AMRL-TR-66-246

A CLOSED SYSTEM RESPIRATORY EVALUATOR

MAX SUSSMAN

GENERAL AMERICAN RESEARCH DIVISION
GENERAL AMERICAN TRANSPORTATION CORPORATION

OCTOBER 1967

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AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the General American Research Division of the General American Transportation Corporation, 7449 North Natchez Avenue, Niles, Illinois, under Contract AF 33(615)-2830. The contract was initiated by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, under Project Nr. 6373, "Equipment for Life Support in Aerospace," Task Nr. 637305, "Analysis and Integration of Life Support Systems." Mr. J. Arthur Brown, Biotechnology Branch, Life Support Division, Biomedical Laboratory, served as Contract Monitor.

The research and development work reported herein was performed for the General American Transportation Corporation by Mr. Max Sussman, Project Scientist. Mr. Joseph Ferro and Mr. Thomas Linnenbrink of the General American Transportation Corporation assisted in the development and fabrication. Work under the contract was initiated in July 1965 and was completed in July 1966.

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This technical report has been reviewed and is approved.

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ABSTRACT

The development of a closed system respiratory evaluator (CSRE) is described. The CSRE simulates human respiration and performs all the metering, sensing, and recording functions necessary to evaluate the performance of space cabin simulators, pressure suit systems coupled to their environmental control systems, environmental control systems, life support systems, and rescue and survival systems. The respiratory functions simulated include oxygen consumption and carbon dioxide, water vapor and heat production. Oxygen consumption is simulated by physically extracting from the system under test gas at a rate sufficient to equal the oxygen consumption rate. Carbon dioxide production is simulated by bleeding carbon dioxide into the system from a storage bottle. Water vapor is introduced by a conventional type humidifier while heat is added by an electrical radiator. The gas rates and heat are computed and automatically controlled by an analog-computer-directed electromechanical control system. The system thereby avoids the delicate problems of control, balance, undesirable by products, and erratic performance found in systems utilizing adsorption-absorption techniques, catalytic oxidation, or organic materials oxidized to provide the correct carbon dioxide, water, and heat input with simultaneous oxygen removal.

The desired values of the parameters of human respiration may be set independently of each other. The CSRE can remove oxygen at a rate of 0.06 to 0.80 pounds per hour at STP, add carbon dioxide at a rate of 0.07 to 0.90 pounds per hour, add water vapor at a rate of 0.07 to 1.00 pounds per hour and add sensible heat at a rate of 240 to 4800 BTU per hour. When the chamber (or space cabin simulator) is occupied by human subjects, the CSRE can perform gas analysis and, with slight modification, can provide a two-gas control system.

An adjustable automatic chamber pressure control system is also provided which maintains the chamber pressure within ± 20 mm Hg. A leakage simulation test system allows testing with leakage rate of from 1.5 to 36 cubic feet per hour at chamber pressure.

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SECTION I

INTRODUCTION

BACKGROUND

Aerospace life support systems must be tested for prolonged periods of time in order to obtain accurate data on system performance and reliability. These tests can be hazardous to human subjects, especially with closed respiratory systems such as algae gas exchangers or chemical reduction - electrolysis units. (Reference 1) Difficulties also arise in attempting to determine equipment and system performance when utilizing a number of human subjects during a series of comparative tests because human respiratory outputs are time variant and nonstandard. An apparatus capable of simulating the respiratory and heat producing processes of a human is, therefore, needed to perform complete, repetitive evaluations of closed respiratory systems before they are used by humans. The Closed System Respiratory Evaluator (CSRE) was developed to satisfy this need. (Reference 2) It not only simulates the human processes referred to above but also simulates certain life support system conditions and provides the necessary instrumentation and recording capability for evaluating life support system performance.

Among the closed respiratory systems that can be evaluated by the CSRE are those employed with emergency and rescue shelters, pressure suits and environmental control systems.

The CSRE was designed for use with the existing Life Support Systems Evaluator (LSSE) (Reference 3) and the Space Vehicle Environment Simulator (SVES) chamber facilities available at the Life Support Systems Division of the Aerospace Medical Research Laboratories. These facilities serve as research tools for determining the technical feasibility of techniques and principles involved in the operation and design of life support equipment through integrated evaluation studies. These studies are planned to develop optimal life support systems, including respiratory equipment, nutritional support, and waste management. The broad spectrum of work involved in biologistics and bioastronautics can also be studied. These facilities are normally monitored utilizing consoles having special purpose gas analysis equipment, total pressure sensors, temperature and humidity sensors, each complete with visual display and recorder printout. (Reference 4) These consoles, as described, also include the necessary communications and closed circuit television for simultaneously monitoring the well-being of human subjects confined to either, or both, of these facilities.

SYSTEM REQUIREMENTS

The features required by AMRL for the Closed System Respiratory Evaluator (CSRE) are briefly summarized for reference purposes.

1. The CSRE shall be designed to be used in conjunction with the existing AMRL facilities to simulate the breathing functions of from one to six men (Reference 5) under various conditions of temperature, pressure and atmospheric composition maintained within the selected chamber.

2. The CSRE shall incorporate all necessary instrumentation to sense, visually display and automatically record the performance of the CSRE and the various chamber parameters.

3. The gas analysis instrumentation shall operate independently of the metabolic and heat units to permit monitoring of the chamber parameters when the selected chamber is occupied by human subjects.

4. A subsystem of the CSRE shall have the capability of simulating chamber outboard leakage. Controls and facilities shall be provided to select and maintain outboard leakage rates of 1.5 to 36 cubic feet per hour at chamber test pressure and temperature.

5. An automatic system to maintain selected test chamber pressures to ± 20 mm Hg tolerance shall be provided. Test chamber pressures will be between 200 and 800 mm Hg.

6. Provisions shall be incorporated to permit the evaluation of a single pressure suit without the need for a human subject.

7. Controls shall be provided to select and maintain:

a. An oxygen extraction rate of 0.06 to 0.80 pounds per hour.
b. A carbon dioxide injection rate of 0.07 to 0.90 pounds per hour.
c. A water vapor addition rate of 0.07 to 1.00 pounds per hour.
d. A heat addition rate of 320 to 4800 BTU's per hour.

Three ranges of control of the oxygen extraction, carbon dioxide injection, heat and water addition shall be provided to simulate 2, 4, or 6-man operation.

8. Controls shall be provided to enable selection of perspiration "break point" temperature and rate of perspiration as a function of temperature rise within the selected chamber.

9. Controls shall be provided to replace any inert gas, e.g., nitrogen or helium, extracted along with oxygen.

10. Instrumentation shall be provided to sense, indicate, and automatically record the following parameters:

a. Partial pressures of oxygen, carbon dioxide, carbon monoxide, nitrogen, and water vapor.

b. *Mass flows of extracted oxygen, injected carbon dioxide, and added water vapor.
c. Heat input rate.
d. Relative humidity.
e. Ambient room pressure.
f. Chamber pressure (i.e., gas analyzer loop).
g. Chamber temperature.

11. The CSRE shall be capable of continuous operation for periods of up to 90 days.

APPROACH

The breathing of a man in a closed compartment can be simulated in several different ways. The method used in the CSRE considers the overall effects of isolated human respiratory processes (e.g., in a closed compartment) and then reproduces these effects on an average basis. Each constituent gas involved is independently controlled so that normal respiration can be simulated and, when desired, abnormal constituent values can be simulated. The wide spectrum of selectable parameter values enables extreme limit testing of the life support systems considered. The ability to readily select input-extraction values makes it possible to perform repeat or comparison tests of life support systems at precise, selected values of the various metabolic products and oxygen consumption.

This respiratory system is described in the remainder of this report.

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* These flows are based on precalibrations rather than sensed by injection.

SECTION II

TECHNICAL DISCUSSION

The following discussion begins with a brief description of the CSRE, including both its physical and operational characteristics. Then its overall capability will be compared with the requirements specified in the work statement. The CSRE is then described in detail in Section III.

An Operation and Maintenance Manual (Reference 6) was delivered to AMRL with the CSRE. Included with the manual were pneumatic, electric, and mechanical drawings, and equipment manufacturer's instruction books.

GENERAL DESCRIPTION OF CSRE

The CSRE comprises six different units or packages. A pictorial view of the Closed System Respiratory Evaluator main console is shown in Figure 1. The main console contains all the controls and calibrating equipment for the entire system. It is located in the main control room.

A second unit, the gas bottle rack, shown in Figure 2, supplies all the calibration gases needed. This rack holds up to six gas cylinders, four of which are piped through a system of valves so that a selection of either one of two calibration gas mixes can be made at the main console. This rack is located directly outside the main control room.

One-hundred-percent gases are supplied from single purpose AMRL gas manifolds.

The relative humidity and temperature probes package (Figure 3) is located within the test chamber and connected directly to an outlet so that the extracted gas stream flows through it just prior to entering the large hose connected to the extraction pump in the console. The relative humidity and temperature of the extracted gas is sensed here. The relative humidity sensor is a lithium chloride type. Both resistance-type temperature probes sense outlet gas temperature. One of the probes senses the outlet gas temperature for display on the main control panel and for the recorder. The other probe senses the outlet gas temperature for use in the breakpoint circuit.

The heat and water production unit, shown in Figure 4, is located within the selected test chamber. The metabolic heat and water injected into the test chamber are introduced via this unit. During tests involving the chamber only, the end domes are removed. During suit testing, the end domes are emplaced and a large variety of suit loops can be achieved by using the various available ports. A water inlet port is provided which can be permanently emplaced.

