Original Article

Indigenisation of life support systems for Indian aircraft : Aeromedical considerations

Wg Cdr N Rattan[*] Sqn Ldr V Gopal[*], Surg Lt Cdr S S Khanuja[@], Gp Capt (Mrs) P Bandopadhyay VSM[+]

[*] *Classified Specialist (Av Med),* [@] *Trainee (Av Med)*
[+] *Senior Adviser (Av Med) and Chief, Aerospace Physiology Division*

Institute of Aerospace Medicine, IAF, Bangalore - 560 017

Life support equipment is vital to ensure safety of man and machine in the air and also contributes to operational efficacy. New factors have emerged which need to be addressed in life support equipment design. Protection against hypoxia and high +Gz forces remains the mainstay of life support equipment. Indigenisation of life support eqipment in India has economic implications. This paper has reviewed some design considerations of life support equipment based on physiological requirements including Indian concepts and possibilities.

Keywords: Life support equipment, flying clothing, oxygen system, aircrew support.

In recent times military aviation has witnessed a quantum jump in the operational capablities of aircraft. The tactical role of the aircraft and its weapon delivery system have been redefined with emphasis on stealth technology, more agile aircraft with higher thrust to weight ratio, longer flight duration and high altitude flight. A single multi role, all weather aircraft which can be used by different wings of the armed forces is the essence of development of modern fighter aircraft. Even though physical stresses may have been mitigated by a better cockpit environment, physiological and psychological stresses on to the pilot have actually increased. Physiological stresses are performance limiting and threaten safety of man and machine and also seriously compromise mission accomplishment. The two inherent physiological stresses of modern military aviation that require consideration are hypoxia and high +Gz stress. It has become imperative to provide protection against these stresses by not only providing appropriate support to life but to optimise operational efficiency in the air.

There are now superior and vastly improved life support systems available in newer generation aircraft. Different personal equipment assemblies worn by the aviator, included under the term 'flying clothing' are interfaced with these life support systems. The aircraft in the IAF inventory are of varied origin and consequently the life support systems are specific for the type of aircraft. Indigenisation of life support systems is a formidable task. This can be indigenous manufacture of existing imported systems, which will carry over problems of design defects in the original equipment, to the indigenously developed product. Improper sizing not appropriate to Indian population, higher thermal load and property rights violations are other considerations. The other and more suitable method to adopt is, de novo development of life support equipment to suit Indian conditions. This will also enable commonalising items between aircraft. Indigenous production may be cost intensive initially, but once established, it is cost effective. Adherence to norms and excellent quality control will also ensure a good export potential.

This paper is an attempt to review some existing physiological norms in life support equipment design. The Indian view point and design considerations are also discussed.

General Conditions

Life support systems in military aviation can be considered those equipment assemblies which protect the pilot from the main physiological stresses of hypoxia, sustained positive acceleration and provide thermal comfort during normal flight conditions; combat, emergencies in the air and escape from aircraft.

Life support equipment which are essential in a modern air superiority fighter aircraft, are a pilot's oxygen system and an anti G system capable of protecting against high sustained G. The oxygen system itself has three essential components viz source, regulator and mask. The oxygen source is of three different kinds GASOX, LOX and in some of the current generation aircraft and in almost all future aircraft, the source will be On Board Oxygen Generating Systems (OBOGS).

For these two systems appropriate flyir clothing assemblies are required depending upc the operational requirement. For low and mediu altitudes, overalls, anti G suit, pressure jerkin ar flying helmet are essential and for high altituc flying, a pressure helmet and partial pressure su would be mandatory.

Oxygen system requirements

In any oxygen system the aim is to maintai adequate oxygen partial pressure in the lungs o 103 mm Hg, which is the sea level equivalen during steady state flight conditions. During th often encountered emergency of rapid decompression (RD) in flight, the PAO_2 should not b allowed to drop below 30 mm Hg. All thes conditions must be fulfilled with minima physiological loading. In addition, supplementa oxygen will be required during inflight emergencies like toxic fumes, NBC, pilot injuries and hig altitude ejection. The basic premise will alway be avoidance of any performance decrement an in emergencies even if some performance i compromised there is no loss of consciousnes such that the pilot can recover the aircraft.

