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USAARL REPORT NO. 76-19

AEROMEDICAL REVIEW OF OXYGEN REQUIREMENTS OF US ARMY AVIATORS

BY

Frank S. Pettyjohn, M.D., LTC, MC

Roderick J. McNeil, LT, MSC

April 1976

US ARMY AEROMEDICAL RESEARCH LABORATORY

Fort Rucker, Alabama

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Aeromedical review of US Army aircraft oxygen design criteria and military specification indicates physiologic inconsistencies. Oxygen duration charts in use for U-21 aircraft are computed on the basis of military specification using inspiratory minute volume (IMV) of 13.12 liters per minute (LPM), normal temperature (70°F), pressure, dry (NTPD). Current oxygen duration charts for the RU-21 aircraft using constant flow regulator have overstated oxygen availability

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of 62.3% at 10,000 feet and 18.7% at 15,000 feet. Type regulator and dilution schedule are listed for U-21 series aircraft. The current design inspiratory minute volume of 13.12 LPM NTPD is the basic design deficiency. The effects of the activity and stress of flight require an increase of design IMV.

ABSTRACT

The US Army Aeromedical Research Laboratory studied available oxygen systems for use in helicopter aeromedical evacuation in mountainous areas. Following this initial study, aeromedical review of the US Army aircraft oxygen design criteria and military specifications was undertaken. Physiologic inconsistencies were found which are reviewed in this report. Specific areas of concern are the oxygen duration charts. Oxygen duration charts in use for U-21 aircraft are computed on the basis of military specification using inspiratory minute volume (IMV) of 13.12 liters per minute (LPM), normal temperature (70°F), pressure, dry (NTPD). Current oxygen duration charts for the RU-21 aircraft using constant flow regulator have overstated oxygen availability of 62.3% at 10,000 feet and 18.7% at 15,000 feet. Type regulator and dilution schedule are listed for U-21 series aircraft. The current design inspiratory minute volume of 13.12 LPM NTPD is the basic design deficiency. The effects of the activity and stress of flight require an increase of design IMV. This study emphasizes the requirement for aeromedical input into the design criteria of life support equipment.

APPROVED: ROBERT W. BAILEY
Colonel, MSC
Commanding

AEROMEDICAL REVIEW OF OXYGEN REQUIREMENTS OF US ARMY AVIATORS

INTRODUCTION

The United States Army Aeromedical Research Laboratory (USAARL) was tasked by The Surgeon General in April of 1973 to evaluate the Required Operational Capability (ROC) for oxygen systems for US Army helicopters.[1]

The Chlorate Candle Oxygen Generator System was developed to meet the specific operational needs of high altitude helicopter rescue and aeromedical evacuation. During the evaluation other sources of oxygen meeting the requirements of low cost, light weight, low maintenance, negligible fire or explosive hazard, and elimination of liquid/gaseous oxygen handling equipment/procedures were sought. New technology utilizing molecular sieve to extract nitrogen from a source of pressurized air was considered feasible for use in US Army fixed and rotary wing aircraft. These systems, however, presented new concepts and operational problem areas requiring an in-depth aeromedical review.[2,3,4]

The evaluation of the prototype Army Molecular Sieve Oxygen Generating System (AMSOG) required validation of the design oxygen requirements of those US Army aircraft currently in the inventory--the OV-1, the U-21, the C-12A, and proposed aircraft. Review of applicable military and Federal Aviation Agency standards and the operational oxygen duration charts and regulator oxygen delivery schedules in use today revealed significant inconsistencies. This report will review the aeromedical basis for aircraft oxygen system requirements in the US Army aviation operational environment.

