Original Article

The elusive oxygen mask - helmet system for Cheetah helicopter: A cause for erosion of accepted norms in the field

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Recently IAM was tasked to evaluate two Oxygen Mask-Helmet systems, one locally modified and one imported, for Cheetah helicopter which has been operationally flying in service for the past 20 years for IAF and Indian Army. An ideal system has remained elusive till date. This paper brings out the continuing erosion of the accepted norms and the compromise with dangers of hypoxia, in terms of high altitude operations of this helicopter. The flight safety issues of this compromise have been brought out and findings of the two system evaluations are presented as a solution, requiring immediate attention.

Keywords: Helicopter mask-helmet assembly; modifications; hypoxia

Cheetah helicopter has been doing operational flying in the IAF and the Indian Army since last 20 years. It is being extensively used in the high altitude operations for multipurpose role. Cheetah Helicopters are equipped with original French Oxygen System, called EROS MRC 511 Series Mask-Regulator Oxygen System. The mask also incorporates the RT mike, and gets fixed on the face by a rubber harness worn on the bare head. The mask shell also carries the regulator. In high altitude Cheetah flying it is mandatory for helicopter pilots to wear ABEU helmet with inner G helmet. This original EROS Mask-Regulator Oxygen System has been found unsuitable for our aircrew due to two major reasons. One, that the mask harness of the original system is not compatible with the indigenous ABEU helmets (which require masks to be attached to the inner helmet G) and secondly, since the original system has mask mounted regulator with RT microphone close to the in-flowing oxygen; the resulting constant noise is annoying to the crew and is a flight safety hazard, even during routine flying.

For the past 20 years, we have been searching for an oxygen system for the Cheetah helicopter pilot, which meets the following requirements:

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a) Light weight integrated helmet with a clean and tinted visor.

b) Option of using mask RT at high altitudes and boom mike at low altitudes without noise induced by oxygen flow.

c) Appropriate additional oxygen on demand for flying above 10,000 ft.

d) Ergonomic integration of the mask and the helmet.

e) If required, night vision devices should get well integrated with the helmet.

f) Oxygen hose suitable for prolonged use and storage in extreme cold conditions.

Such an oxygen system could have resolved the long standing problem of the Cheetah pilots.

Erosion of Accepted Norms in the field

The Cheetah helicopter is cleared for operations upto 20,000 ft. Additional oxygen for day flying is a must for altitudes above 10,000 ft (1, 2, 3, 4). The option of flying without oxygen mask is available to the pilot only for day operations below the altitude of 10,000 ft. During such flying a boom mike is a must for RT communication. Since an ideal oxygen system is not available to the pilots, the present day practice in the field is to use face piece of the oxygen mask for RT communication and random 'pipe stem' oxygen inhalation for high altitude flying. In the absence of the elusive oxygen system, this World War II vintage system is most inappropriate for such type of flying and has unfortunately become an accepted norm despite knowing fully the flight safety hazards.

Compromise with Dangers of Hypoxia in High Altitude Operations

The dangers of hypoxia while operating in the altitude envelope of 11,000 ft to 20,000 ft without oxygen are well documented. It is also well documented that the flying effort required by Cheetah aircrew in their area of operation needs total concentration, peak mental alertness and perfect neuromuscular coordination under adverse weather conditions, for each landing and take off and as long as one is airborne. The single engine Cheetah is the lifeline for the troops on ground. The postage-stamp sized helipads are located at heights varying between 14,000 ft and 21,000 ft. Multiple landings and take-offs are carried out in short periods of time with increasing loads proportionate to weight advantage gained due to consumption of fuel [7,8]. Therefore the flying is intense as compared to flying from bases in plains.

If we focus on, just the neurological effects of hypoxia on the pilots operating Cheetahs, at their upper limits of altitude envelope, without proper oxygen management, the picture which emerges is alarming.