Critical physiology normal flight

Oxygen concentration considerations: It is know that above 10000 ft it is mandatory to provide supplemental oxygen in progressively increasing concentration to overcome the decreasing partial pressure of oxygen associated with falling atmospheric pressure. An ideal lung PAO_2 of 103 mm Hg is optimum and can easily be ensured. With some compromise a PAO_2 of 60 mm Hg can be accepted for a short time and will not normally affect mission effectiveness. However a PAO_2 of below 30 mm Hg will lead to rapid loss of consciousness and loss of both the pilot and the aircraft. At the same time there is a limit 60% O_2 concentration at an altitude of 20000 ft when the cabin altitude will be 10000 ft or so.

This is the zone where almost all acceleration manoeuvres are performed and acceleration related lung collapse and delayed otic barotrauma are potential hazards if 60% oxygen concentration is exceeded.

Oxygen flow and pressure requirements

Steady state flows are defined in MIL specs and range from 19 - 23 lits/min but our own studies have shown that in India the average ventilatory requirements are around 15 lits/min [1]. Maximum steady state flows expected can be up to 60 lits/min for short periods of time. However instantaneous flow rates are important to ensure adequacy of oxygen with minimal breathing resistance. Speech and anti G straining manoeuvres place heavy flow rate demands of upto 300 lits/min and if no resistance to breathing is to be experienced, the rate of change of flow, which is a moment analysis of flow rates, should be 25 lits/sec^2. Oxygen pressures in the system are also relevant in terms of inlet pressure to the oxygen regulator. Finally mask cavity pressure swings should be within laid down parameters [2] and defines resistance to breathing in the system. Resistance to breathing itself should be minimal otherwise, it by itself, imposes another physiological stress of hyperventilation.

Table 1. Critical Physiology - Normal flight

- Oxygen flows
  - Steady state average ventilation 15 lits/min, max ventilation 60 lits/min
  - Peak instantaneous flow rates 300 lits/min
  - Rate of change of flow 25 lits/sec^2
- Swing in mask cavity pressures
  - Resistance to breathing:
  - PIFR/PEFR — Max swing of mask pressure during MSP Cycle (inch water gauge)

PIFR/PEFR	Max swing of mask pressure during MSP Cycle (inch water gauge)
30	2.0
90	3.0
150	7.0
200	12.0

PIFR/PEFR: Peak Inspiratory/Expiratory Flow rate

Critical physiology rapid decompression:

During rapid decompression in a fighter cockpit it is well known that hypoxia is the most severe and most rapid in onset amongst all forms of hypoxia an aviator can encounter. The time of useful consciousness (TUC) in such situations is also half of normal, a critical factor which needs to be considered during high altitude operations. In an RD of above 30000 ft aircraft altitude the PAO_2 will fall below the critical level of 30 mm Hg. The air or air-ox in a large volume hose and mask will expand and will amount to 2-3 breaths of dilute oxygen, requiring 12-15 seconds of time to breathe, enough to render a pilot unconscious in a high altitude RD. Therefore in a high altitude RD it is imperative than 100% O_2 reaches the mask in less than 2 secs or 1 breath. This has important connotations on design of oxygen mask. The piping and tubing from the regulator or back up system has to be kept to a minimum [2,3]. It has now been physiologically studied and proven that at cabin altitudes of 16000 to 20000 i.e. aircraft altitudes of 43000 to 50000 feet the PAO_2 will need to be kept higher than 103 mm upto even 262 mm Hg and this implies giving 60 to 100% oxygen at these altitudes, instead of 40-60% oxygen which the regulator would ordinarily be required to give [4].