DISCUSSION

Military Specification MIL-D-8683A, 3 July 1969, provides the general specification for design and installation of gaseous oxygen systems in aircraft.[5] MIL-D-19326E, 15 June 1971, provides the general specification for liquid oxygen systems.[6] MIL-R-25410F, 15 January 1968, provides the military specification for regulator, oxygen, dilutor-demand, automatic-pressure breathing.[7] For conservation of space and weight, US Army aircraft use the Type I High Pressure Oxygen System with a defined pressure of 1800 per square inch gauge (PSIG). The liters per minute (LPM) rate at sea level, normal temperature (70^{0}F), pressure, dry (NTPD), is used for simplicity although the military specifications provide a variety of units. The following Tables I, II, and III are extracted from MIL-D-8683A and MIL-D-19326 to list values in the usual units.

TABLE I

MIL-D-8683A and MIL-D-19326E

OXYGEN REQUIREMENTS FOR EACH CREW MEMBER
USING MASK WITH 100% OXYGEN

Cabin Altitude (feet)	R (Liters Per Hour) Corrected to Sea Level & 70° F Dry	R (Liters Per Minute) NTPD
Sea Level	787	13.12
5,000	637	10.62
10,000	504	8.40
15,000	405	6.75
20,000	326	5.43
25,000	246	4.10
30,000	190	3.17
35,000 and above	139	2.32

TABLE II

OXYGEN REQUIREMENTS FOR EACH CREW MEMBER
USING MASK WITH "NORMAL" OXYGEN

Cabin Altitude (feet)	R (Liters Per Hour) Corrected to Sea Level & 70° F Dry	R (Liters Per Minute) NTPD
Sea Level	144	2.40
5,000	144	2.40
10,000	144	2.40
15,000	144	2.40
20,000	176	2.93
25,000	198	3.30
30,000	187	3.12
35,000 and above	139	2.32

TABLE III

OXYGEN REQUIREMENTS FOR EACH PASSENGER
(CONTINUOUS FLOW SYSTEM)

Cabin Altitude (feet)	R (Liters Per Hour) Corrected to Sea Level & 70° F Dry	R (Liters Per Minute) NTPD
10,000	96	1.60
15,000	108	1.80
20,000	119	1.98
25,000	133	2.22
30,000	144	2.40
35,000	210	3.50
40,000	270	4.50

From these tables it is apparent the primary design factor is that of the Inspiratory Minute Volume (IMV) requirement of man in the aviator environment. The value used by manufacturers today is 13.12 LPM (NTPD). The origin of this value is unclear to this author. The wide range of variability of aircrew respiratory volumes under the changing stresses of flight must be considered in aircraft oxygen system design. The design mission profile and the overall flight envelope must also be considered in the oxygen system.

The early German studies of the problems of high altitude flight and breathing oxygen provided basic concepts for aviator oxygen system design.[8] The Luftwaffe established the lower limit of safety for flight without oxygen at 8,200 feet (2,500 m). The upper limit with 100% oxygen available was established at 26,200 feet (8,000 m) as decompression sickness was anticipated above 29,500 (9,000 m). This is essentially the concept of US aircraft oxygen usage today.

The Germans selected a peak oxygen flow rate of 100 LPM (NTPD). The mean oxygen flow rate for a man in an aircraft was selected by practical experience at 300 liters per man per hour. The 300 liter volume is 0°C, 760 mHg, standard temperature, pressure, dry (STPD). Studies of measured inspiratory minute volumes at 37°C, saturated, ambient pressure, found 10.3 LPM at 13,100 feet (4,000 m); 14.2 LPM at 19,700 feet (6,000 m); and 20.0 LPM at 26,200 feet (8,000 m). The German value at 17,000 feet (5,250 m) corresponded to the US value of 12.6 LPM at 0°C and 760 mHg (STPD) or

13.57 LPM (NTPD).[8] The German values are acknowledged to be based on practical experience with little in-flight research basis.

