S. Paul, 1992.
athe PD. Centrifuge
Indian experience.
2]: 84–8.
characteristics and
manoeuvre. Aviat.
59–62.
er EM. Anaerobic
combat manoeuvre.
8: 761–7.
SF. The character-
cic and abdominal
ring. Aviat. Space
r experience with
pace Med 1991;
ng X. Zhang LM.
mlessness of the
Environ. Med

Original Article

Ventilatory Requirements of Indian Aircrew - a pilot study

Wg Cdr N Rattan
Sqn Ldr V Gopal
Surg Lt Cdr SS Khanuja

Department of IIAP, Institute of Aerospace Medicine, Vimanapura, Bangalore 560 017

Ventilatory requirements of aircrew form the basis for assessing the quantity of supplemental oxygen to be carried in any aircraft. MIL standard use the oxygen bottle consumption method for assessing inflight ventilatory requirements of aircrew. Indian aircrew are anthropometerically different from western aircrew. Indian flying conditions, and different breathing equipment assemblies may all have a bearing on the ventilatory requirements of Indian aircrew. Using the same method adopted in MIL specs in flight bottle oxygen consumption was measured in four different MiG aircraft in four different pilots during straight and level flight. It was seen that Indian ventilatory requirements were lower than western MIL standards.

Acute hypobaric hypoxia is known to develop when an individual ascends to altitude without supplemental oxygen/pressurisation [1]. The ill effects and dangers of hypoxia are well known. Unlike other physiological aviation stresses prevention of hypoxia has to be catered for in a continuous manner from very low altitudes itself by provision of supplemental oxygen and cabin pressurisation. Supplemental oxygen in the form of gaseous oxygen (GASOX), liquid oxygen(LOX) or more recently On Board Generation of Oxygen (OBOGS) is provided to the aircrew in different aircraft. GASOX is always the emergency source in any aircraft due to the reliability of the system. In OBOGS a GASOX emergency source and in some cases another Back Up Source (BOS) is mandatory.

It is very important that the quantity of oxygen that is consumed during flight by the aircrew (single or more) be known to aviation physiologists and design engineers. This figure would have important connotations in the design of oxygen systems as it would be the guiding principle to determine the quantity of oxygen that should be carried on board the aircraft. For the designer it, enables him to calculate the weight/volume requirements for the oxygen source. Even more important is the need of ventilatory requirement to assess the quantity of the emergency oxygen system and in any OBOGS back up system.

Till date, figures used for this purpose are based on data given in the MIL Standard 19326 of 1971 [2] which are derived from studies of bottle oxygen consumption in flight of US aircrew. The figures given are the average ventilatory requirements for an aircrew flying a combat aircraft. The figure for a single man is 23 L/minute (BTPS). In 1978 US and UK data were reassessed to include changes in pulmonary ventilation during various phases of flight and were incorporated in an amendment to the MIL 19326 F-1978 [3]. This was 18 lit/min (BTPS) with 25% increase for terrain following and 75% increase for combat sorties.

These figures are based on studies done on subjects whose anthropometric standards are very different vis-a-vis Indian population. Indian operating environment and temperatures are also different and therefore the ventilatory requirements may be at variance with the western data. The ventilatory requirements of flight also depend on various factors. The ventilatory requirements for straight and level flight would be much less as compared to combat or strenuous sorties such as low level navigation. The other factors that affect the ventilatory requirements are [1,2]:-

(a) Temperature: Increase in ambient temperature results in increased ventilation.

(b) Age and experience of the aircrew: An experienced aircrew would have a lower ventilatory rate as compared to relatively inexperienced aircrew for a similar sortie.

(c) Presence or absence of personal breathing equipment. Each oxygen system offers a definite and quantifiable amount of resistance of breathing. This factor has a direct bearing on the pulmonary ventilation. Moderate resistance causes slowing and deepening of respiration while high resistance causes rapid and shallow breathing.

The above mentioned factors necessitated a basic study to assess the ventilatory requirement of Indian aircrew flying high performance aircraft.

Materials and methods

The ventilatory requirements were indirectly assessed by calculating the bottle oxygen consumption in flight of four MiG (Type 75) aircraft sorties at medium altitude viz. 3.5 to 6 km (corresponding to cabin altitudes of 2.5 to 3 km). Straight and level flight sorties of four different aircraft flown on four different days by four different pilots of almost same anthropometeric dimensions formed the database for this study. The study required each pilot to resort to breathing of 100% oxygen from the ground during each of the sorties by switching the regulator to 100% from ground level itself. This procedure was adopted because then the role of the airmix controlling unit in the KKO-5 system viz. the KP52 unit is circumvented and the calculations become easier. The sorties were flown with aircrew wearing the KM 32 oxygen mask. The sorties were flown between 0900 and 1030 hours in the month of May when the average ambient temperature at Bangalore is 28 to 29°C.

The MiG 21 (Type 75) is equipped with the KKO-5 GASOX system. The oxygen is carried in three cylinders with a total capacity of 10 litres at a pressure of 150 kg/cm^2. This translates to almost 1500 litres at normal sea level pressure (1 Atmosphere pressure is equal to almost 1 kg/cm^2). The KKO-5 oxygen system is a robust system and is capable of use in flights of extreme high altitude [4,5]. The oxygen system is so designed as to function during pressurised flight (continuous duty) and unpressurised flight (short duty).