Figure 1. MAIN CONSOLE

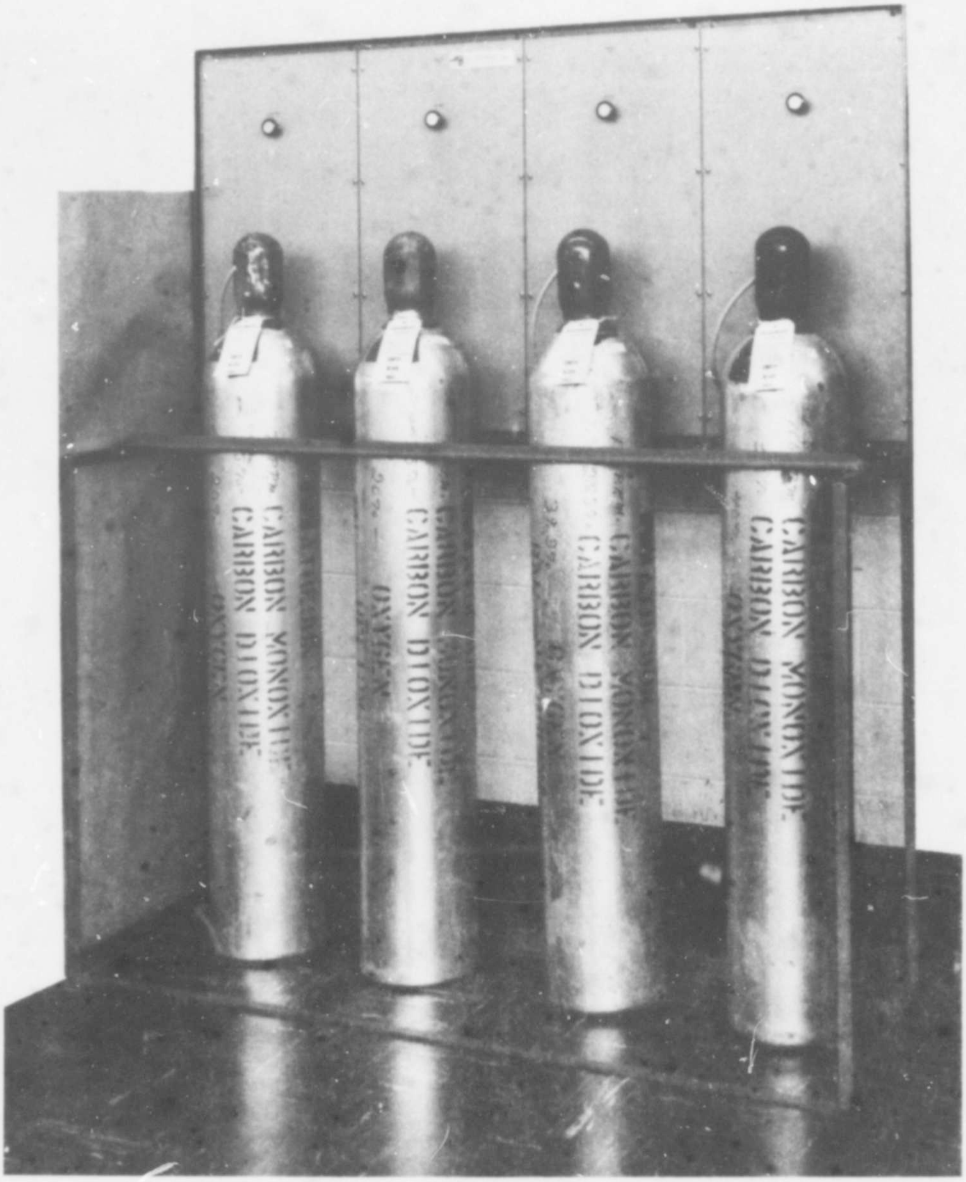


Figure 2. GAS BOTTLE RACK

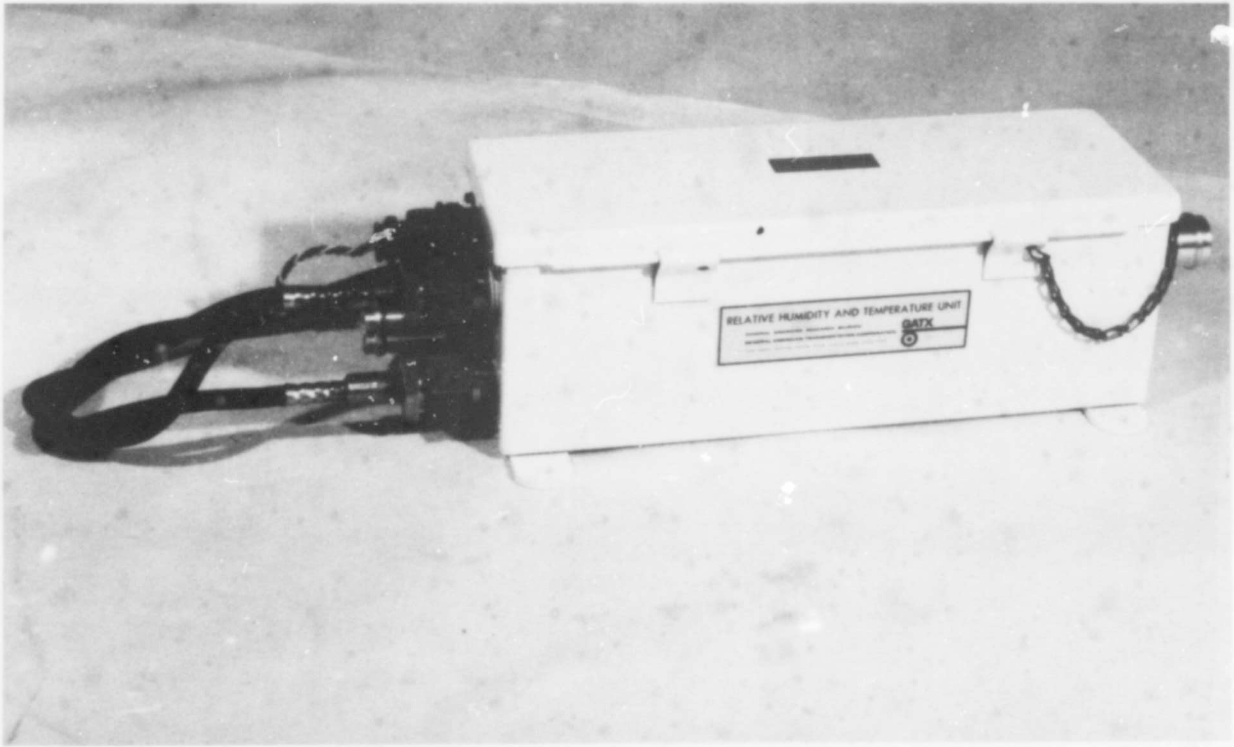


Figure 3. RELATIVE HUMIDITY & TEMPERATURE PROBES PACKAGE

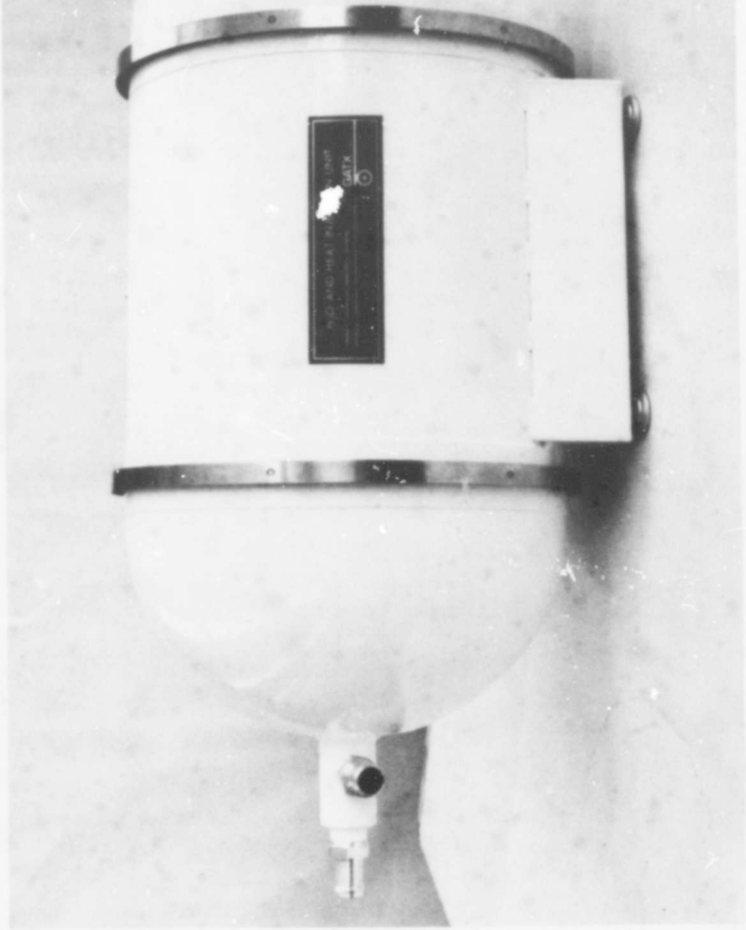


Figure 4. HEAT AND WATER PRODUCTION UNIT

The water control unit (Figure 5) is located on the roof over the LSSE test chamber room. This unit meters in water as demanded at the main control console.

The chamber pressure maintenance unit (Figure 6) is located adjacent to the water control unit. This unit automatically extracts gas from the test chamber if the test chamber pressure exceeds a preset level. It also has provisions for injecting gases to build up the test chamber pressure if the pressure falls below the preset value. AMRL selects and supplies the gas or gas mixture judged suitable to make up any deficiencies.

The CSRE simulates the gas exchange during breathing of up to six men by extracting the amount of oxygen these men would inspire under various conditions and injecting the amount of carbon-dioxide, water vapor and heat they would give off. The ranges of operation are:

(1) Oxygen extraction	0.06 to 0.80 pounds per hour
(2) Carbon-dioxide addition	0.07 to 0.90 pounds per hour
(3) Water vapor production	0.07 to 1.0 pound per hour
(4) Heat production	240 to 4800 BTU/hr.

The inert gas, which can be either nitrogen or helium, is added to account for that lost during oxygen extraction. In addition to the above, the parameters listed in paragraph 10 on page 2 are measured, displayed, and recorded. The recorded values of the programmed extraction-injection quantities are not effected by the X1, X2, and X3 range multipliers. The values recorded are direct reading as noted on page I-2 of the Operation Manual (Reference 6).

A general system block diagram of the simulator portion of the system is shown in Figure 7. The oxygen is extracted by pumping out from the test chamber the volume of gas containing the amount of oxygen to be removed. This is accomplished in closed loop fashion by comparing the desired oxygen mass flow rate, as determined by a dial setting on the control panel, with the actual mass flow rate, as developed by the oxygen mass flow computer, and controlling the extraction flow rate to bring the two into correspondence. Since the extracted gas also contains carbon-dioxide, water vapor and inert gas, corresponding amounts of these are also removed. These gases are later replaced.

The proper amount of carbon dioxide is injected by controlling the flow from a high pressure carbon dioxide source to the system under test by means of a time-modulated control system. The actual rate of carbon dioxide injection is equal to the desired rate, as set by a dial, plus the loss-rate during oxygen extraction, which is determined by the carbon dioxide mass flow computer.

