

In-flight Hypoxia - Still a Worrying Bane

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ABSTRACT

In-flight hypoxia continues to occur in flying even today. This is despite the fact that the present oxygen systems are quite well evolved and technologically advanced. The reasons for in flight hypoxia have been analysed in different studies involving various Air Forces. In most instances, poor oxygen discipline has been found to be the principal cause. This paper discusses an incidence of in flight hypoxia during a sortie of a Modern Combat Aircraft while flying at an altitude of 46,000 ft. After investigations, the cause was revealed to be incompatibility between the mask with the helmet that led to inboard leak resulting in hypoxia. The paper also takes a look at the incidents and causes of in-flight hypoxia in different leading Air Forces of the world and suggests measures to curb its occurrence.

IJASM 2010; 54(1): 6-12

Key Words: In-flight Hypoxia, Concern in flying

Introduction

Incidents attributable to Oxygen (O₂) lack have in the past taken regular toll of both pilot lives and aircraft. O₂ lack during flying not only takes lives but also reduces military effectiveness. In the period 1941-45, USAF had 10,700 reported incidents attributable to hypoxia. There were 110 deaths and 0.3-0.6% of sorties were aborted due to incidence of hypoxia. Royal Air Force Bomber Commands flying usually at 14,000 ft had fewer incidents during this period. But the early return of aircraft due to O₂ failure was a cause of worry for mission accomplishment [1].

As the aircraft started flying higher and faster, the need to prevent in-flight hypoxia was felt more and more acutely. Parallel development of aircraft O₂ system occurred to match the aircraft performance and its ever increasing agility. Though Georges Legagneux, a French pilot, is credited with the first use of supplemental oxygen in an aircraft in 1913, the first practical automatic O₂ delivery system was Dreyer's apparatus designed by Col George Dreyer of British Royal Air Force. By 1919, it was adapted by all US planes flying at high altitude [2]. Considerable research and effort have gone

into the evolution of aircraft O₂ systems ever since. The present systems are very versatile, mature and completely automatic. Despite existence of such well evolved and advanced systems, in-flight hypoxia still keep occurring although the frequency of such events has drastically reduced. A recent incidence of in-flight hypoxia is quoted below to give an insight into the problem.

Brief Narrative of Event

A test pilot was authorized to fly a high altitude sortie on a modern combat aircraft. The pilot was to carry out various flight checks at 14,000 m altitude. He took off at 0915 hr with appropriate flying clothing comprising of Anti 'G' suit, Alpha Helmet and indigenous developed oxygen mask. After about 10 minutes into the flight while operating at 14,000 m (46000 ft) ambient altitude and with the cabin altitude of 5400 m (18,000 ft), the pilot felt some initial mild tingling over the left upper lip. He tightened his mask. The tingling sensation

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Date of submission: 12 Dec 09

Date of approval : 30 Apr 10

progressed to numbness of left upper lip. The regulator at this point was switched to 100% O₂ and thereafter to overpressure position of 'surplus' wherein 100% O₂ is delivered at pressure of 2-3 mm Hg. Even after this, there was no alleviation of symptoms.

Slowly, the symptoms progressed to dull headache. The pilot continued to maintain a cabin altitude of 5400 m for 2-3 minutes. He experienced slight dimness of vision. As the symptoms further aggravated, he started immediate descent and reached to an ambient altitude of 8000 m. The symptoms persisted. At this point, he decided to abort the sortie. During descent to land, the symptoms disappeared completely at an altitude below 3000 m and there was no residual effect after landing.

During discussion after the incidence, the pilot brought out that the helmet and the oxygen mask that he has been using in past sorties was not properly fitting. The mask is hard on nose bridge to the extent that it is felt all the time. Generally, the test pilots flying with this oxygen mask in this modern combat sorties keep the toggle in normal position during flight and it is pulled down and further tightened only during flight manoeuvres and pressure breathing. It is worthwhile to mention here that the modern combat aircraft is using Liquid Oxygen (LOX) as source of Oxygen with HALA regulator of Mirage-2000. The mask used has been developed for this aircraft and it is similar to ABEU. ALPHA helmet is purchased off the shelf from UK.