Inflight ventilation values were calculated from the data provided i.e. the difference in oxygen pressure prior to commencement of the sortie and after the completion of the sortie. Using Boyle's law i.e. $P_1V_1 = P_2V_2$ the difference in the pressure of oxygen pre and post sortie, the consumption of oxygen during the sortie was determined.

The methodology adopted is similar to those adopted by western studies and provides a value of average ventilation during actual flight. However, this method does not allow for determining the flow rate requirements and ventilatory requirements during the different phases of flight, viz. take off and landing, combat and terrain following.

Results

The results of the oxygen pressures pre and post sortie of all the four sorties are presented in Table 1.

From the above Table it is seen that the value for the average pulmonary ventilation in this study is 15.44 l/min with a range of 12.45 to 15.48 l/min (BTPS). What is of considerable interest is that there is a definite and constant relationship between the sortie duration and the oxygen consumption of all the four different pilots who flew four different sorties in four different aircraft.

Discussion

There is only a limited amount of data of pulmonary ventilation of aircrew operating high

Table 1: Oxygen utilisation in four MiG 21 (T-75) sorties.

Parameter of study	*Sortie 1*	*Sortie 2*	*Sortie 3*	*Sortie 4*
Oxygen pressure prior to start of sortie (kg/cm^2)	150	150	150	150
Oxygen volume at NTP conditions (1 atmosphere = 1.035 Kg/cm^2 (litres)	1452.08	1452.08	1452.08	1452.08
Duration of sortie (min)	25	35	25	35
Oxygen pressure at end of sortie (kg/cm^2)	110	100	110	105
Oxygen pressure reduced by (kp/cm^2)	40	50	40	45
Oxygen volume at NTP conditions (litres)	1064.9	968.50	1064.9	1016.46
Oxygen consumption for the sortie (litres)	387.18	484.03	387.18	435.62
Rate of oxygen consumption (l/min)	15.4872	13.83	15.4872	12.45

Average oxygen consumption is = 14.315 litres/min (NTP). Converting to BTPS this would be equal to 14.315 × 1.079 = 15.44 litres/min

performance aircraft [2]. The studies available have used in flight oxygen bottle consumption as a measure of average pulmonary ventilation of aircrew. More sophisticated methods of in-flight ventilation recording are possible [6]. However, for obvious reasons such instrumentation can only be done in a single aircraft and flown by a limited set of pilots. Moreover no significant difference in average ventilation is to be expected using the oxygen bottle consumption method, [6].

Prior to 1978 oxygen requirements were based on disparate figures of ventilatory requirements of aircrew from UK and USA as given in Mil Spec MIL-D-19326. Now oxygen system design is based upon the baseline oxygen requirements given in the Mil Spec MIL-D-19326-F in which figures from both countries are almost similar[2]. The oxygen supply requirements for a GASOX aircraft oxygen system is based on the average inspiratory minute volume of 18 l/min (LPM) which is 300 ml/sec per crew member determined at BTPS conditions. The specifications also mention that the baseline pulmonary ventilation is increased by 75% in aerial combat and 25% during terrain following sorties.

The results from our study where the aircrew were flying straight and level at altitudes between 4 and 6.5 km: corresponding cabin altitudes of 3 km or 10,000 feet give the baseline pulmonary ventilation based on in flight bottle consumption of oxygen during medium altitude flights to be 15.44 l/min (BTPS). Even though only four sorties were flown in this study the results are reliable as evident from the fact that each of the four pilots used up a similar amount of oxygen which was dependent only upon the duration of sortie. The values of oxygen consumption calculated in this study are lower than the figures quoted in the relevant Mil Spec of 18 l/min (BTPS). This can be expected since Indian pilots have lower anthropometric measurements than western aircrew resulting in lower lung volumes and capacities by as much as 15%. Since the values are for average pulmonary ventilation and are lower than western standards it is felt that these Mil Standards can be used for the Indian pilot (Military) population. However other parameters of operating in combat/low level sorties and under different ambient conditions of operations in tropics will need to be determined before more concrete assumptions can be drawn. However, using the baseline data of this study, this relatively easy method can be used to determine the ventilatory requirements in combat/low level sorties in the field which will then help to formulate Indian specifications. It would be prudent that a larger number of sorties flown in different aircraft in different operational roles using different personal breathing systems be analysed for incorporating into specifications.

Conclusion

This project was conducted as a pilot study. The strength of the protocol using bottle oxygen consumption lies in its inherent simplicity. The method adopted is good for measurement of average inflight ventilation and can be used in operational bases to validate the figures obtained in this study. Indian average ventilatory requirements are found to be lower than western standards. However, more work needs to be done to ascertain respiratory demands during execution of operational flying in the tropics.

References

1. Ernsting J, Sharp GR. Prevention of Hypoxia, In: Air Commodore John Ernsting and Air Vice Marshal Peter King Eds., *Aviation Medicine*, Butterworths, 1988, 60–72.
2. Ernsting J, Operational and Physiological Requirements for Aircraft Oxygen systems 1984
3. MIL-D-19326F-1978.
4. Malik D. Aeromedical assessment of Oxygen systems in current use in IAF, Field Project Report, 33rd Advanced Course (Aerospace Medicine), 1994, 71–93.
5. Training Notes on Oxygen systems, KKO 5, IAF publication.
6. Harding RM Human respiratory response during high performance flight. AGARD 312, 1987, 3–8.