calculations shown below were performed to determine the approximate EBSPS sensible and latent heat removal capabilities, assuming that the maximum 8 CFM is passed through a suit.

Sensible Heat Removal

The mass flow corresponding to 8 CFM @ 3.5 psia and $60^oF$ suit inlet conditions is:

$$W = \frac{PV}{RT}$$

where

$W$ = mass flow, lb/hr

$P$ = pressure, $lb/ft^2$ (3.5 psia x 144 $in^2/ft^2$)

$V$ = flow rate, $ft^3/hr$ (480 CFH)

$R$ = specific gas constant, $\frac{ft.}{^oR}$ (assume 100% $O_2$, R = 48.25)

$T$ = absolute temperature $^oR = 520^o$

$$W = \frac{PV}{RT} = \frac{3.5 \times 144 \times 8 \times 60}{48.25 \times 520}$$

$$= 9.63 \text{ lb/hr}$$

Now using a specific heat for oxygen, Cp = 0.219 BTU/lb-$^oR$, the thermal capacity of the ventilating stream, $WC_p$, may be determined:

$$WC_p = 9.63 \times 0.219$$

$$= 2.15 \text{ BTU/hr}^oR$$

The sensible heat removal capability for a $25^oF$ rise through the suit is:

$$T = 85^oF \text{ (Suit Out)} - 60^oF \text{ (Suit In)} = 25^oF$$

$$Q = WC_p \Delta T$$

$$= 2.15 \times (85-60)$$

$$= 54 \text{ BTU/hr}$$

This value is based on the assumption that the suit design configuration is such that its surface film coefficients of heat transfer allow the ventilating air to experience a $25^oF$ rise. At 5 psia suit pressure, the sensible heat removal capability (for the same conditions) is 75 BTU/hr.

Latent Heat Removal Capacity

Assume that the $H_2O$ vapor pressure (specific humidity) @ suit inlet is 0.193 psia (10 mm Hg).

Now if the ventilating stream at suit outlet is $85^oF$ and 75% RH (water vapor partial pressure = 24 mm Hg) the water vapor partial pressure will increase 24-10 = 14 mm Hg (0.27 psia) as it flows through the suit. For a ventilating volume flow of 480 $ft^3/hr$ the amount of moisture picked up, W, is:

$$W = \frac{PV}{RT} = \frac{0.27 \times 144 \times 480}{85.8 \times 545}$$

$$= 0.40 \text{ lb./hr.}$$

Now, at $75^oF$ (average suit temperature) the latent heat of vaporization for water is approximately 1050 BTU/lb.

Therefore, latent heat removal capacity of ventilating stream is:

$$1050 \frac{BTU}{lb} \times 0.40 \text{ lb} = 420 \text{ BTU/hr.}$$

Thus the total heat removal capacity of the ventilating 3.5 psia stream = 420 BTU/hr (latent) + 54 BTU/hr (sensible) = 474 BTU/hr total. At 5 psia, the total heat removal capacity increases to 495 BTU/hr.

## Ventilating Flow Rate Control

Adjustment in gas flow rate to the man can be provided in many ways, such as a variable speed blower, a calibrated system vent, or a blower bypass, all of which may be governed by the man through operation of electrical controls located on the instrument panel. However, for the proposed system, it is recommended that individual manually operated valves be located in the ventilating air line at a point adjacent to the man's suit. These will provide simple and reliable control and will, as will be discussed later, fit in well with the requirement that a change in air flow made by one man not affect the air flow through the suits of the other men.

Gas circulation is provided by a blower which supplies each man with 8 cfm of gas at 740 mm Hg Evaluator cabin pressure. It will operate against a head of up to 20 inches of water of which 16 inches of water will be provided across the parallel suit branches. The remaining pressure head is needed to overcome line and valving flow losses (and the heat exchanger and $CO_2$ absorber pressure drops during emergency circuit usage). Although the design requirements specify only one suited man for the ventilating circuit, the commercial availability and cost of blowers in low flow capacities, and the need for 2-8 cfm regulation, makes it possible to provide a three man capability without increasing cost or complexity. For operation with three men, the maximum air flow requirement is 24 cfm. At constant speed, blowers move essentially the same air volume regardless of gas density; therefore, a blower selected to provide 24 cfm operating at the 3.5-5.0 psia emergency level will continue to move approximately 24 cfm through the same circuits at normal operating ventilating pressure levels (400 or 740 mm Hg), and three man operation is possible for both normal and emergency modes of operation.

An automatically controlled flow bypass circuit is employed to maintain a constant pressure ratio across the suit circuits. This constant pressure ratio is accomplished by bypassing the suit circuits with sufficient of the blower's delivery flow to maintain its total airflow delivery at a constant value.

By maintaining the pressure ratio between suit inlet and outlet (EBSPS outlet and inlet ports respectively) constant, the volume flow rate of delivery to each of the suits is maintained constant no matter what the suit operating pressure. The effect of this control technique is that no matter what flow adjustment a given crewman might make, it will have no effect upon the flow rate in the other suit circuits (because the pressure ratio across each of them is held constant). The flow bypass circuit essentially limits the maximum flow which any suit may obtain from the system, because if the individual flow adjustment valves are wide open, a maximum of 16 in-$H_2O$ pressure will be impressed across the suits, resulting in a total flow of 24 cfm. The blowers have ample capacity to deliver this total flow, thus one crewman cannot increase his airflow beyond 8 cfm at the expense of the airflow in the other suits. The blowers have sufficient reserve capacity to handle future suit designs with less flow resistance (hence, higher ventilating rates) as they evolve. This can best be illustrated by figure 8, which plots the blower flow delivery characteristic on the same coordinate axes with several EBSPS/ suit circuit back pressure characteristics.

## System Packaging Philosophy and Integration Requirements

The EBSPS module layout, GE drawing number 689E674, and figure 1 show the EBSPS as a single modular package which contains all of the components required for its operation. The components are placed in a readily accessible arrangement within the envelope in order to facilitate maintenance and servicing. Only electrical power and coolant fluid from external sources are required to operate the system. The monitoring and control panel is located on the aft face of the module and is readily accessible by either of the two seated crewmen or the third standing crewman who are stationed within the Evaluator nose section.

## Facility Support Requirement and Interface Connections

The following Evaluator - EBSPS interface connections are required:

### Electrical Connections

Electrical connections to the EBSPS are all made on the terminal strip located within the instrument and control panel.

(1) One 115 VAC, 60 cps, single phase line capable of handling 350 watts.
(2) One 115 VAC, 400 cps, single phase line capable of handling 300 watts.
(3) One line for connection of the coolant pump (located outside the evaluator) to the EBSPS control panel.
(4) One line for connection of the depressurization audio alarm signal from the EBSPS control panel to appropriate circuitry for injecting an audio alarm into the pressure suit communication system.

### Hydraulic Connections

Two lines are required to carry the water-glycol coolant from the heat exchanger to the appropriate penetrations in the evaluator wall. Approximately forty feet of 1/2" hose is furnished with the EBSPS for making these connections. The hose should be slipped over the tubing extending from the inlet and outlet fittings on the heat exchanger, clamped, and then run to the wall penetrations,

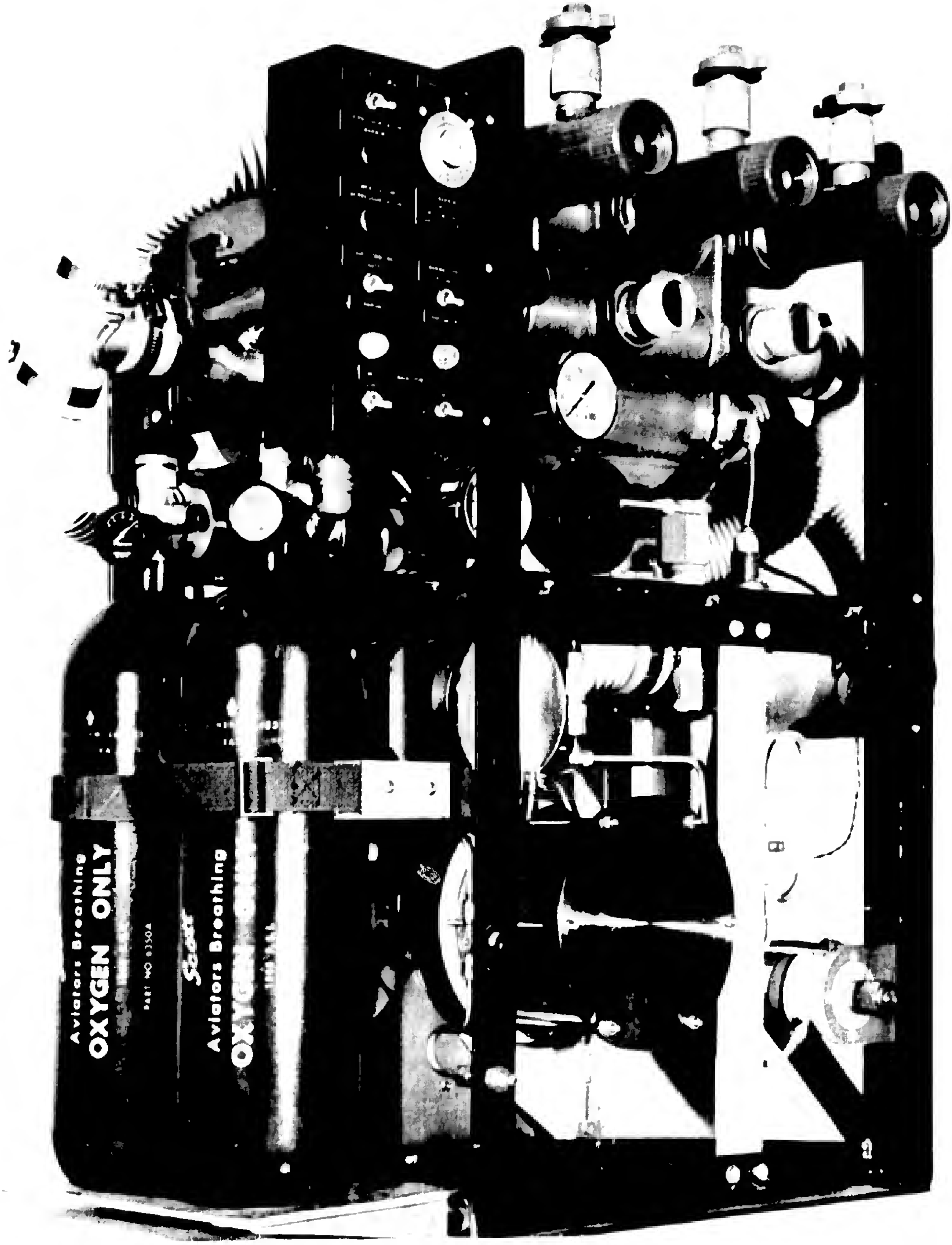

FIGURE 1 EBSPS ASSEMBLY

cut and clamped there when the unit is first installed in the life support systems evaluator.

