MANNED CHAMBER TESTING OF THE APOLLO PROTOTYPE SPACE SUIT*

G. Frankel, M.E., G. Albright, M.D., I. Axelrod, A.E.
Space Environment and Life Sciences Laboratory
REPUBLIC AVIATION CORPORATION
Farmingdale, L.I., New York

Abstract

A heat balance was established between the metabolic heat generated by a suited subject and the heat transferred to his environment in Republic's space chamber. The mass flow rates of the constituents of the ventilation stream both into and out of the suit were calculated from partial pressure data monitored by a mass spectrometer. The mass flow rate of CO_2 was converted into metabolic heat output, while the flow rate of water was used to calculate the ventilation efficiency. Suited subjects, biomedically instrumented, performed work on a bicycle ergometer at a simulated altitude of 35,000 feet. In one series of tests the metabolic output was held at 1500 Btu/hr while the ventilation stream flow rate was successively increased from 2.5 to 5.8 scfm, while in another series the flow rate was held at 4.1 scfm while the metabolic output was established at 1200 and at 1600 Btu/hr.

Introduction

The objective of this study was to determine the ventilation efficiency of the Apollo prototype space suit. Ventilation efficiency is defined as the ratio of the actual amount of moisture picked up by the space suit ventilation stream to the theoretical amount that the stream could pick up if it were to become saturated. Two series of tests were performed, each using a human subject in the entry lock of the Republic space chamber, but different parameters. Republic's space chamber is a stainless steel cylindrical chamber 13 feet in diameter by 8 feet long, with a personnel door and two 24-inch diameter double-glazed viewing ports (see Figure 1). In the first series, the subject performed work on a bicycle ergometer at a constant metabolic rate (1500 Btu/hr) while the ventilation flow rate was increased in discrete increments from 2.5 to 5.8 scfm. In the second series, the ventilation flow rate was maintained constant at 4.1 scfm, while the subject performed work first at the rate of 1200 Btu/hr and then at the rate of 1600 Btu/hr.

In each series of tests, the metabolic rate of the subject was determined by monitoring the carbon dioxide and water vapor removed from the suit by the ventilation stream. The data used for the calculation of the ventilation efficiency was taken at the time when the partial pressure of water in the ventilation stream exhaust was constant. The data was validated by establishing a heat balance between the heat generated metabolically and the heat leaving the subject.

Test Configuration

The chamber tests were performed in the entry lock of the Republic Space Simulator at a simulated altitude of 35,000 feet. Chamber pressure is controlled automatically by a pressure sensor and pneumatically operated throttling valve system. Simulated altitudes from sea level to 250,000 feet can be preset into the instrumentation which will then maintain the pressure and record it on a strip-chart recorder.

The suited subject was ventilated with oxygen supplied from a liquid oxygen source located outside the entry lock (Figure 2). The oxygen was throttled through a valve and then through a flowmeter. The flowmeter was equipped with thermometers upstream and downstream and a mercury manometer upstream. These pressure and temperature readings permitted the flowmeter indication to be corrected to standard conditions.

The oxygen passed through a section of pipe in which it was humidified. A pressurized water reservoir was attached to the pipe with a wick from which the water evaporated into the oxygen stream. A manually operated bypass valve controlled the rate of humidification. The oxygen line penetrated the wall of the entry lock, passed through an ice bath cooler, and a centrifugal flow water trap to remove condensed moisture from the stream.

The oxygen passed through an inlet manifold in which was mounted a mass spectrometer probe, a thermistor, one side of a mercury manometer, and a barometerwhich was monitored from the exterior of the chamber. The oxygen line was connected to the suit inlet hose. The surface of the suit was instrumented with four thermistors, two of which were shielded from radiant heat. The walls of the chamber were heated externally by means of infrared heat lamps, and the wall temperature was monitored by a thermistor.

The suit exhaust was connected to an exhaust manifold in which was mounted a mass spectrometer probe and a thermistor. A mercury manometer was connected across the inlet and outlet lines of the suit. Exhaust gases from the suit flowed into the chamber from which they were exhausted by the pumping system.

A bicycle ergometer was provided on which the suited subject could exercise. The ergometer was calibrated to measure the mechanical work performed by the subject.

The subjects were Republic test pilots who had been familiarized with the space suit. Preliminary tests were performed at sea level conditions to determine their respiratory quotient. They were biomedically instrumented during the test. Forehead, arm, thigh, trunk, foot, and rectal temperatures were monitored as well as electrocardiogram and heart rate.

