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OXYGEN REGULATOR PERFORMANCE DURING DECOMPRESSION. (U)

FEB 77 R D HOLDEN, B F HIOTT, P J ZALESKY

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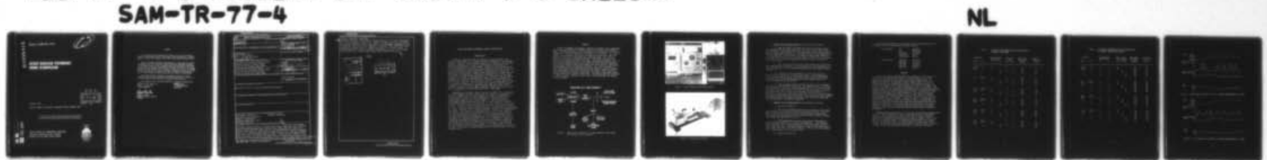

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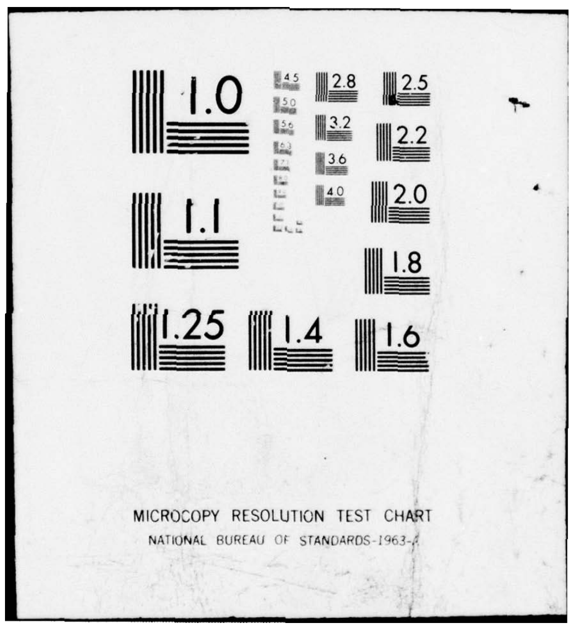
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Report SAM-TR -77-4

OXYGEN REGULATOR PERFORMANCE DURING DECOMPRESSION

February 1977

Interim Report for Period 1 December 1975-31 August 1976

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: SAM-TR-77-4	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): OXYGEN REGULATOR PERFORMANCE DURING DECOMPRESSION.	5. TYPE OF REPORT & PERIOD COVERED: Interim Report, 1 December 75 - 31 August 76
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Ronald D. Holden, B.A.; Bruce F. Hiott, TSgt, USAF; Paul J. Zalesky, Ph.D.	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: USAF School of Aerospace Medicine (VNT), Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas 78235	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62202F, 7164-17-17
11. CONTROLLING OFFICE NAME AND ADDRESS: USAF School of Aerospace Medicine (VNT), Aerospace Medical Division (AFSC), Brooks Air Force Base, Texas 78235	12. REPORT DATE: February 1977
	13. NUMBER OF PAGES: 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Performance evaluation
Performance characteristics
Dynamic decompression
Pulsating respiratory flow
Pulmonary interface
Pulmonary impedance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Both static and dynamic performance characteristics of standard USAF oxygen regulators were evaluated during simulated decompression (loss of cabin pressurization), using the regulator test stand in conjunction with the decompression chamber at USAFSAM. A total of 10 regulators were tested, combining both torso- and panel-mounted types drawn from the standard USAF inventory. Outlet suction pressure, flow, positive pressure, and delivered oxygen dilution schedules were monitored and evaluated for two different decompression rates (4 and 8 seconds) while

next page

Item 20. Abstract - Continued

simulating the same total pressure change (10.9 psi to 4.4 psi) from 2,438 m to 9,144 m (8,000 ft to 30,000 ft). General findings indicate an extremely high initial pressure surge at the moment of decompression simultaneous with an immediate drop in the outlet P_{O2} and a subsequent "lag time" before again maintaining a proper level of oxygen sufficiency at the flyer's mask. A minimum disruptive period of regulator performance was about 10-15 seconds but continued for a considerably longer time in many of the tests.