### Instrument and Control Panel

Figure 2 shows the control panel layout. As mentioned previously, both the control panel and the suit connection ports are located on the aft face of the EBSPS module. The manual air flow adjusting valve for each of the three suit ventilating circuits is located directly above its respective airflow outlet port. Explanations of the details pertinent to each of the monitoring instruments and the control devices which are illustrated in figure 2 are presented in section below.

## System Operation

Now that the system performance specifications have been established, the various system concepts justified, and the overall packaging philosophy presented, the detailed operation of the system can be meaningfully explained. Reference will be made during this explanation, to the EBSPS mechanical and electrical schematics of figures 3 and 4 respectively.

### Normal Operation

During the normal operating mode, the Life Support Systems Evaluator is pressurized to either 400 mm Hg or 740 mm Hg, and the EBSPS serves merely to blow the evaluator atmosphere through the suits, in an open cycle ventilation airflow system. The evaluator atmosphere enters the EBSPS through one of the $CO_2$ canister isolation valves, V-1a, passes through purge valve, V-2, and gains about 20 in $H_2O$ static pressure by action of the blowers. The atmosphere then passes through the heat exchanger, which, during this normal mode of operation, is inoperative. However, if cooling of the suit air is desired, it can be activated by switching switch S4 from auto to manual. In this latter position, the EBSPS exit air temperature (suit inlet air temperature) would be controlled to $60 \pm 5^{\circ}F$. From the heat exchanger, the air enters the suit inlet manifold, passes through the individual suit flow adjust valves MV-1 and/or MV-2 and/or MV-3, is forced through the pressure suits and enters the suit outlet manifold. The pressure suit airflow can be adjusted for each of the crewmen by manually turning the suit flow adjust valve on the port to which his suit is connected. The bypass valve, V-3, maintains a constant $\Delta P$ across the pressure suits (equivalent to 16 in-$H_2O$ at sea level pressure) thereby bypassing some of the ventilating air around the suits when less than the maximum suit ventilation rate is required. From the suit outlet manifold, the air ducted to the other $CO_2$ canister isolation valve, V-1b, where it exits to the Evaluator atmosphere.

### "Emergency" Operation

The emergency mode of operation is initiated by a drop in the evaluator pressure which closes APS-1 or APS-2 (depending on the normal evaluator pressure). Upon closure of the absolute pressure switch, the oxygen purge cycle is initiated. The $CO_2$ canister isolation valves V-1a and V-1b close, cutting off the inlet and exit to the evaluator ambient, and placing the $CO_2$ canister in the airflow path. The purge valve V-2 also closes and the $O_2$ solenoid valve SV-1 opens. When the purge valve V-2 closes, it blocks the flow of air within the EBSPS system at that point, and opens the port to the relief valve RV-2. The purge oxygen flow will build the EBSPS pressure up to 3.0 psig (when 3.5