Analysis

The ventilation efficiency. which is defined as the ratio of the actual increase in the water vapor content of the ventilation stream to the theoretical increase if the stream were to reach saturation, is obtained from the formula:

$$V.E. = 100 \frac{\dot{w}_2 - \dot{w}_1}{\dot{w}_3 - \dot{w}_1}$$

*This study was performed under subcontract to International Latex Corporation. Industrial Products Division, Dover, Delaware who was under contract to Hamilton Standard Division, United Aircraft Corporation, Windsor Locks, Connecticut who has the prime contract for development of the Apollo space suit and related man support systems.

where:

V. E. = Ventilation Efficiency (%)

$\dot{w}_1$ = Water Vapor Flow Rate In (lbs/min)

$\dot{w}_2$ = Water Vapor Flow Rate Out (lbs/min)

$\dot{w}_3$ = Water Vapor Flow Rate Out at Saturation (lbs/min)

In order for this calculation to be meaningful, the water vapor flow rates used in the above equation had to be chosen at a time when the subject was generating the prescribed metabolic output, and when the water vapor flow rate resulting from this exertion was stabilized. This data was validated by establishing a heat balance; i.e., accounting for all heat transfer both into and out of the space suit.

A schematic diagram of the heat exchanges of the space suit is shown in Figure 3. The heat balance is established by equating the heat generated metabolically by the subject, and the change in body heat storage to the total heat removed from the subject by sensible, latent, radiant, and convective heat transfer, and the heat equivalent of mechanical work. This can be expressed mathematically as:

$$Q_{met} + Q_{stor} = Q_s + Q_1 + Q_r + Q_c + Q_{mech}$$

where:

Qmet = Metabolic Heat Output

Qstor = Body Heat Storage

Q_s = Sensible Heat Removed

Q_1 = Latent Heat Removed

Qr = Radiant Heat Removed

QC = Convective Heat Flow

Q_{mech} = Heat Equivalent of Mechanical Work

The calculation of the metabolic heat output of the subject was based on the rate of expiration of carbon dioxide. The flow of carbon dioxide was taken as the ratio of the partial pressure of carbon dioxide to the partial pressures of carbon dioxide and oxygen times the flow of oxygen. The carbon dioxide flow, divided by the respiratory quotient, is equal to the oxygen consumed. The oxygen consumed, times the heat equivalent of the oxygen consumed, is equal to the metabolic heat output. The formula is:

$$Q_{met} = \frac{P_{CO_2}}{P_{CO_2} + P_{O_2}} \times \frac{O_2 \text{ Flow}}{RQ} \times 6230 \left[4.686 + \frac{0.361\,(RQ - 0.707)}{0.293}\right]$$

where:

Qmet = Metabolic Heat **Output** (Btu/hr.)

PCO_2 = Partial Pressure CO_2 (Tors)

P_{O_2} = Partial Pressure O_2 (Torr)

O_2 Flow = Oxygen Flow (cfm STP)

RQ = Respiratory Quotient

Body heat storage was calculated from the equation:

$$Q_{stor} = 60.1\ Wc_p \frac{\Delta T_{MB}}{\Delta\ \theta}$$

where:

W = Weight of Subjects (pounds)

cp = Specific Heat of Human Body ($\frac{Cal}{gm°C}$)

$\frac{\Delta T_{MB}}{\Delta \theta}$ = Time Rate of Change of Mean Body Temperature ($\frac{°F}{min.}$)

Qstor = Body Heat Storage ($\frac{Btu}{hour}$)

Mean Body Temperature was calculated from the equation:

$$T_{MB} = 0.67T_R + 0.33 \left[.07T_{Fd} + 0.27T_A + 0.19T_{Th} + 0.35T_T + 0.12T_F\right]$$

where:

T_{MB} = Mean Body Temperature °F

T_R = Rectal Temperature °F

T_{Fd} = Forehead Temperature °F

T_A = Arm Temperature °F

T_{Th} = Thigh Temperature °F

T_T = Trunk Temperature "F

T_F = Foot Temperature °F

The sensible heat removed by the ventilation stream was calculated by use of the equation:

$$Q_s = 60\ V\ \delta\ c_P\ (T_2 - T_1)$$

where:

Q_s = Sensible Heat Removed (Btu/hours)

V = Volume Flow Rate of Oxygen (cfm STP)

δ = Density of Oxygen (lbs/ft^2)

c_P = Specific Heat of Oxygen (Btu/lb°F)

T_2 = Temperature at Outlet ("F)

T_1 = Temperature at Inlet ("F)

The latent heat removed by the ventilation stream was calculated from the equation:

$$Q_L = 60h_{fg}\ (\dot{w}_{out} - \dot{w}_{in})$$

where:

Q_L = Latent Heat Removed (Btu/hour)

h_{fg} = Latent Heat of Vaporization of Water (Btu/lb)

$\dot{w}_{out}$ = Mass Flow Rate of Water Out (lbs/min)

$\dot{w}_{in}$ = Mass Flow Rate of Water In (lbs/min)

The water flow rates in the inlet and outlet streams were determined by measuring the partial pressure of water vapor in the stream with the mass spectrometer and applying their partial pressure to the flow rate of the entire system.