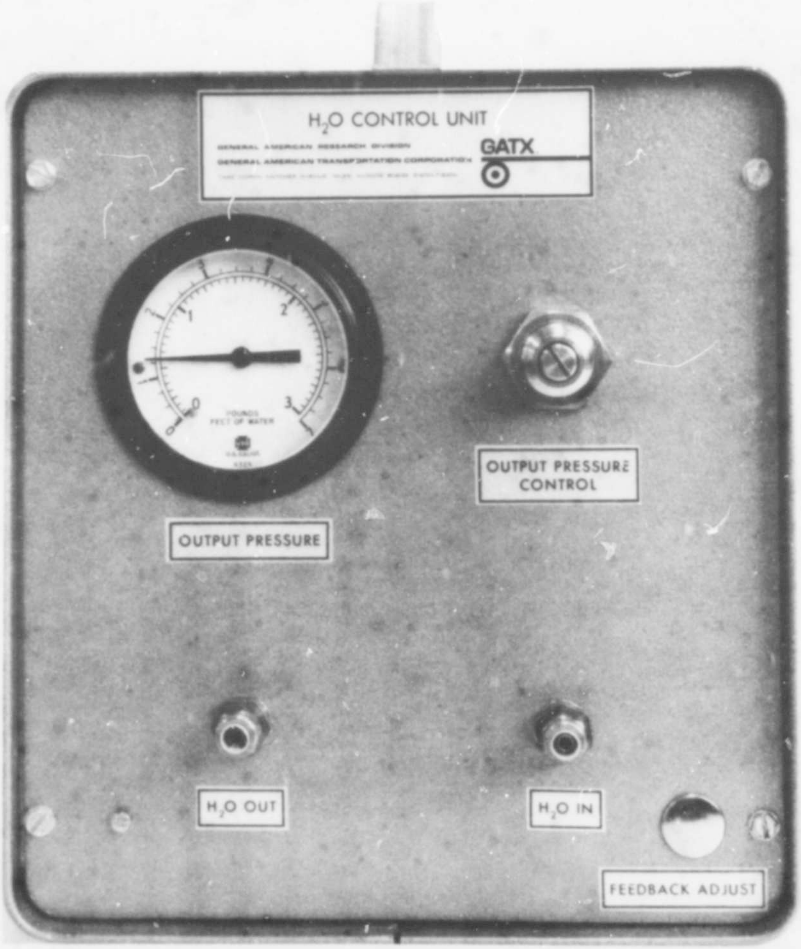


Figure 5. WATER CONTROL UNIT

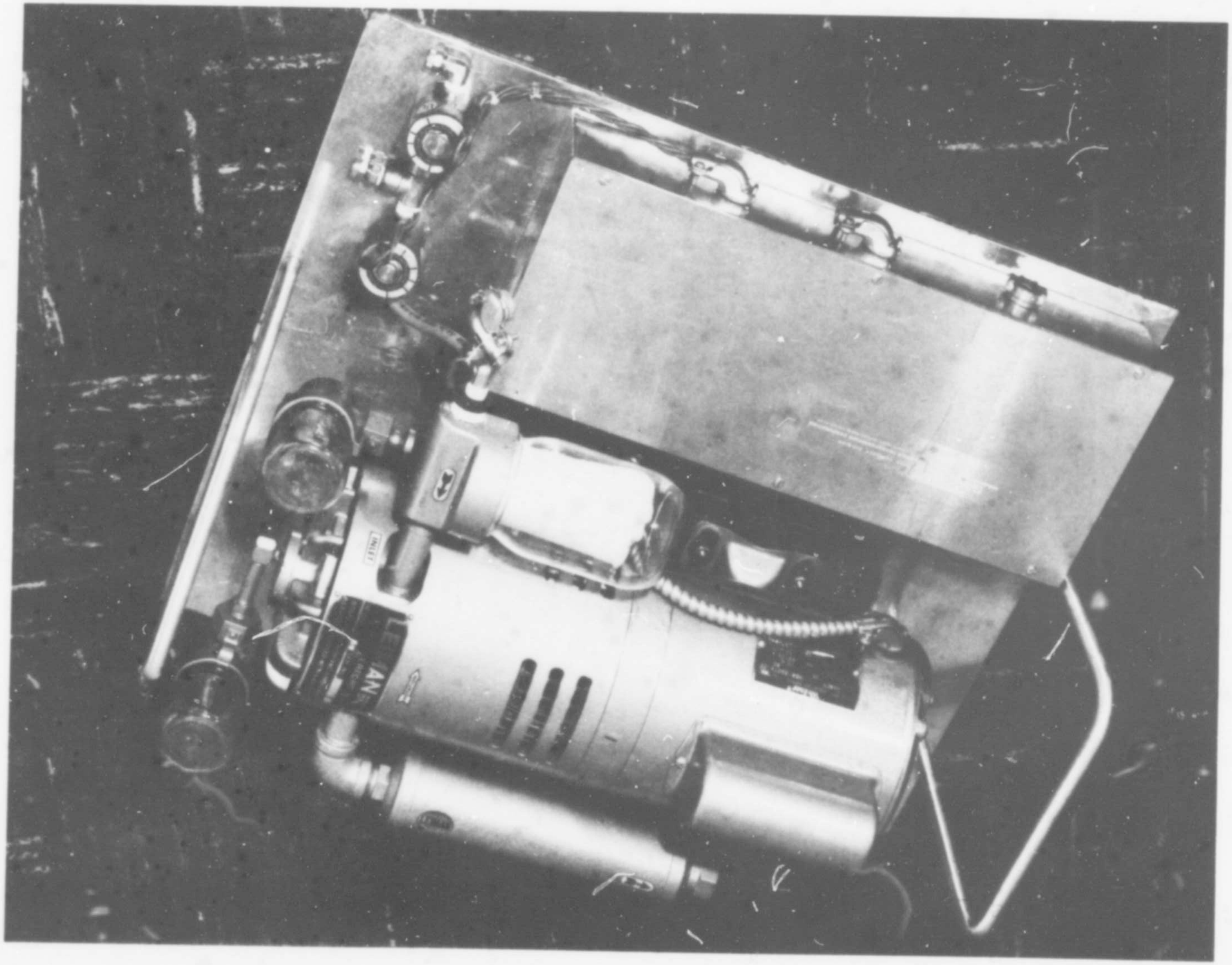


Figure 6. CHAMBER PRESSURE MAINTENANCE UNIT

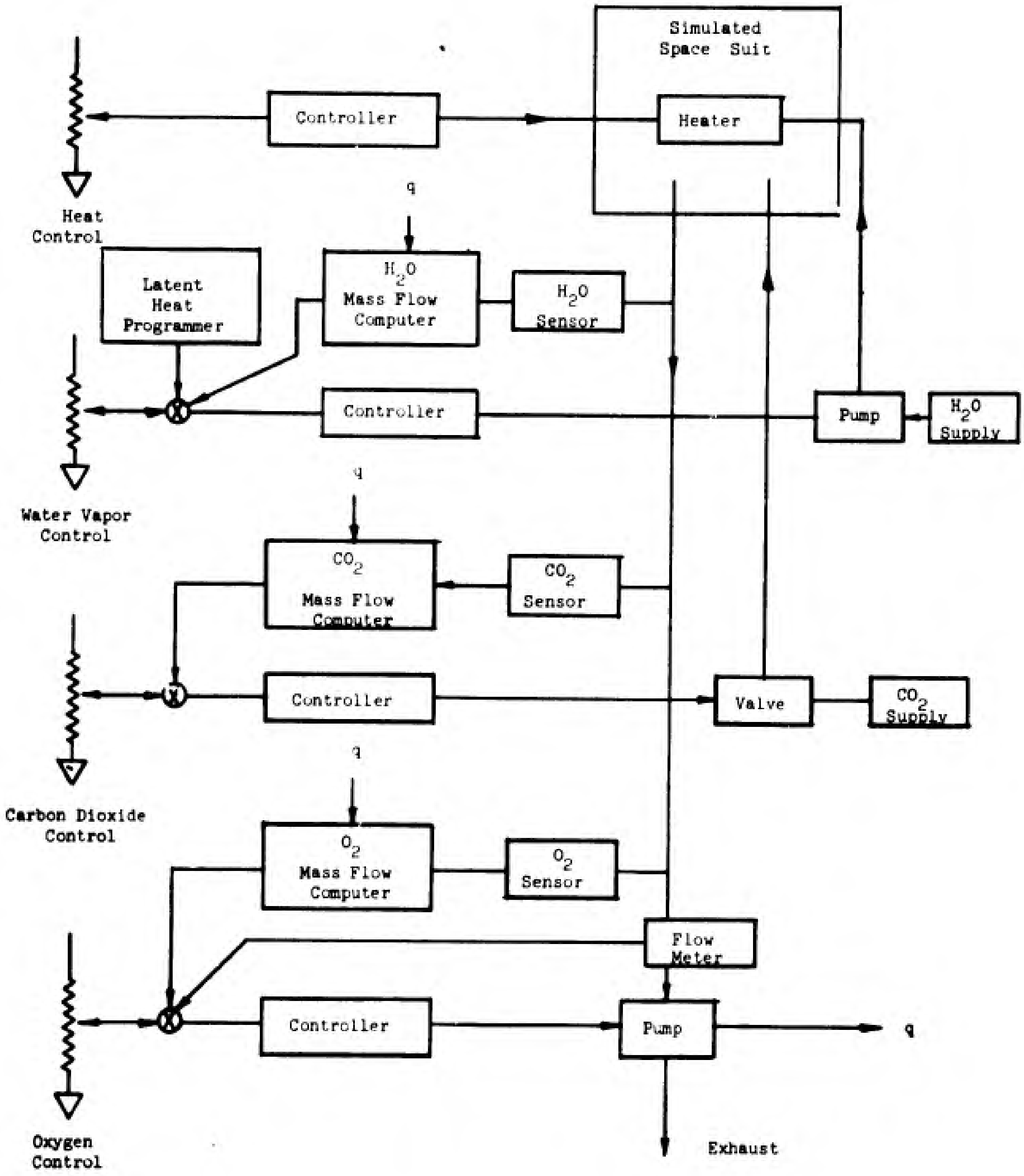


Figure 7. SYSTEM BLOCK DIAGRAM

Water vapor, corresponding to the latent heat, and heat are added by the same basic unit. The total heat input is adjusted by a dial on the control panel. This regulates the current flow through an electrical heater located in the system under test, and provides a corresponding amount of total heat energy. The proper amount of water vapor is added by supplying water to a humidifier, which evaporates the water.

The water flow is controlled with a dial setting representing the desired amount of water vapor. The amount lost during oxygen extraction is automatically compensated for in the same manner as for the carbon dioxide supply. In addition, provision is included for automatically programming and varying the desired water vapor injection rate to compensate for the variation of latent heat with temperature. Both sources of water demanded injection, initial value and the product of breakpoint and slope, are effected by the X1, X2, and X3 range positions on the main control panel.

Nitrogen or helium is introduced through a pressure regulator that maintains the supply pressure constant. The rate of flow is set manually by a metering valve with the aid of a flowmeter array located on the gas calibration panel.

RESPIRATORY CONTROL

Each of the input controls is equipped with a triple-range switch to provide for easily achievable 2-, 4-, or 6-man simulation. Additionally, a relay controlled special three-tap power transformer is utilized to achieve automatic range change for the heat control ranges.

The computer controls the oxygen extraction rate by first computing the volumetric flow required to produce a preselected mass flow and then providing that flow rate. The relationship computed is:

$$q = \frac{1545T \, \dot{m}_{O_2}}{M_{O_2} \, P_{O_2}}$$

where $\dot{m}_{O_2}$ = oxygen mass flow rate

M_{O_2} = molecular weight of oxygen

P_{O_2} = partial pressure of oxygen

q = volumetric flow rate

T = temperature

The $\frac{T}{P_{O_2}}$ ratio is determined by the analyzer while a calibrated pump is utilized to control the output flow (q).

The calibrated pump operates essentially "open loop", and variations or drifts occurring over periods of time cannot be corrected without recalibration of the pump. To reduce this source of error and to improve accuracy, a mass flowmeter is used for continuous pump-calibration correction, as follows:

To remove a fixed amount of oxygen, the CSRE computer determines the volumetric extraction rate required of the gases in the test chamber and directs the vacuum pump controller to remove this rate. The total mass flow of this gas is computed from the available outputs by a summing amplifier. A mass-flow transducer physically measures this flow rate. Then, the two total mass flows, one computed, the other measured, are compared and the pump speed compensation potentiometer is adjusted to bring the two into correspondence. The adjustment is made automatically when nitrogen is used as the background gas and manually when helium is used as the background gas.

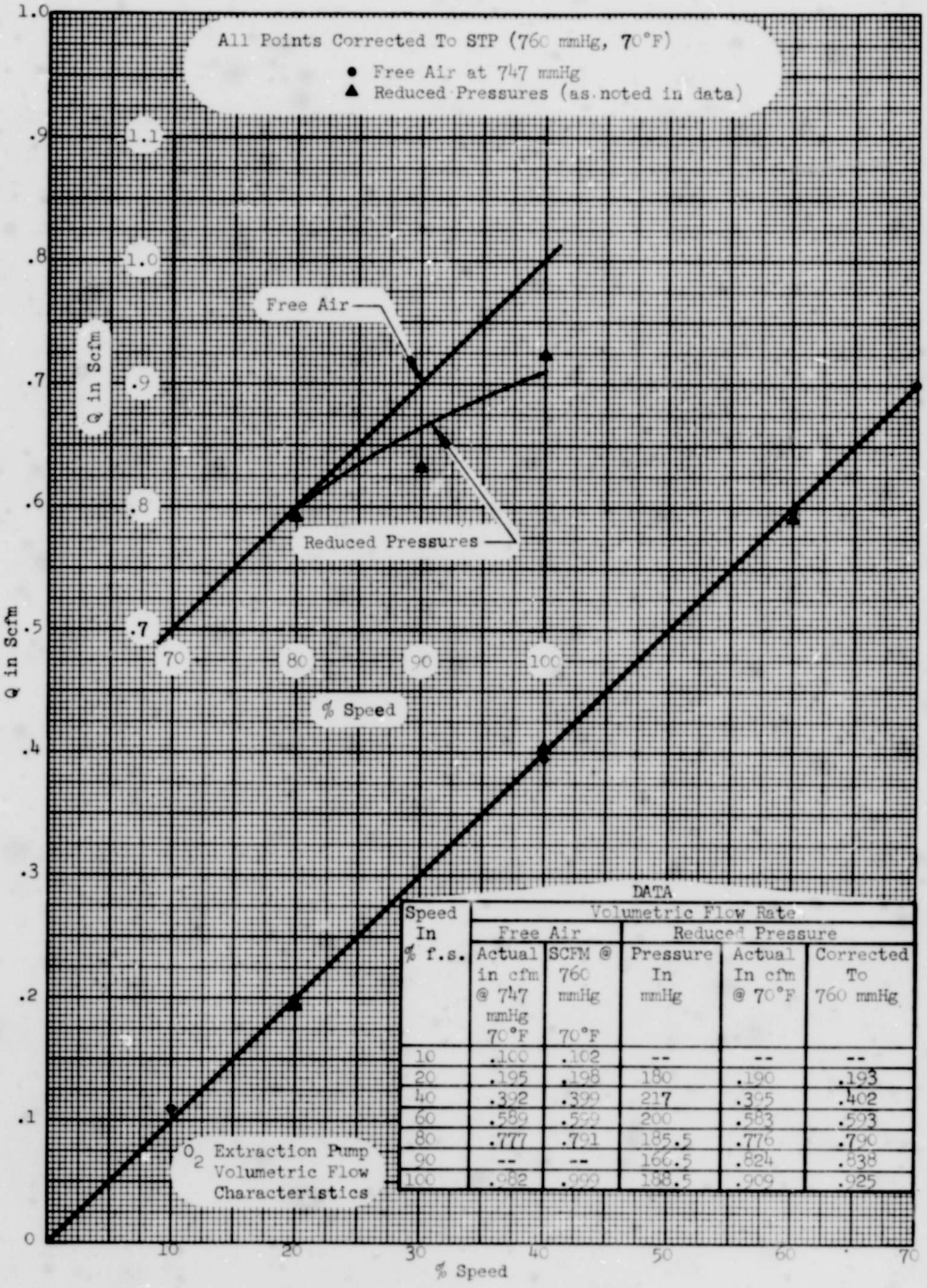
Note that a 2% transducer is rated with reference to full scale and that control accuracies at the lower end are very poor. Therefore, the sensor is used as a check for calibration adjustment, rather than for complete feedback control.

When helium gas is used as the inert background gas, the Technology Incorporated mass flowmeter cannot be used. The flowmeter operates on the principle of cooling by the gas stream of a self heated thermistor bridge. The parameters of specific heat and viscosity of the gas mix constituents controls the heat transfer from the thermistor. Helium has an effect on the mass flowmeter that is almost seven times as great as the other gases in the system. This means that the helium effects mask the effects from any of the other gases.

However, the linearity characteristic of the extraction pump (Figure 8) over the range of interest is so good that only small errors are anticipated when helium makeup gas is employed. Thus the mass flowmeter contribution to the system accuracy is not essential.

CONTROLLED LEAKAGE SIMULATION

A controlled outboard leakage simulation capability of 1.5 to 36 cubic feet per hour at chamber pressure was specified. We considered including this as part of our total extraction flow rate; however, a closer inspection revealed the leakage rates at the lower end of the scale to be below the resolution of our system. Therefore, the approach taken utilizes a separate vacuum pump, coupled with a wide range flow bench and a needle valve to set the desired leakage. This method results in accuracies of ± 2%.



DATA

Speed In % f.s.	Volumetric Flow Rate				
	Free Air		Reduced Pressure		
	Actual in cfm @ 747 mmHg 70°F	SCFM @ 760 mmHg 70°F	Pressure In mmHg	Actual In cfm @ 70°F	Corrected To 760 mmHg
10	.100	.102	--	--	--
20	.195	.198	180	.190	.193
40	.392	.399	217	.395	.402
60	.589	.599	200	.583	.593
80	.777	.791	185.5	.776	.790
90	--	--	166.5	.824	.838
100	.982	.999	188.5	.909	.925

Figure 8. O_2 EXTRACTION PUMP VOLUMETRIC FLOW CHARACTERISTICS

GAS SENSORS

The most important of the measuring elements are the gas analyzers which are three different types, namely, infrared, paramagnetic and ultraviolet. The infrared gas analyzers are used to analyze the gas stream for carbon dioxide, water vapor, and carbon monoxide, while the paramagnetic is employed to measure the amount of oxygen present. The ultraviolet is used to measure the amount of nitrogen. The infrared and paramagnetic analyzers measure the partial pressure of the desired components at operating pressure. The ultraviolet analyzer determines the percentage of nitrogen at operating pressure.

Infrared Analyzers

The infrared gas analyzers used for measuring carbon dioxide and water vapor are Mine Safety Appliances (MSA) Model 300. The infrared analyzer used for measuring carbon monoxide is a Beckman Model 315. The infrared gas analyzers are positive, nondispersive instruments, designed for the precise analysis of gases or liquids in complex streams. These instruments consist of an analysis unit and an amplifier; the analysis unit of the Beckman analyzer is separated from its amplifier, but the MSA unit is integral with its amplifier. The analyzer portion contains the infrared energy source, the energy beam chopper, the sample and reference cells, and the detector. The amplifier contains the operating controls as well as the amplifier. The gas that is to be analyzed is brought through the sample cell. The instrument is sensitized to detect this sample, and when no sample is present, the instrument reads zero. In operation infrared is emitted by the two sources and chopped by a light chopper. The chopped beams pass through the sample cell (filled with sample) and the reference cell (filled with reference material). Any monitored sample absorbs energy from the source radiation; therefore, material in the sample cell absorbs greater energy than material in the reference cell. Thus beams which emerge from the cells to the two compartments of the detector are no longer equal in energy. This causes movement of a diaphragm-condenser between the two compartments of the detector. An electrical signal is produced across the condenser. The signal is proportional to the amount of monitored sample in the sample cell. This electrical signal goes to the amplifier where the quantity of sample is expressed in terms of a meter reading. This signal is also processed for application to the recorder.

Oxygen Analyzer

The paramagnetic analyzer which is used to analyze for oxygen is a Beckman Model F3M3. The F3M3 analyzer system is divided into two components: the analysis unit and the calibration unit. The analysis unit contains the magnetic analysis section, the regulated power supply, the amplifier, and the temperature control circuits. The calibration unit, on the control panel, contains the resistor networks that supply voltages to the vanes and matches the output of the analyzer for further signal processing.

The model F3M3 measures the paramagnetic properties of the sample gas and thus its oxygen content, as oxygen is highly magnetic. Most common gases are only slightly affected by a magnetic field. The magnetic property of oxygen is so pronounced that a few parts per million of oxygen in a gas mixture can be determine by using this method.