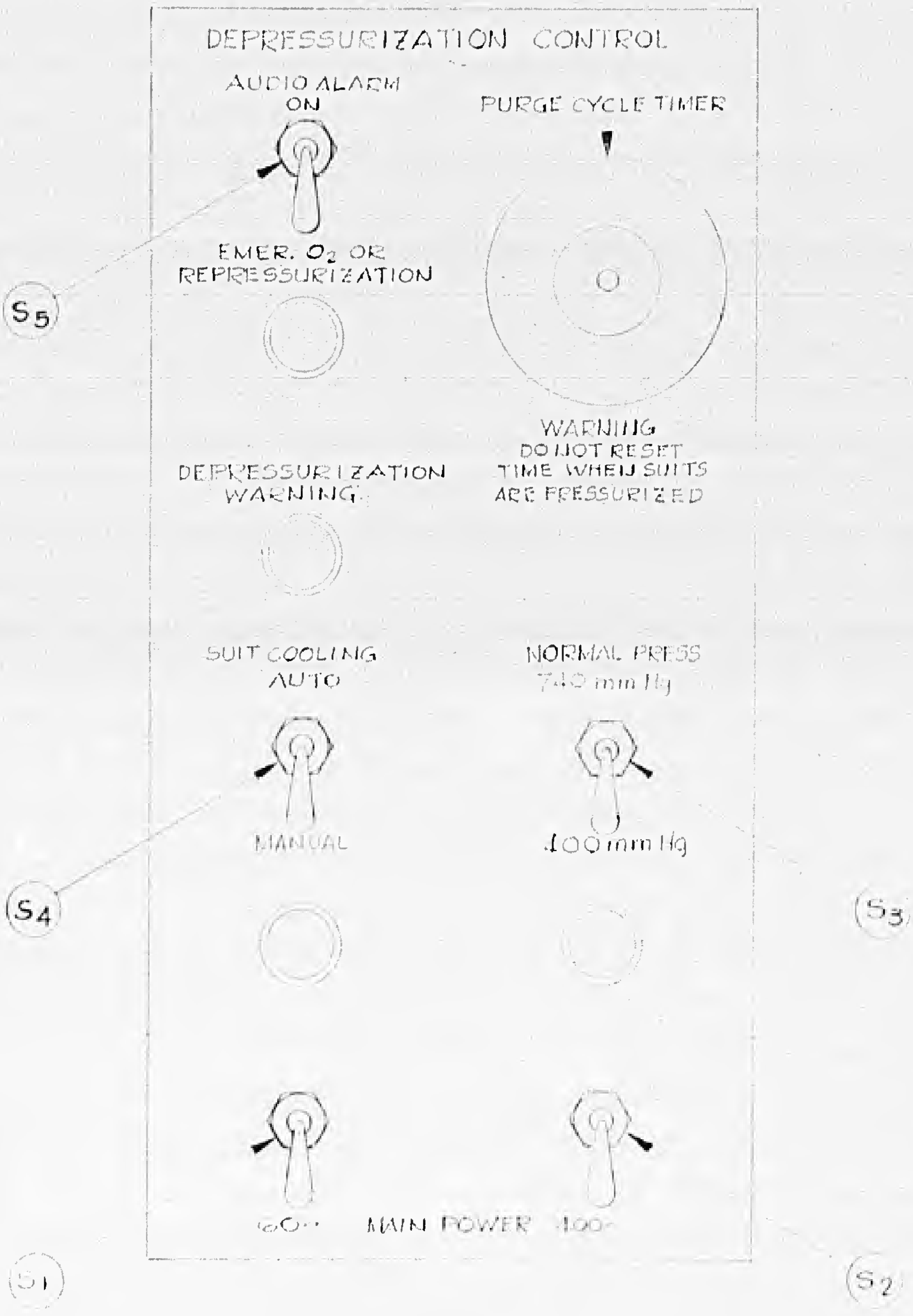

FIGURE 2 CONTROL PANEL, EBSPS

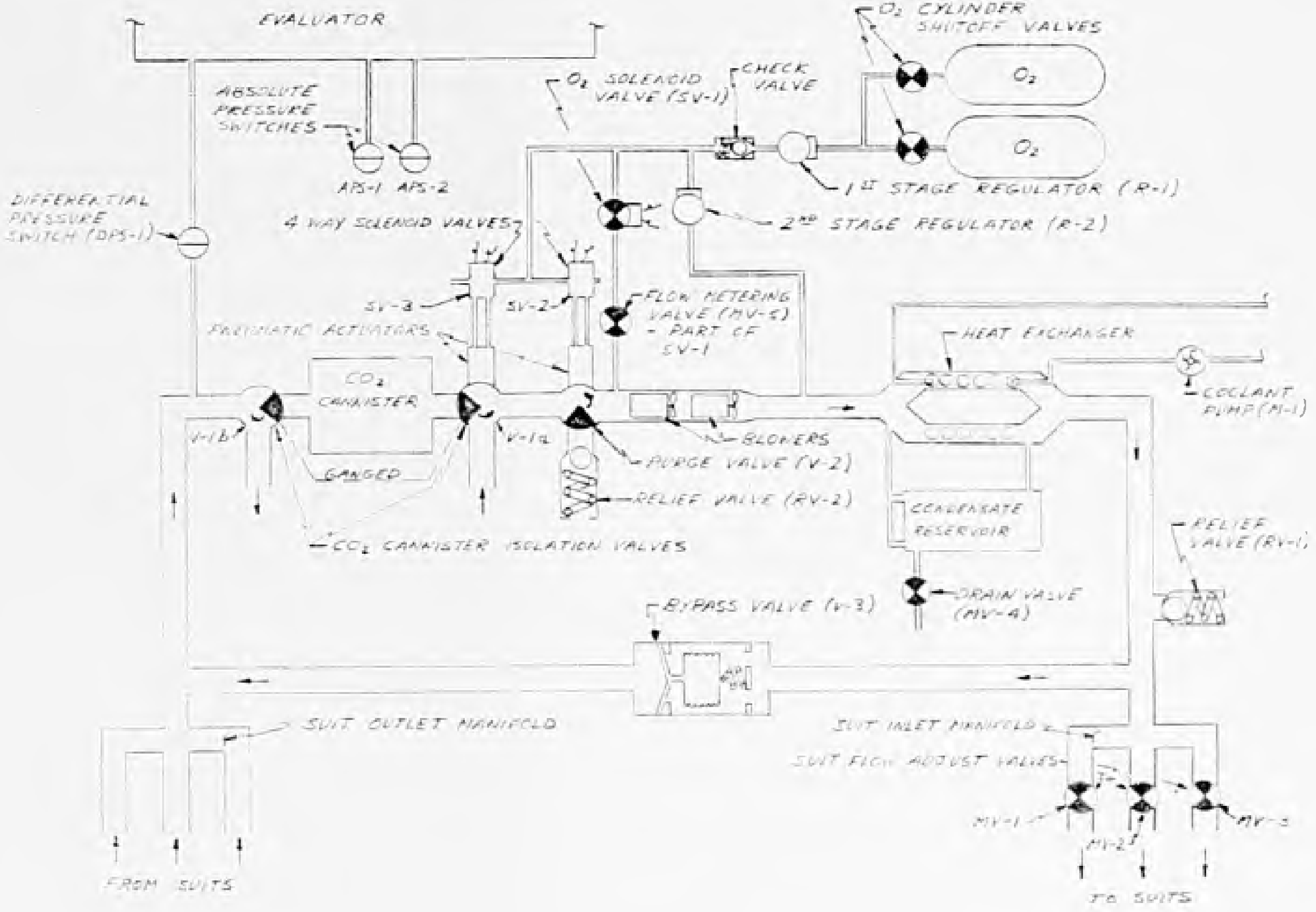

FIGURE 3 EBSPS MECHANICAL SCHEMATIC

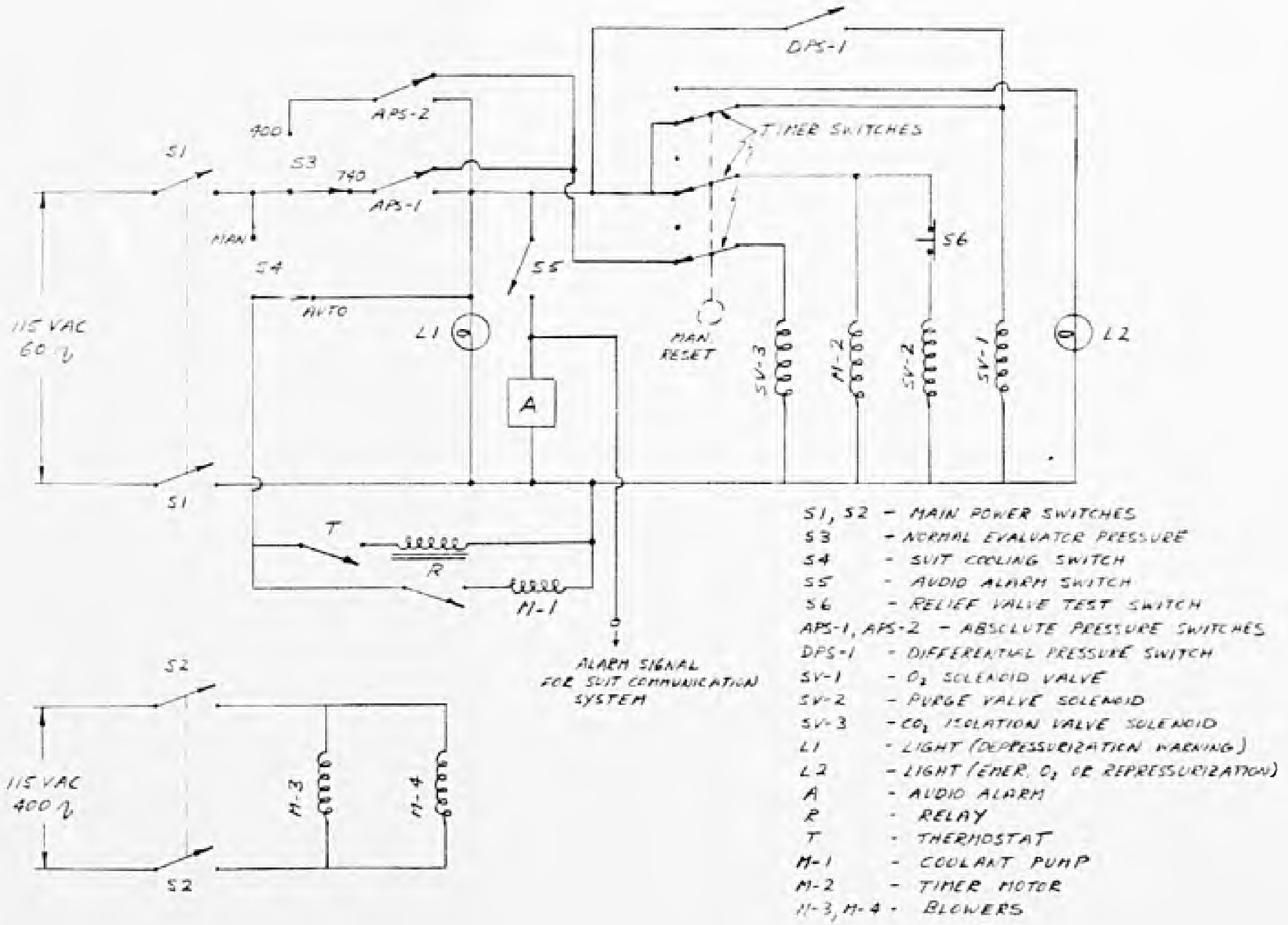

FIGURE 4 EBSPS ELECTRICAL SCHEMATIC

psi suits are used) or 4.5 psig (when 5.0 psi suits are used), whereupon RV-2 will open. Since the evaluator pressure is falling, the EBSPS pressure will also fall, but will maintain a 3.0 or 4.5 psi $\Delta$ P above the evaluator pressure. As seen from the schematic, the purge oxygen flow must pass completely through the system and pressure suits before it passes through RV-2 and exits. At the end of the purge cycle, the purge valve opens, blocking the port to the relief valve, RV-2, and the $O_2$ solenoid valve, SV-1, closes.

At the end of the purge cycle, the EBSPS internal pressure will be near 3.5 or 5.0 psia, and the evaluator (ambient) pressure will be near 0.5 psia. The timing of the purge cycle is set by the purge cycle timer, M-2, and is nominally 2.5 minutes. The purge oxygen flow is regulated by the needle valve MV-5 (an integral part of the solenoid valve) to give a minimum of two complete changes of the atmosphere within the EBSPS and the suits within this time (14 atm-$ft^3$). The timing, and thus also, the end pressures, of the purge cycle was set by calculated values of the evaluator pressure during depressurization. Some adjustment may be required to the purge cycle timing and purge $O_2$ flow when the unit is installed in the evaluator, and the actual depressurization schedule is obtained, in order that the suit pressure, at the end of the cycle, is close to 3.5 or 5.0 psia. This pressure does not have to be exact as the pressure could not go below 3.0 or 4.5 psia or above 4.0 or 5.5 psig because of the action of RV-2 and RV-1, but by being close to the emergency suit pressure, it insures a smooth transition from normal pressure to emergency pressure. More discussion of the purge cycle parameters can be found in the component description of the purge cycle timer, M-2, and $O_2$ solenoid valve, SV-1.

The heat exchanger is also initiated during the emergency mode of operation. A thermostat located in the suit inlet manifold is used to cycle the coolant pump on and off in order to maintain an air temperature of $60 \pm 5^{\circ}$F at the inlet to the suits. Thus the air flowing over the heat exchanger coils is cooled, and the water vapor condensed. The condensate drains by gravity feed to the condensate reservoir.

In the emergency mode of operation, the system is closed, and the pressure is maintained at 3.5 or 5.0 psia by a demand type pressure regulator, R-2. This admits oxygen as required to make up for leakage or metabolic consumption. $CO_2$ is simultaneously absorbed by the baralyme in the $CO_2$ canister. A 5.5 psi relief valve, RV-1, is installed to prevent possible overpressurization of the system. If desired, a 4.0 psi relief valve can be installed instead of the 5.5 psi valve, for possible better protection of the 3.5 psi suits.

As in the normal mode of operation, the bypass valve maintains a set $\Delta$ P across the pressure suits, and part of the airflow is thus bypassed. Each crewman still has the same control over his suit airflow by adjustment of the suit flow adjust valves MV-1, MV-2 and MV-3.

The depressurization warning light will be lit whenever the EBSPS is operating in the emergency mode. The audio alarm will also operate, but in this case, can be turned off, if annoying, by switching switch S5 to off. This will disconnect both the external buzzer alarm, as well as the signal fed into the pressure suit communications headset.

After the purge cycle, if the EBSPS internal pressure falls to within 2.5 psi of the evaluator pressure for any reason, e.g., excessive leakage, or fail closed condition of regulator R-2, differential pressure switch DPS-1 will close. This switch will open the $O_2$ solenoid valve SV-1 and the emergency $O_2$

light, L-2 will light. Thus, this switch acts as an emergency device, whose purpose is to insure that a minimum of 2.5 psia pressure is maintained in the suits. The differential pressure switch DPS-1 and light L-2 are also used during the repressurization of the EBSPS and evaluator cabin as explained in the following discussion.

Repressurization

When the evaluator repressurizes, the differential pressure switch DPS-1, by means of opening and closing the $O_2$ solenoid valve SV-1, maintains the internal EBSPS pressure 2.5 psi above the evaluator pressure. The emergency $O_2$ or repressurization light, L-2, will light every time DPS-1 closes and pressurization oxygen is admitted, and, in this phase, indicates that the suits are being repressurized normally. When the evaluator pressure reaches approximately 1 psi below the normal operating pressure of 400 or 740 mm Hg, APS-1 or APS-2 will open, de-energizing the depressurization warning light, L-1, the differential pressure switch DPS-1, the $O_2$ solenoid SV-1, and light L-2. Thus repressurization of the EBSPS and suits will cease at this point. When the evaluator has fully reached the normal operating pressure the suits will be 1.5 psi above the evaluator pressure, and must then be bled down to the ambient pressure. When the suits have thus been depressurized, and are at the same pressure as the evaluator ambient, the "normal" mode of operation of the EBSPS is restored by resetting the purge cycle timer to 2.5 minutes. This causes the $CO_2$ isolation valves V-1a and V-1b to open to the evaluator ambient, and the evaluator atmosphere is thus drawn into the system and circulated through the suits as described under "normal" operation previously.

## SECTION III

## COMPONENT DESCRIPTION AND DESIGN

### Heat Exchanger

The heat exchanger is housed in a six inch diameter shell, with conical diffuser inlet and exit. The heat exchanger coil is a finned tube type,* manufactured by Rome-Turney Co., and is coiled around a four inch diameter baffle within the heat exchanger housing. In operation, the water-glycol coolant is pumped through the heat exchanger coil, and the air is cooled and excess water condensed as it passes over the finned tube. The condensed water drips down to the bottom of the heat exchanger where it collects in a trough, and ultimately flows, by gravity to the condensate collection. reservoir. All parts of the heat exchanger, except the coil are made of stainless steel, to minimize corrosion problems. The Rome-Turney Co. coil is copper and the outside (air side) is coated with a solder flashing as a result of the manufacturing process. Figure 5 shows the heat exchanger configuration.

The heat exchanger was designed to provide cooling and dehumidification of the pressure suit ventilating air during all phases of the EBSPS operation. It is not optimized for zero g, and contains a large enough safety factor in the design to assure that the required heat rejection capacity is provided under all operating conditions. The calculations used in the design of the heat exchanger are as given on page 19.

