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PRELIMINARY EVALUATION OF OXYGEN USE RATES IN US ARMY AIRCRAFT. PART I - RU-21H.

By

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November 1976

Final Report

US ARMY AEROMEDICAL RESEARCH LABORATORY
Fort Rucker, Alabama 36362

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Accurate inspiratory minute volume (IMV) is required for US Army fixed and rotary wing aircraft oxygen system design. This initial study evaluated oxygen usage rates of US Army aircrew conducting operational missions at altitudes of 19,000 to 25,000 feet flying RU-21H twin turbopropeller driven unpressurized aircraft. Inspiratory minute volume (IMV) was calculated from the crew dilutor demand oxygen regulator pressure gauge and timed mission

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SUMMARY

The US Army Aeromedical Research Laboratory has evaluated aircraft oxygen systems for helicopter aeromedical evacuation use and for fixed wing applications. During these evaluations, inspiratory minute volume (IMV) determinations were found to be in excess of military design standards. Operational evaluation of in-flight oxygen use rates was undertaken in the RU-21H aircraft using oxygen regulator gauge pressures. This study, with consideration of the accuracy limitations of the regulator pressure gauge, provides initial inspiratory minute volume data from the RU-21H aircraft during actual operational missions conducted in Europe and Korea.

Altitude corrected IMV indicates the crewmember averages 8.09 ± 2.14 standard deviation liters per minute (LPM), normal temperature (70°F), pressure (760 mmHg), and dry (NTPD). The range of oxygen use was 4.47 to 13.25 LPM NTPD. The upper range is slightly greater than the Military Standard (MIL-D-8683A) for design oxygen of 13.12 LPM NTPD. These findings emphasize the limited safety margin in design of oxygen system for US Army aircraft.

Further studies to accurately define the IMV will be accomplished for present and future US Army fixed and rotary wing aircraft.

ROBERT W. BAILEY
Colonel, MSC
Commanding

PRELIMINARY EVALUATION OF OXYGEN USE RATES IN US ARMY AIRCRAFT. PART I - RU-21H

INTRODUCTION

The Surgeon General tasked the US Army Aeromedical Research Laboratory (USAARL) in April 1973 to evaluate oxygen systems for US Army helicopers.[1] During the evaluation of current and proposed oxygen systems, operational problem areas were identfied in the design requirements for oxygen usage. A review of the basic requirements for aeromedical oxygen design was reported by USAARL.[2] The study concluded that a primary deficiency in current military specifications is the design Inspiratory Minute Volume (IMV). Aeromedical research was undertaken to obtain operationally determined Inspiratory Minute Volume under varying flight conditions.

MATERIALS AND METHODS

Flight data was obtained from 112 RU-21 crewmembers (pilot and copilot) during 56 operational missions. Flight crews of the 146th Army Security Agency (ASA) Company (AVN), Korea, and the 330th ASA Company (AVN), Germany, participated in the study. Each crew completed an RU-21 Crew Oxygen Data Sheet for each mission (Appendix A).

Pre- and post-mission oxygen pressure gauge readings were recorded from the MS22062-1 Dilutor Demand oxygen regulators of the pilot and copilot in the RU-21H aircraft. Mission parameters to include time to climb, operational altitude, and time of descent (mask off) were also recorded.

The oxygen system in the RU-21H aircraft contains four 64 cubic foot oxygen cylinders with a total capacity of 256 cubic feet or 7,214.92 liters at normal temperature (70°F), pressure 760 mm Hg and dry (NTPD). The aircraft contains four crew stations with the MS22062-1 Dilutor Demand oxygen regulator. Individual aviators utilized the pressure demand oxygen masks of the US Army A-13A or the USAF MBU-5/P type. During this study the crew consisted of pilot and copilot. One hundred percent (100%) oxygen was used throughout the mission profile in fifty missions. Corrections were made for the six missions in which a "normal" setting was used.

