U. S. NAVAL AIR DEVELOPMENT CENTER

Johnsville, Warminster, Pennsylvania

REPORT NO. NADC-AC-6708 22 DECEMBER 1967

PHYSIOLOGICAL EFFECTS OF DIFFERENT OXYGEN FLOW RATES AND AMBIENT TEMPERATURES ON PRESSURE-SUITED SUBJECTS PERFORMING WORK AT ALTITUDE

PHASE REPORT
AIRTASK NO. A34-531-060/2001/F022-01-03
WORK UNIT ASSIGNMENT NO. 5314-060-030

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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

Aerospace Crew Equipment Department

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In a series of tests conducted at different ambient temperatures, the physiological effects of various levels of flow rate of ventilating O_2 were investigated. Pressure-suited subjects underwent moderate work stress on a bicycle ergometer in an altitude chamber maintained at 5 PSIA. The temperature and relative humidity of the ventilating O_2 were maintained constant at 55°F and 90-95%, respectively; the duration of the runs was fixed at 2 hours. Within the limits of the ambient temperatures and ventilating flow rates employed, only slight advantages were gained by increasing flow rate, as observed in terms of the physiological measurements made in this study.

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S U M M A R Y

INTRODUCTION

In certain phases of manned orbital flights, a requirement for more comfortable thermal environments was indicated by elevated body temperatures and increased sweating rates. Earlier ventilation studies at the ACED have shown that increased ventilating flow rates were effective in reducing thermal stress imposed on resting subjects wearing full pressure suits in high ambient temperatures (150°F). In the present study, it was theorized that an increase in ventilating flow rate within a range possible in the capsule environment might likewise be effective in reducing the thermal effects experienced by the astronauts during the orbital flight profile.

RESULTS

At each ambient temperature level employed in the study, a slight decrease in final mean weighted skin temperature was observed as the flow rate of ventilating O_2 was increased from 12 CFM to 18 CFM. Under all conditions of the program, rectal temperature was only slightly affected (<0.2°C). Final heart rate was observed at levels of approximately 82-94 beats/min. under all conditions; during the peak work load period, heart rate levels increased to a range of 102-118 beats/min. Total weight loss ranged from approximately 500 to 800 gms., under the experimental conditions varying in ambient temperature and flow rate; the higher losses (700-800 gms.) were observed in tests conducted at an ambient temperature of 90°F.

CONCLUSIONS

On the basis of mean weighted skin temperature, rectal temperature, heart rate, and total body weight loss, no appreciable advantages are to be gained by increasing the flow rate of ventilating O_2 within the range of 12 to 18 CFM at the ambient temperatures employed in this study.

RECOMMENDATION

In order to gain the advantages of increasing the flow rate of ventilating gas in a pressure suit system, even within the flow rates employed in this study, the constancy of the temperature of ventilating O_2 must be maintained at the control set-point temperature. This might be more successfully accomplished by the effective insulation of the inlet arm of the umbilical system used.

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INTRODUCTION

In gas-ventilated manned suit systems, an increase in ventilating flow rate is expected to enhance the evaporative cooling capacity of a given system. In a study designed to determine subjective flow requirements for the maintenance of thermal comfort in 125°F and 150°F temperature environments in sitting-resting subjects wearing the USN full pressure suit (1), flow demands ranged from approximately 20 to 30 CFM at the ambient temperature levels employed in the experimental approach. In a recent study using ventilated wet suits (2), similar advantages in terms of the mean weighted skin temperature, rectal temperature, and total weight loss of sitting-resting subjects were observed when the flow rate of ventilating air was increased from 5 to 10 CFM in ambient temperature conditions of 90°F and 105°F. In systems limited in regard to the availability of ventilating flow, as might be present in the spacecraft environment, the possible physiological advantages of lesser differences in flow rate levels are of prime interest in the determination of a flow rate conducive to a tolerable thermal state in anticipated spacecraft conditions. Hence, the purpose of this investigation was to determine the effectiveness of varying flow rates of ventilating O_2 at a controlled temperature as a means of maintaining a tolerable physiological state in pressure-suited subjects undergoing moderate work stress in different ambient temperature conditions at a simulated altitude of 27,000 feet.