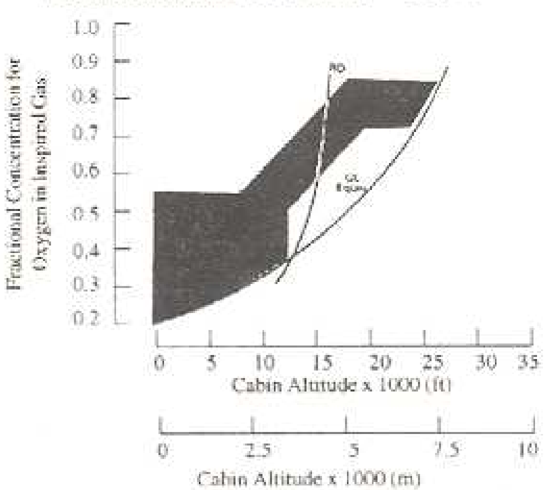

Fig 1. Requirement of oxygen during RD [4]

If OBOGS is in use, which delivers 40% from ground level, a certain degree of hyperoxia will be present. This should theoretically provide added protection during an RD and possibly improve +Gz tolerance. This important concept is however experimental and needs to be studied.

By virtue of presence of a mask on the face there is impedance to the large mass of air venting from the lung when RD takes place due to the mass of air expanding in the mask cavity. The trans-thoracic pressure differential for lung damage is now reduced from the permitted 80 mm Hg with airways open to 50 mm Hg. Lesser the volume of air in the mask cavity, lesser the expanding mass of air. Therefore a small volume mask will be advantageous.

Physiological requirements and equipment design

GASOX remains the gold standard because it is immediately available in the manner and concentration that the lungs use oxygen. GASOX is always used in aircraft emergency stores or back up oxygen store. The limitations of GASOX in terms of quantity and storage volume are well recognised. LOX has numerous advantages. However its use in tropical conditions results in reduction of the efficiency of the LOX convertor, resulting in considerable wastage. The world is now turning to OBOGS, of which the 3 bed molecular sieve oxygen generation system is presently considered the most optimal system. With OBOGS all aircraft operations are greatly facilitated, space and volume requirements are low, there are minimal logistical requirements and it may provide extra protection against hypoxia but also possibly, G protection. The limitations are mainly O_2 purity as only 94-96% purity can be achieved at best. Therefore O_2 support under RD is compromised. The newer oxygen concentrators are the carbon molecular sieves which provide upto 99% pure oxygen [5]. Oxygen generation and distribution system (OGADS) include the connector and back up oxygen system [6].

Oxygen regulators

The current demand oxygen regulator must fulfil certain requirements in order to effectively deliver the right concentration of oxygen to the pilot at the right flows and pressures. Seat mounted regulators are preferred to keep the tubing requirements to a minimum. Safety pressure from sea level is a useful feature as it reduces breathing resistance, converts inboard leaks from mask to outboard leaks, will have value in an NBC environment and if toxic fumes are encountered in the cabin. The flow rate required from modern regulators has already been elucidated. A pressure breathing facility of 60 mm Hg will be needed in any aircraft flying upto 50-55000 ft altitude and when used as pressure breathing for G (PBG) can provide protection upto 9 +Gz. An NBC filter, a dump valve to release excess pressure during RD are also equally necessary. Utilities like emergency change over, press to test and a flow sensor, which may now be electronic, are built in all conventional regulators. The present

Table 2. Physiological requirements for a pressure demand oxygen regulator

- Demand oxygen regulator
  - High pressure/Low pressure seat mounted
  - Safety pressure from sea level
  - High peak flow rates upto 300 lits/sec[2]
    - Speech, hypervent, PBG/PPB
  - PPB facility upto 60mm Hg
    - Short term high altitude protection upto 18000 m (60000 ft)
  - PBG facility upto 60 mm Hg +Gz protection upto 9 +Gz
  - NBC filter
  - Dump valve - for RD

Table 3. Pressure demand oxygen regulator: possibilities for the future

- Built in flow sensor with display
- Built in concentration sensor with display
- Audio-visual no/low oxygen system failure

generation oxygen regulators do not incorporate digital flow sensors with display as also an concentration sensor. Audio visual Hi/Low oxygen system warnings are also surprisingly not available in these regulators considering the criticality of such equipment. These should be essential requirements in any future OBOGS system.