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* Ref. 1 "Compact Heat Exchangers" [illegible] Kays, A. L. London, National Press, 1955 p. [illegible] fig. [illegible]

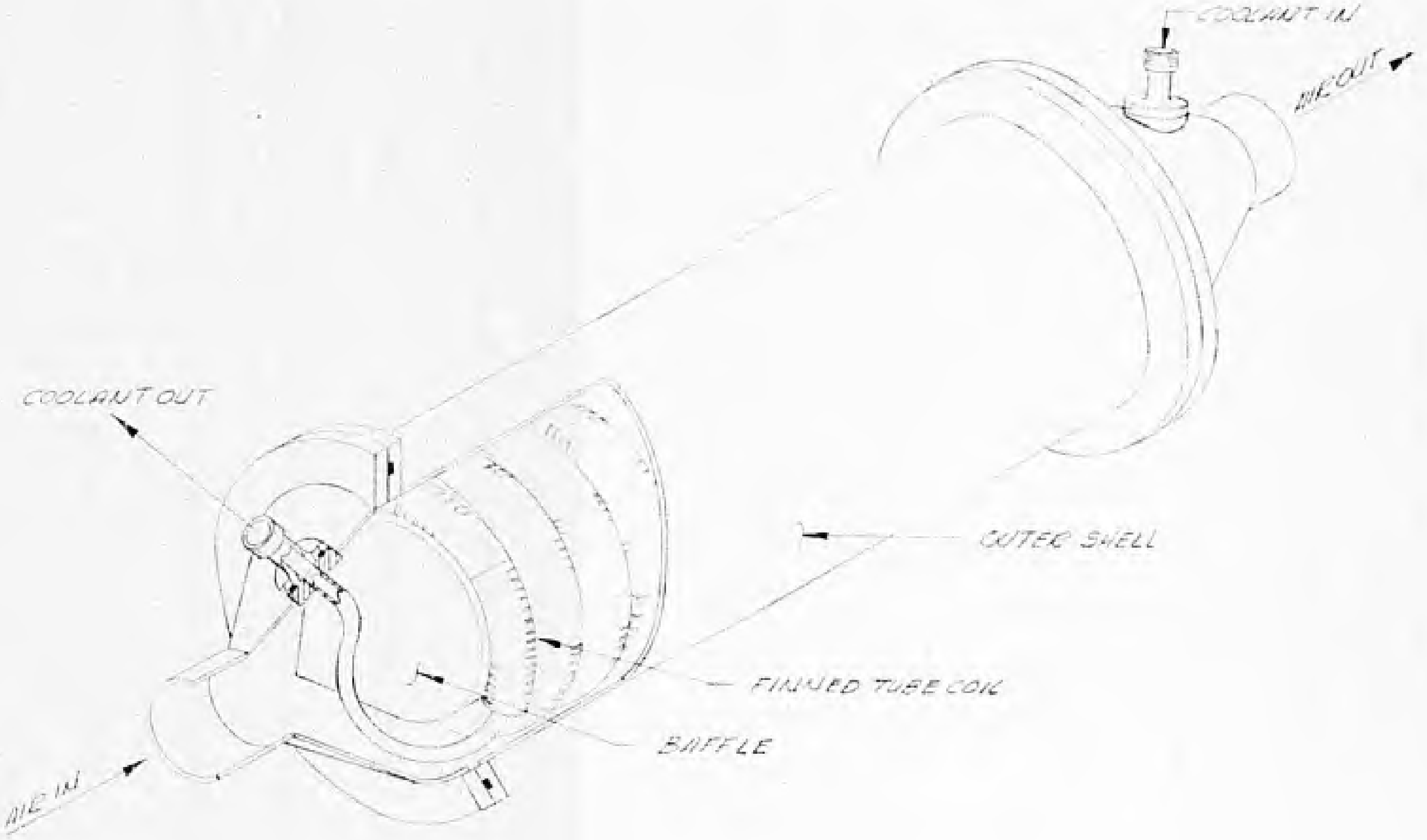

FIGURE 5 HEAT EXCHANGER

## NOMENCLATURE USED IN HEAT EXCHANGER DESIGN CALCULATIONS

$Q$ - heat flow, BTU/hr

$m$ - mass flow rate, $lb_m/hr$

$C_p$ - specific heat at constant pressure, $\frac{BTU}{lb_m - {}^{o}R}$

$T$ - temperature, $^{o}R$

CFM - cubic feet per minute

$\rho$ - density, $lb_m/ft^3$

$P$ - pressure, $lb_f/in^2$

$R$ - gas constant = 1544 ft - $lb_f/lb_m$ - $^{o}R$

$M$ - molecular wt.

$L$ - latent heat of vaporization of water, BTU/lb

Rey - Reynolds number, dimensionless

$V$ - velocity ft/sec

$r_h$ - hydraulic radius, ft

$\mu$ - viscosity, $lb_m/ft$-sec

$A$ - area, $ft^2$

$h$ - heat transfer surface film convective coefficient, BTU/hr.-$ft^2$-$^{o}F$

Pr - Prandtl number, dimensionless

$K$ - conductive heat transfer coefficient, BTU/hr-$ft^2$-$^{o}F$/ft

$U$ - overall coefficient of heat transmission, BTU/hr-$ft^2$-$^{o}F$

## Heat Load

Sensible metabolic - assume a 25°F $\Delta T$ across pressure suits (60°F to 85°F), and flow rate equals 24 CFM (actual) for three men.

at 5 psia

$$Q = mC_p \times \Delta T \text{, and since } m = (CFM)(\rho)(60) \text{ and}$$

$$\rho = \frac{PM}{RT} \times 144$$

$$Q = \frac{(CFM)(P)(M)(144)(60)(C_p)(\Delta T)}{(R)(T)}$$

$$Q = \frac{(24)(5)(32)(144)(60)(.219)(25)}{(1544)(532)}$$

$$Q = 221 \text{ BTU/hr}$$

similarly, at 3.5 psia

$$Q = 155 \text{ BTU/hr}$$

Latent metabolic - assume $pH_2O$ at the inlet air to the suits is 10 mm Hg, and the air leaving the suits is 75% saturated.

$$pH_2O \text{ inlet} = 10 \text{ mm Hg} = 0.193 \text{ psi}$$

$$pH_2O \text{ outlet} = 0.453 \text{ psi}$$

and

$$\Delta pH_2O = 0.26 \text{ psi}$$

then the total amount of water added, $\Delta H_2O$ is

$$\Delta H_2O = \frac{(CFM)(\Delta pH_2O)(144)(M)}{RT}$$

$$= \frac{(24)(.26)(144)(18)}{(1544)(530)} = .0197 \text{ lbs/min}$$

$$= 1.18 \text{ lb/hr.}$$

and

$$Q = (L)\Delta H_2O$$

$$Q = (1050)(1.18) = 1250 \text{ BTU/hr}$$

## Baralyme sensible

The heat of absorption for baralyme is 330 BTU/lb $CO_2$ absorbed then, assuming $CO_2$ output of 2.2 lbs/man/day

$$Q = \frac{(330)(2.2)(3)}{(24)} = 90 \text{ BTU/hr} \quad \text{(for 3 men)}$$

Baralyme latent

The absorption of 1 lb of $CO_2$ by baralyme produces about 3/4 of a lb of $H_2O$

$$Q = CO_2 \text{ prod} \times 0.75 \times L$$

$$= \frac{(2.2)\ (3)}{(24)}\ (0.75)\ (1050) = 210 \text{ BTU/hr}$$

Blowers

Since the blowers are completely enclosed within the system, it can be assumed that all of the electrical power consumption is dissipated as heat

$$Q = \text{pwr. (watts)} \times 3.415$$

$$= (360)\ (3.415) = 1230 \text{ BTU/hr}$$

The heat load on the heat exchanger is summarized in the following table.

| 5 psia | Sensible | Latent | Total |
|---|---|---|---|
| Metabolic | 221 | 1250 | 1471 |
| Baralyme | 90 | 210 | 300 |
| Blowers | 1230 | | 1230 |
| | 1541 | 1460 | 3001 BTU/hr |
| **3.5 psia** | | | |
| Metabolic | 155 | 1250 | 1405 |
| Baralyme | 90 | 210 | 300 |
| Blowers | 1230 | | 1230 |
| | 1475 | 1460 | 2935 BTU/hr |

The inlet temperature, $T_1$, to the heat exchanger can now be calculated

$Q = mCp\ (T_1 - T_2)$ where $T_2$ is heat exchanger outlet temperature = 60°F

Q = sensible heat load

and $m = CFM \times \rho \times 60$ where CFM = 53 (total output of blowers)

for 3.5 psia

then $T_1 = \dfrac{Q + mCp\ (60)\ T_2}{mCp\ (60)}$ or

$$= \frac{Q + (CFM)(\rho)(Cp)(T_2)(60)}{(CFM(\rho)(Cp)(60)}$$

substituting 1541 BTU/hr for Q, and the density at 3.5 psia

$$T_1 = 167^{\circ}F$$

similarly, for 5 psia, $T_1 = 138.5^{\circ}F$

The coefficient of heat transfer, h, for the air side of the heat exchanger can now be estimated

For 3.5 psia

$$Rey = \frac{\rho\, V\quad 4rh}{\mu}$$ where the properties are

evaluated at the average temperature of $\frac{T_1 - T_2}{2} = 113^{\circ}F = 573^{\circ}R$

$$\rho = \frac{PM \times 144}{RT} = \frac{(3.5)(144)(32)}{(1544)(573)} = 0.0182 \text{ lbm/ft}^3$$

$$V = \frac{CFM}{60\ A}$$ ft/sec where A is the free flow area

From ref. 1, $\sigma = 0.538$ = free flow area/frontal area and the frontal area $= \dfrac{\frac{\pi}{4} \times (6^2) - \frac{\pi}{4} \times (4^2)}{144} = 0.109 \text{ ft}^2$

Thus $A = (.538)(0.109) = 0.0586 \text{ ft}^2$

and $V = \dfrac{53}{(60)(.0586)} = 15.1$ ft/sec

also, from ref. 1, $4\ rh = 0.0154$ ft

$$\mu = 14.5 \times 10^{-6} \ \frac{\text{lbm}}{\text{ft-sec}}$$

and $$Rey = \frac{(.0182)(15.1)(.0154)}{14.5 \times 10^{-6}} = 292$$

From ref. 1, $\dfrac{h}{G\ cp} \quad Pr\ 2/3 \cong 0.022$

where $G = \rho \times V \times 3600 \quad \text{lbm/ft}^2 - \text{hr}$

and $PR = \dfrac{C_p \mu}{K} \times 3600 = \dfrac{(0.219)(14.5 \times 10^{-6})(3600)}{(.0162)}$

$PR = 0.707$

and thus $h = \dfrac{(0.022)G\ cp}{(Pr)^{2/3}} = \dfrac{(0.022)(.0182)(15.1)(3600)(.219)}{(.707)^{2/3}}$

$h = 6 \ \mathrm{BTU/hr\text{-}ft^2 - {}^{o}F}$

For 5 psia, h can be determined in a similar manner, and

$h = 8.5 \ \mathrm{BTU/hr\text{-}ft^2 - {}^{o}F}$

The above heat transfer coefficients are based on a dry airflow. Because half of the heat load is latent, and condensation takes place in the heat exchanger, the heat transfer coefficients will be higher than the above calculations show. Therefore assume that

for 3.5 psia $h = 9 \ \mathrm{BTU/hr\text{-}ft^2 - {}^{o}F}$
and for 5 psia $h = 12 \ \mathrm{BTU/hr\text{-}ft^2 - {}^{o}F}$

Now, the h for the water-glycol side of the heat exchanger can be determined.

Properties

fluid 50-50 water-glycol solution
$T$ inlet $= 50^{o}F$
$m = 1.5$ gal/min $= 0.223$ lb/sec
$\rho = 66.7 \ \mathrm{lbm/ft^3}$
$C_p = 0.775 \ \mathrm{BTU/lbm\text{-}{}^{o}R}$
$K = 0.242 \ \mathrm{BTU/hr\text{-}ft^2 \text{-} {}^{o}F/ft}$
$\mu = 0.00354 \ \mathrm{lbm/ft\text{-}sec}$

$\mathrm{Rey} = \dfrac{\rho V D}{\mu}$ where D is the tube inside diameter, ft.