METHOD

Two subjects equipped with a Model G-3C full pressure suit were exposed to ambient temperature (T_a) environments of 70, 80, and 90°F for a period of two hours. The tests were conducted at a simulated altitude of 27,000 feet (5 PSIA) in the York Chamber at the ACED with ascents and descents being executed at a fixed rate of 5,000 ft/min. The altitude-heat chamber, approximately 10 ft. in depth, 8 ft. in width, and 6-1/2 ft. in height, was prepared for the test by allowing wall and air temperatures to reach equilibrium well in advance of the start of the run.

Ventilating O_2 was maintained at a 55°F temperature and a relative humidity of 90-95% while flow varied at 12 CFM, 15 CFM, and 18 CFM at each ambient temperature level. The temperature and relative humidity of the ventilating O_2 were measured and controlled at the inlet fitting of the uninsulated umbilical, forming a flow loop consisting of the inlet umbilical fitting, uninsulated hose to the pressure suit inlet, the manned pressure suit, the uninsulated hose from the pressure suit outlet, to the outlet of the umbilical fitting. The ventilating flow rate was monitored and controlled by a periodic adjustment of a 0-500 LPM rotameter, located just downstream of the outlet fitting of the umbilical. The temperature of the ventilating O_2 was measured by means of thermistors inserted in the ventilating loop system; the temperature output of the sensors was read directly on a YSI Thermistemp indicator. The relative humidity of inlet ventilating O_2 was monitored by the Yellow Springs Temperature-Humidity-Flow Controller; outlet relative humidity of the ventilating O_2 was measured by means of resistance-type, wafer-thin humidity sensors positioned within the ventilating duct, parallel to the line of flow in order to minimize obstruction. The output of the humidity sensor was read on a General Radio Co. Type 1650A Impedance Bridge, using AC supply, and converted to relative humidity by means of a calibration chart.

Copper-constantan thermocouples were used to measure skin temperatures at points on the body surface; mean weighted skin temperature (MWST) was derived from the individual temperature according to conventional methods. Heart rate (HR) and rectal temperature (T_r) were measured by means of the NASA Prototype Bioinstrumentation Harness and the respective outputs were recorded on a Sanborn Model 350. The signal conditioners for the various physiological determinations were supported in a row of pockets located at the anterior belt-line of a full length, light cotton underwear. Total weight loss (TWL) was measured by weighing the subject nude and dry before and after the test exposure on a human weighing device sensitive to 0.5 gm. changes.

The actual exposure to the experimental conditions were of two hour duration unless terminated prematurely by reason of extreme subject discomfort and/or the attainment of pre-determined physiological end points. Preceding the actual test exposure, the subject underwent a two-hour period of denitrogenation at sea-level conditions in the lock adjoining the main chamber. During this time, the subject, with visor closed, was ventilated with O_2 at a flow of approximately 120 LPM for ten minutes followed by a reduction in flow to 100 LPM for the remainder of pre-oxygenation period. The source of the pre-test ventilating oxygen was a portable 30-gallon liquid oxygen converter. Following this conditioning period, the lock was decompressed to 5 PSIA and the subject was transferred to the test cell wherein the experimental conditions had been pre-set and controlled. At this point, the subject was disconnected from the LOX converter supply and immediately reconnected to the conditioned O_2 source established for the exposure conditions.

In the course of test, the subjects were seated in an astronaut-type form-fitting couch. The position of a Collins bicycle ergometer was adjusted so that the subjects were comfortable while pedaling. Metabolic rates were determined by conventional indirect calorimetric methods in order to approximate a specified metabolic work load. The aim was to simulate the following work profile during the 2-hr period; 0-60 min., 500-600 BTU/hr; 60-70 min., 1500-1600 BTU/hr; and 70 to 120 min., 500-600 BTU/hr. As a result of training the subjects in the performance of this work profile, it was established that the watt setting on the bicycle ergometer would be fixed at 15 watts for the first hour of exposure, followed by a work period of ten minutes with the wattage set at 70 and a return to the 15 watt setting for the final 50 minutes of the test period. The subjects maintained pedaling rate at 60 RPM.