A review of the Royal Air Force (RAF) work indicates efforts to establish respiratory minute volume (RMV) criteria for oxygen system design found a wide individual variation. Ernsting summarized data from unspecified sources to provide a reference of activity and respiratory minute volume in aircrew free of anoxia.[9]

TABLE IV

AIRCREW	RESPIRATORY MINUTE VOLUME		
	LPM (BTPS)	LPM (NTPD)	CURRENT DESIGN CRITERIA MIL-D-8683A
Seated inactive	10-15	8.9-13.35	13.1
Seated active	15-25	13.35-22.25	13.1
Ambulatory active	25-40	22.25-35.60	13.1
After running to A/C	100	89	13.1

As can be seen, design criteria in current use are at the upper limits of seated inactive aircrew and lower limits of a seated active crewman. Further studies of bomber aircrew, conducted by Carlsen and Wulff in 1944, indicate inactive aircrew require approximately 13.0 LPM body temperature, pressure, saturated (BTPS) (11.6 LPM NTPD) while active aircrew require approximately 22.0 LPM BTPS (19.6 LPM NTPD).[9]

Another design factor is the maximal (peak) instantaneous flow rates during the respiratory cycle. The changes in mass flows during cyclic respiration at rest or exercise provide a wide range of requirements for the oxygen system. The use of low resistance systems to minimize inspiratory and expiratory effort is required.

The "stress" of operational fixed wing and rotary wing flying is a difficult value to measure. Difficulty of flying task due to weather, type aircraft, expected danger due to enemy attack, thermal effects, vibration, and fatigue are all participants in the cumulative term "stress." Studies to evaluate stress have usually attempted to control the variables while measuring one or two physiologic responses. Inspiratory minute volumes, in addition to heart rate, oxygen consumption,

indirect calorimetry, urine and blood steroid and electrolyte levels, have all been measured during various flight conditions with a wide range of results.

Vibration at various frequency and acceleration levels has produced divergent respiratory effects. In general, it is suggested by Guignard that respiratory changes are due to hyperventilation which is a combination of mechanical effect and the physiological response to vibration stress.[8] At frequencies of 4 hertz (Hz) or greater, the pulmonary ventilation is increased. At frequencies above 6 Hz, there is an increase in oxygen consumption and respiratory exchange ratio. In the aviation environment these factors would serve to increase the overall design parameters for oxygen supply.

It is generally accepted that the stress factors listed would serve to increase markedly the design inspiratory minute volume.

Oxygen Duration Charts. A review of current oxygen duration charts and capabilities of operational aircraft was conducted. The design oxygen systems available on operational aircraft are listed in Table V. The TM-55-1510-209-10 series provide the oxygen duration charts purported to be compatible with Military Specification MIL-D-8683A.

In TM 55-1510-209-10/1, Change 3, oxygen duration charts are presented for the available cylinder combinations in cubic feet for the U-21A. The available charts are listed:

11 cubic feet, Figure 6-7 (Sheet 1 of 4), page 6-15.
64 cubic feet, Figure 6-7 (Sheet 2 of 4), page 6-16.
75 cubic feet, Figure 6-7 (Sheet 3 of 4), page 6-17.
203 cubic feet, Figure 6-7 (Sheet 4 of 4), page 6-18.

As noted in Table V, other combinations of cylinders possible include 86 and 150 cubic feet. Oxygen duration charts are not available for these configurations. The combinations above are also possible in the U-21G aircraft which has only a single oxygen duration chart available for 214 cubic feet (Fig. 6-8, page 6-18, TM 55-1510-209-10/3). Figure 6-9, page 6-19, provides a 128 cubic foot chart for the RU-21E only.

The oxygen duration charts were recalculated by Military Specification MIL-D-8683A using known aircraft oxygen regulator type and inspiratory minute volumes. The results of recalculation indicate significant error at 10,000 feet using dilutor-demand with conservative error for 100% oxygen in all current oxygen duration charts.