Improved Nitrogen Analysis

The ultraviolet analyzer is used to determine percentage of nitrogen present in the gas stream. It is called the Nitralyzer, Model 305 AR. The Nitralyzer consists of a rack-mounted chassis, a vacuum pump, an ionization chamber unit, and a fine-flow control valve. The meter on the front panel continuously reads out the percentage of nitrogen in the gas stream. A continuous, small (3 ml/minute at operating pressure) sample of the gas mixture is drawn through the ionization chamber unit by a vacuum pump. To this basic system GARD has added a significant improvement that overcomes a system deficiency when working at pressures below atmospheric.

The Nitralyzer vacuum pump reduces the line pressure and then maintains a 20 micron absolute pressure at its input. The gas flow to the pump is through the flow control valve. Just before the gas enters the flow control valve it is passed through a pressure regulator that maintains a fixed pressure on its output of 140 mm Hg absolute. This system provides fixed upstream and downstream pressures across the flow control valve. By this means the nitrogen analyzer is freed of line or chamber pressure fluctuations that normally require constant manual flow correction for proper functioning of the analyzer. If the input pressure to the flow control valve is permitted to vary, the flow through the valve varies and the pressure in the analyzer chamber varies and the analyzer output is not representative of the actual nitrogen content in the gas stream. This improved gas pressure handling provision tends to ignore system pressure changes above 160 mm Hg absolute.

The basic measuring system is comprised of an ionization chamber, a radiation filter, and a photocell. Pressure in the ionization chamber is regulated by the flow control valve as described above. Gas in the ionization chamber is ionized by a strong electric field. The filter transmits only the high intensity ultraviolet radiation from the nitrogen spectrum to the photocell. The output of the photocell is electronically linearized and amplified to drive the meter and recorder.

The intensity of ultraviolet emission from the ionization chamber in the nitrogen analyzer is effected by helium as well as by nitrogen. But the helium effect is much less pronounced. One hundred percent helium effects the Nitralyzer in the same way that 6.4% nitrogen does. Thus a pure helium gas stream going through the analyzer registers as 6.4% nitrogen. In the CSRE a helium derivation computation in the analog computer supresses this apparent discrepancy and displays actual helium partial pressure (within certain tolerances) on the helium partial pressure indicator. But the Nitralyzer meter shows the helium content as if it were nitrogen in the ratio of 100% helium to 6.4% nitrogen.

CHAMBER PRESSURE

The total pressure of the chamber, or gas analysis loop, is measured by a Robinson-Halpern P69-026P pressure transducer having a full range of 3 to 15.5 psia (absolute). A bourdon tube is the force-summing element of this variable-resistance-transducer. Pressure changes in the bourdon tube produce a displacement, changing the potential pickoff position of the element and causing an electrical output precisely proportional to the applied pressure.

MASS FLOWMETER

The mass flow of the outlet gas stream is measured by a mass flowmeter which consists of a self-heating thermistor bridge cooled by the mass flow of gases through it. The 0 to 5-volt output is linearized in the signal-conditioning unit.

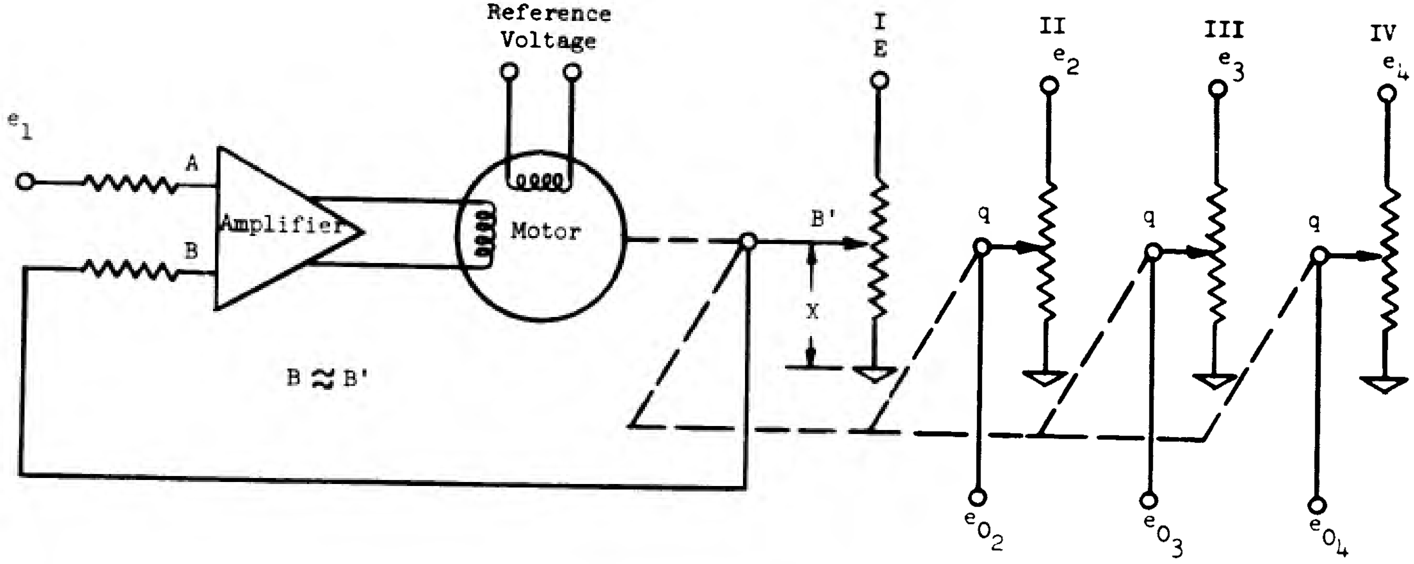
TEMPERATURE SENSING

Two temperature sensors are used at the chamber outlet and two distant-reading thermometers are used in the gas-calibration section in the console.

COMPUTING ELEMENTS

The computing elements of the respiratory evaluator are basically d-c operational amplifiers which perform addition-subtraction operation and two servo-multipliers which perform multiplication. Twelve operational amplifiers are used, ten for outlet stream calculations and two for converting double-ended outputs to single-ended outputs. The set of ten amplifiers is housed in a Philbrick Model K7-A10 manifold. This manifold is a versatile and precise instrument. With the addition of appropriate external circuitry, a wide variety of instrument or computing configurations can be set up quickly. This computing instrument is unusually flexible and provides the analog "simulator" or basic computer. The chopper-stabilized wide-band dc USA-3 amplifiers incorporated in the manifold are responsible for its versatility. The manifold is powered by a well-regulated power supply. The power supply consists of two regulated power supplies on one chassis, slaved to a common reference. It furnishes plus and minus 300 v d-c, each rated at 300 ma. The supply also provides straight-through a-c power, fused and switched at the main power switch, at each of the two output connectors.

The servo-multipliers consist basically of a servo amplifier, a two-phase induction motor, and several precision potentiometers with their shafts ganged and coupled to the rotor shaft of the motor. Figure 9 is a schematic diagram of such a multiplier. The dashed line indicates mechanical but not electrical connection. One of the variables to be multiplied, e_1, is applied to one input terminal of the servo amplifier, while the voltage appearing at point B in the diagram is applied to another input terminal of the same amplifier. Point B' is at the moving arm of the precision potentiometer I, one end of which is grounded while the other end is connected to



$$e_{O_2} = \frac{e_1}{E} e_2$$

$$e_{O_3} = \frac{e_1}{E} e_3$$

$$e_{O_4} = \frac{e_1}{E} e_4$$

Figure 9. SERVO MULTIPLIER

a fixed d-c voltage source E, the polarity of which is the same as that of e_1. The voltage appearing at B' is therefore equal to XE, where X is the position of the potentiometer arm, as a fraction of full scale.

The servo amplifier effectively transforms the two d-c input potentials to a single 60-cps signal, the magnitude of which is proportional to the difference between the input voltages. This a-c signal is applied to one winding of the motor, while a fixed a-c reference signal is applied to the other winding. The motor characteristics are such that rotation takes place as long as both windings are excited. The direction of rotation is determined by the phase relationship of the voltages in the two windings. As a result of the mechanical coupling of the motor shaft and the potentiometer arm, the rotation of the motor effects an alteration in the potential at point B' and, consequently, in the voltage at B. The motor finally comes to rest when the potential (A-B) is equal to zero, that is when the voltage at point B' is equal to e_1, or $XE = e_1$. The angular position X, of the ganged potentiometers as a fraction of full scale, are then equal to $\frac{e_1}{E}$. If a variable voltage e_2 is applied to potentiometer II, the potential appearing at its moving arm is equal to $\frac{e_1 e_2}{E}$ and the desired multiplication is accomplished. By a similar process, the potentials appearing at the moving arms of potentiometers III and IV are, respectively, $\frac{e_1 e_3}{E}$ and $\frac{e_1 e_4}{E}$.

The previously described servo-multiplier is used in the respiratory evaluator to perform the multiplication indicated by $\dot{m}_1 = \frac{Qp_1 \, M_1}{1545 \, T}$.

RELATIVE HUMIDITY

The specifications on relative humidity call out a range of 5% to 90% and an accuracy of 2%. The relative humidity sensor, a lithium chloride type, has an accuracy of 2% and a range of 5% to 95%.

SECTION III

DETAILED SUBSYSTEM DESCRIPTIONS

GENERAL CONSOLE LAYOUT

The console consists of three standard racks that are bolted together to form a single unit. Each of the three racks is referred to as a bay that has certain items distributed within it. Figure 10 shows the arrangement of panel indicators, controls, analyzers, recorder, and other component locations. The contents of the bays are described and some sections of these bays are more highly detailed.

Center Bay

The carbon dioxide and water vapor analyzers share the space at the top of the center bay. The oxygen analyzer controls and the carbon monoxide analyzer controls share the panel directly below. The Nitralyzer is located directly below the oxygen and carbon monoxide panel. Under this panel is the sloping panel that contains the main system controls. Details of this panel are given in the next paragraph entitled "Control Panel". Under the sloping panel, behind the door, are three circuit breakers: one for 110 volts, 60 cps; one for 208 volts, 60 cps; and one for 28 volts dc. To the left of the circuit breaker panel is a plus-24-volt regulator and above the plus-24-volt regulator is a minus-24-volt regulator.

Control Panel

The sloping panel (Figure 11) contains six indicators, namely; heat input, relative humidity, ambient room pressure, derived partial pressure of helium, chamber temperature, and chamber pressure. Directly below the chamber pressure indicator is the chamber pressure SET control and the manual RAISE and LOWER controls to affect the chamber pressure. The chamber pressure off-limits light alarms are also located here; audio alarms are located within the sloping panel.

Across the top of the sloping panel are 16 lights that appear in sets of 4; the designations per set are OFF, X1, X2, X3. Associated with each set of indicator lights is a switch that points to the selected designation upon setting of the selector switch. Setting the selector switch on a lamp position lights the lamp and provides a multiplying factor for its associated control. The controls are located directly below their range selector switches. Starting from the left, the sections are: heat input, water input, carbon dioxide input, and oxygen extraction. Below the main water input control is the BREAKPOINT control (onset of latent heat), and to the right of the BREAKPOINT control is the SLOPE control (rate of perspiration). Under the EXTRACT O_2 control is a small section labeled MODE CONTROL. This section contains three lighted pushbutton controls: OFF, STANDBY/CALIBRATE and OPERATE