The MS22062-1 Dilutor Demand oxygen regulators, FSN 1660-991-7411, have a pressure gauge to reflect available oxygen supply pressure. The change in oxygen pressure gauge reading pre- and post-flight provided an approximation of total oxygen usage. The gauge is marked to indicate 2000, 1500, 1000 and 500 pounds per square inch gauge (PSIG) in 100 PSIG increments. The aircrew was thus required to estimate the pressure to the nearest 25 PSIG.

Oxygen usage rates for the 112 RU-21H crewmembers were calculated for two time periods. Oxygen use was calculated from the total time of the mission and total oxygen used without consideration of altitude effect. To obtain a more accurate Inspiratory Minute Volume, the effect of operational altitude was utilized.

Sample calculations are provided based on oxygen data sheet:

1. Pre-mission oxygen gauge pressure: 1005 PSIG.

2. Post-mission oxygen gauge pressure: 485 PSIG.

3. Cylinder Oxygen:

Cylinder oxygen using Boyles Law: $\frac{V_1}{V_2} = \frac{P_2 \text{ (absolute)}}{P_1 \text{ (absolute)}}$

V_1 = Volume, liters (NTPD) = 7,214.9 from 1800 PSIG cylinder.

V_2 = Volume, liters NTD, at pressure of 1800 PSIG.

P_1 absolute (sea level) = 0 gauge pressure + 14.7 PSI.

P_2 absolute = Gauge pressure of oxygen (1800 PSIG) + 14.7 PSI.

$V_2 = \frac{V_1 \times P_1}{P_2}$ V_1 = 7,214.9 liters (NTPD)

P_1 = 14.7 PSI

P_2 = 1800 PSIG + 14.7 PSI = 1814.7 PSIA

$$V_2 = \frac{7{,}214.9 \times 14.7}{1814.7}$$

V_2 = 58.44 Liters NTPD (1800 PSIG)

4. Pre-mission Oxygen (Oxygen Gauge = 1005 PSIG)

Oxygen gauge = 1005 PSIG; thus volume has been removed indicated by loss of pressure. Relation of volume to pressure is now directly proportional as shown by:

$$\frac{V_1}{V_2} = \frac{P_1}{P_2}$$

$$V_2 = \frac{V_1 \times P_2}{P_1}$$

V_1 = 58.44 Liters NTD (1800 PSIG)

P_1 = 1800 PSIG + 14.7 PSI = 1814.7 PSIA

P_2 = 1005 PSIG + 14.7 PSI = 1019.7 PSIA

V_2 = 32.84 Liters NTD (P = 1005 PSIG)

Allowing this volume to expand to NTPD condition, the volume of gas becomes:

$$V_2 = \frac{V_1 \times P_1}{P_2}$$

V_1 = 32.84 Liters NTD (P = 1005 PSIG)

P_1 = 1005 PSIG + 14.7 PSI

P_2 = 14.7 PSI

$$V_2 = \frac{32.84 \times 1019.7}{14.7}$$

V_2 = 2278.02 Liters NTPD oxygen available at cylinder pressure of 1005 PSIG

5. Post-mission Oxygen (oxygen gauge = 485 PSIG)

Again the pressure loss indicates volume of oxygen loss and thus is directly proportional.

$$V_2 = \frac{V_1 \times P_2}{P_1}$$

V_1 = 58.44 liters NTD

P_1 = 1800 PSIG + 14.7 PSI

P_2 = 485 PSIG + 14.7 PSI

$$V_2 = \frac{58.44 \times 499.7}{1814.7}$$

V_2 = 16.09 liters NTD (P = 485 PSIG)

Allowing this volume to expand to NTPD condition, the volume of gas becomes:

$$V_2 = \frac{V_1 \times P_1}{P_2}$$

V_1 = 16.09 liters NTPD at 485 PSIG

P_1 = 485 PSIG + 14.7 PSI

P_2 = 14.7 PSI

$$V_2 = \frac{16.09 \times 499.7}{14.7}$$

V_2 = 547.02 liters NTPD

6. Volume of oxygen (liters NTPD) consumed during flight:

Volume available @ cylinder pressure 1005 PSIG = 2278.02 liter NTPD

Volume remaining @ cylinder pressure 485 PSIG = 547.02 liter NTPD

Oxygen utilized during flight = 1731.00 liter NTPD

7. Flight Time Information:

Time to climb	25 mins.
Time at operational altitude 23,000 feet	175 mins.
Time to descent to mask off	25 mins.
Total Oxygen Breathing Time	225 mins.