Investigation into the incident

To ascertain the cause of this incidence, a defect investigation team was constituted with experts from different agencies. The team formulated the approach of looking into various aircraft factors and the aircrew factors those could have contributed to the incidence which apparently

seemed to be due to in-flight hypoxia.

(a) **Aircraft Factor.** The cabin pressurisation system was thoroughly checked which did not reveal any evidence of malfunction. The LOX converter was checked for output of O₂ and pressure, immediately after the sortie was aborted. It showed O₂ content of 99.85% with a normal operating pressure. The HALA regulator was also checked. The regulator function of demand, dilution and pressure were within the prescribed acceptable limits. Peak flow rates and maximum pulmonary ventilation provided were commensurate with the highest level of human needs. The HALA regulator does not have any provision for automatic safety pressure to prevent inboard leak. There is facility to manually create an overpressure by putting on the 'Surplus' switch. This provides 100% Oxygen at a pressure of 3-4 mmHg. As per pilot manual, it is resorted to in case of cockpit is contaminated by toxic fumes and gases. The ALPHA helmet and the indigenous mask combination used in this sortie were evaluated by DEBEL for compatibility to preclude possibility of an inboard leak. The regulator function was also assessed. It was revealed that the regulator does not provide any safety pressure till 20,000 ft though it provided appropriate oxygen concentration at different altitudes. The functions of the inspiratory and expiratory valves of the mask were satisfactory. But the interface trial of the mask helmet assembly revealed inadequate face mask seal over the chin area within comfortable tightening. This was also corroborated by all the pilots who are flying with this combination.

Aircrew factor. Post incident, the pilot was medically evaluated at IAM. The pilot had completed his annual medical examination and had been in medical category A1G1 (flying fitness) throughout his flying career. Clinically, no contributory finding was evident. Routine blood and urine examination, biochemical parameters,

pulmonary function test and ECG (R) were within normal limits.

It was then decided that he will be evaluated in the hypobaric chamber with the intention of reproducing the symptoms he experienced in air during the said sortie. To simulate the cabin altitude of the said sortie, he was exposed to the same altitude of 54000 m (18,000 ft) for 5 minutes without oxygen in the hypobaric chamber. Before exposure to hypobaric hypoxia his pulse was 70/min, blood pressure was 118/70 mm of Hg, respiratory rate was 12/min and SaO₂ was 98%. As per the FDR analysis, his cabin altitude was between 18,000 ft to 10,000 ft for about 5 minutes during the sortie. After removal of mask at 18,000 ft in the hypobaric chamber the pilot experienced the following:-

- (a) No symptoms for first three minutes.
- (b) Minimal numbness on the upper lip. There was however no tingling sensation.
- (c) Mild pressure effect above his eyes.
- (d) He subjectively quantified the symptoms to be 10% of what he experienced during his sortie in LCA. After donning the mask and reverting to breathing 100% O₂, all symptoms disappeared rapidly.

It is obvious that the type of symptoms experienced by the pilot in hypobaric chamber is very much similar to what was experienced during the sortie. The difference in intensity of the symptoms may be attributed to the fact that perhaps, the level of hypoxic insult he was exposed to in the cockpit could not be fully replicated in the chamber due to variety of reasons like amount of inboard leak and actual duration of the hypoxic exposure in the said sortie. During the simulated hypoxic exposure in the chamber his pulse, BP and respiratory rates and SaO₂ were measured. The

values were similar to pre-exposure levels. However, there was a decrease in the SaO₂ value to 85% when he started becoming symptomatic and the hypoxic exposure was terminated by providing 100% O₂ through an aviator's mask.

Discussion

In April 1875, two young French scientists Croce Spinelli and Sivel became the first victims of aviation hypoxia trying to reach an altitude of 26,200 ft in their balloons. Even today, hypoxia has remained a constant hazard during high altitude flights. It may arise from failure of pressure cabin, failure of O₂ system to deliver adequate concentration and or pressure of oxygen. The latter may be due to inefficient ground servicing, mechanical failure of O₂ equipment, faulty O₂ drill or an ill fitting O₂ mask.