The ideal gas equation was used with appropriate conversion factors to make units compatible. The actual equation was:

$$w = 0.0325 \frac{PV}{T}$$

where:

- w = Water Vapor Flow Rate (lbs/min)
- P = Partial Pressure of Water Vapor (Torr)
- V = Oxygen Flow Rate (cu. ft/min)
- T = Temperature (°R)

Radiant heat exchange between the suit and the walls of the entry lock was calculated from the relationship:

$$Q_R = F_g F_e A \sigma (T_2^4 - T_1^4)$$

where:

- Q_R = Radiant Heat Flux (Btu/hr)
- F_g = Geometry Factor
- F_e = Emissivity Factor
- A = Area (ft^2)
- σ = Stefan-Boltzmann Constant
- T_2 = Wall Temperature (°R)
- T_1 = Suit Surface Temperature (°R)

Convective heat flow from the suit to the ambient environment was determined by the equation:

$$Q_c = \frac{4 AKP_r^{1/2} (0.952 + P_r)^{-1/4} G_r^{1/4} (T_2 - T_1)}{3X}$$

where:

- Q_c = Convective Heat Flux (Btu/hr)
- A = Area (ft^2)
- K = Thermal Conductivity of Oxygen (Btu/hr/ft/°F)
- P_r = Prandtl Number of Oxygen
- G_r = Grashof Number of Oxygen
- T_2 = Temperature of Oxygen (°F)
- T_1 = Temperature of Suit Surface (°F)
- X = Characteristic Dimension of Suit (assumed to be unity)

It was also necessary to convert the mechanical work performed on the ergometer into its heat equivalent. This was calculated by multiplying the peripheral speed of the flywheel by the tangential force acting at the periphery, and correcting for discrepancies in the units. The formula for heat equivalent of mechanical work is:

$$Q_{mech} = 3.34 F \omega$$

where:

- Q_{mech} = Heat Equivalent of Mechanical Work (Btu/hr)
- F = Tangential Force (kilograms)
- ω = Pedal speed (rpm)

Data Acquisition

Because of the necessity of recording many parameters at frequent intervals, and reducing some data immediately, the data acquisition was accomplished at six different stations around the chamber simultaneously.

Each of the parameters was recorded with respect to the time of day. The data was then collected on a master data sheet. Where necessary, certain datapoints were interpolated. Some data was plotted in order to determine maxima, and to eliminate minor variances. One station recorded three manometer indications, oxygen pressure into and out of the suit, and pressure differential between inlet and outlet. The observer inside the chamber recorded the temperature of the oxygen into the suit as indicated by a mercury thermometer, the chamber pressure, and the chamber ambient. He also monitored the ergometer pedal speed and tangential load. Another station recorded the parameters of the oxygen supply, flow rate, pressure, and temperatures. The thermistor outputs were recorded automatically on a strip chart recorder and also recorded on a data sheet at another station. These included chamber, chamber wall, suit inlet stream, suit outlet stream, outlet flowmeter, and four suit surface temperatures.

The time-of-flight mass spectrometer, a precision gas analyzer which separates the constituents of a complete gas sample according to molecular or atomic mass by means of the time separation principle, measured the partial pressure of each component of the gas sample and indicated the partial pressure of each component in Torr. The mass spectrometer was used to monitor the partial pressure of oxygen and water vapor in the suit inlet ventilation stream, and the partial pressure of oxygen, water vapor, and carbon dioxide in the suit outlet stream.

The mass spectrometer capillary attached to the exhaust manifold continually sampled the gas and analyzed its composition. The presentation of the mass spectrometer was highly specific in sensing the partial pressure of carbon dioxide as it varied with each breath of the subject. Figure 4 shows a typical strip-chart record of carbon dioxide partial pressure with respect to time during these tests. The lower trace is the partial pressure of carbon dioxide generated by the subject. The variability of output, which normally occurs, can be readily observed, including an interval (A) during which the subject was speaking. Note the fairly regular cyclic pattern interrupted by the conversation. and the return to regular cyclic carbon dioxide production.

Prior to the performance of each test, the predicted metabolic load and ventilation gas flow rate were used in conjunction with the predetermined respiratory quotient of the subject to calculate the predicted partial pressure of carbon dioxide in the exhaust stream.