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OXYGEN REGULATOR PERFORMANCE DURING DECOMPRESSION

INTRODUCTION

Except for subjective data of affected aircrew personnel, very little is known about actual oxygen regulator performance during decompression. Because of the stressful nature of the exposure and the probability of hypoxia and/or loss of consciousness, the exactness of subjective information is questionable. Objective self-examination as to one's condition both mentally and physically is difficult at any time but is especially so under conditions of decompression. This paper attempts to scientifically examine oxygen regulator performance criteria both during and immediately following a simulated loss of cabin pressurization. A dynamic breathing machine in conjunction with the oxygen regulator test stand and decompression chamber closely simulates the man/regulator interface and eliminates the danger of using human volunteers as test subjects. Certain factors such as the semirigidity of the test system in comparison to the human lung compliance and the absence of pressure loss around the oxygen breathing mask make these tests possible instances of "worst case" phenomena. These worst-case factors will be addressed in the discussion portion of this paper.

Hypoxia was a probable cause of aircraft accidents in at least 30% of cases examined; of these, roughly 20% were directly attributable to regulator malfunction or failure, primarily leakage of oxygen due to deterioration or rupture of the diaphragm (5). The time of useful consciousness (TUC) for the aircrew member at 9,144 m (30,000 ft) approximates 60-90 seconds while at rest (1), and stress and exercise considerably shorten this TUC; therefore, if cabin pressure is lost, the potential hazard to the physiological sufficiency of the aircrew member is clear. From these data it is apparent that oxygen regulator performance is a major component in determining crewmember efficiency in a decompressed environment. Due primarily to the development of the oxygen regulator test stand, rapid and effective performance analysis is now available for many oxygen delivery systems (6). A more detailed explanation of the actual operation and component parts of the regulator test stand is discussed in a previous publication (6). For the purpose of evaluating crewmember physiological adequacy, the band of deliverable oxygen concentrations proposed by Ernsting will be utilized (3). This relationship between the concentration of oxygen in the inspired gas and cabin altitude generally fulfills requirements of an oxygen delivery system in the face of possible in-flight decompression up to an altitude of 13,124 m (40,000 ft)(3).

METHODS

Static and dynamic performance testing of standard oxygen regulators during decompression were performed using the following test equipment (Figs. 1-3) and procedures. Each regulator was decompressed from 2,438 m (8,000 ft) to 9,144 m (30,000 ft) in either 4 or 8 seconds. For static testing, two different flow rates for regulator output were used, and dynamic testing was accomplished with three different cyclic minute ventilations using a breathing simulator. The oxygen regulator test stand was positioned adjacent to the small decompression chamber (Fig. 1, B-2) and was interconnected by two lengths of large internal diameter, thick-walled pressure tubing with manual shutoff valves for controlling decompression rate and equalizing pressure. Data were obtained on a Gould Brush Mark 200 pressurized ink-writing system, using an extremely rapid chart-drive speed while monitoring the signal outputs from the digital voltmeters, pressure transducers, flow meter, and oxygen sensor incorporated in the regulator test stand. Parameters measured consisted of cabin altitude, regulator outlet flow, outlet pressure, and oxygen partial pressure.