Sample calculations are reviewed for the 64 cubic foot system, U-21A (Fig. 6-7 (Sheet 2 of 4), page 6-16, TM 55-1510-209-10/1, Change 3). One man at 2,000 PSIG, dilutor-demand:

TABLE V

A/C SERIES	CYLINDER CONFIGURATIONS Cu Ft	Total Cu Ft (Actual)	Liters (NTPD)	REGULATORS	OUTLETS	DURATION CHARTS
U-21A	[11(10.98) + 64(63.7)]	= 75 (74.68)	= 2114.64	2 Dilutor-Demand MS 22062-1	2 Crew	TM 55-1510-209-10/1, Change 3 (75) Fig 6-7
U-21G	75 + 11	= 86 (85.66)	= 2410.13	1 Const Flow ALAR A-2000	6 PAX	
	75 + 11 + 64	= 150(149.46)	= 4229.28			TM 55-1510-209-10/3, Change 5 (214) Fig 6-8
	75 + 11 + 64(2)	= 214(213.06)	= 6033.01			
RU-21A	64	= 64(63.7)	= 1803.73	2 800308-00 Scott Const Flow	2 Crew 2 Operators	TM 55-1510-209-10/1, Change 3, Fig 6-9
RU-21B				2 800308-00 Scott Const Flow	2 Crew 3 Operators	TM 55-1510-209-10/2, Change 2, Fig 6-6
RU-21C				2 800308-00 Scott Const Flow	2 Crew 2 Operators	TM 55-1510-209-10/2, Change 2, Fig 6-6
RU-21D	64 x 2	= 128(127.4)	= 3607.46	4 Dilutor-Demand MS 22062-1	2 Crew 2 Operators	TM 55-1510-209-10/1, Change 3, Fig 6-10
RU-21E				4 Dilutor-Demand MS 22062-1	2 Crew 2 Operators	TM 55-1510-209-10/3, Change 5, Fig 6-9
JU-21A				5 Dilutor-Demand MS 22062-1	2 Crew 3 Operators	MIL TM not available
RU-21H	64 x 4	= 256(254.8)	= 7214.92	4 Dilutor-Demand MS 22062-1	2 Crew 3 Operators	MIL TM not available
U-21F	22	= 22	= 622.95	12 Constant Flow 2R800-1-A Puritan Zep	2 Crew 10 PAX	MIL TM not available
RU-21F	Scott chlorate candle approx 15-20 min/candle				2 Crew	MIL TM not available
C-12	49	= 49	= 1387.48	2 ZMR-151-M-48B-48A1 Dil.-Dem Puritan Zep	2 Crew	MIL TM not available
				1 ZR 807 Puritan Zep	8 PAX	

10,000 feet: V = [64 (63.7 actual) X 28.316 liters/cu ft ÷ 60 min/hour = 30.062 liters hour/min]

V ÷ 2.4 liters per min	= 12.53
Value from Fig. 6-7	= 16.70
Overstated duration error	= 4.17 hr. = 33.3%

15,000 feet:

V ÷ dil. demand 2.4 liters/min	= 12.53
Duration from Fig. 6-7	= 12.70
Overstated duration error	= 0.17 hr. = 1.4%

20,000 feet:

V ÷ dil. demand 2.9 liters/min	= 10.366
Duration from Fig. 6-7	= 10.400
Overstated duration error	= 0.034 hr. = 0.3%

For 100% oxygen for one man, 2000 PSIG, the calculations are:

10,000 feet:

V ÷ minute volume 8.4 LPM	= 3.579
Duration from Fig. 6-7	= 3.6
Overstated duration error	= 0.021 hr. = 0.6%

15,000 feet:

V ÷ minute volume 6.8 LPM	= 4.421
Duration from Fig. 6-7	= 4.4
Understated duration error	= 0.021 hr. = 0.5%

20,000 feet:

V ÷ minute volume 5.1 LPM	= 5.895
Duration from Fig. 6-7	= 5.50
Understated duration error	= 0.395 hr. = 6.7%

Normal dilutor-demand schedule for two-man crew plus one passenger using constant flow regulator, 2000 PSIG, provides the following:

10,000 feet:

Crew minute volume 2.4 LPM/man X 2 men	= 4.8
One passenger minute volume 1.6 LPM	= 1.6
Total minute volume	= 6.4