Even in the resting subject, the symptoms and signs of hypoxia appear on exposure to altitudes greater than 15,000 ft when breathing air [1]. Higher mental processes and neuromuscular control are affected, and in particular there is a loss of critical judgment and will-power. Because of the loss of self-criticism, the subject is usually unaware of any deterioration in performance or indeed of the presence of hypoxia; and it is this effect that makes the condition such a potentially dangerous hazard in aviation. Thought processes are slowed, mental calculations become unreliable, and psychomotor emotional state are common. Thus there may be disinhibition of basic personality traits and emotions, and the individual may become elated or euphoric or pugnacious and morose. Occasionally the victim may become physically violent. Tunneling of vision may occur.

In parallel with this group of cerebral features, disturbances due to hypocapnia commonly occur, and indeed may dominate the clinical picture, as hyperventilation occurs. Light-headedness, visual disturbances and paraesthesiae of the extremities and lips occur. Central and peripheral cyanosis may develop and there is decreased muscular co-ordination with loss of the sense of touch, so that delicate or fine movements are impossible [1].

Additional factors which are inherent to high altitude operation, further influence the individual's susceptibility to hypoxia. Cold environment reduces tolerance to hypoxia by virtue of the additional metabolic workload required to maintain body temperature. Physical exertion, ill health and alcohol exacerbate greatly the severity of all of the symptoms and signs of hypoxia. Such a situation would compromise flight safety gravely and is naturally unacceptable.

The Consequences

In the retrospective analysis of accidents during 10 years of helicopter operations by the Indian Army, there is no evidence that poor oxygen management was a direct cause of any accident [6]. Nevertheless, its role as contributory factor towards accident causation was more than apparent in as many as 24.83% of all the accidents and of 34.43% human factor accidents. It was noted in this study that this proportion is not surprising, in view of the inadequacies existing in the oxygen management in vogue in the field. In another survey (upto 1992) of helicopter accidents (IAF & AOP) involving 16 Cheetah and 2 Chetak accidents (Cat I to Cat III) it was found that 8 accidents were due to behavioural factors and 6 due to environmental factors [5]. In behavioural group, all were pilot errors, which included two as 'error of judgement', two as 'faulty technique' and one each as 'delayed action', 'poor airmanship' and 'breach of flying discipline'. Physiologically, the effect of low-grade hypoxia is well documented [1]. It is also well known as to how difficult it is to extrapolate the subtle effects on higher functions as contributory cause in aviation accident analysis. Additive effect of low grade hypoxia on judgement, orientation errors and aircrew fatigue can never be quantified, however the dangerous consequences of these effects do not require much convincing in aviation circles. Despite this, a suitable oxygen management system has not been evolved till date for Cheetah operations at high altitude.

Search for Solutions

Since the requirement of the IAF was urgent, it tackled the issue by attempting a number of modifications at local levels trying to match the ABEU helmet and ABEU masks with various available oxygen systems and not by going in for an 'Off the Shelf' imported oxygen system. However, Indian Army opted for an imported, custom made 'Ulmer' helmet, mask and regulator system made in France, to match the original EROS oxygen cylinder of the Cheetah helicopter. IAF meanwhile tried a number of local modifications such as using ABEU helmet, ABEU mask with Mk 17D series of British regulator being used in Kiran aircraft, matching a boom mike facility with the original EROS system and the latest attempt to connect the ABEU mask with the EROS regulator (Mask Mounted). None of these modifications had satisfied the users and since an ideal system was not made available to the users for a long period of time, it gradually led to the erosion of the accepted norms in prevention of Hypoxia, by default.

The two systems i.e. IAF's modification (ABEU mask with the EROS regulator) and

Army's 'Ulmer' helmet, mask and regulator system were evaluated at IAM. The relevant aspects of these studies are discussed below.

Evaluation of IAF's ABEU Oxygen Mask - EROS Regulator Assembly

One assembly was sent to IAM by ASTE in which the following modifications had been carried out:-

a) The original French mask was separated from the MRC 511 regulator.

b) Interface coupler of HE-9 toughened aluminium manufactured by HQ WAC was connected to the original MRC-511 regulator.

c) The indigenous ABEU Mk-I oxygen breathing mask currently in use, in Kiran aircraft was connected to the MRC-511 regulator through interfaced Coupler.

The above modifications were aimed to overcome the problems of the original system, in that the ABEU mask is compatible with the Helmets of Cheetah pilots and the RT system of the mask is time tested being in use in Kiran aircraft.