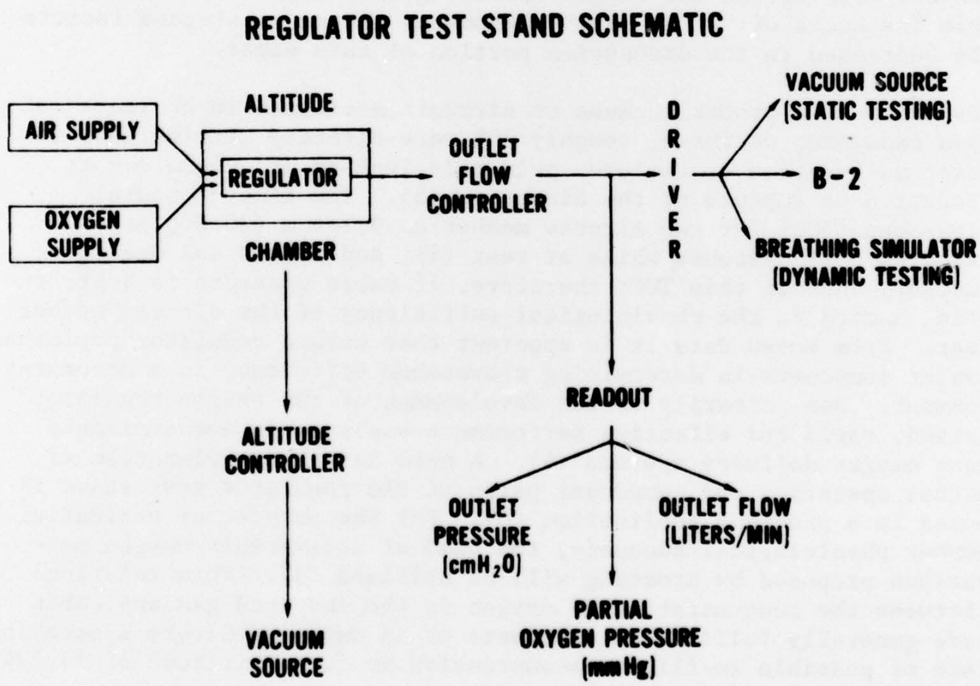

Figure 1. Operational schematic of oxygen regulator test stand (B-2 decompression chamber).

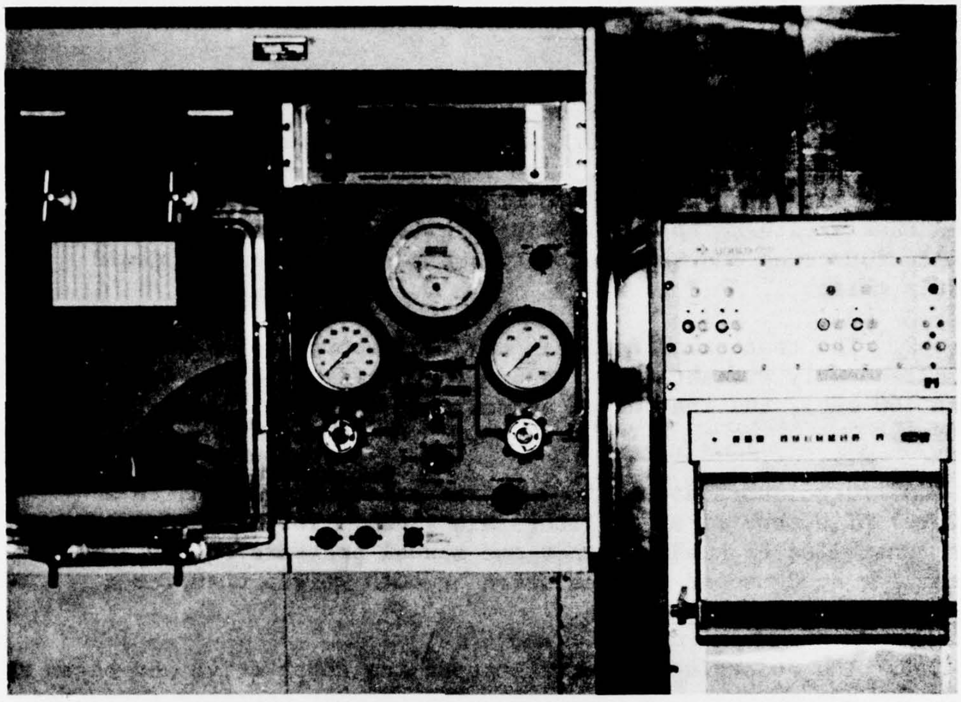

Figure 2. Test stand and recording system.