Hence,

V ÷ 6.4	= 4.698
Duration from Fig. 6-7	= 5.700
Overstated duration error	= 1.002 hr. = 17.6%

15,000 feet:

Crew minute volume 2.4 LPM/man X 2	= 4.8
One passenger minute volume 1.8 LPM (Extrapolated)	= 1.8
	= 6.6

Hence,

V ÷ 6.6	= 4.555
Duration from Fig. 6-7	= 4.500
Understated duration error	= 0.055 hr. = 1.2%

20,000 feet:	Crew minute volume 2.9 LPM X 2	= 5.8
	One passenger minute volume	= 1.98
		7.78
Hence,	V ÷ 7.78	= 3.864
	Duration from Fig. 6-7	= 3.800
	Understated duration error	= 0.064 = 1.7%

100% oxygen setting for two-man crew and one passenger produces:

10,000 feet:	Crew member 8.46 LPM X 2	= 16.8
	One passenger	= 1.6
		18.4
Hence,	V ÷ 18.40	= 1.634
	Duration from Fig. 6-7	= 1.600
	Understated duration error	= 0.034 hr. = 2.1%
15,000 feet:	Crew member 6.8 X 2	= 13.6
	One passenger	= 1.8
	(Extrapolated)	= 15.4
Hence,	V ÷ 15.4	= 1.952
	Duration from Fig. 6-7	= 1.900
	Understated duration error	= 0.052 hr. = 2.7%
20,000 feet:	Crewmember 5.1 X 2	= 10.2
	Passenger	= 1.98
		12.18
Hence,	V ÷ 12.18	= 2.468
	Duration from Fig. 6-7	= 2.300
	Understated duration error	= 0.168 = 7.3%

A summary of calculated error for the 64 cubic foot system at 2000 PSIG using a combination dilutor-demand regulator for the crew and constant flow regulator for passengers (U-21A, Figure 6-7, TM 55-1510-209-10/1, Change 3) is as follows.

TABLE VI

PERSONS	ALTITUDE	NORMAL OXYGEN	100% OXYGEN
One-man crew	10,000	+4.17 hours (33.3%)	+0.021 hours (0.6%)
	15,000	+0.17 hours (1.4%)	-0.021 hours (0.5%)
	20,000	+0.034 hours (0.3%)	-0.395 hours (6.7%)
Two-man crew One passenger	10,000	+1.002 hours (17.6%)	-0.034 hours (2.1%)
	15,000	-0.055 hours (1.2%)	-0.052 hours (2.7%)
	20,000	-0.064 hours (1.7%)	-0.168 hours (7.3%)

NOTE: + = Oxygen duration in chart in excess of calculated.
- = Oxygen duration in chart less than calculated available.

Oxygen duration chart, Figure 6-6, page 6-13, TM 55-1510-209-10/2, Change 2, provides the guidance for use of the 64 cubic foot oxygen system in the RU-21B and RU-21C aircraft. These aircraft use constant flow regulators which are required to meet the standards of Military Specification MIL-D-8683A. Use of Table VII provides for a flow of 1.6 LPM NTPD at 10,000 feet; 1.8 LPM NTPD at 15,000 feet; and 2.0 LPM NTPD at 20,000 feet. These flows are for a sitting passenger and not for an active crewmember. The required schedule is thus immediately open to criticism. Calculations also cannot be made using the constant flow requirements above as the MS 800308-00 Scott Aviation constant flow regulator has a higher flow schedule (Table VII). Thus, the oxygen duration chart 6-6, page 6-13, TM 55-1510-209-10/2, should have been calculated on the basis of the 800308-00 regulator for the highest flow.

A sample calculation would indicate for a one-man crew at gauge pressure of 2000 the following duration at altitude indicated.