In the present episode, the pilot was using ALPHA helmet purchased from UK and an indigenously developed mask. The indigenously developed helmet being used previously with the compatible mask fell out of favour with the pilots due to improper noise attenuation. But unfortunately, no compatibility study was carried out to see how the ALPHA helmet purchased off the shelf and the indigenous mask combination fit on to the pilot. After this episode when the mask helmet combination was tried on the pilot in question, it was found that the anchoring for the mask in ALPHA helmet was bit higher and led to imperfect face mask seal leaving a gap at the lower part of the mask and the chin. This, perhaps, led to inboard leak and resulted in hypoxia in this case. The problem was compounded by the fact that HALA regulator does not provide any safety pressure automatically. It can provide 100% O₂ with overpressure which has to be selected manually and is used in case of cockpit contamination by toxic gases, smokes and fumes.

Hypoxia due to helmet mask incompatibility and other mechanical problems of the oxygen system keep occurring quite often. There has been no organised and comprehensive study conducted in IAF to find out the incidence of in-flight hypoxia. However, a study conducted by Tripathi et al from 1986 to 1995 in Army Aviation helicopter flying high altitude sorties revealed 29 accidents. Out of this, in 24% of all and 30% of human factors accidents, hypoxia was a contributory factor [3]. In one study in RAF, the analysis of the relative incidents of 397 cases of hypoxia revealed that failure of O₂ regulator and decompression of pressure cabin accounted for 57% of all cases of hypoxia. The other important causes include breach of hose connection between regulator and mask, inadequate face mask seal and malfunction of mask valves [4].

Rayman and McNaughton reviewed 298 aircrew who experienced in-flight hypoxia in the USAF during a period of 1970-1980. 48 occurred in fighters, 144 in trainers, 28 in transport, 23 in bombers and 1 in U2 reconnaissance aircraft. A total of 193 cases (64.7%) occurred in aircraft where oxygen equipment is routinely used and mask is worn all the time. The most common symptoms experienced were paraesthesias, lightheadedness, dizziness, decreased mentation and visual changes. Most crew men had more than one symptom. Other symptoms were extremely variable. The symptoms reported by the pilot in this case study are consistent with findings of the USAF study. This study also revealed 16 cases of loss of consciousness. In 98 cases (33%) the cause was not determined. However, 134 cases (45%) were due to mask, regulator, hose and oxygen supply problems. 58 cases (19%) were due to cabin pressure failure and 8 cases (3%) due to mask removal in flight. It was also revealed that 50% of cases occurred in training aircraft highlighting the fact that breaches of O₂ discipline is more likely in student pilot. Though

many of the episodes were unavoidable, rest were like O₂ hose disconnect, poor mask fit, regulator in off position, breach in O₂ hose and depleted O₂ supply. Leak due to mask, mask removal in flight accounted for 84 cases, which were attributable to poor O₂ discipline and could have been avoided if correct procedures were followed [5].

Another study conducted into the causes of incidents of in-flight hypoxia from 1990-2001 by Director of Flight Safety of the Australian Defense Forces revealed 29 incidents of in-flight hypoxia amongst aircrew and there was one fatality. All these aircrew had indoctrination training on hypobaric chamber. There were 20 (75.9%) trained aircrew who recognized their own symptoms of hypoxia made possible by the previous hypobaric chamber training. 3 cases (10.3%) were recognized by the other crew members and in 4 cases (13.8%), hypoxia was not recognized. In 2 out of 4 unrecognized cases there was loss of consciousness, one being a fatality. The majority of cases numbering 16 (59.2%) occurred in Pilatus PC9/A aircraft which is unpressurised, requiring constant O₂ breathing through a regulator and used for basic training. This finding is in consonance with the USAF study where maximum cases were from the student pilots flying unpressurised T-37 aircraft. As far as the altitude is concerned most cases (55.6%) happened at an altitude between 10,000 ft-19,000 ft and more importantly, 4 cases occurred even below 10,000 ft [5].

