Review Article

Oxygen System for Advanced High Performance Combat Aircraft : Changing Requirements and Current Options

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In modern high performance aircraft, changing operational and physiological needs of the aircrew demand an advanced oxygen system which will integrate well with the various life support and escape systems. This paper reviews these changing requirements and evaluates the different types of oxygen systems available to the aircrew.

Keywords: Hypoxia, pressure breathing, acceleration atelectasis, on board oxygen generation system.

Indian Air Force has, in its inventory, advanced combat aircrafts from both the Western and the Eastern blocks. In addition, there is an ongoing project to indigenously design and develop an advanced multirole, light combat aircraft. The oxygen system in a modern high performance aircraft should meet the changing operational physiological needs of the aircrew. Associated with these are the ever increasing lists of personal protective equipment assemblies, for protection against high sustained acceleration forces, NBC agents, flash blindness, thermal burns, accidental immersion and impact forces. An advanced oxygen system which will integrate well with various options of life support equipment and escape system of the aircraft, is an essential requirement.

Oxygen Systems - IAF Experience

IAF joined the jet age on 24th May 1948 with the induction of Vampire aircraft into service. In the fifties, IAF possessed Spitfires, Vampires and Tempests as fighter aircraft. These aircraft used a simple, continuous flow oxygen system with economiser which was sufficient to protect the aircrew from the effects of hypoxia below 12,192 m (40,000 ft). The rapid expansion of the bomber/combat aircraft fleet, following the Sino-Indian conflict in 1962, saw the introduction of high pressure (150 kg/cm^2 or 1800 psi) oxygen systems, with demand diluter oxygen regulators and counter pressure garment inflation facility for the aircrew. Such an oxygen system weighs more, is relatively bulky and complicated. Till the late seventies, the source of oxygen supply remained high pressure gaseous oxygen (GASOX). Only in 1979, with the induction of Jaguar, was liquid oxygen (LOX) introduced in the IAF fighter stream as another source of oxygen supply. This is a low pressure oxygen system having weight and space advantage over GASOX and uses miniaturised body- or seat-mounted servo control regulators. In the eighties, the oxygen system is integrated with ready pressure high flow anti-G valve which is currently in use in Mirage aircraft. The possibility of a viable On Board Oxygen Generation System (OBOGS) has added a new dimension to the aircraft oxygen systems for future tactical aircraft.

Changing Operational and Physiological Requirements

a. Prevention of Hypoxia, Requirement of Pressure Breathing and Counter Pressure Garments:

In the earlier days, high altitude flying for bombing and deep penetration into enemy territory was an important tactical requirement. Thus, there was a necessity for using various combinations of oxygen systems and counter pressure equipment like partial pressure suits, pressure jerkins, pressure helmets etc., depending upon the service ceiling of the aircraft. Tactical doctrine of modern warfare emphasises on "flying faster but definitely at much lower altitudes". This restricts the combat aircraft's operational ceiling to 15,240 m (50,000 ft) for most of the operations. The role of flying at higher altitudes, having been made specialised, is given to a different aircraft altogether. Thus, for a modern combat aircraft, the oxygen system should cater to meeting the aircrew requirements from ground level to a maximum of 15,240 m altitude. A low pressure differential system of pressurisation with maximum pressure differential of 0.26 kg/cm^2 (3.8 psi) will restrict the cabin altitude to below 7,620 m altitude when the ceiling altitude of the aircraft is 15,240 m. Some of the requirements from an oxygen system used in conjunction with such a pressurisation system are:

(i) Minimum concentration of oxygen in the inspired air should be such as to maintain alveolar

P_{O2} of 103 mm of Hg, i.e., ground level conditions. Most regulators currently in use, start additional oxygen into the inspired gas only after the cabin altitude has reached 2,438 m. Ernsting [1] recommends that P_{O2} should not be allowed to fall below 75 mm of Hg, i.e., conditions of 1,524 m while breathing air. On sudden decompression the alveolar P_{O2} should not fall below 30 mm Hg under any circumstances. So long as the oxygen equipment delivers 100% oxygen at and above 10,058 m and pressure breathing above 12,192 m, hypoxia is unlikely to occur on sudden decompression. The design of the oxygen system should be such that the concentration of oxygen in the mask rises rapidly to 100%. For this, the volume of breathing system between the air inlet of the regulating device and the mask cavity should be kept to a minimum (500 ml). The pressure breathing should become operative within 3 sec of the time that the pressure in the respiratory tract falls below 141 mm Hg absolute (equal to 12 km).[2]

(ii) Positive pressure breathing with 100% oxygen is required to be given to prevent hypoxia above the altitude of 12,192 m. Maximum positive pressure breathing that can be tolerated without serious discomfort is 30 mm Hg, which can be easily delivered by oronasal mask, without using counter pressure garment. This degree of positive pressure breathing at 13,716 m (45,000 ft, P_B=111 mm Hg) will ensure an alveolar oxygen pressure of 60 mm Hg. This altitude being the limit of acceptable degree of hypoxia may be considered the operational ceiling for routine flying and 15,240 m as the emergency ceiling for short period of time[3].