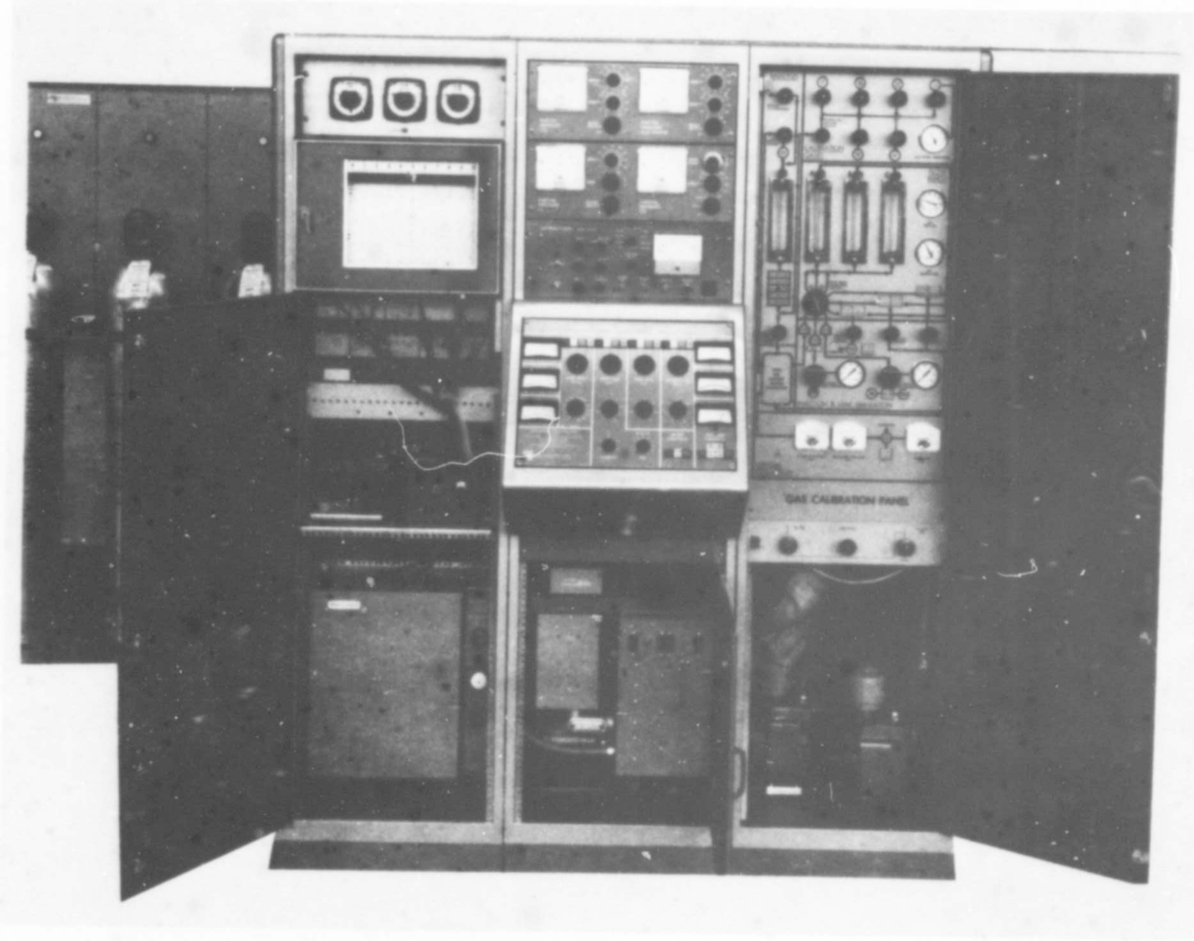


Figure 10. MAIN CONSOLE - DETAILS

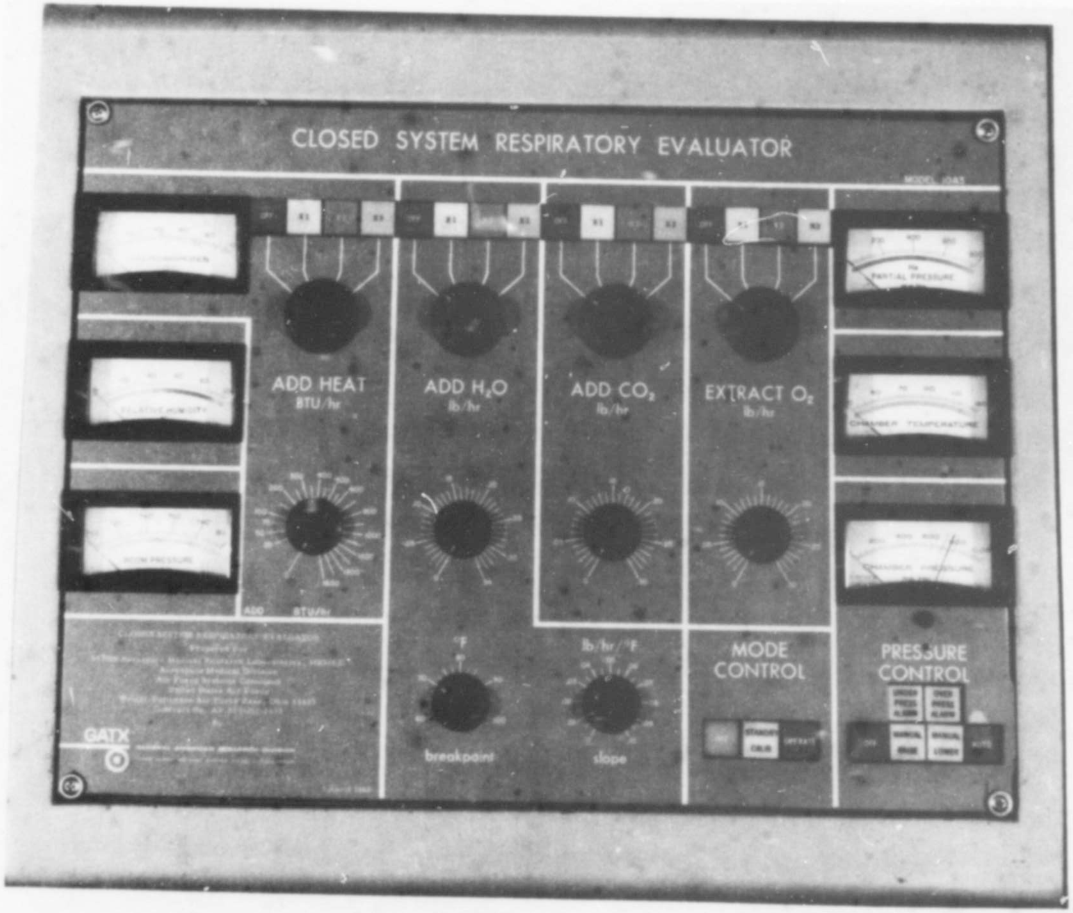


Figure 11. CONTROL PANEL

Left Bay

The left bay of the console contains the three recorder timers. One timer controls the nonprint time of the recorder. One timer controls the print time of the recorder. The third timer provides the space between groups of data. An Auto/Norm switch is on the panel to enable cyclic or continuous printing. In the NORMAL position the recorder is fully controlled by the recorder controls. An Electronik 16 recorder is located directly below the timer panel. It is a 24-channel recorder with front panel controls to enable continuous printing or "hold on" to a particular channel or "Selectaprint." The Selectaprint feature enables one to choose a particular channel, or channels, for "hold on" or "print out", skipping those channels not selected. Channel selection is achieved by pulling out the recorder on its slides so that one can get to the cam buttons on the cam wheel on the left-hand side of the recorder. Any cam set on its extended position will cause that channel to print. Any depressed cam will cause its channel to be skipped over.

The power supply is located behind the recorder timer.

The manifold containing the 10 operational amplifiers is located immediately below the recorder. Each amplifier has an associated "mini-box" attached to it. These mini-boxes contain the computer networks.

Below the manifold is the recorder potentiometer panel. These potentiometers control the input signal levels to the recorder.

The servo chassis is located below the recorder potentiometer panel. The servo chassis contains two servo systems. The left hand one is used to control the oxygen extraction while the right hand one provides the automatic speed compensation of the oxygen extraction pump when nitrogen is used as the background inert gas.

The ramp generator for carbon dioxide injection, the servo panel control panel, and several other computer elements make up the balance of the equipment on the servo panel.

At the bottom of the bay is the analysis part of the oxygen analyzer and its bypass panel. The bypass panel is designed to protect the oxygen analyzer from transient pressure surges which may damage the magnetic unit of the analyzer.

Right Bay

The right-hand bay contains the gas calibration panel (Figure 12) which enables complete system calibration from front panel controls, the oxygen extraction pump and the speed control unit, the leakage simulation pump, and the extraction and speed indicators.

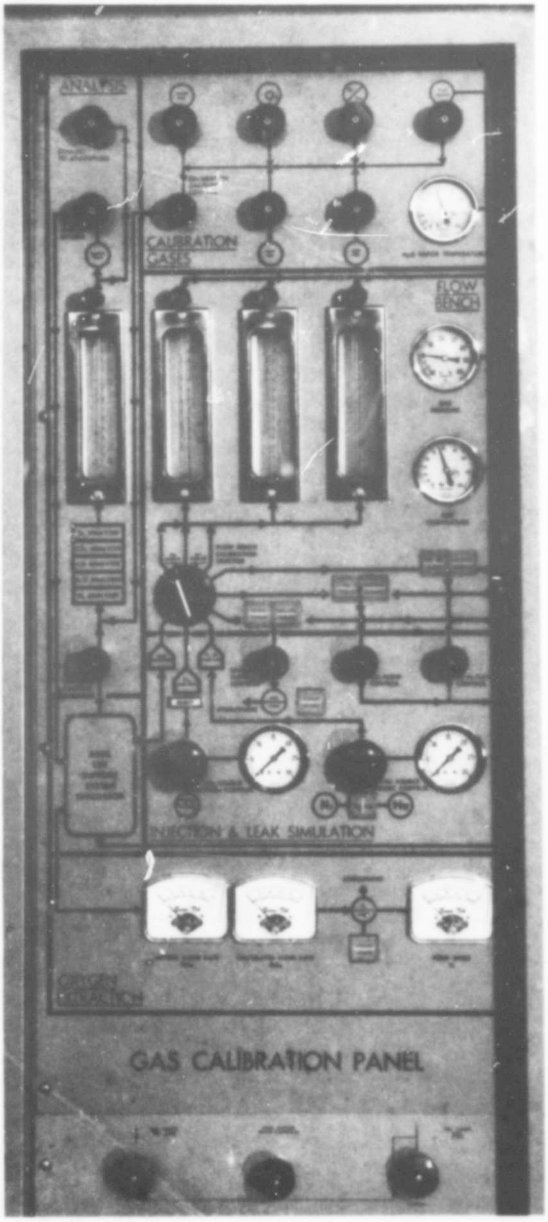


Figure 12. GAS CALIBRATION PANEL

Gas Calibration Panel

The gas calibration panel is marked off into six segments. These segments, their locations, and their internal functions are:

(a) **ANALYSIS** - located along upper left hand side of panel. This segment contains the LSSE sample gas flow control valve, the analyzer group graphic, the air flowmeter (with attached exhaust flow control valve), the sample pump graphic, the gas return shutoff valve, and the exhaust to atmosphere valve.

(b) **CALIBRATION GASES** - located in upper right hand corner of the panel. This segment contains six valves that function as calibration input gas shutoff valves, the calibration gas flow control valve, and the calibration water vapor temperature sensor and indicator.

(c) **FLOW BENCH** - located directly below the calibration gases segment. The three injection and leak simulation flow meters, the outlet gas pressure meter, the outlet gas temperature meter, the flow bench calibration selector switch and the three standby/operate switch-and-indicator modules are contained here.

(d) **INJECTION & LEAK SIMULATION** - located directly below the flow bench. This segment of the panel contains the carbon dioxide input pressure regulator and gauge, the inert background gas (nitrogen or helium) input pressure regulator and gauge, the three flow control valves. for carbon dioxide and background gas injection and outboard leakage simulation control, the leakage simulation pump standby/operate switch, the N_2/He selector switch, and the carbon dioxide inject light indicator.

(e) **OXYGEN EXTRACTION** - located at the bottom of the panel. This segment contains the actual flow rate meter indicator, the calculated (computed) flow rate meter indicator, the pump speed (in % of full scale) meter indicator, and the standby/operate oxygen extraction pump control switch.

Under the gas calibration panel is a small panel containing three valves. These valves are from left to right: the inject gases to LSSE shutoff, the water vapor flow control, and the inject gases calibration exhaust. The two outer valves enable bypassing the gases used to calibrate the carbon dioxide full scale flow, the inert background gases flow, and the leak simulation gases. The center valve is used when calibrating the water vapor analyzer.

Flowmeter Calibrations

The flowmeters in the flow bench segment of the gas calibration panel have been calibrated under closely simulated operating conditions. Three calibration graphs are included for illustration (Figures 13, 14 and 15). These graphs describe the response of the "B", center unit of the three, flowmeters on the flow bench segment of the panel. The other flowmeters (including the air flowmeter) have been equally well calibrated and their descriptive curves are part of the Operation Manual (Reference 6).

The first graph (Figure 13) shows the flowmeter response to three different gases as a function of their mass flow rates at 70°F and inlet pressure of 30 psig. Since the pressure drop to the receiving vessel or line is taken across the controlling flowmeter, no reference is made to the outlet pressure.

The second graph (Figure 14) shows the flowmeter volumetric response to several gas mixtures at two different pressures. The temperature was held at 70°F. Any other operating temperature can then be used and the compensation can be calculated.

The third graph (Figure 15) shows the flowmeter volumetric response to 100% oxygen at 70°F for three different pressure values. These graphs illustrate the comprehensive coverage of the flowmeters so that a large variety of possible conditions can be handled directly or interpolated to acceptable accuracies.

OXYGEN EXTRACTION

The oxygen extraction process includes the following procedures:

Mathematical Relationships Mechanized

The mass flows of the various gases are determined by the following relationships.