During preliminary tests, an attempt was made to determine the average value of carbon dioxide partial pressure visually. The difficulty of estimating an average value can easily be seen. The partial pressures of carbon dioxide determined in this manner were not in agreement with predicted values. The output was therefore integrated electronically, using a Sanborn integrator. The upper trace in Figure 4 is that of the integrated value of the partial pressures of carbon dioxide recorded in the lower trace. Each vertical excursion represents a constant time-pressure product (torr-seconds) of carbon dioxide partial pressure output. The sum of the vertical excursions during a representative number of respiratory cycles was divided by the time interval for these cycles to determine the average partial pressure of carbon dioxide during the interval. The pressures determined by this method were in excellent agreement with those predicted for the metabolic rates of the subjects.

Because this figure was so clearly a specific energy output indicator, and because it was available almost immediately, (within the time constraint of accumulating enough breaths to generate a representative rate), the medical observer was kept constantly informed of the carbon dioxide output level by a private telephone line to the mass spectrometer operator. Periodically a carbon dioxide background determination was made so that the indicated measurement could be corrected.

The water vapor determinations were relatively steady state for these tests. As the subject approached a state of equilibrium at a given metabolic output level, the partial pressure of water vapor increased to a plateau and remained constant. There were momentary fluctuations in vapor levels due possibly to mixing variations.

These values were also relayed to the medical monitor via the private telephone line. This, plus the continuous surveillance of body temperatures and heart rate by,biomedical instrumentation, gave him continuous information concerning the subject's condition. The physiological data acquisition station recorded the electrocardiogram, rectal temperature, head, arm, foot, thigh, and trunk temperature of the subject via a "hard wire" link through the chamber wall to a multi-point biomedical connector in the suit at the subject's right thigh.

Several attempts were made to measure the exhaust flow. Initially, a velometer was placed at the outlet of the exhaust pipe and calibrated against the inlet flowrater. In the second test, a special flowrater was installed in the exhaust line, together with a thermistor and a barometer, to enable corrections for temperature and pressure. Neither of these methods proved satisfactory. The first method was inadequate because of errors due to non-uniform velocity across the pipe, while the second method was unsatisfactory because the respiration and motion of the subject introduced excursions of the float in the flowmeter making accurate reading impossible.

Test Procedure

During the preflight phase of the chamber run the test subject was assisted by two chamber technicians - one of whom was to be his inside observer, the other was to be the chamber operator. After instrumentation and dressing had been completed and all pertinent baseline data recorded, the test subject and his inside observer entered the chamber and were placed on 100% oxygen discipline for 2 to 2-1/2 hours before actual flight (Figure 5). During *this* period all instrumentation connections were completed, and operation of each component was verified.

In order to avoid confusion in the communication system, three distinct networks with one cross-os-er between medical supervision and the chamber test director were provided. This enabled data acquisition to be accomplished and simultaneously provided the subject with a clear open line at all times to the test director and medical supervision.

Following completion of ground-level checkout and acquisition of pertinent data, ascent to experimental altitude was accomplished at a rate of approximately 1500 feet per minute. There was continuous adjustment of flow rates, humidity, and temperature control of the suit inlet stream and the chamber environmental temperature. At experimental altitude the chamber was placed on automatic altitude control and carefully monitored. The excursions on automatic control were less than ± 50 feet from the experimental altitude. The test subject was under constant surveillance by the inside observer, the medical observer, the test director, and the chamber operator. The data acquisition teams performed their functions independently so that in all there were fifteen professional and technical personnel outside the chamber supporting the experimental programs for the two personnel within the chamber (test subject and inside observer).

In the first test, the subject performed work at a given metabolic rate (1500 Btu/hr.) while the ventilation flow rate was successively increased from 2.5, 3.9, 4.6 to 5.8 scfm. In the second test, the subject performed at two different metabolic rates (1200 Btu/hr. and 1600 Btu/hr.) while the ventilation flow rate was held constant at 4.1 scfm. Descent to ground level following conclusion of the experimental run was accomplished manually at a rate of approximately two thousand feet per minute. When ground level was reached final data was taken and the test subject was then taken to the medical office for debriefing. All preflight data acquisition was reaccomplished at this postflight period.

Results and Discussion

The results of the first test are plotted as four points on a curve of oxygen flow versus total heat removed by the stream (Figure 6). Curve "A" represents the theoretical maximum amount of heat (both sensible and latent) that could be carried by the stream at various flow rates if the stream were to enter at 43°F carrying the water present at 32°F saturated, and were to leave saturated at temperatures from 88°F to 91°F. Curve "B" represents the theoretical heat carrying capacity of the stream taken at inlet conditions of 43°F saturated, and outlet conditions of 93°F saturated with an inlet pressure of 3.73 psia. The temperature of 93°F was chosen as a realistic theoretical outlet temperature based on experimental data. Curve "C" represents the interpolated data line of the actual heat removed by the gas stream, at various flow rates during the test.