This eliminates the use of counter pressure garments in normal operations.

(iii) Incidence of acceleration atelectasis in flight has been reported [4-6]. These studies have also demonstrated that the condition does not occur if the concentration of nitrogen in the breathing gas does not fall below 40% but it is a likely occurrence in pilots flying high speed aircraft involving + Gz accelerations, breathing 100% oxygen and wearing an anti-G suit. In a study[7] carried out in IAF, acceleration atelectasis has not been found to be a compelling aero medical problem in low level combat sorties.

(iv) Various studies 8-14 have indicated that there is an improved tolerance to + Gz acceleration with positive pressure breathing. The magnitude of positive pressure and the method of delivery are still under investigations. This may become an important future requirement for the aircraft oxygen system.

b. Nuclear, Biological and Chemical (NBC) Protection and Oxygen System:

Reports are available on the use of chemical and biological weapons in the current wars. Our aircrew may also get exposed to such hazards in future wars. It is, therefore, imperative, that the aircraft oxygen systems are capable of providing protection to the aircrew in the air or on ground at the ORP. The special equipment for protection against flash blindness has also to be integrated with the personal oxygen equipment.

c. Inflight Refueling and Extended Flight Time Capability:

With the availability of inflight refueling facility the flight time capability of the aircraft can be extended considerably. To match this extended flight time, it will be required to carry additional oxygen on board which will be disadvantageous in terms of weight and space which are at a premium in the present context. OBOGS which gives unlimited supply of oxygen is one of the options available to meet this requirement of extended flight time.

d. Operation from Frontline Bases:

A modern light combat aircraft will have the capability of operating from unprepared runways, grass fields, jungle clearings, road strips and carriers. To take full advantage of such an aircraft for frontline operations, the "support" requirements should be as less as possible. Replenishment of breathing oxygen for aircrew is one of the important requirements. The storage is not a problem at permanent and well established air bases but while operating at short notice from frontline positions and unprepared airstrips it may become a serious logistic problem. OBOGS which needs minimum ground support facilities will not only eliminate this logistic requirement but also reduce the aircraft turn around time which may be a crucial factor in war. OBOGS also eliminates fire and explosion hazards in storage on aircraft carriers and small ships.

Current Options

Four types of oxygen system are available. These are gaseous oxygen system (GASOX), liquid oxygen system (LOX), on board oxygen generation system (OBOGS) and solid chemical oxygen generators. Of these, GASOX and LOX are in extensive use in aviation. Solid chemical oxygen generators have been used in some fixed, portable and under water oxygen systems. They have some inherent disadvantages like contamination of the oxygen with chemical dust, limited oxygen supply, large bulk and weight, and as such are not favoured as a standard aircraft oxygen system.

a. *Gaseous Oxygen System*

GASOX has been in use in IAF ever since the inception of aviation. Its subsystems are well developed and are reliable for use in fighter aircraft. However, the main disadvantages of this system are its pronness to the danger of explosion/fire and the requirements of large space and weight which are at a premium in a light combat aircraft. To obviate the requirement of large space and weight, very high pressure gaseous systems (300 to 400 kg/cm^2) are being proposed for use in future aircraft. The infrastructure to provide gaseous oxygen at such high pressure is currently not available in India but efforts to establish such facility could be explored.

b. *Liquid Oxygen System (LOX)*

Liquid oxygen has about 3.5:1 weight advantage over gaseous oxygen system and an 8:1 advantage in terms of space saved. LOX is extensively used in military aircraft all over the world, though IAF experience in this field is limited. Despite these advantages, the disadvantages in terms of production, supply, handling, charging into the aircraft and very high evaporation losses are the practical problems while operating from dispersed/forward air bases. Another disadvantage is a constant danger of contamination of LOX by concentration of contaminants whose boiling point is higher than that of liquid oxygen. The source of contaminants is the atmospheric air from which the liquid oxygen is produced and the common contaminants are nitrogen oxides, carbon monoxide, carbon dioxide, hydrogen sulphide and hydrocarbons. Frequent quality control checks are thus essential to eliminate entry of such contaminants into the breathing gas.