Oxygen mask

In a study of some physiological parameters of all the oxygen masks in use in the IAF, it was evident that each of the masks had drawbacks, some were noticeably limiting in the modern flying environment [7]. Therefore we have adopted a concept of a low volume high flow pressure breathing mask, one that will offer minimum breathing resistance. Various modules of such a mask would be the connector, the hose and face piece. The design considerations which should go into an appropriate hose is minimal length and diameter which will reduce volume of expanded air on RD and will also support higher flow rates when necessary. A non corrugated armoured breathing hose will offer breathing noise attenuation and avoid milking and pumping. A dump valve in the breathing hose or in the regulator is now considered mandatory. The face piece should be light weight at the same time support 60 mm Hg PPB/PBG. It should be well contoured which contributes in three ways viz good over nose and lateral vision, lesser expansion of gas on RD and the pressure changes, as we have seen in our own laboratory, will be under 40 mm Hg. The centre of gravity of such a mask should be appropriate for high Gz environment. Silicone or viton rubber is preferred especially for tropical operations due to its non allergen nature, better flexibility and long shelf life. An antisuffocation valve is essential in an OBOGS compatible masks. The compensatory tube, valves and ports also need to be given due attention to attain optimal functioning. The expiratory valve should be split compensated in case an internal compensatory tube is used. Expiratory resistance should be low < 1.3 to 2.3 cm H_2O depending upto the flow rates.

Table 4. Physiological requirements for an Indian oxygen mask

- Oxygen mask:
  Low volume high flow pressure breathing mask with minimal breathing resistance
- Hose:
  - Minimal length and diameter reduces volume on RD, supports higher O_2 flow rate
  - Non corrugated armoured breathing hose - no milking/pumping
  - Breathing noise attenuation
  - Dump valve
- Light weight face piece:
  - Support 60 mg PPB/PBG upto 55,000 ft/9 +Gz
  - Well contoured
  - Good over nose and lateral vision (upward and lateral visual field as for normal eye. 10^0 restriction in lower and lower nasal field acceptable)
    - Lesser expansion of gas on RD
    - Pressure change under RD < 40mm Hg
  - C of G appropriate for high +Gz environment
- 3 sizes for Indian population (Total face length distance)
  - Small (111 cm)
  - Medium (122 cm)
  - Large (130 cm)
- Automatic tensioner system
- Silicone/viton rubber
  - Tropicalised
  - Non irritant
  - Long life
- Compensatory tube
  - External with dump valve preferable

Emergency oxygen:

A back up or emergency oxygen system is a mandatory part of any life support system and is always GASOX. It needs to be seat mounted with mimimum piping. In an OBOGS set up a separate BOS may be required and that entails rapid sensing using a fast response PO_2 oxygen sensor. The cylinder capacity well depend upon the operational capability of the aircraft.

Flying overalls

Flying overalls provide a comfortable garment platform for life support add on garments like anti G suit, pressure jerkin and air/liquid cooled system. In India pilots operate under diverse operating weather conditions from the extreme cold of Siachen to the deserts of Rajasthan. Incorporating a cooling system may be desirable if cabin conditioning cannot be optimised. For cold weather protection add on clothing is a highly desirable requirement to support pilots during escape. Appropriate fabric for such overalls would essentially be a breathing cotton fabric with fire retardant properties of appropriate clo value to suit Indian conditions. Added NBC protection would also be helpful (Table 5).

Table 5. Outline requirements of Indian flying overalls

- Appropriate Indian sizing
- Critical parameters
  - Light weight, breathing fabric, fire retardant, NBC protected, Clo value of 0.85 to 1
  - Can incorporate
    - Full coverage anti-G suit
    - Pressure jerkin
    - Air/liquid cooling system
  - Add on cold weather protection (Clo value: 2.5-3)

Anti-G system

Modern aircraft are agile and can pull rapid onset high G rates leading to GLOC and pilot incapacitation. While 9 +Gz is the limit presently, aircraft with loadings of upto 12 or even 15 +Gz may be flying in the not too distant future. To cater to this high rapid onset +Gz it is critical to use multiple modalities to provide quick cumulative protection with minimum distraction of the pilot who may be engaged in combat at that time. The use of anti G suit is standard to G protection and methods to enhance protection by anti G straining manoevres and PBG are also well entrenched in the training schedules of fighter pilots all over the world and in the IAF as well. The anti G valve is central to the operation of both the anti G suit and the pressure jerkin. The aim of this valve is to raise suit pressure in the G suit. Modern valves already in use have a ready pressure of 0.1 to 0.2 PSI and then build up at a rapid rate to a maximum pressure of 10 to 10.5 PSI. Newer developments in anti G valves as reported in the literature are the servo controlled AGV and bang bang AGV [8].