The vertical lines through each data point on Curve "C" represent the range of data recordings resulting from the inaccuracies in the reading of the individual parameters. The ranges are calculated by summing the probable error inherent in each measurement and estimating the effect of this error on the data. The ventilation efficiency is represented by the position of the data point on Curve "C" with respect to the theoretical lines. The ventilation efficiency decreases as the flow rate increases and the increase in heat carrying capacity of the stream as the flow rate is increased above 4 cfm is very small.

The results of the second test are plotted as two points on a curve similar to that used for the first test (Figure 7). In this case Curve "A" represents the heat carrying capability of a stream at various flow rates if inlet conditions are 43°F saturated, and outlet conditions are 93°F saturated. Curve "B" represents the same stream but with inlet conditions at 60°F and water level equal to 43°F saturated.

The following thermal balances were established during the second test:

Mechanical Load:		
Ergometer Setting	1.5 Kp	1.0 Kp
Heat Generated:		
Metabolic Output (Q_{met})	1,655 Btu/hr	1,080 Btu/hr
Body Heat Loss (Q_{stor})	0	167
	1,655	1,247
Heat Removed:		
Sensible (Q_s)	149	121
Latent (Q_1)	1,292	956
Loss to Ambient ($Q_r + Q_c$)	-50	-50
Mechanical Work (Q_{mech})	250	167
	1,641 Btu/hr	1,194 Btu/hr

Although the ventilation flow rate, 4.1 cfm STP, remained constant, the heat load removed by the stream at 1.5 Kp work load and 1.0 Kp work load was 1441 Btu/hr. and 1077 Btu/hr., respectively. The mean body temperature was 1.2°F higher at stabilization during the 1.5 Kp work load than during stabilization at 1.0 Kp work load. The relatively lower mean body temperature would result in a decreased sweating surface area and total amount of sweating. Hence, there would be less available moisture for the ventilation flow to pick up with a corresponding decrease in ventilation efficiency or heat load removed. Excessive sweat, during the 1.5 Kp work load period, "pooled" in the lower sections of the space suit and was relatively unavailable to the ventilation flow. The mean body temperature was steady during the stabilization period at 1.5 Kp work load and continued to decrease during the 1.0 Kp work load. Hence, with a ventilation flow of 4.1 cfm STP the test subject would undoubtedly, at a work load of 1.0 Kp, and probably, at a work load of 1.5 Kp, have maintained an acceptable mean body temperature indefinitely within the physiological limitations of dehydration and fatigue.

The mean body temperature of the subject during the first test probably did not vary more than 0.2°F to 0.3°F at the stabilization periods for the various flow rates. If the slope of the heat removal curve in relationship to the inlet flow (Figure **6**) with a constant mean body temperature (first test) were to be verified by further experimentation, there would appear to be little value in increasing the inlet flow above 4.0 cfm STP to obtain a greater heat removal capability. Indeed, the inlet flow rate might be reduced and maintain the same heat carrying capacity if further experimentation demonstrates a higher efficiency with a higher mean body temperature. With a higher mean body temperature, a greater body surface area would sweat, resulting in a higher efficiency of the ventilation flow, until 100 percent of the body surface area effectively exposed to the ventilation flow was sweating. The proportionate increase in ventilation efficiency with increased mean body temperature in relationship to physical performance and endurance should be established. This is particularly critical at the lower ventilation flow rates where heat carrying capacity of the ventilation flow is reduced.

During peak work loads of short duration, the efficiency of the ventilation stream would be maximal with the increase in mean body temperature. Since there is wide individual variation in sweating surface in relationship to mean body temperature, the maximal ventilation flow efficiency will differ and may not be obtainable in some subjects who sweat only at high mean body temperatures. Other subjects may sweat completely over the effectively ventilated body surface area at relatively low mean body temperatures, representing - from the thermal balance consideration - ideal candidates for space-suited lunar exploration.

In these tests, latent heat loss (evaporation) was about fifteen times that of all other types combined. While heat exchange by radiation and conduction is a fairly rapid process, evaporation is much slower. Therefore, for maximum efficiency the ventilation should be slow and wide-spread to produce a maximum water absorbing capacity. Since evaporative heat loss is a function of volume flow, a large ventilatory volume at low pressure would be more efficient than the same mass flow would be at higher pressure.