c. *On Board Oxygen Generation System (OBOGS)*

Ever since the early days of aviation, the most logical and attractive proposition for supply of oxygen to the crew was by on board generation of oxygen from the atmosphere. It was only in the latter half of the 1960s that technological advancements gave this idea a practical shape and study programmes got underway. Many methods of on board oxygen generation have been studied. The important ones out of these are :

i. *Fluomine temperature swing system:*

The system involves use of fluomine, i.e., Cobalt-bis (3 Fluorosalicylaldehyde), which has the property of absorbing oxygen in weak reversible reaction, similar to that of haemoglobin with oxygen. With this system it is possible to produce oxygen with a purity standard of 98.5%.

The system consists of two beds of metal chelate fluomine. Engine bleed air under pressure is introduced into the beds alternately. Oxygen combines with the fluomine and the remaining air which has been stripped of oxygen is vented overboard. At a predetermined time, the air is turned off and the bed is heated. The pressure of the beds is then reduced thus liberating oxygen absorbed previously. At the same time the other bed is pressurised. A control system automatically regulates the pressurisation/depressurisation and heating/cooling of beds. The system has been flight tested on American B-1 test aircraft where it was routinely flown as the sole source of aircrew oxygen. It has been used in the US Navy Air Force Oxygen Generation System (NAOGS) Programme. The limitation of this system rests in producing Fluorimine metal chelate which can retain its oxygen absorbing capacity for a long time. The system used in B-1 aircraft had a Fluomine generator life of 300 hrs.

ii. *Barium oxide/dioxide system:*

This system involves a specially prepared barium oxide/dioxide mixture which is kept at a constant temperature of 760°C. The oxygen is extracted from the air at high pressure by this mixture and it is released when the pressure is reduced.

$$2\,BaO + O_2 \longleftrightarrow 2\,BaO_2$$

The disadvantages of the system are complexity of design, high electrical power requirement for maintaining high temperatures and pressures, and frequent break downs. Moreover, the air which is introduced into the beds should be free from CO_2, moisture, oil and other contaminants.

These problems have led to the rejection of this system for use in aircraft.

iii. *Water electrolysis system:*

Development of a system where water is electrolysed to produce oxygen was tried and it was abandoned because of the requirement of replenishment of the system with water of very high purity and the high electrical power requirements.

iv. *Electrochemical system:*

Utilising the ion exchange principle, the system electrochemically introduces oxygen from the airstream through a sulphonated solid polymer electrolyte. Oxygen combines with H^+ ions in the electrolyte to form H_2O which is later electrolysed to release oxygen, and H^+ ions return to the electrolyte. Its performance has not been found to be satisfactory and system development for aircraft oxygen has been discontinued.

v. *Permeable membrane system:*

Pressurised air is introduced to a polymeric material membrane surface which has the quality to separate and enrich gases on the basis of their permeability co-efficient. With current technology in this field, it is not possible to produce oxygen above 90% purity level. Since the demand diluter requirements of oxygen for an unpressurised operation to an altitude as high as 7,620 m is about 50%, this system may find application in aircraft that operate at lower altitude. The attractiveness of this approach is enhanced by the simultaneous production of N_2 enriched gas for fuel tank inerting.

vi. *Molecular sieve oxygen generation system (MSOG)*

The heart of the system is the concentrator unit. It uses the molecular sieve separation process to enrich a source of engine bleed air to produce oxygen gas. The system is based on a three bed molecular sieve oxygen generator (MSOG). The MSOG unit is located in an unpressurised zone of the aircraft. Gas pressure is controlled by a pressure reducing valve fitted at the engine bleed inlet of the generator unit. Separation of oxygen from nitrogen is achieved by the adsorption properties of synthetic zeolites (hydrated alumino silicate mineral) which can discriminate between the size and degree of polarisation of gas molecules. The MSOG unit has three containers of zeolites. Pressurised air is fed into each of the bed in turn. The pressure initiates adsorption phenomenon with oxygen being the least adsorbed gas. The oxygen rich product gas flows out of the system until the bed become saturated with nitrogen. The process is then stopped and the bed is depressurised by venting it to ambient atmosphere and purged with a reverse flow of product gas from the successive bed. This restores the bed (by desorption) and the cycle continues. The combination of three beds operating sequentially, produces a continuous and smooth supply of optimum quality product gas.