$$\dot{m}_{O_2} = \frac{M_{O_2} P_{O_2} Q}{1545\ T} \qquad (1)$$

$$\dot{m}_{CO_2} = \frac{M_{CO_2} P_{CO_2} Q}{1545\ T} \qquad (2)$$

$$\dot{m}_{H_2O} = \frac{M_{H_2O} P_{H_2O} Q}{1545\ T} \qquad (3)$$

$$\dot{m}_{N_2} = \frac{M_{N_2} P_{N_2} Q}{1545\ T} \qquad (4)$$

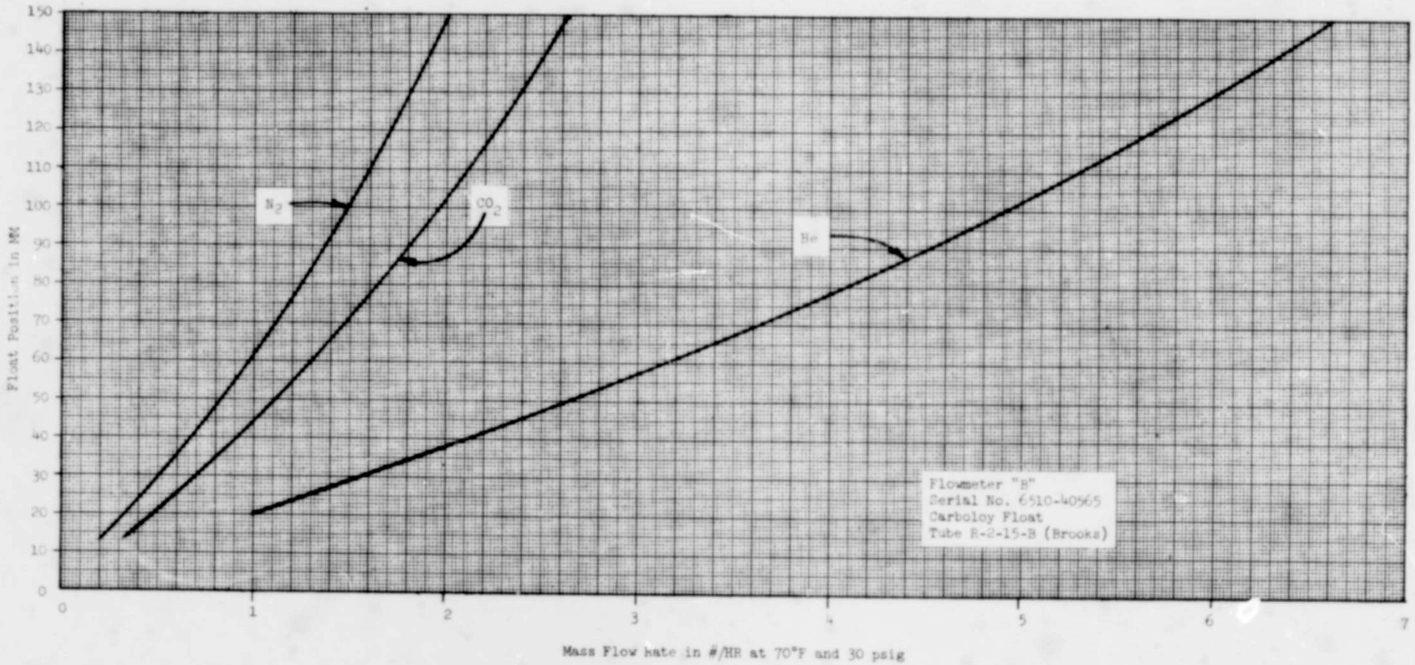


Figure 13. MASS FLOW RATE CURVES

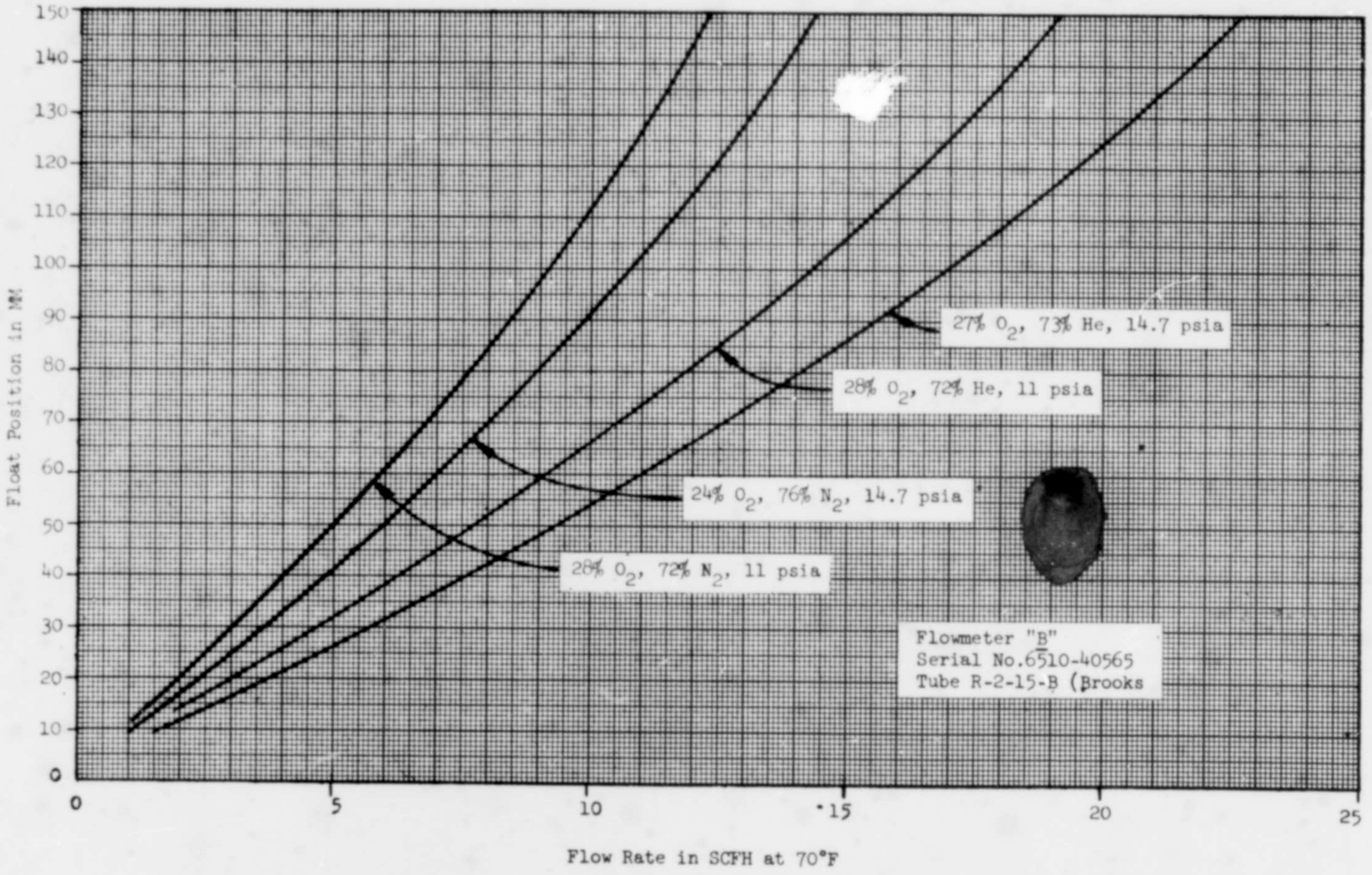


Figure 14. FLOW RATE

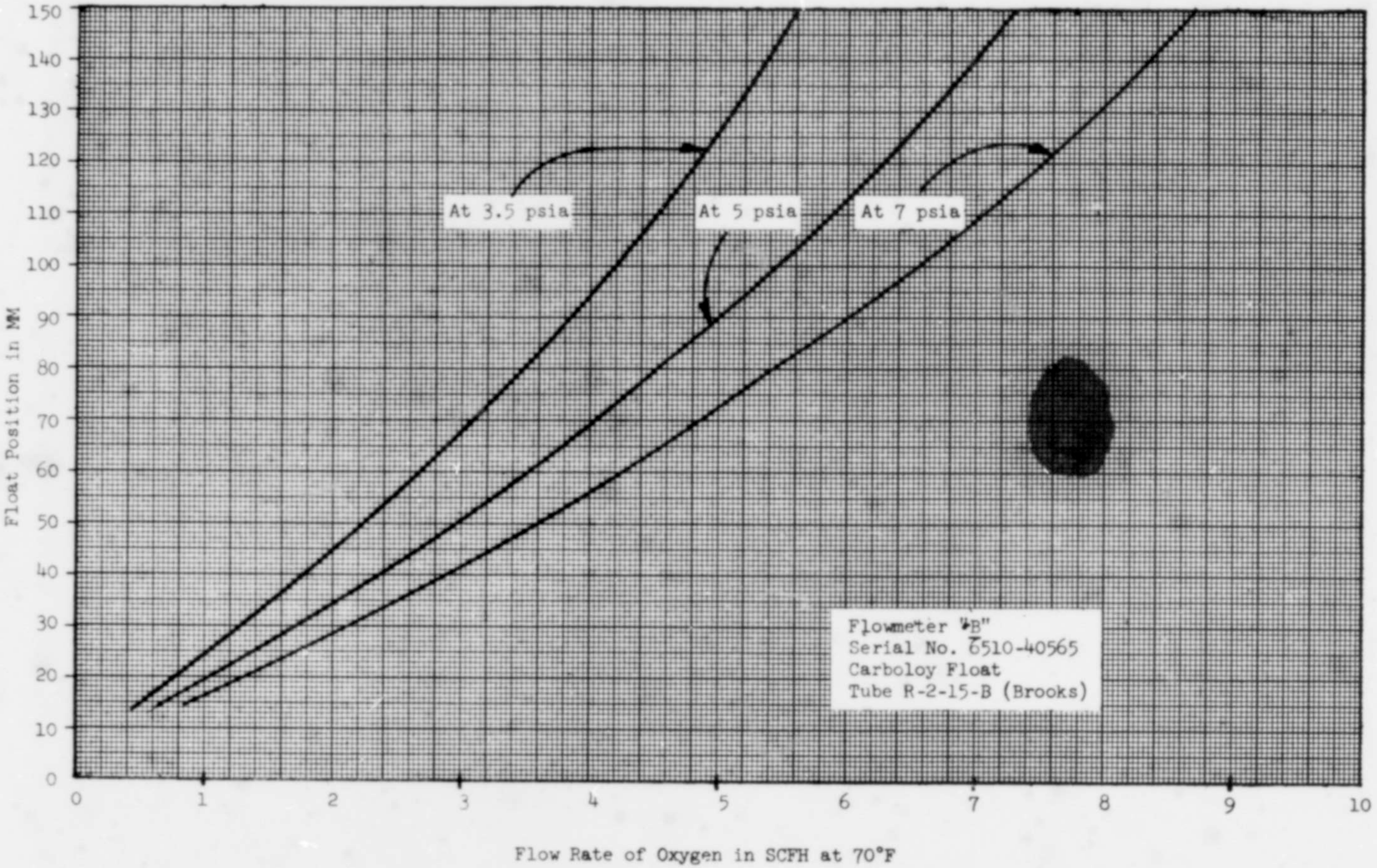


Figure 15. FLOW RATE OF OXYGEN

where $\dot{m}_{O_2}$, $\dot{m}_{CO_2}$, $\dot{m}_{H_2O}$, $\dot{m}_{N_2}$ are mass flow rates

M_{O_2}, M_{CO_2}, M_{H_2O}, M_{N_2} are molecular weights

Q, is the volumetric flow rate of the extracted gas

T, is the gas temperature (absolute)

Equation 1 is used to calculate the mass flow rate of oxygen extracted from the system and supplies the feedback signal for the oxygen extraction system. Equations 2 and 3 are used to determine how much of these constituents (CO_2 and H_2O) were also removed during oxygen extraction so that they can be later replaced. These equations plus equation 4 are used in the computer to determine total flow, by the equation: $\dot{m}_T = \dot{m}_{O_2} + \dot{m}_{CO_2} + \dot{m}_{H_2O} + \dot{m}_{N_2}$

Oxygen Extraction Control System

A block diagram of the oxygen extraction control system is shown in Figure 16. The desired oxygen extraction rate is adjusted on the front panel by a dial coupled to a potentiometer. The potentiometer output is fed into a positional servo operated as a divider to produce a shaft displacement proportional to flow. A potentiometer coupled to this shaft controls a velocity servo driving a positive displacement pump. The output gas flow of the pump is proportional to the pump speed.

Coupled to the positional servo's output are four additional potentiometers which permit the multiplication of the flow, Q, with

$$\frac{P_{O_2} M_{O_2}}{1545\ T}, \quad \frac{P_{CO_2} M_{CO_2}}{1545\ T}, \quad \frac{P_{H_2O} M_{H_2O}}{1545\ T} \quad \text{and} \quad \frac{P_{N_2} M_{N_2}}{1545\ T}.$$

The signal from one of the potentiometers is proportional to the actual mass flow of oxygen, and is fed back to the input of the oxygen extraction system to close the loop. Two potentiometers supply control signals for the carbon dioxide and water vapor injection systems for makeup of the overboarded amounts which were expelled with the desired oxygen consumption. The other potentiometer plus the oxygen, carbon dioxide and water vapor potentiometers supply signals to the mass flow computer.

The preceding circuitry is basic to the CSRE. The outputs labeled 1, 2, 3, 4, which represent the calculated mass flows of oxygen, carbon dioxide, water vapor and nitrogen being extracted are summed by an operational amplifier as shown at the bottom of Figure 16 and its output is displayed on a meter. This represents the total computed mass flow output of the pump.

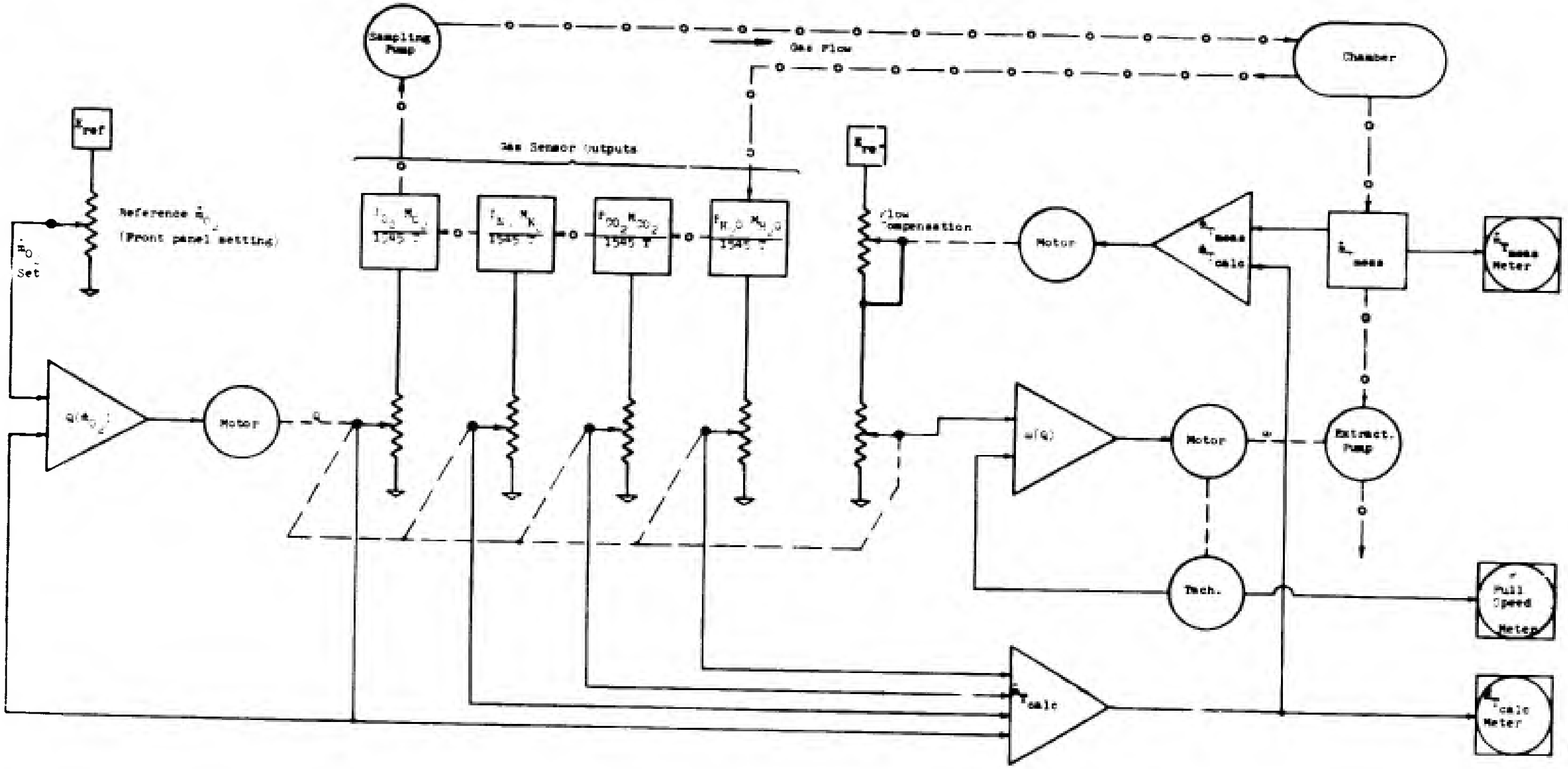


Figure 16. OXYGEN EXTRACTION SYSTEM

This is compared with the measured mass flow as displayed on another meter. If they do not correspond, the manual Q compensation potentiometer is adjusted until they agree. If nitrogen is the background gas, compensation is automatic. This forces the pump volumetric output to agree with the computed Q value within the accuracy of the flowmeter. Generally, this is used primarily as a check on the calibration of the basic system as the stabilization times of the analyzers are very slow and only the long term average is correct.