Table 6. Outline requirements of an anti-G valve

- Aim- Rapid acting mechanism to raise suit pressure to 90% within 1 sec
- Present status of AGS-AGV combination-
  - Present day AGS-AGV combination acts as venous occlusion cuff.
  - Max pressure - 10 PSI
  - Ready pressure high flow valves
  - Suit pressure pre inflated with 0.1-0.2 PSI
  - High flow valves reduce inflation time by 33%
  - Under development:
    - Servo controlled AGV
    - Bang bang servo AGV

Anti G suit

Along with the modern anti G valves the full coverage anti G suit provides encompassing bladders covering 93% of the lower half of the body measured from xiphisternum, as against the present 30% of a standard AGS. Such suits incorporate 5 bladders and a foot bladder in some cases. Most modern aircraft will now have an O_2 regulator which receives and gives pneumatic signals to the anti G valve activating its operation during high G or during PPB of altitude. PBG normally comes on at above 4 +Gz and progressively increases @ 12 mm Hg/G, with high flow rates and 90% inflation within 1 sec. Adequate physiological protection against lower limb pooling and drop in hydrostatic pressure is therefore immediately available. In the USA higher onset rates of PBG have been advocated and upto 40 mm Hg/G rates of PBG have been tried with 95% of target suit and mask pressures being reached in < 0.2 sec. [9, 10].

In the future it is proposed that the calf bladders are siamesed and air delivery into the thigh and abdominal bladder will be microprocessor controlled to not only inhibit venous pooling, but also to milk the gravitating blood back to the heart. Straining +Gz protection afforded by these modern systems can be in the range of 10.5 G against a value of 9.4 G with a standard anti G suit. Relaxed G tolerance can also be improved by almost 1 G by use of such anti G suits [11].

Table 7. Outline requirements of an anti-G suit

- Full coverage anti-G suit
  - 93% coverage of lower body
  - 5 bladders with foot bladder
  - Inflation co-ordinated with O_2 reg
  - High flow starts at +2Gz
  - 90-95% inflation within 1 sec/0.2 sec
  - PBG at above 4 +Gz @ 12-15mm Hg/G
  - 60-80 mm Hg at 9 +Gz
- Possible future concepts
  - Calf bladders siamesed, thigh and abdominal bladders microprocessor controlled to provide high pressure milking action to promote venous return

Pressure jerkin

With positive breathing pressures of 60 mm Hg, for altitude pressure breathing or for high G protection, a chest jerkin is advocated to be integrated with the anti G suit and oxygen mask. The same pressures are provided in the mask and jerkin. Such an assembly eases breathing, prevents over distension of the lungs and thereby decreases fatigue. The drawbacks of such a system especially in the tropics would be a high heat load and an extraordinary large volume of air in case of an RD. 400 ml of air can become 7-9 lits and the associated rise in pressure can impede breathing and lead to cessation of venous return and rapid loss of consciousness. Therefore it is absolutely essential to incorporate a non return compensated valve in the circuit to let off the excessive air and pressure [2].

Conclusion

A modern life support equipment assembly as envisaged in the western aeromedical literature, would include a pressure jerkin integrated with an appropriate mask, both being connected to the oxygen regulator, being fed by a OBOGS system. The oxygen regulator is in turn connected by pneumatic signals from the anti G valve which feeds on cooled engine air. For PPB the regulator activates the anti G valve and both the jerkin and full coverage anti G suit gets simultaneously inflated. During PBG the anti G valve signals the oxygen regulator, above 4 +Gz to provide linearly increasing positive breathing pressure upto 60 mm and can afford protection upto 9 +Gz.

Though design and concept of life support equipment is the same the world over, it would be appropriate to suit Indian development to operational flying as practised in the Indian subcontinent, to Indian pilot population and to our weather conditions. It would be prudent to adapt and modify as well as to innovate our own life support system, be it an oxygen system or an anti G system, rather than indigenise western systems.

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