10,000 feet:	V ÷ 2.92 LPM Flow	= 10.29 hours
	Figure 6-6	= 16.70 hours
	Overstated duration error	= 6.41 hours (62.3%)
15,000 feet:	V ÷ 2.81 (interpolated)	= 10.70 hours
	Figure 6-6	= 12.70 hours
	Overstated duration error	= 2.00 hours (18.7%)
20,000 feet:	V ÷ 2.7	= 11.13 hours
	Figure 6-6	= 10.40 hours
	Understated duration error	= 0.73 hours (15.25%)

This indicates an error of overstated duration of 62.3% for 10,000 feet, 18.7% for 15,000 feet, and understated by 15.25% for 20,000 feet.

With the use of standard dilutor-demand schedules as per MIL-D-8683A for "normal oxygen," the errors of this chart are slightly less.

Example calculations for one-man crew, 2000 PSIG, are:

10,000 feet:	30.062 ÷ 2.4	= 12.53 hours
	Figure 6-6	= 16.7 hours
	Overstated duration error	= 4.17 hours (33.3%)
15,000 feet:	30.062 ÷ 2.4	= 12.53 hours
	Figure 6-6	= 12.70 hours
	Overstated duration error	= 0.17 hours (1.4%)
20,000 feet:	30.062 ÷ 2.9	= 10.366 hours
	Figure 6-6	= 10.400 hours
	Overstated duration error	= 0.034 hours (0.3%)

TABLE VII

OXYGEN REGULATOR FLOW SCHEDULES

ALTITUDE	DILUTOR DEMAND REGULATORS			CONSTANT FLOW			
	MS 22062-1	Puritan Zep ZR 807 Press. Reducer ZMR 151-M Dilutor Demand Reg & Mask		A 2000 ALAR[10,11]	Scott Aviation 800308-00[12]	Puritan Zep	
		Dilutor	100%			ZR 800-1A Const Flow ZM 498-22-1 Mask	ZR 807 Const Flow ZM 498-22-1 Mask
S.L.		6.0	13.4	1.1 ± 0.2	3.04 + 0.2	3.7 +0.0 (Reg 50 LPM	3.7 +0.0
10,000		3.8	9.0	1.6 ± 0.2	2.72 + 0.2	-0.2 Max, 70±20	-0.2
15,000		(2.9)	(7.2)			PSIG)	
20,000	Unavailable	2.0	5.6	2.0 ± 0.2	2.50 + 0.2	(Values Constant	(Values Constant
25,000			(4.4)			0-30,000)	0-20,000)
30,000		100% above 20,000	3.4	2.4 ± 0.2	2.50 + 0.2		3.2 +0.0 -0.2

ALL VALUES LITERS PER MINUTE (NTPD)

The following errors are thus apparent in the oxygen duration chart 6-6, TM 55-1510-209-10/2, for the RU-21B and RU-21C.

1. The term "normal oxygen" would imply a dilutor-demand regulator as opposed to constant flow regulator being used in the RU-21B and RU-21C aircraft. This is misleading.

2. The duration stated for the RU-21B and RU-21C using constant flow regulators has an error of +52.3% to -15.25%.

3. Derivation of the duration charts cannot be fully defined. The errors are inconsistent with any known military specification or physiological principle.

Constant Flow Oxygen Regulator--Evaluation of Physiologic Oxygen Levels.

The Alar 2000 constant flow regulators have the minimum flow schedule of Table VII of this review, which is compatible with Table III of MIL-D-8683A. An immediate inconsistency is seen in that the regulator specifications allow the regulator to vary ±0.2 LPM, thus permitting the flow to decrease below that specified by MIL-D-8683A. To evaluate the actual percent oxygen in the inspired volume, a review of Sea Level (S.L.); 10,000; 20,000; and 30,000 feet is presented.

At 10,000 feet, 8.40 LPM (NTPD) was used as the basic IMV and the range of oxygen flow for the Alar 2000 is 1.4 to 1.8 LPM. A sample calculation for 10,000 feet with 8.40 LPM, NTPD, IMV, follows. The range of oxygen delivery for the Alar 2000 is 1.4 to 1.8 LPM (NTPD).