With a theoretical external heat load of 120 Btu/hr and a sensible heat loss from the ventilated space suit of 200 Btu/hr. at a heat production rate of 1600 Btu/hr., 1520 Btu/hr. would be lost as insensible heat. One gram of water on evaporation decreases the heat load by 2.22 Btu, thus requiring the vaporization of 685 grams of body water to remove this heat. As some perspiration water will remain in the suit or underwear without contributing to evaporative heat loss, at a work load of 1600 Btu/hr., roughly two pounds of body water would be lost every hour. Due to the shift from radiative and convective heat loss to evaporative heat loss, dehydration will result with prolonged use of the space suit. Hence, facilities and means for the replacement of the lost water and electrolytes must be provided in the final space suit design and included in the space suit's operational requirements.

Conclusions

1. Suited subjects at 35,000 feet simulated altitude, instrumented for electrocardiograms, rectal and skin temperatures, performed work satisfactorily on a bicycle ergometer at a constant metabolic rate (1500 Btu/hr.) while the ventilation rate was successively increased from 2.5 to 5.8 cfm STP and at different metabolic rates (1200 and 1600 Btu/hr.) while the ventilation rate was held constant at 4.1 cfm STP. At a work load of 1.5 Kp on the ergometer, the heat in Btu/hr. leaving the subject was calculated as: sensible, 149; latent, 1292; mechanical, 250; radiant, -50: for a total of 1641 Btu/hr. The heat generated metabolically (as indicated by carbon dioxide production) was 1655 Btu/hr. The ventilation efficiency was 53 percent.

2. A ventilation flow rate of 4.1 cfm STP at an inlet pressure of 3.73 psia will maintain an acceptable mean body temperature indefinitely, within the physiological limitations of dehydration and fatigue, during work performance generating 1440 Btu/hr.

3. The heat removed by the ventilation stream probably will not be significantly increased by a flow rate greater than 4.0 cfm STP.

4. Flow rates less than 4.0 cfm STP may remove more heat than 1440 Btu/hr. if the suited subject has a higher mean body temperature which results in greater sweat production.