Out of the reported cases, 17 (63%) were due to regulator failure, connection failure, mask leak and other mask related problems. In 18.5% cases there were no readily identifiable cause but presumably, it was due to mask-regulator failure. Many aircrew experienced multiple symptoms of hypoxia. In 4 cases, no symptoms were specified. The most common symptoms in order of frequency were cognitive impairment, dizziness/

lightheadedness, tingling/numbness feeling of nonspecifically unwell, hot/cold flushing, shaking of limbs, numbness, visual changes and loss of consciousness. Headache and lethargy were uncommonly reported. High rate of recognition of own symptoms in this study reinforces the value of hypoxia training. [5]. These symptoms are in agreement with the findings of the study conducted by Rayman and McNaughton [5].

In a study involving USAF from 1963-70, Munson brought out that 80% of incidents of in flight hypoxia was due to operator error. In the study by Russell and McNaughton during the period 1970-1980, it was found to be 28% [5].

Hypoxia training as a preventive tool

There have been many incidents of in-flight hypoxia due to failure of the O₂ system. It is further complicated and compounded by the fact that subjective effect of O₂ lack may be so slight that there is no recognition of its symptoms as in alcoholic intoxication. The subject may have no insight into his condition and no ability to criticize his own actions. As a result the required corrective action is unlikely. This may lead to unconsciousness and complete loss of aircraft control. There is enough evidence that repeated exposure of an individual to hypoxia facilitates its recognition despite the fact that these are difficult to describe and vary from person to person.

An analysis of USAF hypoxia incidents from January 1976 to March 1990 revealed 656 reported incidents. Of these, 606 involved hypobaric chamber trained aircrew and 3.8% of these experienced loss of consciousness. Of the 50 untrained passengers, 94% experienced loss of consciousness. This major difference between the trained aircrew and untrained passengers reinforces the benefit of hypobaric chamber training in the recognition of hypoxia. Of the 520 trained aircrew who recognized

their own symptoms, 26.2% stated that the symptoms were similar to what they had experienced in the chamber. The affected pilot in our case study was indoctrinated for hypoxia during his flying training at Air Force Academy and suffered from the similar symptoms during his chamber training on hypoxia. This has gone a long way to appreciate that he was suffering from hypoxia during this episode during flying and helped him adopt corrective measure early and on time. The pilot had corroborated this fact [6, 7].

Conclusion and Recommendation

Despite the improvements in the performance and reliability of cabin pressurization and oxygen delivery system, hypoxia still occurs, though the incidents and accidents due to hypoxia have greatly reduced. In keeping with the increase in aircraft performance, the sophistication of O₂ system has also improved. The bottom line of a system is that the aviators' physiological needs must be satisfied under variety of conditions like altitude, acceleration, workload, temperature and psychological stress. The system testing must be done under simulated operational conditions across full range of anticipated use. Mercifully, the currently used oxygen systems do meet these requirements. Notwithstanding, to reduce the incidents of in-flight hypoxia the following facts need to be bone in mind:-

- (a) Hypoxic symptoms are extremely variable and may be incapacitating as revealed in different studies.
- (b) Incidents of in-flight hypoxia have reduced considerably world wide, still there is room for further improvement. This can be achieved by stricter adherence to O₂ system discipline by the aviators.
- (c) Properly fitting mask, importance of helmet mask compatibility, leak checks, meticulous O₂

equipment checks, both pre-flight and in-flight, should be taught to all aircrew and reinforced regularly.

- (d) The importance of hypoxia indoctrination training is highlighted by the fact that so many aircrew trained in the procedure could recognize their symptoms early and could take timely corrective action. Therefore, hypoxia indoctrination training should be made mandatory and be reinforced periodically.
- (e) There is a definite need to conduct a study to find out the incidents of in-flight hypoxia in IAF and formulate effective preventive strategy.
- (f) In-flight hypoxia still remains a serious and worrying threat to aviators in particular and aviation community in general. This calls for constant vigilance and awareness throughout the aviation community to fight the menace.

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