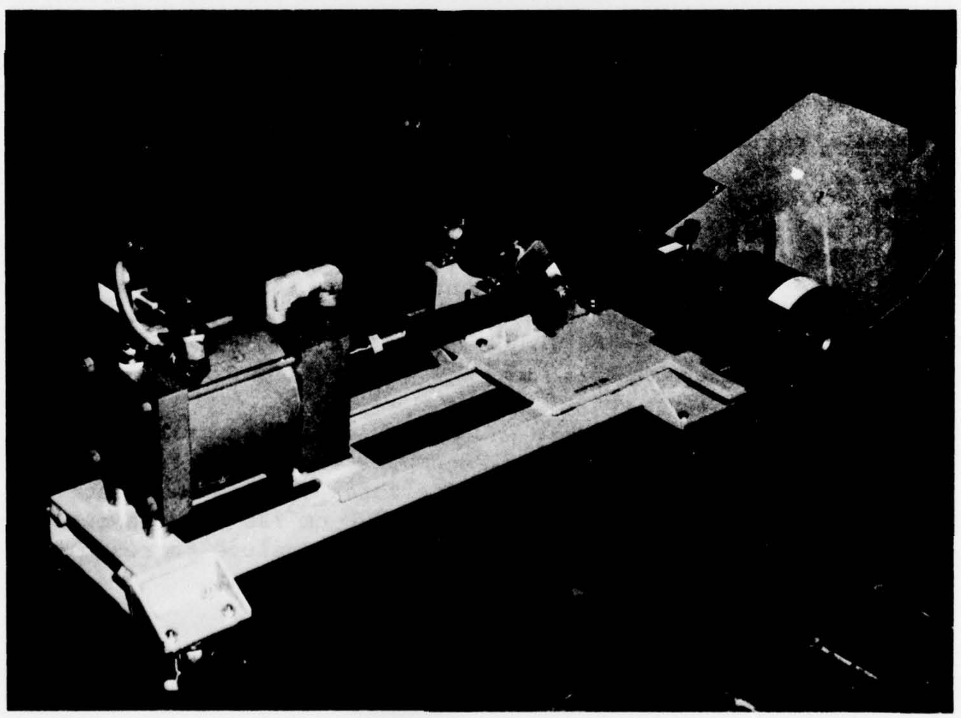

Figure 3. Breathing simulator.

A. Static rapid decompressions were performed as follows:

1. The unit under test (UUT) was placed in the bell jar of the regulator test stand and connected to an inlet oxygen supply pressure of 50 psi. The automix lever was positioned in the normal dilution mode and the regulator turned on. The regulator outlet was connected to the test stand via a short length of flexible rubber tubing similar to an oxygen mask breathing hose, allowing digital displays of the regulator performance functions and subsequent recording of data on the Gould Brush strip chart.

2. The test-stand bell jar and the decompression chamber were then simultaneously evacuated to 2,438 m (8,000 ft) at a moderate rate of ascent (60 sec), and the vacuum accumulator was stabilized at 9,144 m (30,000 ft).

3. Regulator outlet flow was set on the test stand to a static level of either 15 or 85 liters/min (lpm). The decompression rate was controlled by having either one manual pressure equalization valve open for an 8-second decompression or both valves open for a 4-second decompression simulation.

4. The recording operator started the chart drive and began a countdown for decompression activation. The chamber operator activated the pneumatically controlled rapid decompression valve on cue and closed the valve upon stabilization of the bell jar and the chamber at 9,144 m. The elapsed time for all regulator performance characteristics to stabilize at particular values upon reaching 9,144 m and the physiological adequacy of those values were then noted. The recording operator signaled the chamber operator for descent to ground level only after verifying complete cessation of parameter disruption.

B. Dynamic rapid decompressions were performed as follows:

1. Same as section A-1.

2. The cyclic breathing simulator was turned on after having been preset at one of the three minute ventilations tested. (See B-3 below.) The test-stand bell jar and the decompression chamber were then slowly (60 sec) decompressed in unison to 2,438 m, and the vacuum accumulator was stabilized at 9,144 m.

3. The decompression rate was controlled as described in section A-3 to simulate 8- or 4-second decompression. Each regulator tested underwent rapid decompression with calibrated volume and rate settings on the cyclic breathing simulator of 500 cm^3/20 breaths/minute (bpm), 1000 cm^3/18 bpm, and 1500 cm^3/20 bpm. These values correspond to minute ventilations of 10, 18, and 30 lpm.