8. Oxygen Use Rates:

a. Total flight usage rate (altitude correction not used):

1731 liters NTPD oxygen used ÷ 2 crew ÷ 225 minutes flight duration; total flight usage rate = 3.85 LPM (NTPD)/Man

b. Altitude correction:

A factor for operational altitude correction (K_{OAC}) is obtained by the barometric pressure ratio:

$$K_{OAC} = \frac{\text{Sea Level}}{\text{Altitude(23,000 ft)}} = \frac{14.7 \text{ PSIA}}{5.95 \text{ PSIA}} = 2.471$$

This factor cannot be applied to the volume as it is unknown during operational altitude. The K_{OAC} is, however, applied to the time to provide a proportional change in oxygen usage rate for the mission.

Thus:

$$\text{Time } K_{OAC} = \frac{\text{Time at operational altitude}}{K_{OAC}}$$

$$\text{Time } K_{OAC} = \frac{175 \text{ minutes}}{2.471} = 70.8 \text{ minutes}$$

Altitude correction factor for time to climb and descent ($K_{C/DAC}$) is based on mid-point of altitude. Mid-point of this example of 23,000 feet is 11,500 feet. The $K_{C/DAC}$ for 11,500 feet is $\frac{14.7 \text{ PSI}}{9.53 \text{ PSI}} = 1.54$

$$\text{Time } K_{C/DAC} = \frac{\text{25 minutes ascent + 25 minutes descent}}{1.54} = 32.47 \text{ minutes}$$

To obtain altitude corrected oxygen usage rates for mission would thus be shown by:

Time to climb/descent corrected for pressure	32.47 minutes
Time at operational altitude corrected for pressure	70.8 minutes
Total $Time_{AC}$	103.27 minutes

Total flight oxygen usage rate altitude corrected (IMV):

$$IMV_{AC} = \frac{\text{Oxygen Utilized}}{\text{Total time}_{AC} \text{ X 2 crew}}$$

$$IMV_{AC} = \frac{\text{1731.0 LPM NTPD}}{\text{103.27 min X 2}} = \text{8.38 LPM (NTPD)/Man}$$

Correction for use of time of normal oxygen setting required the use of a standard oxygen use rate per minute by the Dilutor Demand regulator of 2.4 LPM (NTPD) per man. Thus:

> Correction of volume of oxygen utilized by subtraction of 2.4 LPM (NTPD) X 2 crew X time of use of "normal" oxygen

The time of descent or ascent was reduced by the time of use of normal oxygen. These corrections were applied only to the overall minute volume. The six missions during which normal oxygen was utilized were not considered in the altitude corrected IMV.

RESULTS

The 56 flight profiles evaluated ranged from 105 to 335 minutes with an average 218 minutes. Operational altitudes ranged from 19,000 to 23,000 feet. Time at operational altitude was 40 to 225 minutes with an average 148 minutes.

During the 56 flight profiles evaluated, oxygen was used in the 100% regulator mode in all but six missions. The oxygen usage rates are thus equated with correction factors to the aircrewman's inspiratory minute volume (IMV). Table I summarizes the calculated oxygen usage rates or IMV. All values are liters per minute [LPM], Normal Temperature (70°F) Pressure (760 mmHg) and Dry [NTPD].