R E S U L T S

In Table 1, the temperature of the ventilating O_2 at the inlet disconnect of the umbilical, the suit inlet, the suit outlet, and the outlet disconnect of the umbilical is presented for the different ambient temperatures and flow rates employed in this study. With average inlet disconnect temperatures varying only within 1.0°F of the desired 55°F O_2 temperature in the majority of tests, inlet suit temperature increased by approximately 5°F as the ambient environment was changed from 70° to 90°F at a flow rate of 12 CFM. At a flow rate of 15 CFM, the inlet suit temperature increased only slightly at T_a of 70°F and 80°F, but at a T_a of 90°F the increase was of the order of 5°F above those at the lower ambient temperatures. At a flow rate of 18 CFM, the temperature of ventilating O_2 at the suit inlet increased by 4.7°F going from

TABLE I

VENTILATING O_2 TEMPERATURES AT DIFFERENT SITES OF THE UMBILICAL SYSTEM UNDER DIFFERENT AMBIENT AND VENTILATING TEMPERATURE CONDITIONS

T_a	Flow Rate	I-Disc	I-Suit	O-Suit	O-Disc
70°F	12 CFM	12.3°C (54.1°F)	15.7 (60.2)	26.4 (79.6)	22.4 (72.4)
	15 CFM	12.4°C (54.3°F)	15.2 (59.4)	26.7 (80.1)	22.9 (73.2)
	18 CFM	12.1°C (53.8°F)	13.8 (56.8)	25.4 (77.8)	21.8 (71.2)
80°F	12 CFM	12.6°C (54.6°F)	17.5 (63.5)	27.7 (81.9)	24.8 (76.7)
	15 CFM	12.4°C (54.4°F)	15.4 (59.7)	26.5 (79.8)	24.3 (75.8)
	18 CFM	12.7°C (54.8°F)	16.3 (61.5)	27.0 (80.6)	24.8 (76.7)
90°F	12 CFM	12.6°C (54.6°F)	18.7 (65.6)	28.2 (82.8)	26.7 (80.1)
	15 CFM	12.3°C (54.1°F)	18.1 (64.6)	29.4 (85.0)	27.6 (81.8)
	18 CFM	12.2°C (54.0°F)	17.5 (63.5)	29.3 (84.8)	27.3 (81.2)

I = Inlet
O = Outlet
T_a = Ambient Temperature
Disc = Disconnect

70°F to 80°F and by 2.0°F going from 80°F to 90°F. At the suit outlet, O_2 temperature ranged from 78-80°F at T_a 70°F, from 80-82°F at T_a 80°F and from 83-85°F at T_a 90°F. At the outlet disconnect of the umbilical, O_2 temperature ranged from 71-73°F at T_a 70°F, from 75-77°F at T_a 80°F, and from 80-82°F at the 90°F T_a. Except for the increase in ventilating O_2 temperature at the suit outlet and at the outlet disconnect of the umbilical at the different ambient temperatures, an increase in controlled flow rate affected ventilating O_2 temperature randomly within the narrow limits of temperature ranges just noted.

In Table II, average values of the physiological measures of the study are presented. At 90°F T_a, final MWST ranged between 33.7°C-34.1°C; at 80°F T_a, between 32.8°C-33.6°C; and at 70°F, between 32.5°C-33.4°C. At each ambient temperature, notwithstanding this narrow range of variability in MWST as affected by the controlled flow rates, the lowest order of final MWST was observed when the highest flow rate of ventilating O_2, i.e., 18 CFM, was employed. Rectal temperature varied at most between 37.0°C and 37.4°C throughout the experimental conditions. Average values of final heart rate were only slightly elevated (up to 94 B/min.); at the peak work load interval, however, heart rate was observed at levels between 98 and 118 beats per min. Total weight loss ranged between 700-800 gms. at ambient temperatures of 90°F and between approximately 500-700 gms. at ambient temperatures of 80°F and 70°F, regardless of the level of ventilating O_2 flow rate. Weight deficit, the percent total weight loss as related to initial weight, ranged slightly above 1.0% for those exposures at an ambient temperature of 90°F. Generally for those exposures at 80°F and 70°F, weight deficit ranged between 0.75 and 1.0%.

The pressure at the suit gas supply of the umbilical disconnect varied between 5.5 and 6.0" water above chamber ambient pressure at flow levels of 12 CFM. The flow was metered at a point nearest to the outlet of the umbilical disconnect. The pressure of the ventilating oxygen at the inlet of the suit varied between 5.0 and 5.5" water; at the outlet of the umbilical disconnect it varied between 2.0 and 2.5" water. The measurements of ventilating line pressure were made only in the course of pre-exposure testing. Since the umbilical disconnect, as originally made available, did not contain the proper gasket separating the inlet flow from the outlet flow of ventilating oxygen, several trial runs designed to determine line pressures were rejected and, therefore, not included in this study. The appropriate seal, subsequently obtained from North American Aviation, Inc., allowed for the proper measurement of pressure and temperature of the ventilating O_2 in the disconnect-umbilical-pressure suit loop.