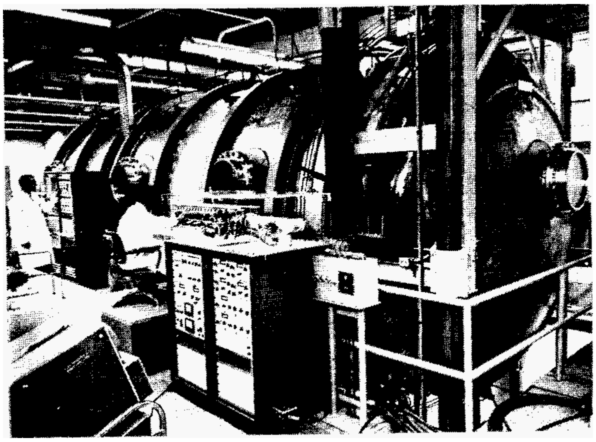

Figure 1 Space Simulation Chamber

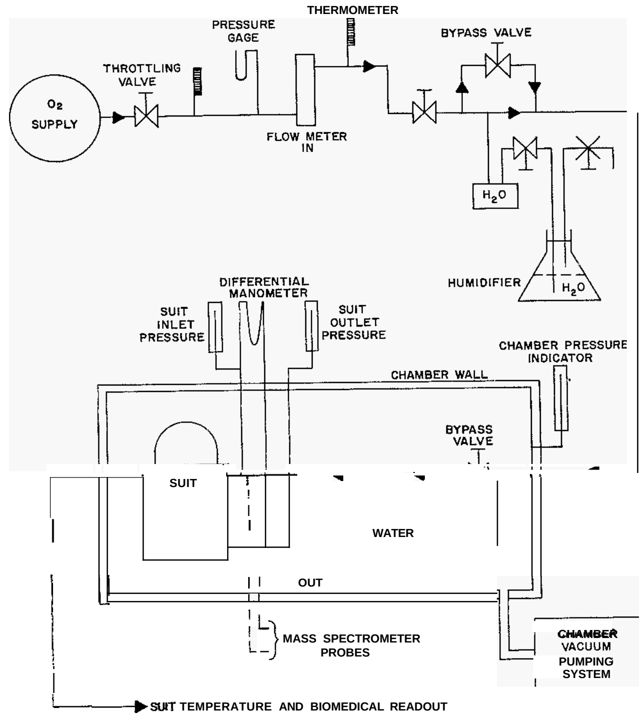

Figure 2. Liquid Oxygen Ventilation System

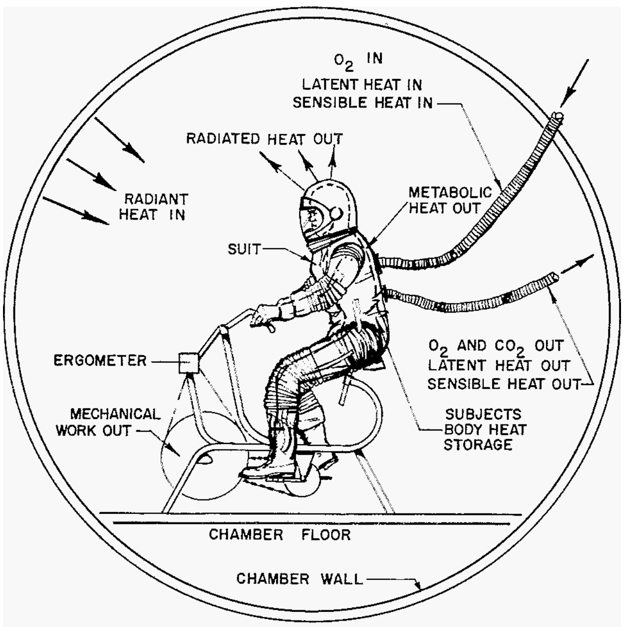

Figure 3. Heat Exchanges of Space Suit Ventilation Tests

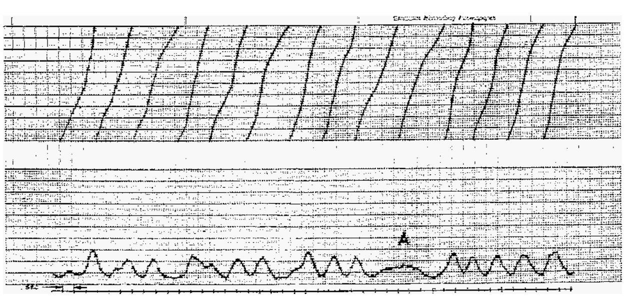