Volume of Ambient Air (V_{aa}) = IMV_{10_k} - Volume O_2 Added

V_{aa} = 8.40 - 1.8 = 6.60 NOTE: All V = LPM, NTPD
8.40 - 1.4 = 7.00

$VO_{2_{aa}}$ = Volume of Oxygen in Ambient Air

$VO_{2_{aa}} = V_{aa} \times \%O_2$

$VO_{2_{aa}}$ = 6.60 x 0.2094 = 1.382
7.00 x 0.2094 = 1.466

$VO_{2_{IMV}}$ = Volume of Oxygen in the Inspired Minute Volume

$VO_{2_{IMV}} = VO_{2_{aa}} + VO_2$ Added

$VO_{2_{IMV}}$ = 1.382 + 1.8 = 3.182
1.466 + 1.4 = 2.866

TABLE VIII

COMPARISON OF THE A 2000 SCHEDULE TO THE pO_2 REQUIRED TO MAINTAIN TRACHEAL pO_2 AT SEA LEVEL, 5,000 AND 10,000

ALAR A2000					
ALTITUDE	OXYGEN DELIVERED LPM, NTPD	TOTAL OXYGEN DELIVERED %	REQUIRED OXYGEN % TO MAINTAIN TRACHEAL pO_2 EQUIVALENT TO Sea Level	5,000	10,000
Sea Level	0.9 - 1.3	26.36 - 28.77	20.94	17.11	14.03
10,000	1.4 - 1.8	34.12 - 37.88	31.32	25.64	21.02
20,000	1.8 - 2.2	52.97 - 58.80	49.25	40.33	33.05
30,000	2.2 - 2.6	75.81 - 85.78	83.18	68.11	55.83
SCOTT AVIATION 800308					
Sea Level	3.04 - 3.24	39.26 - 40.46	20.94	17.11	14.03
10,000	2.72 - 2.92	46.54 - 48.42	31.32	25.64	21.02
20,000	2.5 - 2.70	57.34 - 60.25	49.25	40.33	33.05
30,000	2.5 - 2.70	83.29 - 88.28	83.18	68.11	55.83

$$\% \, O_2 \text{ by Volume} = \frac{VO_{2\,IMV}}{V_{IMV}} = \frac{3.182}{8.40} = 37.88\% \qquad \frac{2.866}{8.40} = 34.12\%$$

Table VIII compares the Alar 2000 oxygen delivery schedule with the required physiologic oxygen to maintain tracheal pO_2 at Sea Level, 5,000 feet, and 10,000 feet. It is thus apparent that the Alar 2000 constant flow regulator used for passengers is adequate to 30,000 feet altitude. The 800308 Scott Aviation constant flow regulator is used in the RU-21A, RU-21B, and RU-21C series aircraft. (The effect of a rebreather mask is not considered in these calculations.)

Proposed Inspiratory Minute Volumes.

The Tri-Service Oxygen Standardization Meeting was held at Lakehurst Naval Air Station in October 1975. At this meeting a proposal for design inspiratory minute volumes was presented (Table IX).

TABLE IX

DESIGN INSPIRATORY MINUTE VOLUMES

AIRCREW NUMBER (N)	IMV LPM	
	BTPS	NTPD
1	17.50	15.575
2	16.03	14.267
3	15.38	13.688
4	15.00	13.350
6	14.54	12.941
8	14.27	12.700
10	14.08	12.531

Based on IMV = $12.5 + 5/\sqrt{N}$

A second table was proposed to provide a factor for flight activity and stress (Table X).

TABLE X

MISSION CONDITION	FACTOR
Routine	1.0
Pressure suit wear	1.2
Aerial Combat	1.7
Carrier Landing	2.0
Nap of the Earth (NOE)	1.5
Safety press. breath.	1.2

The source of this information was not available at the time of this report. Initial information indicates all values are estimates and not based on any research data base.

Data collected by USAARL during evaluation of available oxygen systems for helicopter use provided IMV of 17 to 18 LPM BTPS (15.13-16.02 LPM NTPD).[1] These values are roughly comparable with the empiric values of Table IX of 15.575 - 14.267 for one and two men.