$V = \dfrac{m}{\rho A}$ where A is the tube inside area, $\mathrm{ft^2}$ and equals $.000556 \ \mathrm{ft^2}$

$$V = \frac{(0.223)}{(66.7)(.000556)} = 6.02 \ \mathrm{ft/sec}$$

$$\mathrm{Rey} = \frac{(66.7)(6.02)(.0266)}{0.00354} = 3020$$

$$\mathrm{Pr} = \frac{C_p \mu}{K} \times 3600 = 40.5$$

and the generalized formula for heat transfer in this case is

$$\frac{hD}{K} = 0.022 \ \mathrm{Rey}^{0.8} \ \mathrm{Pr}^{0.33} = 46$$

and $h = \dfrac{(46)(0.242)}{.0266} = 420 \ \mathrm{BTU/hr\text{-}ft^2 - {}^{o}F}$

The temperature rise of the fluid can also be determined

$$Q = m \, C_p \, \Delta T$$

and $\Delta T = \dfrac{3000}{(0.223)(.775)(3600)} = 4.8^{o}F \cong 5^{o}F$

The amount of heat exchanger tubing required can now be calculated

For 3.5 psia

$$Q = UA(\text{LMTD})$$

where

$$\text{LMTD} = \frac{(\text{T air in-T coolant out}) - (\text{T air out-T coolant in})}{\ln \frac{(\text{T air in - T coolant out})}{(\text{T air out - T coolant in})}}$$

$$= \frac{(167-55) - (60 - 50)}{\ln \frac{(167-55)}{(60-50)}}$$

$$= 42^{\circ}\text{F}$$

now $Q = UA\ (\text{LMTD}) = 2935 = UA\ (42)$

$$UA = 70$$

and $\frac{1}{UA} = \frac{1}{\text{h air} \quad \text{A air}} + \frac{1}{\text{h coolant} \quad \text{A coolant}}$ (neglecting conduction through the tube, and using a fin effectiveness of 1)

From data of the heat exchanger tubing

$\text{A air} = 0.89\ L\ \text{ft}^2$ where L is length of tubing and
$\text{A coolant} = 0.0835\ L\ \text{ft}^2$

Therefore $\frac{1}{70} = \frac{1}{(9)(.89)L} + \frac{1}{(420)(.0835)L} =$

$$\frac{1}{8.01L} + \frac{1}{35L}$$

and $\frac{1}{L}(.125 + .0286) = .0143$

and $L = 10.7$ ft

In a similar manner, for 5 psia, L = 10.8 ft.

Thus approximately 11 ft of Rome Turney heat exchanger coil is required to reject the heat load. The heat exchanger, as designed, contains about 19.5 ft of coil, thus giving a reasonable safety factor in the design.

Condensate Reservoir

The condensate collection tank is cylindrical in shape and is 12 inches long by 4.5 inches in diameter. Its function is to collect and store the condensate condensed in the heat exchanger coils. A valve is provided to drain the condensate tank after each use of the EBSPS. Again, stainless steel was used in the construction of the reservoir to minimize corrosion problems.

The internal volume of the condensate reservoir is about 188 $\text{in}^3$. Thus it is capable of storing 6.75 lbs of condensate. Since the total amount of condensate collected during the 90 minute emergency mode of operation will, at the most, be about 2 lbs, the tank is oversized. However, it is felt that there will be times when cooling of the suit ventilating air will be desireable during normal operation of the EBSPS, and provisions for cooling during this mode have been provided. If the ventilating air dew point were above 50°F (equivalent to 75°F, 40% R. H.), condensation would take place in the heat exchanger, and thus the condensate tank is oversized to accomodate this extra amount of water.

## Purge Valve

The purge valve is located within a square aluminum housing that attaches directly to the blower housing (see fig. -6). The valve itself is a flapper that rotates through an angle of 90° by means of a pneumatic actuator which, in turn, is controlled by a four way solenoid valve. When the solenoid is de-energized, 65 psi oxygen is directed to one side of the pneumatic actuator piston, which causes the piston and rod to extend, and forces the flapper valve against the upper port, thus sealing it. A 3.0 or 4.5 psi relief valve is screwed into this upper port. Thus when the purge valve is open, the relief valve is effectively shut off from the system, and cannot operate. This is the normal position for the valve during all EBSPS operations except the purge cycle. During the purge cycle, the solenoid valve is energized and directs 65 psi oxygen to the other side of the pneumatic actuator piston, which causes the piston and rod to retract. The flapper valve is thus rotated 90° and seats against the port which leads to the relief valve. During the purge cycle, oxygen is fed into the system on the blower side of the valve, and exits from the system through the relief valve. Since the valve blocks the direct flow of oxygen from the inlet to the relief valve, the oxygen is forced to travel completely through the system before it can exit.

Since no off-the-shelf valve was found that would fully meet the requirements for the purge valve, it was designed and built by G. E. Several features are noteworthy in the design. The ports are large, being 1 1/4" in diameter, thus minimizing the pressure drop through the system. Also, the flapper valve, when rotated in either direction, is completely out of the path of the air stream, thus assuring free flow conditions. Since the pneumatic piston is always pressurized, the valve is continuously forced and held against either seat, giving leak tight operation. The valve shaft is also sealed with O-rings to insure a negligible leakage loss.

## $O_2$ Solenoid Valve, SV-1; Flow Metering Valve MV-5; and Purge Cycle Timer M-2

These three components will be treated together because they jointly control the operation of the purge cycle. The $O_2$ solenoid valve is a two way normally closed valve (opens when energized) manufactured by Wright Components, Inc. It operates on 115 VAC power, is suitable for continuous duty, and draws a maximum of 10 watts. The flow metering valve, MV-5, is built into the body of the solenoid valve and can be adjusted, by means of a screwdriver, to control the flow through the 3/16" orifice of the solenoid valve. The valve itself is suitable for operation at 80 psi, with a maximum pressure range of up to 100 psi.

The purge cycle timer is manufactured by A. W. Haydon Co. The timer motor, by means of a gear train, turns a cam shaft which actuates the three

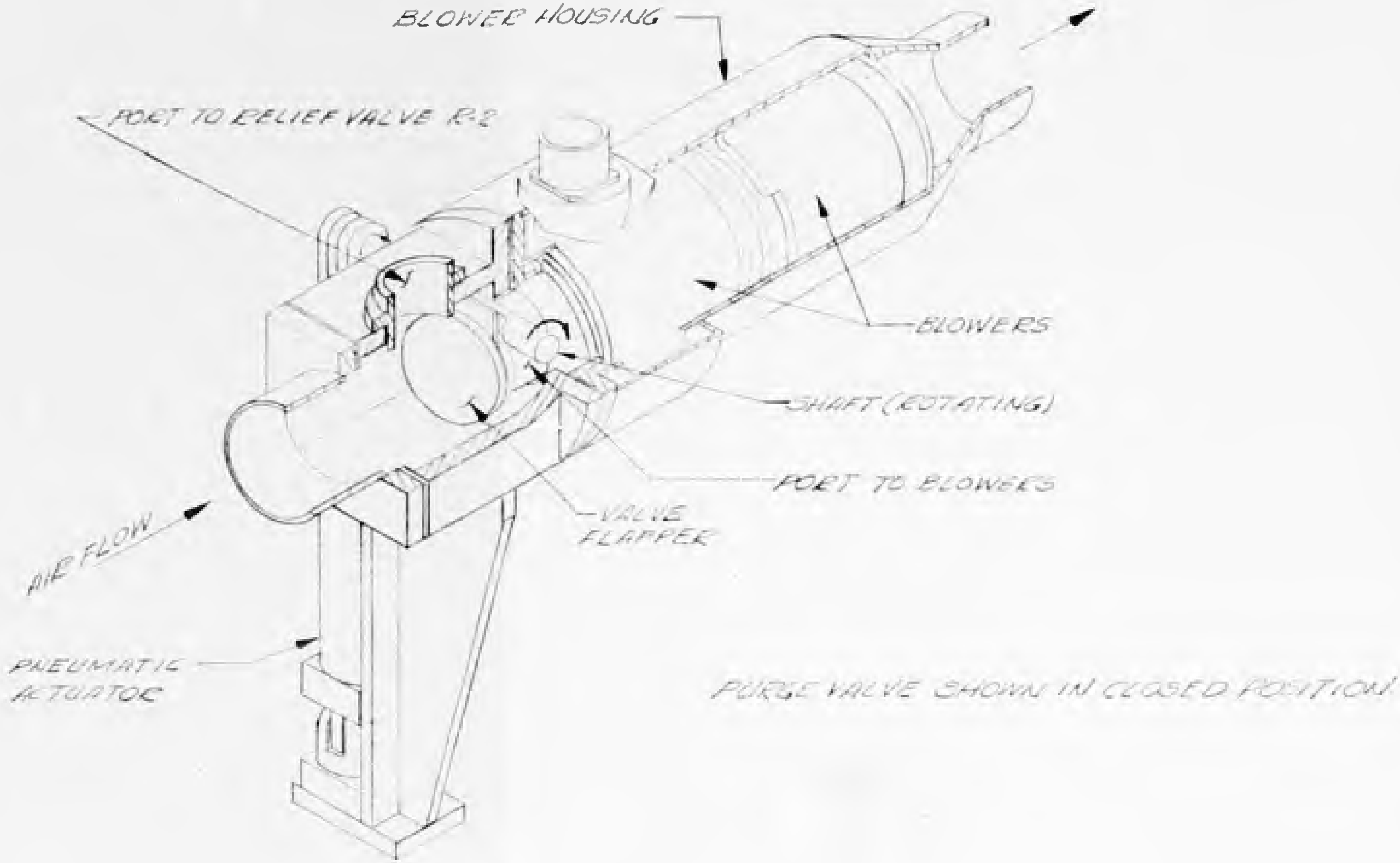

FIGURE 6 PURGE VALVE AND BLOWERS

timer switches. The timer motor operates on 115 VAC and draws about 2.5 watts. The cam shaft extends through the front face of the timer to which a dial is attached. By turning the dial, the timer can be set for any interval from 0 to 15 minutes. The three switches are used to control the various valves as shown in the electrical schematic, Figure 4 . When the absolute pressure switch APS-1 or APS-2 closes, the timer motor starts and the purge cycle is initiated by closing the purge valve and opening the $O_2$ solenoid valve. At the end of the time interval set by the dial, the three timer switches flip and the purge cycle is ended by opening the purge valve and closing the $O_2$ solenoid valve, and the timer motor stops.