4. Same as section A-4.

The procedures described in sections A and B were performed on the following torso- and panel-mounted regulator units:

Torso mounted	A-3	SN-902722
	A-3	SN-211527
	CRU-66/A	SN-102094
	Robertshaw	SN-015
	Robertshaw	SN-335
Panel mounted	CRU-68/A	SN-01019
	CRU-68/A	SN-306499
	CRU-69/A	SN-16264
	CRU-73/A	SN-00246
	CRU-73/A	SN-055

RESULTS

Static flow during decompression was conducted at flow rates of 15 and 85 lpm and decompression rates of 4 and 8 seconds so that each regulator was tested at four different parameter combinations. In general the time for the regulator outlet oxygen tension to reach an acceptable level was considerably shorter at the higher flow rate of 85 lpm. The initial outlet pressure burst was lower at the higher flow rate and also lower at the longer decompression rate of 8 seconds. Mean pressure values at the regulator outlet immediately following decompression ranged from 40 to 60 cmH_2O depending upon the UUT, although some values approached 100 cmH_2O in the worst instances. The time for delivered oxygen values to stabilize averaged 12-15 seconds, while the longest time observed was 25 seconds and occurred at a flow rate of 15 lpm and a decompression rate of 8 seconds. As seen in Table 1, the magnitude of the static flow appears to be the overriding factor in determining the length of disruptive influence upon regulator performance and should be weighted more heavily in evaluation than the decompression rate itself. The static flow rates of 15 and 85 lpm were chosen as test parameters because of their use in current specification MIL-R-83178 on regulator performance.

Dynamic minute ventilations of 10, 18, and 30 lpm during decompression rates of 4 and 8 seconds were used in examining regulator performance. Because of the practicality of the data in terms of human interface, representative dynamic decompressions are shown in Figures 4 thru 7 and Table 2. As seen in Table 2, no significant differences were noted in the initial pressure surge at the three different respiratory volumes tested. Thus pressure variances were minimal, especially when considered in light of the vast differences obtained in the static flow tests.

TABLE 1. REGULATOR PERFORMANCE DURING DECOMPRESSION AT STATIC FLOW RATES

Regulator Type	S/N	Decompression rate (sec) 4	8	Flow rate (lpm) 15	85	Peak pressure burst (cmH_2O)	Time P_{O_2} disrupted (sec)
Robert-	015	X		X		74	19
shaw	"	X			X	53	7
"	"		X	X		58	18
"	"		X		X	20	10
A-3	211527	X		X		81	20
"	"	X			X	58	7
"	"		X	X		71	22
"	"		X		X	20	10
CRU-	102094	X		X		81	18
66/A	"	X			X	61	8
"	"		X	X		69	20
"	"		X		X	20	8
CRU-	306499	X		X		94	20
68/A	"	X			X	56	8
"	"		X	X		76	22
"	"		X		X	25	7
CRU-	16264	X		X		94	18
69/A	"	X			X	58	10
"	"		X	X		84	20
"	"		X		X	20	10
CRU-	00246	X		X		86	20
73/A	"	X			X	53	8
"	"		X	X		69	20
"	"		X		X	19	10

TABLE 2. REGULATOR PERFORMANCE DURING DECOMPRESSION AT DYNAMIC MINUTE VENTILATIONS

Regulator		Decompression rate (sec)		Min. ventilation (lpm)			Peak pressure burst (cmH_2O)	Time P_{O_2} disrupted (sec)
Type	S/N	4	8	10	18	30		
Robert-	335	X		X			74	32
shaw	"		X	X			58	39
"	"	X			X		86	26
"	"		X		X		66	27
"	"	X				X	76	32
"	"		X			X	64	36
CRU-	102094	X		X			69	29
66/A	"		X	X			58	31
"	"	X			X		69	28
"	"		X		X		64	28
"	"	X				X	66	28
"	"		X			X	58	46
CRU-	01019	X		X			81	40
68/A	"		X	X			71	44
"	"	X			X		89	30
"	"		X		X		76	30
"	"	X				X	81	25
"	"		X			X	74	36
CRU-	00246	X		X			64	33
73/A	"		X	X			51	41
"	"	X			X		71	24
"	"		X		X		61	28
"	"	X				X	69	25
"	"		X			X	51	37