CARBON DIOXIDE INJECTION SYSTEM

A block diagram of the carbon dioxide injection system is shown in Figure 17. The gas flow is controlled by a time modulated control system. The reference carbon dioxide mass flow injection rate is set by a dial on the front of the control panel. The output from a potentiometer coupled to the dial shaft is added to a signal proportional to the carbon dioxide removed during oxygen extraction (obtained as shown in Figure 16) to form the desired carbon dioxide injection rate.

This control signal is compared with the output of a ramp generator. The latter generates a linear saw tooth voltage of constant maximum amplitude and with a period of 6 seconds. When the ramp voltage is lower than the control signal voltage, the amplifier has a positive output. When the ramp generator voltage exceeds the signal voltage, the amplifier output swings negative. The amplifier gain is very high and the change in polarity is obtained the moment the ramp voltage exceeds the signal voltage.

During the period the amplifier output is positive, the solenoid valve is open, allowing carbon dioxide to pass into the system. The moment the amplifier output swings negative, the valve is shut off. Thus the time period, during which the solenoid valve is open, is proportional to the input control voltage.

The above process repeats every six seconds so that the average flow of carbon dioxide is proportional to the composite control signal.

The carbon dioxide gas is brought from its high storage pressure to approximately 30 psig by the pressure regulator. The output flow of the regulator is passed through a visual indicating flowmeter, the solenoid valve, and a metering valve before entering the system under test.

The flowmeter and the metering valve set the initial full-scale flow through the valve. Three flowmeters are provided which enable the selection of any value over a large range. During actual operation the flowmeter is bypassed by the gas flow. The bypass line contains a C_v compensation valve that provides the same conditions for gas flow as that through the flowmeter.

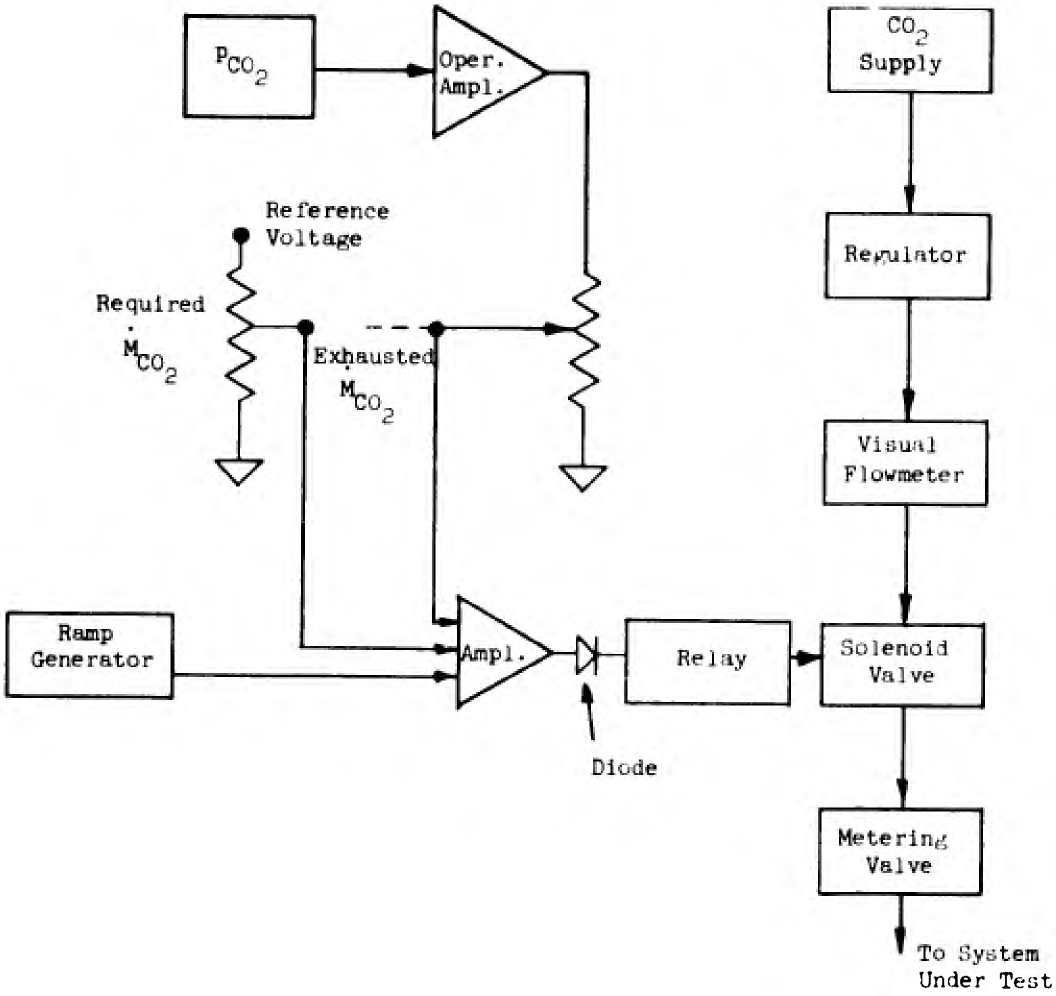


Figure 17. CARBON DIOXIDE INJECTION SYSTEM

HEAT AND WATER VAPOR ADDITION

The Closed System Respiratory Evaluator (CSRE) heat and water production can be compared to that of a human (Reference 7). The CSRE is designed to produce up to 4800 BTU/hr of heat and up to 1.0 lb/hr of water at any selected system temperature. Water production is further controllable on a temperature dependent basis by setting the Breakpoint and Slope controls. The Breakpoint control is set for the onset of perspiration (or sweat) while the Slope control is set for the rate of perspiration as a function of temperature. This group of controls (heat, initial value of water, breakpoint, and slope) provides the means to simulate human heat and water production. A typical curve describing the heat output from a man at rest is shown in Figure 18.

Figure 18 shows two curves of heat output. The upper curve is a straight line and represents total body heat output. The lower curve represents the "sensible heat" output. Sensible heat refers to that portion of the total body heat output that is not used to evaporate water from the human body. The difference between the total body heat and the sensible heat is called the "latent heat". Latent heat is defined as the sum of the skin insensible water loss, respired water loss, and sweat. This heat energy is used by the body to convert body water to vapor. Notice that the latent heat becomes highly temperature dependent at about 64°F and increases at a linear rate with temperature to beyond body temperature. Above body temperature, the body starts accepting heat; it literally starts to "cook". Figure 18 assumes a particular body chemistry and a particular level of unchanging activity.

Much of the heat energy generated by a human is for maintaining body temperature. The remainder of the energy is used up in the heart functions, the breathing apparatus, and the physical performances. Much of the heat used in maintaining body temperature evaporates perspiration from the skin, which tends to cool the person. Ninety percent of man's heat and water output leaves the body through his skin (Reference 8).

Confusion often sets in when the Figure 18 heat curves are displayed because the total latent plus sensible heat, summed as the total metabolic heat, is displayed as a constant quantity at all ambient dry bulb temperatures. However, recall that this is true for a particular level of unchanging activity. The curve shows what happens to the heat; that is, how it is used. Any water that is evaporated is part of the total water leaving the body. Ordinarily, if the surrounding environment is not water-saturated, the vaporized water enters the air. If the environment is water-saturated, the perspiration will not be evaporated.

For purposes of human simulation, the latent heat can be considered in the same light as heat of vaporization. In the machine, simulation water is injected into the closed system without any energy conversion such as that in the vaporization of water. However, when the added water enters the chamber it absorbs heat and vaporizes similarly to the vaporization of perspiration of a human. Thus the CSRE follows real life action, as it should.

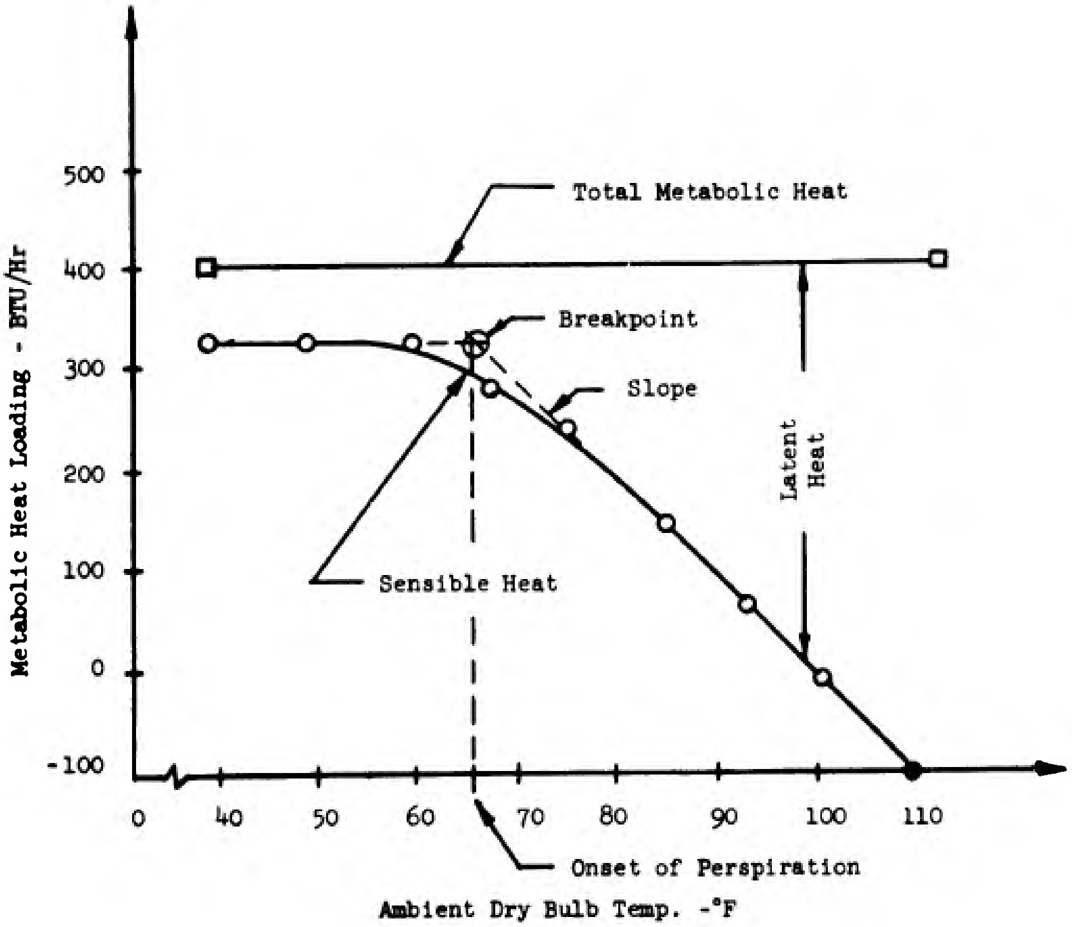


Figure 18. METABOLIC HEAT AS A FUNCTION OF TEMPERATURE

In the CSRE, the total metabolic heat rate is set by a variable transformer on the control panel. This supplies a proportional amount of electrcal energy to the heat unit. The latent heat, represented by the difference between the two curves in Figure 18, is provided by pumping a corresponding amount of water into a humidification unit located in the heat and water production unit. The humidifier converts all this water into water vapor.

The variation in water vapor production with temperature is approached by a straight line approximation of a curve similar to that shown in Figure 18.

WATER VAPOR ADDITION CONTROL SYSTEM

The water flow is regulated by three dials, one controlling the initial vapor rate (initial difference between the two curves), a second controlling the breakpoint temperature (the temperature at the intersection of the asymptotes of the sensible heat curve) and the third controlling the slope of the asymptote to the sensible heat curve.

The manner in which the above controls are mechanized is shown in Figure 19. The initial value is set by potentiometer 3. The breakpoint temperature is set by potentiometer 1 which is inserted in series with a resistance bulb, located in the relative humidity and temperature probes package (Figure 3). The diode will pass the bridge output voltage when the latter exceeds the diode forward voltage drop. The slope is adjusted by potentiometer 2. The composite water vapor signal is summed with the output from the water vapor mass flow potentiometer to obtain a signal proportional to the desired water flow rate. This signal controls a cam controlled motor driven pump through a positional servo to provide the proper water output.