As seen, the purge cycle timer controls the length of the purge cycle and the flow metering valve controls the flow rate of the purge oxygen. These two valves together determine the amount of oxygen consumed during the purge. As stated previously, about 14 ATM-$ft^3$ of oxygen should be used to purge the EBSPS and suits. This allows for a minimum two complete changes of the suit atmosphere at STP conditions during this time (assuming a 7 $ft^3$ internal volume for EBSPS and suits). (Actually, there will be more than 2 air changes since the volumetric flow rate will increase with a decrease in pressure.) Also, the purge cycle timing should correspond to the rate at which the evaluator is depressurized so that the suits, at the end of the purge cycle, are near the emergency pressure of 3.5 or 5.0 psia.

Figure 7 illustrates the purge cycle. The two curves labeled chamber pressure show the fall in chamber pressure as would be experienced in an emergency condition. These curves were calculated from available data on the pumping speed of the vacuum pumps, and the volume of the forward section of the evaluator. The upper curve corresponds to normal evaluator pressure of 740 mm Hg and the lower curve to 400 mm Hg. When the chamber pressure drops 1 psi below the normal pressure, the purge cycle starts. Oxygen is bled into the system through valves SV-1 and MV-5. In the case of the upper curves, where a 5.0 psi suit is used, the pressure in the EBSPS and suits builds up momentarily until the relief valve RV-2 opens. This valve maintains a 4.5 psi differential between the EBSPS and evaluator and thus the EBSPS pressure falls with the evaluator pressure, but remains 4.5 psi above the evaluator pressure. The purge cycle continues to a point where the evaluator pressure is 0.5 psia and the EBSPS pressure is 5.0 psia, where it is stopped. The timing required for the purge cycle can then be determined from the curve and is approximately 150 seconds. Similarly, for the lower curves which are based on a 3.5 psia suit and a 3.0 psi relief valve, RV-2, the purge cycle should stop at about 150 seconds. Some misalignment of the purge cycle timing and rate of chamber depressurization can be tolerated as the suit pressure can not exceed ± 0.5 psi of its design pressure because of the action of RV-1 and RV-2.

The purge cycle flow rate required can now be readily calculated. Since a total of 14 ATM-$ft^3$ are desired in a 2.5 min. period, a flow rate of $14/_{2.5}$ = 5.6 ATM-$ft^3$/min should be provided by adjusting the metering valve MV-5.

Since the above example of purge cycle timing is based on calculated values for chamber depressurization, it is desirous to determine, empirically, the rate of evaluator pressure loss to avoid errors. Once the actual rate of chamber depressurization is determined and graphed, as in figure 7 , the purge cycle timing can be determined as above. The metering valve, MV-5, should then be adjusted to yield a total flow of 14 ATM-$ft^3$ within this time period.

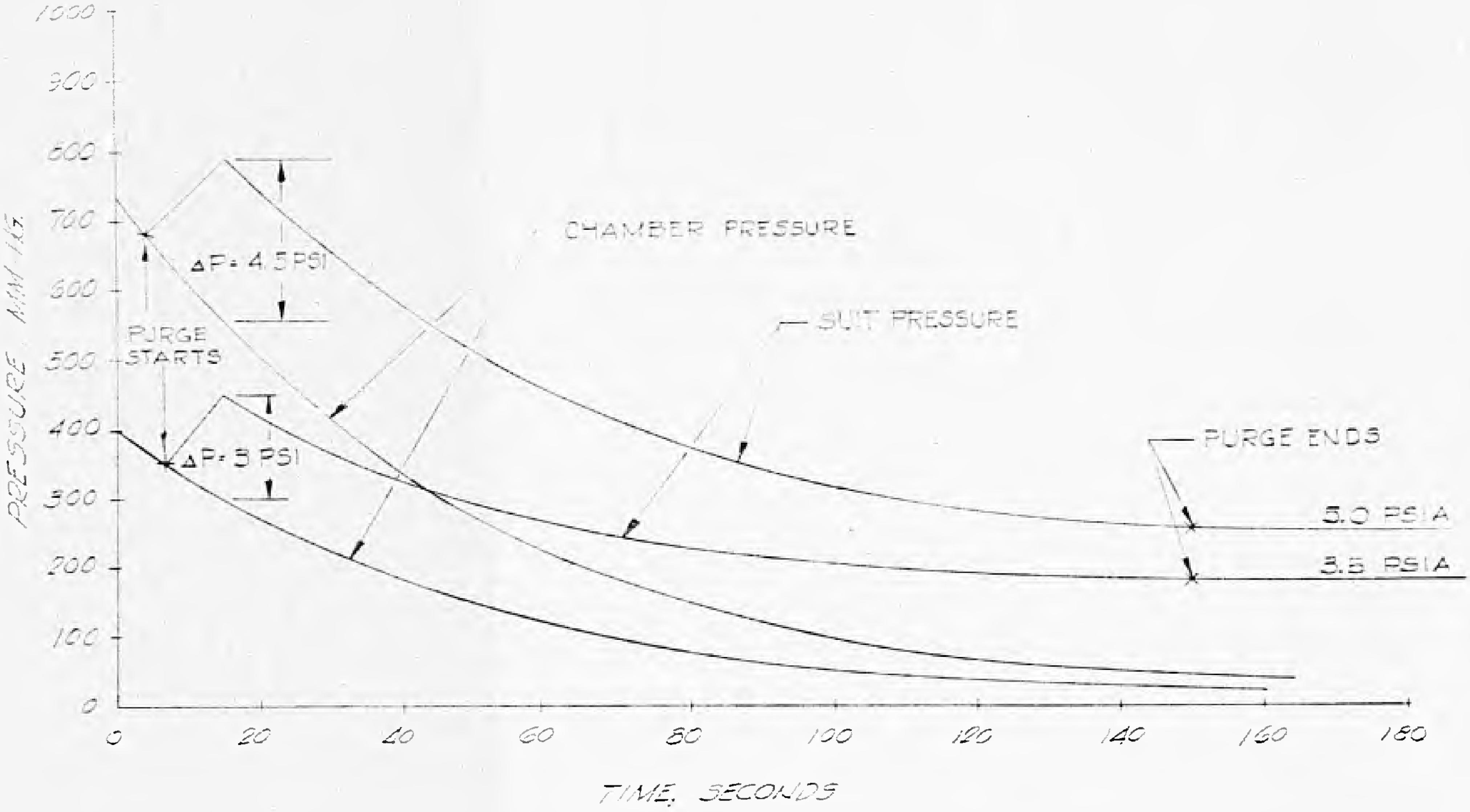

FIGURE 7 PURGE CYCLE

## Blowers

Two blowers are installed in a series flow arrangement to provide the ventilating flow for the pressure suits and EBSPS. The blowers used are manufactured by Globe Industries, Inc., type STAX-3-FC, part number 19A1073. Each blower is a 3 stage vaneaxial type, capable of providing 62 CFM @ free air conditions or 32 CFM @ 13 in-$H_2O$ static pressure. Combining both blowers in series essentially doubles the static pressure delivery, while maintaining the same CFM output. The blowers operate on 115 VAC, 400 cps, single phase power and, at the design operating point, consume approximately 170 watts each.

Figure 8 presents the performance curve for the two blowers. It also shows the flow characteristics of the pressure suit circuit and bypass valve. From these curves, an explanation can be developed of the system used to provide a ventilation flow to the pressure suits. First, the bypass valve maintains a constant $\Delta$ P of 16 in-$H_2O$ across the inlet and outlet manifold to the suits. The flow resistance curve of this bypass valve is essentially flat, because it automatically opens if the $\Delta$ P rises above 16 in-$H_2O$. When the manual flow control valves MV-1, MV-2 and MV-3 are full open, this 16 in-$H_2O$ $\Delta$P is applied directly across the suits, and a maximum flow of 8 CFM is obtained for each suit.

This normal suit circuit flow resistance is plotted on figure 8. The point where this curve crosses the bypass valve flow resistance curve is the nominal operating point for the suits (when valves MV-1, MV-2 and MV-3 are full open) and corresponds to a total flow of 24 CFM. Similarly, the point where the bypass valve flow resistance curve crosses the blower performance curve is the operating point for the blowers. This corresponds to a flow rate of 46 CFM. The difference between 24 CFM and 46 CFM represents the flow that is bypassed through the bypass valve.

The bypass valve effectively limits the maximum flow which can be forced through the suits because it limits the maximum $\Delta$ P across the suit. If more flow for the suits is desired, the bypass valve would have to be modified to maintain a higher $\Delta$ P. As seen from figure 8, if the bypass valve was blocked off or held closed, the maximum flow available for the 3 suits would be about 30 CFM. Thus the blowers have ample reserve capacity to supply higher than the specified suit flow rates if required.

It can also be seen from figure 8 that if suits with less than the specified flow resistance (16 in-$H_2O$ at 8 SCFM) are used, the maximum flow rate would be greater for the same setting of the bypass valve. The maximum suit ventilation flow obtainable from the blowers for such "free flow" suit designs would be 46 CFM at 16 in-$H_2O$ back pressure.

The curve of figure 8 is also used to show what happens when a suited crewman closes his manual suit flow adjust valve MV-1, MV-2 or MV-3. This increases the flow resistance of the suit circuit, thus decreases the flow through the suit and increases the flow through the bypass valve. The total output of the blowers is unaffected as is the flow in the other two suits, because the 16 in-$H_2O$ $\Delta$ P is maintained by the bypass valve.

