A Case Report

In-flight Cold Injury from LOX System

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Liquid Oxygen (LOX) is extensively used in modern fighter aircraft due to its advantage in saving space and weight. Cold injury due to accidental contact, is a well known hazard to ground servicing personnel handling LOX. However, in-flight cold injury as a hazard of LOX system is almost unknown. A case of inflight cold injury due to leak in the anti-G suit, inflated by Oxygen from LOX, is reported. This paper discusses the accident, the cold injury to the pilot, damage caused to Oxygen hose and the mechanism of cold gaseous Oxygen entering the anti-G suit.

Keywords : Liquid Oxygen (LOX), Cold injury, Aerobatics, Anti-G suit, Oxygen hose.

Military aircraft use liquid Oxygen (LOX) system because of its advantage in saving space and weight. In modern fighter aircraft like Mirage-2000, the LOX system is integrated with ready pressure, high flow anti-G valve. Ground servicing personnel are prone to cold injury due to accidental contact with LOX. However, in-flight cold injury as a hazard of LOX system is almost unknown. A case of in-flight cold injury is reported because of its unique occurrence.

The Incident. On 14 Jan 1991, a Mirage 2000 trainer with two aircrew took off for an aerobatic sortie from an Air Force base in Central India at 1120 hrs. After take-off, the aircraft climbed to 10,000 ft and was operating overhead. The pilots carried out consecutive loops and 'clover'. In the aerobatic 'clover', the direction of the aircraft is changed either in the ascending or in the descending limb of a series of loops so as to form a pattern like the clover leaf. In this incident during the 'clover', the front cockpit pilot felt slight irritation on his right thigh. On completion of the 'clover' manoeuvre, the rear pilot took over the controls. At this juncture, the front pilot felt a cold, tingling sensation on his right thigh. On looking inside the cockpit, he found that the anti-G valve hose was frosted. When he tried to disconnect the hose, he felt it too cold to touch. He communicated this to the rear pilot and they decided to abandon the sortie and carry out immediate landing. They landed at 1142 hrs, 6 to 7 minutes after the incident. During the landing run, the pilots observed the Oxygen warning light coming on, followed by an indication of emergency Oxygen supply.

Findings

On landing, the pilot complained of pain and burning sensation over the right thigh. Local examination revealed an erythematous area of 3 x 4 inches over the upper part of the right thigh. On the second day, blisters of 1.5 to 3 inch size appeared over this spot (Fig :1). Examination of

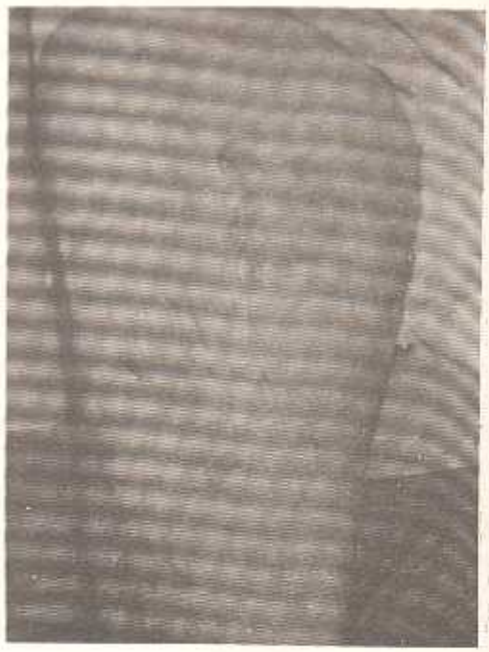

Fig - 1.

anti-G suit revealed no external damage. On inflation, it showed a leak in its right thigh section. Examination of bladders removed from the suit showed a gap of 1 cm on the inner sealed edge at