The correct oxygen concentration appropriate to the physiological requirements of the crew depending upon the cabin altitude is achieved by electronic control of the cyclic duration of each bed. The maximum concentration of oxygen that can be obtained by the system is 95%, the rest being argon which does not appear to have any adverse physiological effects.

Since the system depends upon engine bleed air for producing oxygen, standby oxygen is provided which can be automatically/manually initiated in case of emergencies, e.g., turbine failure and also rapid decompression.

Table - I Comparison of LOX, GASOX and OBOGS for single seat combat aircraft

	System		
	LOX	GASOX	OBOGS
Storage means	5 L Convertor	5 x 750L Cylinders	Oxygen Generator (Molecular sieve)
Normal storage pressure (kg cm^2)	4.9	126	—
Normal storage capacity (L)	3800	3750	On Board Generation #
Actual usable gas capacity (L)	3420	2900	—
Envelope installation space (m^3)	0.022	0.074	0.0229
Weight empty (kg)	6.87	35.04	20.5 ##
Weight full (kg)	12.04	40.12	22.7 ##

\# Maximum oxygen concentration obtained is 95%.

\# # With back up oxygen cylinder of 200 L capacity.

Conclusion

From the physiological requirements, all the three systems, i.e., gaseous, liquid oxygen and OBOGS, have the same capability for a fighter aircraft, where requirement to stay at high altitude after loss of pressurisation is only for a few minutes. A comparative study of weight and space requirements for the three oxygen systems for a single seater combat aicarft is given in Table I.

The protection offered by OBOGS under nuclear, biological and chemical warfare environment is not fully known/evaluated as yet. Adequate information regarding capability of OBOGS to eliminate likely contaminants from engine bleed air, e.g., CO and methane, is lacking. Available literature indicates that this problem is not likely to pose a serious hazard and OBOGS can efficiently eliminate these contaminants with additional filters.

REFERENCES

1. Ernsting J: Advanced oxygen system for future combat aircraft. In: Recent advances in Aeronautical and Space Medicine. Editor: RH Murray, AGARD-CP-265, NATO, Paris, 1979.

2. Dhenin G: Aviation Medicine - Physiology and Human Factors. London , Tri-Med Books, 1978.

3. De Hart RL: Fundamentals of Aerospace Medicine. Philadelphia, Lea, & Febiger, 1985.

4. Glaister DH: Acceleration atelectasis - some factors modifying its occurrence and magnitude. Report 299. IAM, Farnborough, 1964.

5. Green ID: Synopsis of recent work done on the problem of pulmonary atelectasis associated with breathing 100% oxygen and increased positive 'G'. Report 230, IAM, Farnborough, 1963.

6. Harwell MS, Tacker WA, Baldin UI: Influence of inspired oxygen concentration on acceleration atelectasis. Preprints of Annual Scientific Meeting, Aerospace Medical Association, 1983; pp 29-30

7. Jairath CS: A study of incidence of acceleration atelectasis among IAF pilots flying low level combat sorties in Gnat and Hunter aircraft using 100% O2 and Anti-G suit. Student's Dissertation, IAM IAF, Bangalore, 1975

8. Ackles KN, Polier JAG, Holness DR, et al : Protection against the physiological effects of positive pressure breathing. Aviat Space Environ Med 1978; 49:753

9. Balldin UI, Weanne B: Haemodynamic effects of extreme positive pressure breathing using two types of pressure flying suit. Aviat Space Environ Med 1980; 51:851

10. Burns JW, Balldin UI: +Gz protection with assisted positive pressure breathing. Preprints of Annual Scientific Meeting, Aerospace Medical Association, 1983; pp 36-37

11. Marwah SC: Assessment of positive pressure breathing during positive 'Gz'. Student's Dissertation, IAM IAF, Bangalore, 1979

12. Shubrooks SJ: Positive pressure breathing as a protective technique during +Gz acceleration. J Appl Physiol 1973; 35:194

13. Kuldip Rai: Effect of positive pressure breathing on +Gz tolerance of normal subjects. Student's Dissertation, IAM IAF, Bangalore, 1980

14. Damaszwe J: The application of positive pressure breathing for improving +Gz acceleration tolerance. Aviat Space Environ Med 1983; 54 : 334

15. Marratt SA: On board oxygen generation system. Aviat Space Environ Med 1981; 51:645