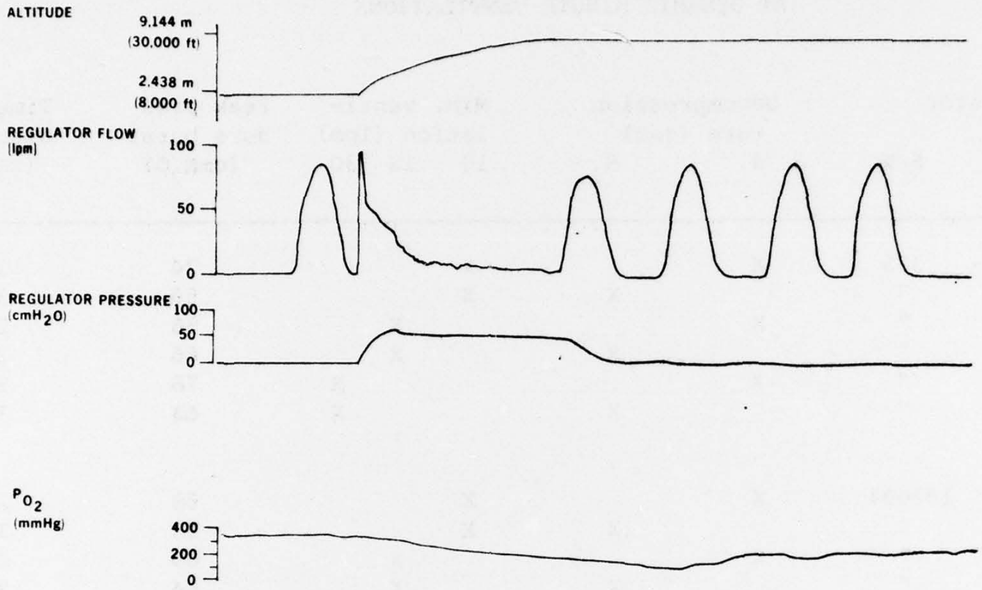

Figure 4. Robertshaw regulator S/N 335, 8-second decompression, 30 lpm.

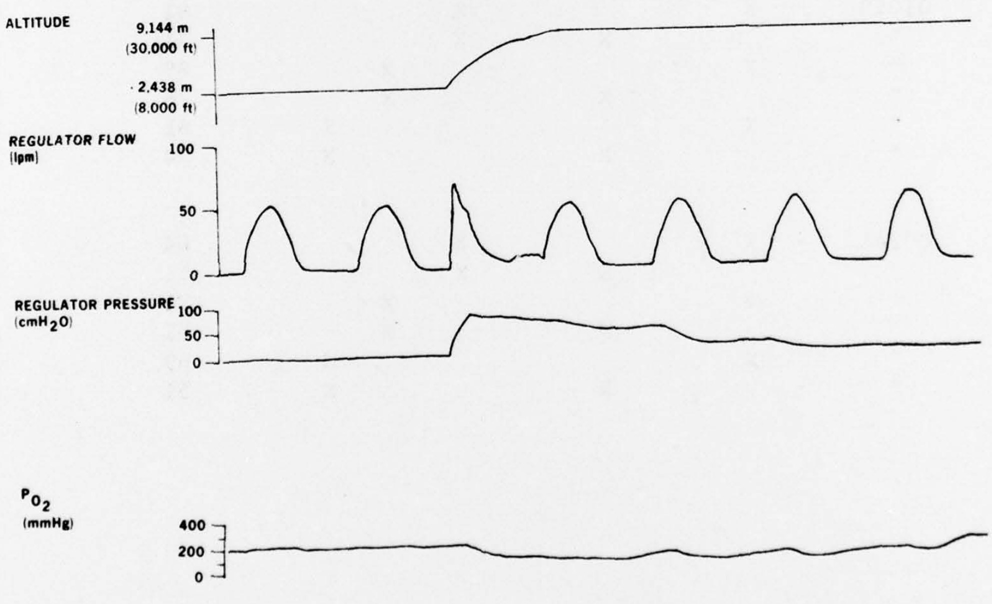

Figure 5. A-3 regulator S/N 902722, 4-second decompression, 18 lpm.