An, in-use Original EROS Oxygen System including Cylinder + Mask Shell with Harness + Regulator + Supply Hose with Flow Indicator + Coupling + Microphone, was procured from ASTE and was compared with the Modified System.

Physiological Considerations

The major differences, of physiological significance noticed were:

a) Oxygen Mask which, in the original system is mounted on the regulator itself was shifted away from the regulator by the length of corrugated hose of the ABEU mask thereby increasing the operating volume between regulator and the pilot's face.

b) Modified assembly had introduced TWO INSPIRATORY VALVES [one in the ABEU mask (IV-1) & one in the MRC 511 Regulator (IV-2), which has inspiratory valve incorporated in its design itself, for use with a mask mounted on it]. The effect of this, on performance of the modified system was studied.

c) Modified assembly had also, introduced TWO EXPIRATORY VALVES [one in ABEU mask (EV-1) & one in MRC 511 Regulator (EV-2)], instead of ONE in original or any other conventional systems. The effect of this new element on performance of the modified assembly was studied.

In view of the above, this unconventional Oxygen System Assembly could not be made to undergo Tests which are generally carried out on a conventional mask assembly. The Functional test schedules were, therefore, devised specific to the modified assembly, keeping in mind that the modified system will be used for the flight envelope of Cheetah Helicopter, even though it incorporates a mask used for fighter aircraft. Theoretical analysis for possible failure modes have been brought out in IAM's Test Report.

Tests Methodology and Results

The detailed methodology, experimental set-ups for various tests are available in the IAM's test report. The relevant results are enumerated below:

General External Examination

(a) Observations:

It was observed that soft, circular, plastic diaphragm of expiratory valve (EV-2) was torn in one of the samples. This was replaced by one spare cover available at Oxygen System Test Lab at IAM.

The Warning Intel Connector, usually a part of standard ABEU mask had been replaced by interface coupler made of HE-9 toughened Aluminium. One end of the coupler is screwed on to the MRC 511 Regulator's inspiratory end, while the Oxygen hose of ABEU mask is fixed to the other end.

Inspiratory Valve Overload Test

a) **Methodology:** The ice guard over the inspiratory valve (IV-1) was removed and the French supply hose was disconnected from the oxygen cylinder, which automatically blocks the inflow of air from the loose end of the hose. The corrugated tube of ABEU mask was then compressed along its axis to expel the air from inside the tube. The tube was then quickly stretched along its length. IV-1 and EV-2 were observed. The regulator switch was in 100% position to prevent entry of air.

b) **Result:** Normally if only ABEU mask was being tested, the rubber mushroom diaphragm of IV-1 would not invert and would remain uniformly supported over its plastic valve seat, while the corrugated tube would have puckered. In this modified assembly, the test showed that, the corrugated tube did not get puckered. The reason was some inboard leak in the modified assembly, which would need rectification in the modified assemblies to be used in flight trials. The expected loads in IV-1 and EV-2 could not be created due to the inboard leak. The quantum and importance of the leak has been brought out in the oxygen concentration test as part of dynamic testing.

Leakage Tests

a) **Test for regular and mask tube leakage upto inspiratory valve-1 (inboard leak)**

Methodology: The supply hose was blocked after the 'Flow Indicator' and the corrugated hose of mask was compressed axially. The mask with its connections was then allowed to hang down by holding the regulator.

Result: The tube did not remain compressed for any time, there by indicating presence of inboard leak.

b) **Test for leakage from composite mask-regulator assembly (outboard leak)**

Methodology: The composite mask with mic. with IV-1, EV-1, regulator with IV-2, EV-2 and hoses with Flow Indicator were tested on the Mask Mounting Rig at IAM. Oxygen was delivered from the cylinder into the airtight mask fixed on the mask-mounting stand, with outlet connection to the water manometer to ascertain outboard leak rates.