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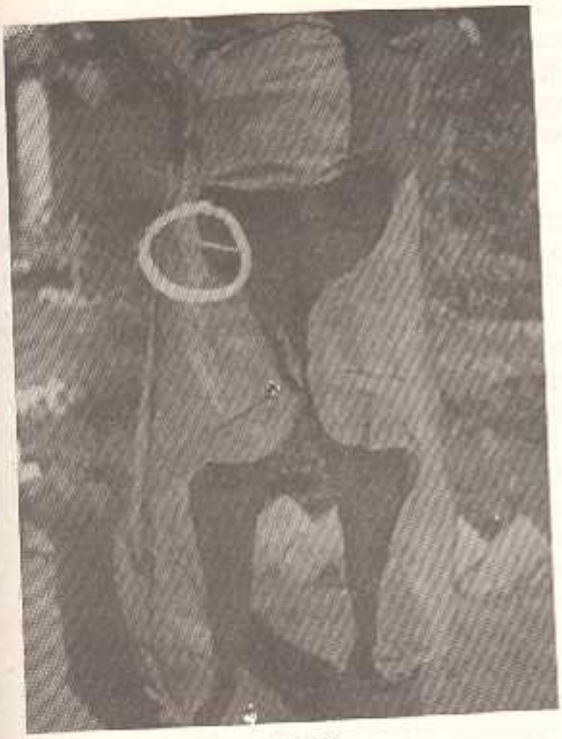


Fig 2

a point just above right thigh bladder (Fig 2). Tests carried out on the anti-G valve revealed no mal-function. The LOX container was found to be empty. The hose bringing Oxygen into the emergency Oxygen unit was found to be damaged in the form of cracks with frayed ends on its outer rubber cover.

Trials: It appeared from the findings that the cause of the incident was the tear in the anti-G suit leading to a continuous high flow of Oxygen during aerobatics which resulted in cooling of Oxygen. Therefore, a trial was conducted to see whether a continuous flow of Oxygen at high rate could cause a significant drop in its temperature.

The trial was conducted in the aircraft on the ground. The defective bladder was fitted to the anti-G valve. To simulate the effect of G forces, a small metal plate was mounted on the anti-G valve. The pressure was applied manually over this plate. Though a precise quantification of flow could not be gauged, it was assessed on the test bench earlier that thumb pressure on the plate gives suit inflation pressure similar to that encountered at 9G situation.

After creating a continuous flow through the valve, the bulb of the thermometer was kept on the leak point of the anti-G suit. The temperature started falling slowly initially falling very fast after sometime. It came down from 27°C to 13°C in 1 minute 30 seconds. At this point, the Oxygen hose connecting seat aircraft disconnect to emergency Oxygen supply unit was covered with frost. Simultaneously, condensation and misting was noted on the anti-G valve hose. To avoid further damage to hose, the trial was stopped at this stage.

Discussion

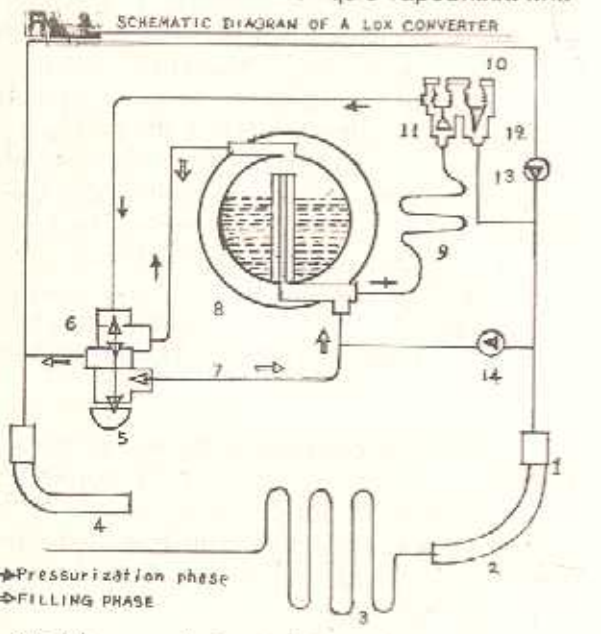
The LOX system in the Mirage-2000 consists of a 5 litre container also called LOX converter, a heat exchanger, emergency Oxygen supply unit, Oxygen regulator and associated pipings. The anti-G valve which inflates the anti-G suit with Oxygen is integrated with the LOX system. It is of the high flow, ready pressure type. It inflates the anti-G suit with a ready pressure of 5 to 10 mbar which is maintained upto 2G[1]. When exposed to acceleration above 2 G, it allows a further flow of Oxygen into the suit. A regulating diaphragm cuts off Oxygen flow when pressure on either side of it equalises. In this incident, because of leak in the anti-G suit, the pressure on the suit side of the diaphragm never rose and therefore the valve allowed the continuous flow of Oxygen till the LOX container emptied. Under 2G condition, the continuous flow did not produce any significant effect since the pre inflation pressure is only 5 to 10 mbar. The inflation pressure increases to 144 to 210 mbar at 4 G simulation on the test bench[1].