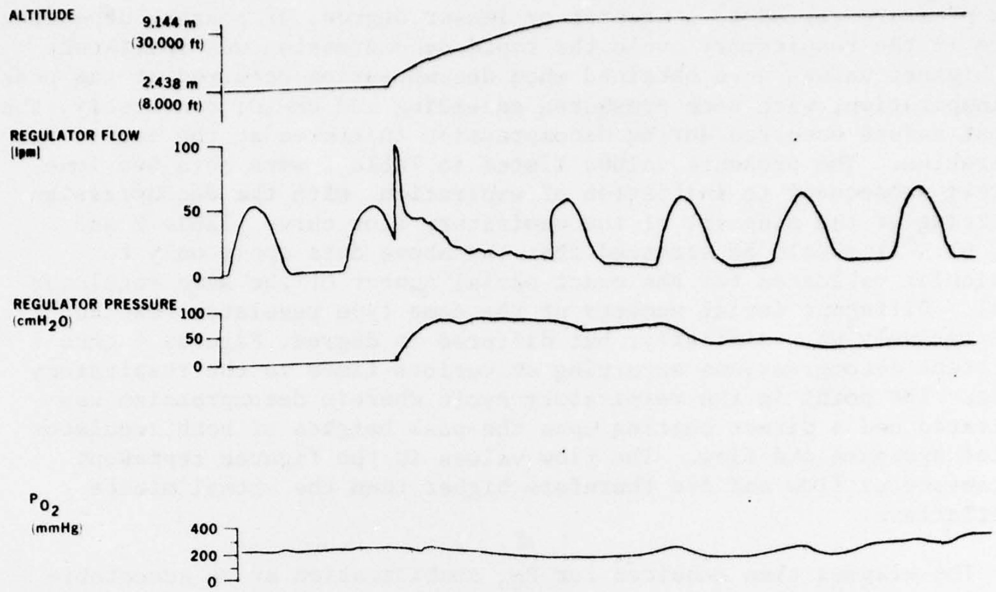

Figure 6. A-3 regulator S/N 902722, 8-second decompression, 18 lpm.

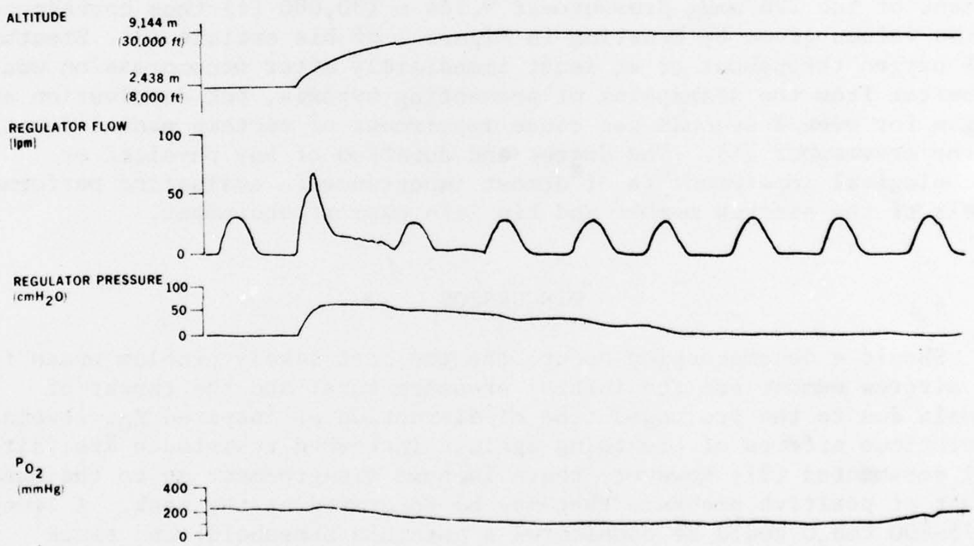

Figure 7. CRU-73/A regulator S/N 00246, 8-second decompression, 10 lpm.