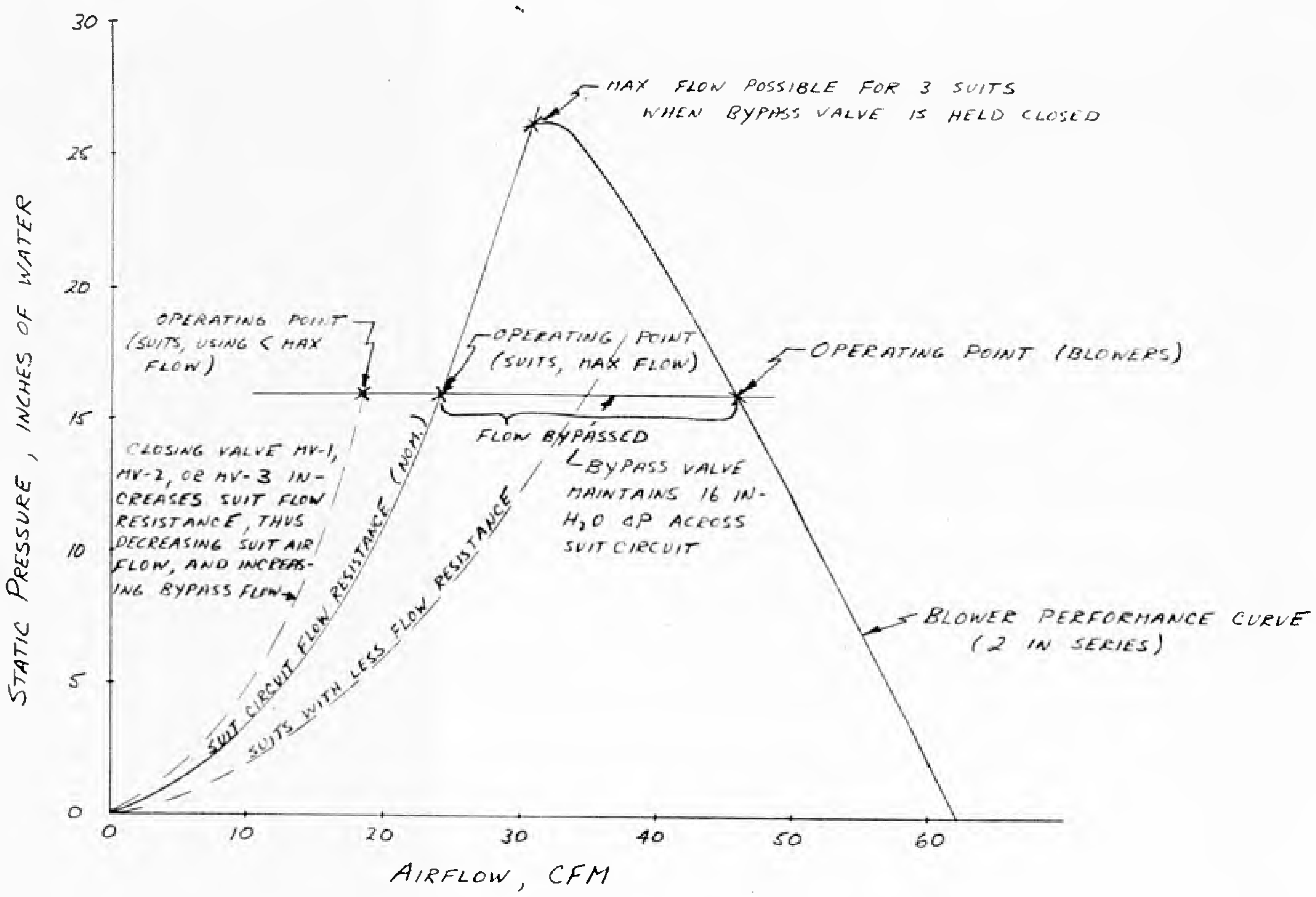

FIGURE 8 BLOWER PERFORMANCE

## Regulators R-1 and R-2

The first stage regulator, R-1, is a standard cylinder oxygen regulator manufactured by Hoke, Inc. It is capable of delivering regulated pressures of up to 140 psig, and can handle inlet pressures of up to 2500 psig. A safety relief valve is incorporated within the regulator, and is set for approximately 155 psig. A filter screen is included in the inlet connection.

The function of the first stage regulator is to reduce the oxygen bottle pressure (maximum of 1800 psi) to a fairly constant intermediate pressure suitable for the pneumatic actuators, the $O_2$ solenoid valve, and the second stage regulator R-2. In operation, the first stage regulator is adjusted to deliver 65 psig oxygen to these components, and will maintain this value until the oxygen bottles are almost empty. Because this regulator maintains a constant gauge pressure at the outlet, the absolute pressure at the outlet will drop from 80 psia to 65 psia when the evaluator is depressurized. This will not affect the operation of the system, however.

In contrast to the first stage regulator, the second stage regulator R-2, is an absolute pressure regulator. That is, it will maintain a constant absolute pressure at the outlet irrespective of the ambient pressure. This regulator is manufactured by the Linde Division of Union Carbide Corp. It can be adjusted to maintain a constant downstream pressure of 50 to 350 mm Hg absolute a . can handle inlet pressures of up to 165 psia.

The function of the second stage regulator R-2 is to maintain the EBSPS emergency pressure of 3.5 or 5.0 psia. By maintaining this pressure, the regulator automatically bleeds oxygen to the system to make up for leakage and metabolic consumption. The regulator has a demand type of action, that is, when the pressure at the outlet drops below the set pressure of 3.5 or 5 psia, the regulator opens and admits oxygen, and when the pressure rises above 3.5 or 5.0 psia, the regulator closes and stops the flow of oxygen. The regulator thus operates only during the emergency mode, as when the evaluator is pressurized, the ambient pressure is above the outlet delivery pressure of the regulator.

## $CO_2$ Canister and Isolation Valves V-1a and V-1b

The $CO_2$ canister and isolation valves are designed as one integral unit. (See figure 9.) The design of the isolation valves is similar to the design of the purge valve described previously, in fact, the ports are identical. Each valve, V-1a and V-1b, consists of a flapper which can be rotated through a 90° angle, and two ports. The two flappers are fixed to a common shaft which rotates by means of a linkage and pneumatic cylinder. The pneumatic cylinder is in turn actuated by 65 psig oxygen directed to either side of the piston by means of a four way solenoid valve. When the piston is retracted, the valves are open and both flappers are forced against the ports leading to the $CO_2$ canister while the ports leading to the evaluator ambient are open. This is the position of the valves when the EBSPS is operating in the normal mode. The ventilating air stream exits to the evaluator through V-1b and evaluator air is drawn into the EBSPS through valve V-1b. At the same time, the ports to the $CO_2$ canister are sealed off, preventing premature deterioration of the baralyme absorbent.

On the other hand, when the pneumatic actuator piston is extended, the

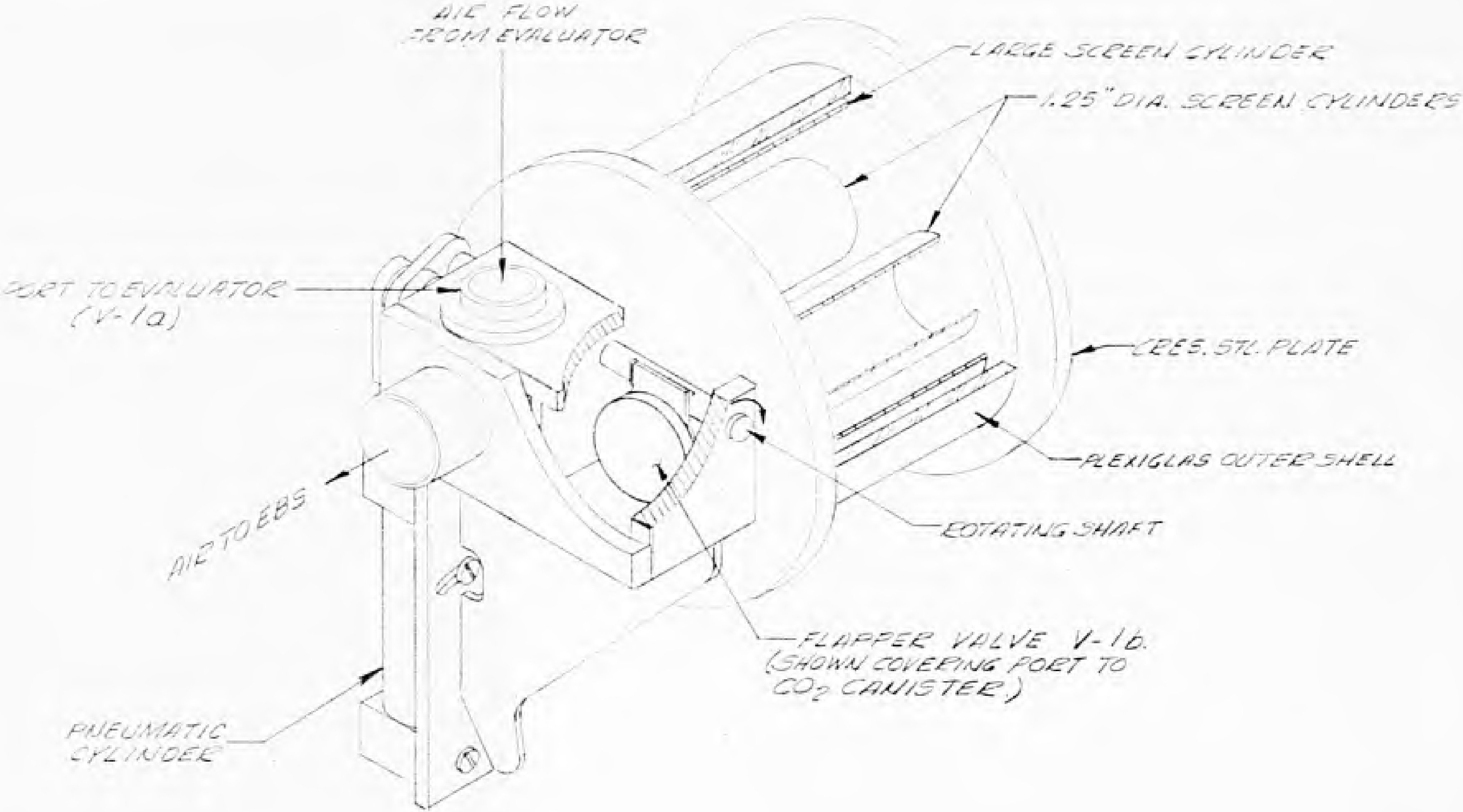

FIGURE 9 $CO_2$ CANISTER AND ISOLATION VALVES

valves close and the flappers are forced against the ports leading to the evaluator while the ports leading to the $CO_2$ canister are open. This is the position of the valves when the EBSPS is operating in the emergency mode. The EBSPS in now closed, and the ventilating air stream instead of exiting to the evaluator, flows through the $CO_2$ canister.

The $CO_2$ canister isolation valves were designed by G. E. since no off-the-shelf item was suitable for this application. Since the design is similar to the purge valve, it shares the same advantageous features. One, the ports are large, 1 1/4" in diameter thus minimizing the pressure drop. Free flow conditions are met by utilizing a 90° rotation of the flapper, thus it is completely out of the way of the air stream. The pneumatic piston, because it is pressurized continuously on either one side or the other, constantly applies force to the flapper valve, thus assuring a tight seating of the flapper over the port and negligible leakage.

The $CO_2$ canister itself consists of a plexiglas cylindrical outer shell and a stainless steel wire mesh screen inner shell concentric with the plexiglas. A stainless steel plate is butted against one end of the cylinder, while the other end is held against the $CO_2$ isolation valve assembly by six threaded rods and fasteners. When thus fitted to the isolation valves, smaller diameter (approximately 1 1/4" diameter) wire mesh screen cylinders line up with the ports leading to the valves V-1a and V-1b. These smaller cylinders run the full length of the canister, and their axis is parallel to that of the larger screen and plexiglas cylinders. The baralyme $CO_2$ absorbent is loaded between the 1 1/4" diameter wire screen cylinders and the larger diameter wire screen cylinder. A plate is inserted between the two smaller cylinders and extends to the circumference of the larger wire screen cylinder, thus cutting the canister in half.

In operation, with the EBSPS operating in the emergency mode, the airflow enters the $CO_2$ canister through port V-1b into the inside of one of the 1 1/4" diameter screen cylinders. The air then flows through the screen mesh, and passes through the baralyme between the 1 1/4" diameter cylinder and the larger screen cylinder where the $CO_2$ is absorbed. The air then passes through the larger diameter screen cylinder into the circumferential air space between this cylinder and the plexiglas. Passing halfway around the cylinder, the air next flows through larger diameter screening, through the baralyme, into the other 1 1/4" diameter screen mesh cylinder and out valve V-1a to the EBSPS.