Figure 4. Carbon Dioxide Partial Pressure Curv

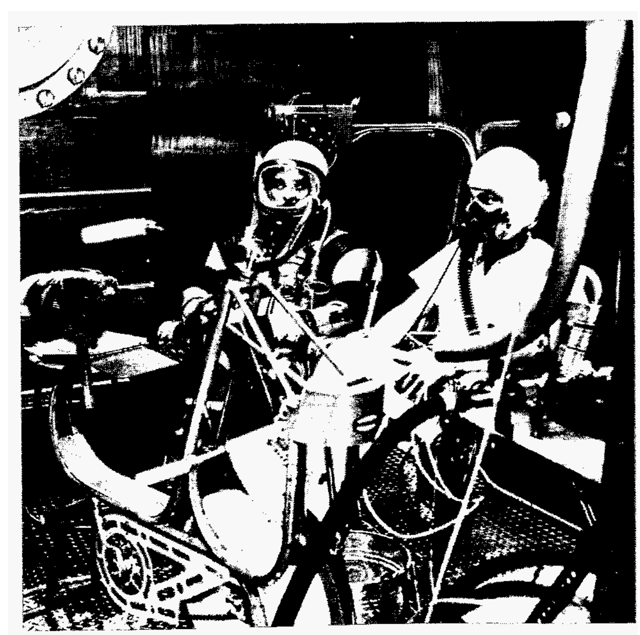

Figure 5. Subjed and Assistant in Space Chamber

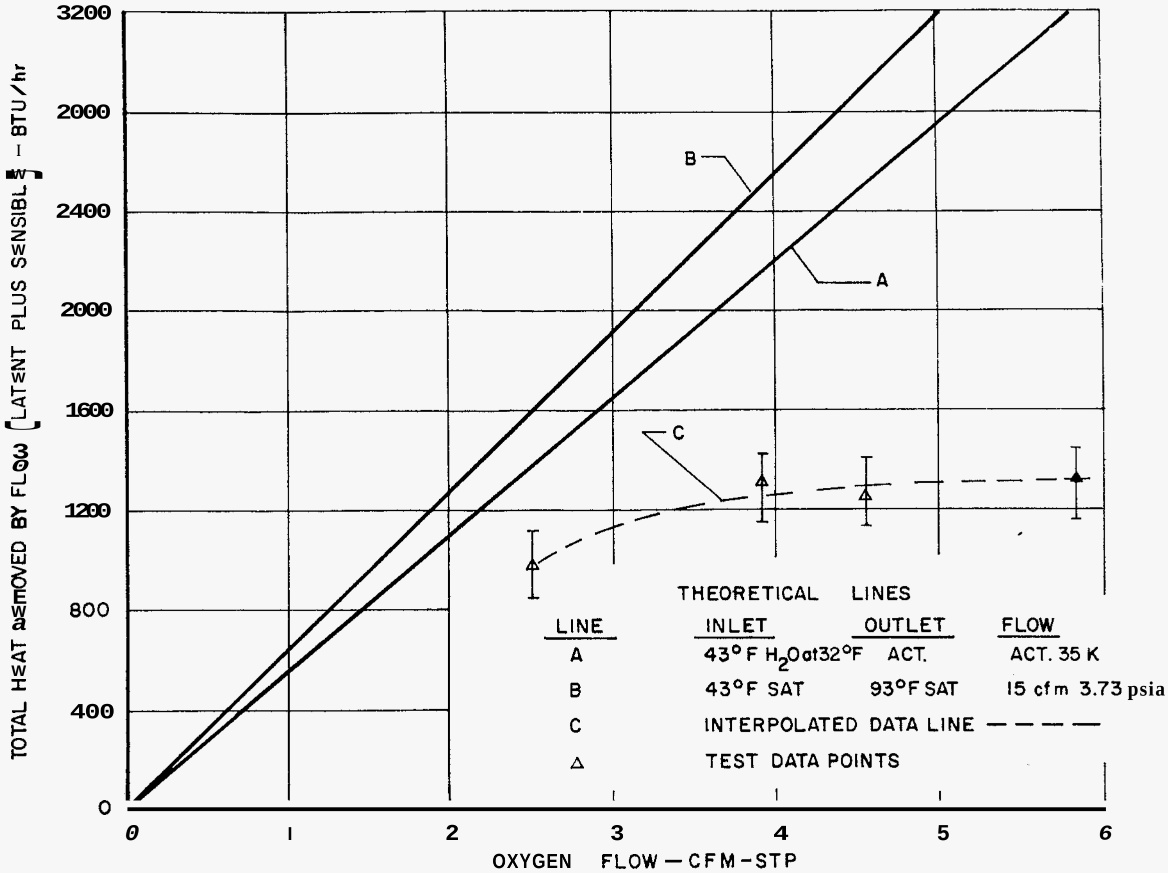

Figure 6. Oxygen Flow vs Heat Removed - Test #1

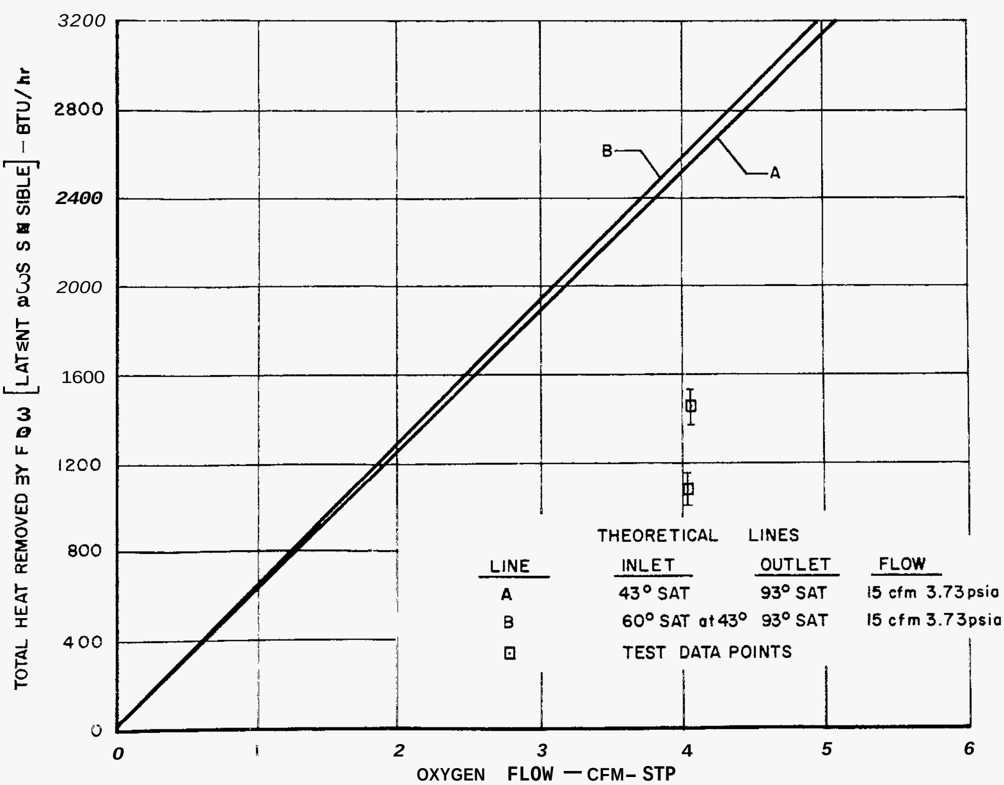

Figure 7. Oxygen Flow vs Heat Re-