Peak pressure varied to a greater or lesser degree, of course, depending where in the respiratory cycle the rapid decompression was initiated. The highest values were obtained when decompression occurred at the peak of inspiration, with some pressures exceeding 100 cmH_2O; conversely, the lowest values occurred during decompression initiated at the end of expiration. The pressure values listed in Table 2 were obtained immediately subsequent to initiation of expiration, with the decompression occurring at the midpoint of the expiratory flow curve (Table 2 and Fig. 6). It should be stressed that the above data apply only to particular variances for the exact serial number of the same regulator model. Different serial numbers of the same type regulator reacted qualitatively very similarly, but differed in degree. Figures 4 thru 7 represent decompressions occurring at various times in the respiratory cycle. The point in the respiratory cycle wherein decompression was activated had a direct bearing upon the peak heights of both regulator outlet pressure and flow. The flow values in the figures represent instantaneous flow and are therefore higher than the actual minute ventilations.

The elapsed time required for P_{O_2} stabilization at an acceptable level after dynamic decompression showed no significant variations other than stabilization times for ventilations of 18 lpm, which were slightly less in most cases. Respiratory simulation data, when compared with those of the static flow decompression, showed a longer period of disruption before the outlet oxygen percentage attained an acceptable level. The method for determining minimal physiological sufficiency for P_{O_2} levels was taken to be 0.9 P_b in this particular case (3). Ninety percent of the 226 mmHg pressure at 9,144 m (30,000 ft) thus corresponds to the values given by Ernsting in Figure 1 of his article (3). Breathing 100% oxygen throughout or at least immediately after decompression would be better from the standpoint of preventing hypoxia, but deprivation of oxygen for even 2 seconds can cause impairment of certain mental facilities of the crewmember (4). The degree and duration of any physical or psychological impairment is of utmost importance in evaluating performance levels of the aircrew member and his life support equipment.

DISCUSSION

Should a decompression occur, the two most likely problem areas for the aircrew member are the initial pressure burst and the threat of hypoxia due to the prolonged time of disruption of inspired P_{O_2} levels. Deleterious effects of breathing against increased resistance are fairly well documented (2); however, there is some disagreement as to the exact amount of positive pressure that may be tolerated at the mask. A level of 75-100 cmH_2O could be considered a possible threshold; and since several of the pressure values fell within this range, possible alveolar damage could occur. Ernsting et al. (4) reported nothing more than slight abdominal gas expansion in human subjects decompressed from 2,438 m (8,000 ft) to 11,585 m (38,000 ft) in 1.5 seconds, and remaining there for 1.5 minutes. (Apparently, however, high pressure levels were not encountered in their experiments, as none were reported. Experimental design and basic equipment differences in the British oxygen delivery system are thought to be the explanation for this.) Depending upon what gas was breathed (air or oxygen) and for what duration, some impairment of psychomotor activity and significant change in the subject's electroencephalogram (EEG) were reported. EEG changes lasted no longer than 25 seconds, and significant psychomotor performance decrement lasted 30-50 seconds, depending on how soon after decompression (either 2 or 8 sec) 100% oxygen was delivered to the subject. These data are consistent with those found in Tables 1 and 2.

It was previously stated that these tests represent a possible "worst case" (when viewed with respect to the very high initial pressure surge) since all pressure remained in the delivery system. This may not be the case in the aircraft since partial venting of excessive pressure would probably occur around the mask's face seal in actual flight. There still remains, however, the distinct possibility of deleterious pressure levels at the user's pulmonary interface. The considerable differences between Tables 1 and 2 (static and dynamic test values) demonstrate that static testing procedures may be considered only a precursory type evaluation and should be supplemented by or replaced with actual pulsating respiratory flows. These pressures of variable waveform would constitute dynamic testing which should be applied to all phases of oxygen regulator performance evaluation (7). Decompression data further solidify the fact that design criteria for new-generation oxygen delivery systems must provide adequate matching impedance with the pulmonary interface of the user.

ACKNOWLEDGMENTS

The combined support of the research chamber technician personnel was greatly appreciated and was of significant importance in the successful completion of this task.

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