NITROGEN OR HELIUM ADDITION SYSTEM

The nitrogen or helium is added through the manually operated flow control system. The flow control system consists of a pressure regulator, a metering valve and the flow bench. The flow is adjusted to the desired value while visually monitoring the selected flowmeter. After adjustment the flowmeter is shut off and the flow bypasses the flowmeter. The bypass line contains a C_v compensation valve that provides the same gas flow conditions as that through the flowmeter.

CALIBRATION OF THE GAS ANALYZERS

Calibration of the analyzers is accomplished at ambient room pressure while closed loop operation is performed at the chamber pressure (i.e. chamber pressure and analyzer loop pressure are identical). The analyzers can be calibrated without interfering with the extraction-injection processes of the CSRE.

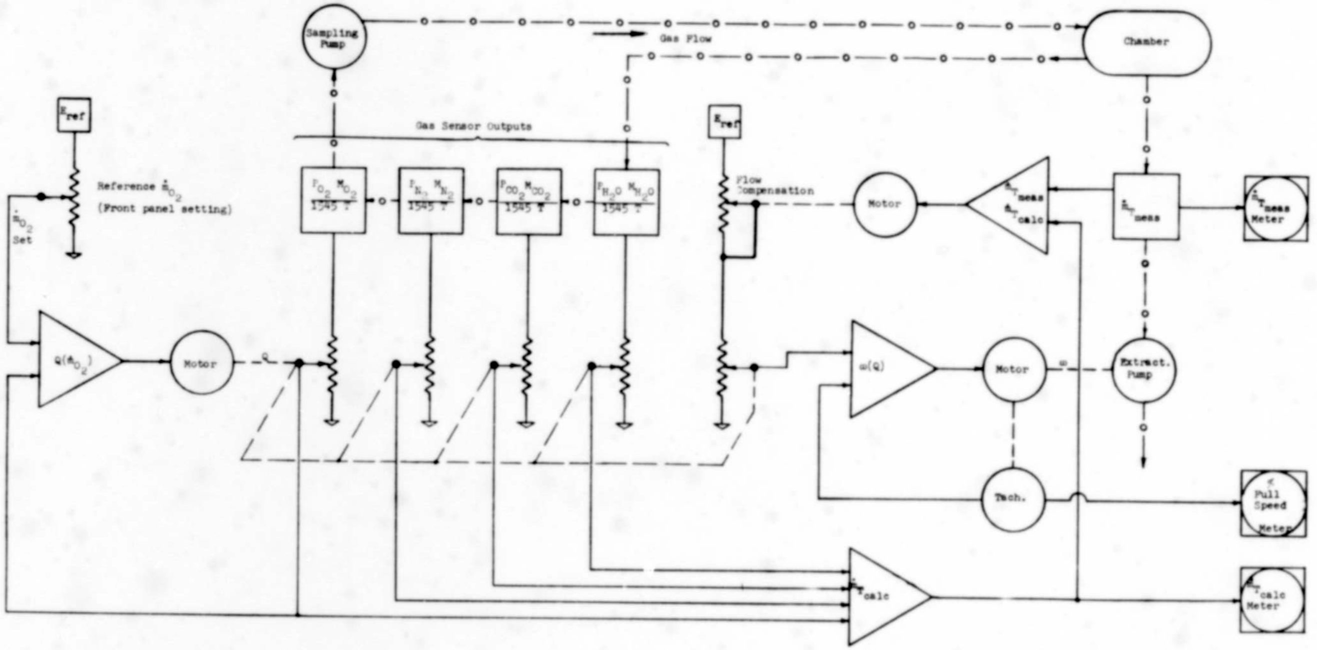


Figure 16. OXYGEN EXTRACTION SYSTEM

The gas calibration panel allows the operator to control the calibrating gases and the stream gas by the use of valves. The pressure of the gases introduced to calibrate the analyzers is limited to a positive pressure of five inches of water. This low pressure drop permits more accurate calibrations and deliberately reduces the hazards to the magnetic sensing unit in the oxygen analyzer. The analyzers are vented to atmosphere during calibration to keep the calibration gases out of the system being tested. Thus the analyzers are calibrated at atmospheric pressure.

The calibration of the analyzers consists primarily of passing reference gases through the instruments and setting their outputs to correspond to the concentrations of gas content. Usually two reference gases are employed, the zero gas and span gas. The zero gas contains zero percent of the desired gas and the span gas contains a known percentage of the gas near the full range or at selected operation points of the instrument. Rather than using water equivalence gases that may contaminate the system, to calibrate the water vapor analyzer, it was decided to calibrate directly with water vapor.

The water vapor analyzer is calibrated by first zeroing the analyzer and then passing a stream of water - saturated zero gas through the analyzer. A two bottle bubbler system is provided as well as a distant reading thermometer, located on the gas calibration panel, which indicates the water-laden gas temperature. A curve of partial pressure vs. the temperature of the water saturated gas is provided in the Operation Manual (Reference 6). GARD drawing 1285D101 and the Operation Manual fully detail the method of accomplishing the calibration of the water vapor analyzer.

The infrared analyzers are factory calibrated and each is supplied with a calibration curve. The curves show the actual partial pressure of the gas stream and the corresponding meter indication. When close tolerances are required, the meter indication must be correlated with the factory supplied curves.

GAS ANALYSIS USE OF CSRE

The CSRE can be used to analyze a gas stream without using any other function of the equipment. A bypass line and a metering valve are incorporated to speed up the gas flow so that faster system response can be realized. This bypass line parallels the gas analyzer loop and can handle about 40,000 cubic centimeters per minute via the sample pump. The analyzers require a flow rate of only 150 cubic centimeters per minute so that little time is consumed unnecessarily in flushing the lines prior to the sample gas passage through the analyzers. The higher rate possible by way of the bypass can speed the initial system response by a factor greater than 200 to 1.

CHAMBER OUTBOARD LEAKAGE

Outboard leakage is simulated with a vacuum pump coupled to the sample chamber. The leakage simulation gas is drawn through the selected flow bench meter and a needle valve is used for setting the simulated leakage rate. After the proper leakage rate is established, the flow is caused to bypass the flowmeter. The bypass line contains a C_v compensation valve that provides the same gas flow conditions as that through the flowmeter.

The outboard leakage pump is located in the right hand bay of the console.

PRESSURE SUIT TEST SYSTEM

A typical pressure suit test system is shown in Figure 20. The LSSE is the vacuum chamber in which the suit is tested. The LSS is the life support system (environmental control system) for the suit. The R.H. and TEMP. package is the relative humidity and temperature probes package (Figure 3). The INJECTOR is the heat and water production unit (Figure 4). The sample chamber is contained within the console of the CSRE labeled unit (Figure 1).

Three flow loops are shown. The first loop includes the LSS input oxygen, or gas mix, to the suit where the incoming gas is mixed and then extracted to flow back through the LSS for processing. The second loop consists of the extracted gas through the R.H. and TEMP. package, through the sample chamber, through the analyzers, and then exhausted to the atmosphere. The exhausted non-oxygen products are replaced along with the injected carbon dioxide, water vapor, and the inert gas through the injector unit. The third loop is an optional one. It consists of the suit-to injector-to suit. This loop may be required to provide sufficient gas flow through the injector so that the heat and water injection rates may be maintained. At low flow rates the water vapor injection may be insufficient unless the recirculation loop is used.

Extra ports and couplings are provided on the heat and water injection unit so that many variations in hookup may be effected depending on the suit-LSS components being tested.

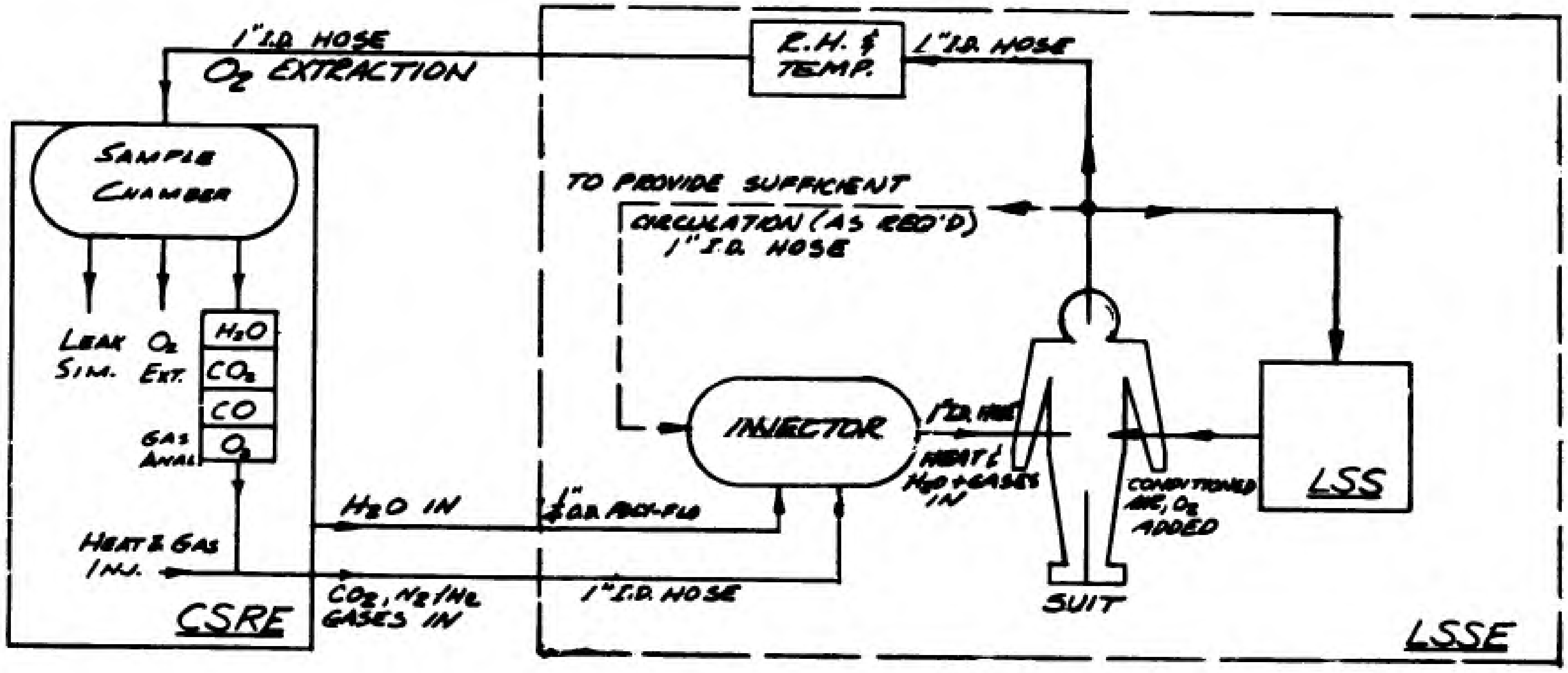


Figure 20. PRESSURE SUIT TEST SYSTEM

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The CSRE is compatible with the Life Support Systems Evaluator (LSSE) and the Space Vehicle Environment Simulator chamber facilities located at the Life Support Systems Division of the Aerospace Medical Research Laboratories.

All system performance requirements as stated on page 2 have been met or exceeded.

The Closed System Respiratory Evaluator described herein utilizes electro-mechanical techniques controlled by an analog computer to compute the various mass flow rates to affect the physio-chemical nature of closed respiratory systems. This approach is judged as superior to other approaches to the problem in that each parameter is capable of selected change without affecting other parameters, avoids the problems of continuous balance and control of system parameters found in other techniques employed and avoids the undesirable by-products found therein with too great a frequency.

The respiratory evaluator described herein will continue to be an essential research tool for use when it becomes desirable or mandatory to perform validation testing of integrated aerospace life support systems or a multitude of subsystems. The respiratory evaluator will:

(a) Permit empirical verification of systems performance and reliability over extended mission durations.

(b) Permit testing of various systems with known inputs-extraction rates where the factor of safety of the system being investigated is not large.

(c) Permit testing of various systems with known inputs-extraction rates changed one variable at a time independent of other variables, rates maintained constant for comparison testing of competitive systems and rates unaffected by variations attributed to human subjects.

(d) Permit testing of various systems without the need to immediately expose human subjects to the unknown hazards of the system being investigated.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Aerospace Medical Research Laboratories Aerospace Medical Div., Air Force Systems Command, Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

The development of a closed system respiratory evaluator (CSRE) is described. The CSRE simulates human respiration and performs all the metering, sensing, and recording functions necessary to evaluate the performance of space cabin simulators, pressure suit systems coupled to their environmental control systems; environmental control systems; life support systems; and rescue and survival systems. The respiratory functions simulated include oxygen consumption and carbon dioxide, water vapor and heat production. Oxygen consumption is simulated by physically extracting from the system under test gas at a rate sufficient to equal the oxygen consumption rate. Carbon dioxide production is simulated by bleeding CO_2 into the system from a storage bottle. Water vapor is introduced by a conventional type humidifier while heat is added by an electrical radiator. The gas rates and heat are computed and automatically controlled by an analog computer directed electromechanical control system. The system thereby avoids the delicate problems of control, balance, undesirable by products, and erratic performance found in systems utilizing adsorption-absorption techniques, catalytic oxidation, or organic materials oxidized to provide the correct carbon dioxide, water, and heat input with simultaneous oxygen removal.

The desired values of the parameters of human respiration may be set independently of each other. The CSRE can remove oxygen at a rate of 0.06 to 0.80 pounds per hour at STP, add carbon dioxide at a rate of 0.07 to 0.90 pounds per hour, add water vapor at a rate of 0.07 to 1.00 pounds per hour and add sensible heat at a rate of 240 to 4800 BTU per hour. When the chamber (or space cabin simulator) is occupied by human subjects, the CSRE can perform chamber gas analysis and, with slight modification, can provide a two-gas control system.

An adjustable automatic chamber pressure control system is also provided which maintains the chamber pressure within ± 20 mm Hg. A leakage simulation test system allows testing with leakage rate of from 1.5 to 36 cubic feet per hour at chamber pressure.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Space Vehicles						
Life Support						
Environmental Conditions						
Habitable Atmosphere						
Instrumentation						
Bioastronautics						