DISCUSSION

Previous work at the ACED has substantiated the assumption that the physiological effects of a stressful thermal environment using impermeable suit systems are attenuated by increases in ventilating flow rate at ventilating temperatures below that of the body core temperature. The physiological parameters considered as indicators of the stress response were body temperature, heart rate, and body weight loss. In an experimental program designed to determine the ventilating requirements to maintain subjective comfort in subjects equipped with the USN full pressure suit, it was found that the necessary flow rate increased from

TABLE II

PHYSIOLOGICAL MEASURES
UNDER DIFFERENT AMBIENT AND VENTILATING CONDITIONS

T_a	Flow Rate	MWST (°C) Final	T_r (°C) Final	HR (B/Min.) Final	HR (B/Min.) Pk. Wk.	TWL (Gms.)	W.D.%
90°F (32.2°C)	12 CFM	33.9	37.1	94	112	720	1.12
	15 CFM	34.1	37.2	88	110	690	1.11
	18 CFM	33.7	37.0	90	112	790	1.23
80°F (26.6°C)	12 CFM	33.6	37.3	82	98	565	0.74
	15 CFM	33.5	37.3	84	106	500	1.01
	18 CFM	32.8	37.4	88	116	620	1.06
70°F (23.9°C)	12 CFM	32.8	37.2	78	102	488	0.90
	15 CFM	33.4	37.0	86	104	658	0.77
	18 CFM	32.5	37.2	86	118	672	0.98

T_a = Ambient Temperature
MWST = Mean Weighted Skin Temperature
T_r = Rectal Temperature
HR = Heart Rate
TWL = Total Weight Loss
WD = Weight Deficit
Pk. Wk. = Peak Work Period

approximately 22 CFM to 29 CFM as the ambient temperature was increased from 125°F to 150°F, the ventilating temperature remaining constant at 60°F. Under identical ambient conditions with ventilating temperatures of 90°F, the increase in flow rate demand was from approximately 29 CFM to 33 CFM.

In a study concerning the physiological assessment of ventilated wet suits under different environmental conditions, certain physiological advantages, in terms of body temperature and weight loss, were observed as flow rate was increased from 5 to 10 CFM using ventilating temperatures of 75°F and 90°F in ambient environments of 90°F and 105°F. Under the conditions of the experimental programs just described, the principle that increased ventilating flow rate at lower ventilating temperatures reduces the elements of physiological strain in high thermal environments was observable.

In the program under consideration, the effect of increasing ventilating O_2 flow rate at different environmental temperatures was likewise observed to be operative in the reduction of thermal stress. The resultant physiological effects, however, were conducive to a thermal state considered to lie in a comfortably cool to comfortable zone, rather than in zones characteristic of hyperthermic states. Evidence for the comfortably cool to comfortable zone is presented by the attainment of the lowest MWST of 32.5°C in an ambient of 70°F using a flow rate of 18 CFM and of the highest MWST of 34.1°C at an ambient of 90°F employing a flow rate of 15 CFM. Rectal temperature was hardly affected by the experimental treatment. Except for anticipated increases during the period of peak work load, heart rate was likewise only slightly affected. Body weight loss ranged overall between 500-800 gms. for the period of experimental treatment, including a two-hour period of denitrogenation which preceded the test run. During this period, the temperature of the ventilating O_2 originating from a liquid O_2 source was considered to be approximately 70°F at the pressure suit inlet; the flow rate was metered at 100-120 LPM at the outlet of the pressure suit.

Under the conditions of the experimental program, therefore, it is concluded that only slight physiological advantages in terms of heart rate, mean weighted skin temperature, rectal temperature, and weight loss are gained by the increase of flow rate of the ventilating O_2 from 12 to 18 CFM. The advantages are indicative of a more than comfortable state; if conditions such as duration or energy expenditure should be even slightly extended than those considered in this program, then the advantages of the environment conducive to reduced physiological responses, however slight, should be explored in the light of anticipated changes.

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13. ABSTRACT

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