Result: No pressure could be built up in the assembly, as instant leak rates of more than 4 litres/minute developed, even at oxygen delivery pressure of 2 inches of W.G. The leakage in the assembly was from the expiratory valve EV-2 of the regulator, as this valve does not have any compensatory characteristics.

c) **Inspiratory valve opening pressure test:**

Methodology: The modified mask was worn and anchored on a suitably sized inner 'G' helmet. Normal breathing was initiated. It was noticed, that when the regulator was either on 'NORMAL' or on 100% mode, there was no flow of oxygen, as indicated by the 'Flow Indicator'. The flow occurred only at the sharp and severe, peak inspiratory effort and not during normal breathing. This was noticed by three different subjects. Either the modification was the cause of this malfunction or the regulator sent for testing along with the modification was not functioning. The inspiratory valve opening pressures were then tested on four different tests created on IAM Test Rig.

Results: Four different tests were conducted and it was found that the EROS regulator, sent by ASTE was unservicable and therefore not fit for flight trials. However the modification with a serviceable EROS regulator was found to be acceptable as the Inspiratory Valve Opening pressures were within the acceptable physiological ranges (Table - 1).

Expiratory Valve Tests

There are two expiratory valves in the system. While EV-1 of ABEU mask has compensatory characteristics, EV-2 of regulator does not. Since EV-1 forms part of the already approved mask ABEU it meets the required specifications. The following test was therefore carried out for Expiratory Valve EV-2 of EROS regulator.

Table 1

Observations	Suction Pressure inches wg
1	0.4 in wg/0.75 mm Hg
2	0.5 in wg/0.93 mm Hg
3	0.5 in wg/0.93 mm Hg

(a) **Test for inboard leakage through expiratory valve (EV-1)**

Methodology: After mounting the mask on the stand gradually increasing suction was created in the mask cavity through one of its two openings, while the supply hose after the Flow Indicator was kept blocked. Suction pressure to create inboard flow from the expiratory valve EV-2 into the regulator were measured.

Results: It was observed that the diaphragm of EV-2 caved into its housing at inspiratory suctions of pressures as given in Table-2. Any inspiratory suction pressure of more than 7 mm Hg will thus cause a failure mode of the modified mask assembly.

Table 2

Sl. No.	Valve opening pressure (suction pressure)
1	3.8 inch wg. (7.09 mm Hg)
2	3.9 inch wg (7.09 mm Hg)
3	4.3 inch wg (8.03 mm Hg)

a) **Subjective Comfort Test:** While there was no discomfort reported by six non aviators who wore the assembly, it was felt that a suitable anchoring ring for attachment of regulator portion on the pilot's overall or jacket etc. is required to take the direct weight of the assembly from the face and to make the assembly fixed to the flying clothing to prevent fouling with pilot's body during flight. It was also observed that since the warning inlet connector has been replaced by locally made, screw in Aluminium connector, it will adversely affect the time of egress from a disabled helicopter in emergency.

b) **Oxygen concentration studies during simulated flight conditions in an altitude chamber:** Measurements were made of the concentration of oxygen in the expired gas by tapping the sample from the Expiratory Valve of modified mask. Readings of percentage of oxygen were taken using the SERVOMEX@ Oxygen Gas Analyser.

Results:

The results were satisfactory, except for 25000 feet with regulator in Normal position as the oxygen concentrations given by the regulator was found to be 52% which is inadequate to maintain PA O_2 (Alveolar partial pressure oxygen) of 103 mm Hg. This performance is considered unsatisfactory.

Recommendations

This modified mask regulator assembly was found unsuitable for Cheetah operations due to its limitations and following recommendations were made:

a) For flying above altitudes of 18,000 ft, the regulator should be used in 100% oxygen mode.

b) The limitation of the diaphragm of the expiratory valve of the regulator is that it will create an inboard leak in case of deep inspirations without any warning to the pilot. The diaphragm opening was recommended to be permanently sealed.

c) The procedure for emergency escape from the aircraft be evolved in consultation with ASTE, IAM and No. 1 AMTC, including any further modifications envisaged for the same.

d) In view of the ABEU mask having not been used for operational flying in subzero conditions and the incidence of oxygen hose failures in flight at Ladakh region it was recommended that the modified assembly be also tested in subzero temperature conditions at ADE (Aeronautical Development Establishment) Bangalore where the test facility exists.