The $CO_2$ canister was designed and built by G. E. and several comments should be made on the design. One, the plate between the two smaller screen cylinders prevents the air from passing directly from one to the other. This assures complete utilization of the baralyme absorbent, as the airflow is forced to flow equally through the entire chemical load. Secondly, the airflow through the chemical bed is directed perpendicular to the longitudinal axis of the cylindrical canister. This presents the maximum flow area to the canister airstream. Velocity through the bed is thus lowered, giving a low pressure drop and higher retention time to the ventilating air. The canister design might be called an annular flow, two-pass absorbent canister. Third, all materials used in the canister are noted for their resistance to corrosion. Thus corrosion problems, which could occur due to the caustic nature of the absorbent and the fact that water is evolved as the $CO_2$ is absorbed, are minimized.

## Bypass Valve Assembly (V-3)

The bypass valve assembly was designed specifically for this application to satisfy the design requirement that stipulates that the system must operate such that any flow adjustment (by manual valves in each suit circuit) in any one of the suit circuits must not affect the flow rate through the other suits on the line. At a single given system operating pressure this requirement could be satisfied by a spring loaded poppet type bypass valve that functions by diverting around the suit circuits varying amounts of flow, and thus maintain the blowers at the same operating point (constant delivery pressure and flow rate). Maintaining a constant delivery pressure from the blowers results in a constant flow rate through the suit circuits since flow through a suit is directly proportional to the $\Delta$ P across it and the suits are connected in parallel to the EBSPS delivery ports.

Now in order to satisfy the design requirement specified above for various operating total pressures (between 14.7 and 3.5 psia in this case), something more specialized than a simple bypass type relief valve must be utilized. Actually, a device that maintains a constant pressure ratio across the suits, no matter what the system total pressure or suit circuit flow resistances, is necessary. In order to maintain a constant volume ventilating flow rate through a given suit circuit configuration for various operating pressures, the $\Delta$ P across the suit circuit must be varied in direct proportion to the operating pressure. This is true because the pressure drop across a flow resistance varies in direct proportion to the density of the effluent and directly as the square of its velocity. Therefore, in order to maintain velocity (volume flow) constant the $\Delta$ P must be varied directly in proportion to the density (operating pressure within the system/suits). In other words, a constant pressure ratio must be maintained across the suits.

The pressure ratio controller (bypass valve) design utilizes an internally evacuated bellows and a helical coil tension spring connected in series with its poppet to bypass excess blower delivery flow (see figure 10) to accomplish the pressure regulation function described in the preceding paragraph. At standard pressure (14.7 psia) the bellows is compressed to a nearly nested position by the surrounding pressure and the tension spring is extended such that approximately 18" W.G. is required to unseat the poppet. With no flow through the suits approximately 44 CFM would be passed through the valve, at design flow (24 CFM) through the suits approximately 20 CFM are passed through the valve. Over this entire suit ventilating flow rante (6 to 24 CFM) the pressure ratio controller maintains blower delivery pressure at 18 ± 1" W.G. which corresponds to the design requirement $\Delta$ P across the EBSPS outlet and return ports of 16 ± 1" W.G.

Now, as system operating pressure is decreased the bellows will expand due to the lowered surrounding pressure and the spring tension (poppet unseating pressure) will be correspondingly reduced linearly with operating pressure. Thus, blower delivery pressure ( $\Delta$ P across the suits) will be varied in direct proportion to operating pressure and the design requirement is satisfied as discussed above (e.g. at 1/2 atmosphere pressure suit $\Delta$ P will be 8" W.G. instead of 16" W.G. and so forth).

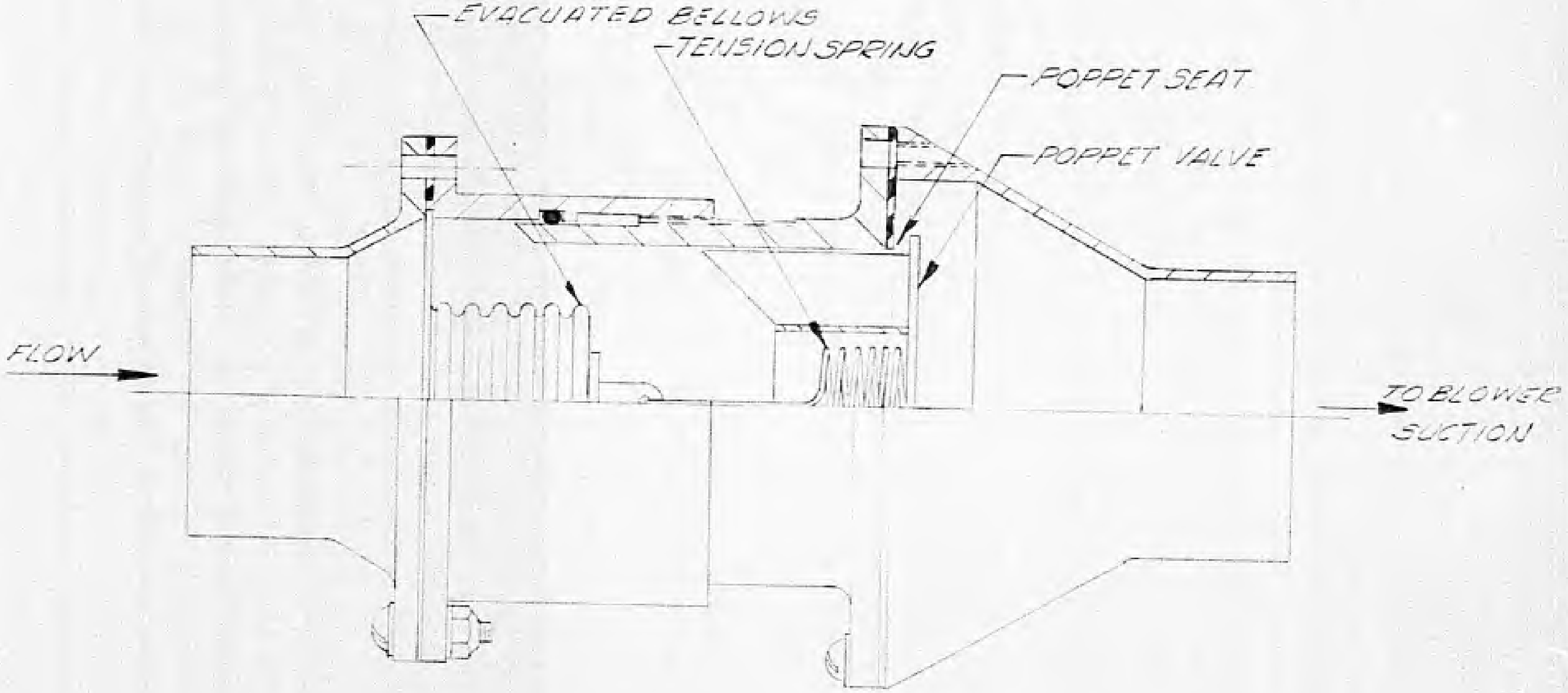

FIGURE 10 BYPASS VALVE

# SECTION IV

# EVALUATION TEST PROGRAM

Following completion of the program hardware fabrication phase, the EBSPS underwent evaluation and acceptance tests.

## Test Objectives

The primary objectives of the tests performed at G. E. were to check out the system to ascertain that it was functioning properly, and to test certain key equipment to establish that their performance was within the limits imposed by the specification.

## Test Results

The system was checked out satisfactorily in the laboratory. All components were found to operate in the normal and proper sequences as called for in the system check out procedures.

System leakage was minimal, on the order of 50 to 100 cc/min which is 5 to 10 times less than the leakage expected from one pressure suit.

The EBS blowers are capable of delivering the maximum airflow of 24 CFM to the suits at the specified back pressures at 3.5, 5.0 and 14.7 psia total pressure.

The second stage regulator is capable of delivering gas at 3.5 or 5.0 psia to the EBSPS. The regulator was adjusted for each of these pressures and adjustment knob and shaft marked at each setting. The marked settings were then checked for repeatability accuracy by unscrewing the adjustment knob, then turning it back to each marked setting. When the regulator is thus set to either mark, the outlet delivery pressure will be within ± 0.1 psia of the intended pressure of 3.5 or 5.0 psia.

The $O_2$ solenoid valve and integral flow metering valve were adjusted to (and are thus capable of delivering) deliver 5.6 SCFM at an inlet pressure of 65 psi.

With glycol coolant flowing in the heat exchanger, the thermostat maintained an outlet air temperature of 60 ± 5°F to the suits, by means of cycling the coolant pump on and off.

During evaluation and acceptance tests at AMRL, the EBSPS system was operated in the altitude chamber under preselected flight test conditions. Tests involved a full pressure suited airman being sustained at varied reduced pressure levels. The system continued to operate satisfactorily, demonstrating its capability to meet the specified design requirements.

# SECTION V

# CONCLUSIONS

The following conclusions can be derived as a result of this program:

All phases of this program as reported herein have physically satisfied the objectives and requirements set forth at the inception of the program.

All subsystems and components functioned as intended, and their performance was within the specification limits.

The Emergency Breathing and Suit Pressurization System is a suitable means for providing ventilating airflow for pressure suited astronauts, when the suits are unpressurized, but the cabin is pressurized.

The Emergency Breathing and Suit Pressurization System is a suitable means for providing secondary pressure protection and conditioned viable atmosphere to pressure suited astronauts, when a failure of the cabin pressure occurs.

The check out and evaluation tests which have been performed indicate that the system should satisfy all the design goals specified in the performance specification.

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13 ABSTRACT

The design and fabrication of an Emergency Breathing and Suit Pressurization System (EBSPS) that is capable of sustaining three full-pressure suited crewmen within the AMRL Life Support System Evaluator has been investigated. Two operating modes are provided. One, when the Evaluator is pressurized, the Emergency Breathing and Suit Pressurization System operates as an open loop system and ventilates the pressure suit with the ambient air. Two, when the Evaluator is depressurized, the Emergency Breathing and Suit Pressurization System operates as a closed environmental control system, and provides the crewmen with a habitable atmosphere. In this latter mode, the system regulates the suit pressure, the $CO_2$ partial pressure, relative humidity, composition (100% $O_2$), and temperature of the ventilating air, and supplies oxygen for breathing and leakage make up as required. In all modes, the Emergency Breathing and Suit Pressurization System regulates the flow of ventilating atmosphere through the pressure suits.

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| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Pressure suits | | | | | | |
| Pressure breathing | | | | | | |
| Flight clothing | | | | | | |
| Emergency Breathing and Suit Pressurization System | | | | | | |
| Life Support Systems Evaluator | | | | | | |
| Habitable atmosphere | | | | | | |

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