During this particular sortie, the aircraft was subjected to approximately 4 G during the 'clover' manoeuvre for period of about 1 to 1.5 minute. Hence significant high flow first came about only during the 'clover' and the pilot noticed symptoms.

The continuous high rate of demand of Oxygen resulted in cooling of gaseous Oxygen entering the anti-G suit. There were three factors, all related to the physical properties of a gas, which caused this cooling. These are :-

(a) **Expansion of gas due to fall in pressure** : The LOX converter is filled at a pressure of 55 PSI[2]. Immediately after filling, pressure build up starts and goes on till container reaches the operating pressure of the converter which is 70 - 115 PSI (483 - 793 K Pa)[3]. Under normal conditions, any demand by the user is met in gaseous state from the top of the liquid (Fig :3). The subsequent fall in the pressure is resorted by allowing liquid into the pressure build up coil. If the demand is more and the pressure level in the delivery line falls below a pre set value, then the demand is met in the liquid state from the bottom of the container via a non-return valve/differential check valve[3,4]. In this incident, the continuous flow during the 'Clover' manoeuvre caused a large fall in operating pressure resulting in expansion and cooling of the gas.

(b) **Shortage of warming up time** : The fall in the operating pressure did not occur because of the continuous high rate of demand during the 'clover' manoeuvre. Therefore the demand was met in the liquid state from the bottom of the container. The liquid vapourised and directly entered the heat exchanger short circuiting the normal process of pressure build up (Fig :3). The heat exchanger could not handle this large flow of low temperature, low pressure gas. Therefore cold Oxygen entered the cockpit.



(c)**Temperature stratification** : As the process of pressure build up continues, the vapour pressure rises till it is in equilibrium with the liquid at the operating pressure of the system. At this point, the liquid attains uniform temperature and is said to be stabilized. This stage is reached 10-12 hours after filling. Any agitation of the liquid before stabilization disturbs the liquid-gas interface, bringing colder liquid into contact with the gas which then condenses and pressure consequently falls in the gaseous phase[3]. This phenomenon is called temperature stratification. In the present case, even though a stabilized LOX Converter was used, the high rate of demand caused fall in pressure of the gas resulting in destabilization of the liquid. During aerobatics, agitation of destabilized liquid resulted in temperature stratification[3] leading to further fall in pressure and cooling of gas.

The effect on breathing was not pronounced since the Oxygen regulator was functioning normally and the demand was very small. Considering the physical properties of the gas, the length of the hose between the regulator and mask was adequate to warm up the small amount of gas.

Similarly, the normally functioning anti-G valve and the Oxygen regulator combined with extra length of pipings from the common LOX converter, did not produce any effect on the rear pilot.

Conclusion

The leak in the anti-G suit combined with high demand for 1 to 1.5 min during the 'clover' manoeuvre resulted in cold Oxygen entering the anti-G suit causing cold injury at the site of leak. This incident has brought to light that the use of LOX in fighters can lead to in-flight cold injury in case of equipment malfunction. Such incidents during combat manoeuvres can produce serious consequences to the mission as well as to the

pilot. Therefore, the use of LOX in fighters require a review with all aspects of its role during normal operation as well as under emergencies.

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