Evaluation of army's 'Ulmer' helmet, mask and regulator system

IAM was approached by Army Aviation to carry out aeromedical trials on Flying helmet, oxygen mask and regulator assembly items for Cheetah, manufactured by Ms Ulmer Aeronautique and give recommendations on the suitability of the items for induction into Indian conditions. The following documents were also provided for reference:

a) Constructor Tests General Dossier Aeronautic Helmet.

b) Sizing schedule: "Ulmer Oxygen Mask (No. 82H)"

c) Technical manual: "Ulmer Oxygen Regulator 100% demand or diluter".

Since the army aviation aircrew at NFTC had already commenced flight trials with this assembly in Cheetah aircraft, issues of in-flight comfort, subjective evaluation was done by the Army test pilots. In the initial trials, it was observed that the microphone in the mask reverberated causing poor RT reception by ATC (Strength 1 or 2) and the change over from Boom microphone to the mask microphone or vice versa was difficult.

There were no other drawbacks observed like helmet/mask vibration in-flight, tendency of the helmet to tilt forwards, neck/head symptoms, mask related allergy, mask instability/discomfort, suffocation during the use of the mask etc. The testing protocol and the observations were made after trials to assess broadly the following aeromedical aspects.

Helmet:

General workmanship/defect analysis

Noise Attenuation

Field of vision (Along with mask)

Optical assessment of visor

C of G studies

Human Factors

Mask and Regulator:

General workmanship
Leak tests
General workmanship
Valve performance tests
Anthropometric considerations
Decompression chamber trials

Additional tests conducted by manufacturer with certifications:

Shock Absorption Tests & Perforation Resistance Test
Opthalmologic Tests: Colour Perception
Visual acuity
Contrast of vision
Oculomotor equilibrium,
Stereoscopic vision,
Astigmalism
Retention system resistance
Resistance to pulling off
Breakage of ladder locks
Fire resistance test
Storage tests

Observations:

Oxygen Mask

Mask is made of Silicon rubber and is large in size. The mask cavity volume of the given piece of the mask is 155 cc. The length of the hose and the regulator attachment is 48cm (normal) and 50.5cm (Stretched). No inspiratory valve leaks was detected. The same type of the mask is being used in the IAF for Mirage 2000 aircrew and study carried out earlier at the Institute has shown that the sizing schedule is adequate.

Oxygen Regulator

The regulator is a demand-diluter type of oxygen regulator with additional 100% oxygen delivery capabilities. It is a man mounted regulator and was required to be clipped on to the harness of the aircrew by means of a metallic clip provided at the rear of the regulator. For the passengers in Cheetah helicopter however, the harness system consists of only a lap belt. It was found that the regulator when connected to the lap belt had fouling possibilities. The passenger needs to be carefully briefed about this. The selection switch for 100% oxygen can be easily operated and not too loose to cause inadvertent selection of 100% oxygen. The quick release connector of the mask-regulator assembly was satisfactory and unlikely to get disengaged in-flight.

Dynamic testing of the sample mask-regulator assembly in the altitude chamber was satisfactory.

Recommendations:

The Ulmer helicopter helmet was found satisfactory in workmanship and finish. The weight of the helmet and the C of G was within acceptable range. The protection afforted by the helmet was in accordance with the required standards. The helmet mask combinations provided acceptable range of the field of vision. The visor had adequate transmittance and did not have any distortions.

The mask and the regulator was found to be satisfactory and provided protection upto the

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The assembly was recommended to be flight tested in the glacier region for extreme climatic conditions.

The helmet was recommended for testing by the manufacturer at higher range of temperatures for Indian Climatic conditions. The change over switch for boom and mask microphones, provided over the helmet was recommended for better ergonomically design.

Assembly was recommended for operational inductance into army aviation.

Conclusion:

The French system meets all the requirement of Cheetah helicopter operations, while the indigenous effort falls short of the requirements on many counts. Army is already in the process of procuring the French system for its needs. It is recommended that the IAF should also go for the same system, to immediately fulfil its long standing need for an appropriate oxygen system for Cheetah operations.

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