An increase in the design IMV of 13.12 to a nominal 15 LPM (+1.88 LPM) will produce significant changes in duration delivered by the dilutor-demand regulator. Examples of the changes in duration for 100% oxygen, one man, 2000 PSIG, 64 cubic foot system, using a dilutor-demand system, are:

10,000 feet:	V ÷ 8.40 + 1.88 LPM	=	2.92 hours	
	Duration from Fig. 6-7	=	3.6 hours	
	Overstated duration error	=	0.68 hours	(23.1%)
15,000 feet:	V ÷ 6.75 + 1.88 LPM	=	3.48 hours	
	Duration from Fig. 6-7	=	4.40 hours	
	Overstated duration error	=	0.92 hours	(26.3%)
20,000 feet:	V ÷ 5.43 + 1.88 LPM	=	4.11 hours	
	Duration from Fig. 6-7	=	5.5 hours	
	Overstated duration error	=	1.39 hours	(33.8%)

The increased IMV will substantially affect the values for duration and the percentage of oxygen delivered by the constant flow regulators. The changes in percent oxygen delivered for the Scott Aviation constant flow regulator 800308 are shown in Table XI which demonstrates a limitation of constant flow to approximately 20,000 feet.

TABLE XI

ALTITUDE	% OXYGEN DELIVERED	% OXYGEN REQUIRED TO MAINTAIN S.L.	5,000	10,000
S.L.	36.96 - 38.02	20.94	17.11	14.03
10,000	41.86 - 43.40	31.32	25.64	21.02
20,000	47.98 - 50.14	49.25	40.33	33.05
30,000	60.08 - 63.21	83.18	68.11	55.83

Military Specification.

Tables I of MIL-D-8683A and MIL-D-19326A provide the basic design oxygen criteria establishing the sea level IMV of 13.12 LPM (NTPD).

Calculation of Table I using barometric pressure and Boyle's Law, Column B, provides a curve different from that of military specification. If one calculates the curve using barometric pressure minus water vapor pressure, the values approximate that of the MIL-D-8683A, Column C. These volumes are not NTPD, normal temperature (70°F), pressure 760 mHg, and dry. The volume would be normal temperature, pressure saturated (NTPS) as shown in Column C, Table XII.

TABLE XII

ALTITUDE (Feet)	LPM (NTPD)		LPM (NTPS)
	A MIL SPEC	B Calculated From Barometric Pressure	C Barometric Pressure -Water Vapor (47 mHg)
Sea Level	13.12	----	12.309
5,000	10.62	10.910	10.106
10,000	8.40	9.020	8.213
15,000	6.75	7.410	6.596
20,000	5.43	6.035	5.223
25,000	4.10	4.870	4.064
30,000	3.17	3.904	3.092
35,000	2.32	3.096	2.284

The source of this inconsistency cannot be defined. With consideration of the physiology of respiration and the additive stress factors, the values of inspiratory minute ventilation should be greater than required by MIL-D-8683A and MIL-D-19326E. Oxygen system designs based on the values of Tables I, MIL-D-8683A and MIL-D-19326E, are thus underdesigned.

CONCLUSIONS

Aeromedical review of oxygen requirements in US Army aviation revealed design inadequacies in the military specifications and the oxygen duration charts. The primary design deficiency is in the design inspiratory minute volume. This value is based on limited research data. Proposed changes to Military Specifications MIL-D-8683A and MIL-D-19326E recognize an increased IMV and a factor based on mission conditions. Unfortunately, these suggested changes are empirical and are not based on clinical research data.

RECOMMENDATIONS

1. Intensive aeromedical research to establish accurate inspiratory minute volumes be undertaken.

2. Accurate oxygen duration charts be constructed for US Army aircraft oxygen systems.

3. Update of current US Army aircraft oxygen systems to dilutor-demand systems be implemented.

4. Military specifications be revised to provide accurate design criteria.

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