TABLE I

OXYGEN USAGE RATES (IMV) RU-21H

IMV (LPM, NTPD)	MEAN	S.D.	RANGE
Altitude and climb/descent corrected (N = 100)	8.09	±2.14	4.47 - 13.25
Without altitude correction (N = 112)	3.99	±2.15	2.32 - 7.86

IMV = Inspiratory Minute Volume, Liters Per Minute, Normal Temperature (70°F) Pressure (760 mmHg) Dry.

DISCUSSION

The average oxygen usage rate for the total oxygen mask wear time without altitude correction was approximately 4 LPM, NTPD/man. With operational altitude correction, the usage rate becomes 8.09 LPM, NTPD/man. The range of altitude corrected oxygen usage rates varies from 4.47 to 13.25 LPM, NTPD. These values would correspond with the Military Standard MIL D-8683A of 13.12 LPM, NTPD for design IMV.

This operational study documented the mean ($\overline{IMV}$) to be 8% greater than the usual resting IMV in normal man of 7.5 LPM BTPS. The upper limits of IMV obtained exceeded the current design criteria of 13.12 LPM, NTPD; however, indicating little safety margin is afforded for the RU-21H aircraft.

The average expired volume ($\dot{V}_E$) which approximates IMV ($\dot{V}_E$) averaged for the flight profiles of a previous study of energy cost of piloting fixed wing aircraft by USAARL is 12.04 LPM STPD or 13.05 LPM NTPD[5] which is compatible with the current design criteria. Safety factor for design is however shown to be negligible.

US Army and US Air Force aeromedical research personnel at the Tri-Service Oxygen Standardization Meeting held at Fort Rucker in May 1976 proposed a moderate increase of the design IMV to 15 LPM, NTPD (14% increase). This recommendation was rejected by USAF and USN engineer personnel present.

USAF engineer personnel proposed the design IMV be based on number of crew and operational conditions.[4] A sample calculation using this latter method demonstrates the narrow safety margin of the proposed standard.

Example: IMV proposed is 14 LPM BTPS for aircrew numbering 10 or more. For single pilot the baseline is to be increased by 25% and for two crewmembers by a 15% increase. Applying these standards to this RU-21H study, the proposed design IMV would be:

14 LPM BTPS X 115% = 16.10 LPM BTPS

16.1 LPM BTPS X 0.89 NTPD/BTPS = 14.33 LPM NTPD which provides a 77% increase over the average value reported. Using the upper limit found in this study, however, provides a safety margin of only 8%.

It is noted that the mission profile provides for further increase of IMV under threat conditions.[4] For example, nap-of-the-earth or terrain following has a 25% increase (factor 1.25). This increase is tempered in the design by restriction to only the estimated portion of mission being flown under the condition. This is considered only a tenuous estimate at best.

Of interest is the fact that although the USN design standard has in the past been 23.7 LPM BTPS or 21.1 LPM NTPD,[6] the USN engineers continued to reject the limited increase proposed by aeromedical personnel.

SUMMARY

This study provides calculated IMV from actual RU-21H mission profiles. The data must be considered approximations as the source of pressure gauge readings was the crew Dilutor Demand oxygen regulators. The accuracy of the pressure gauge is limited. Additionally, the possibility of incorrect oxygen setting during study could have decreased total oxygen utilized. Crew position effect on IMV could not be obtained from this data collection. This data represents an initial attempt to document an operational IMV.

Altitude corrected calculated IMV indicates the crewmember averages 8.09 ± 2.14 S.D. LPM, NTPD with a range of 4.47 to 13.25 LPM, NTPD. Current design specifications require 13.12 LPM, NTPD. The average IMV calculated is 62% of design specification. The upper range of calculated IMV is, however, in excess of design requirement. This data demonstrates the limited margin of safety in oxygen design in US military aircraft.

RECOMMENDATIONS

Aeromedical research should be continued to obtain accurate IMV in fixed and rotary wing aircraft under varying flight conditions. This research data will establish valid design IMV.

The use of IMV is also recommended to directly reflect the stress and/or workload of aircrew in the rapidly advancing operational techniques and employment of USA aviation.

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