Symposium: HIGH SUSTAINED G FORCES

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G-INDUCED LOSS OF CONSCIOUSNESS AND ITS PREVENTIVE ASPECTS

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DURING 1983-84, the United States Air Force (USAF) officially acknowledged nine aircraft accidents in which loss of consciousness (LOC) under high G was considered as the primary cause (1). Northrop had recently confirmed that G-induced loss of consciousness (G-LOC) was the cause of accident of the second prototype F-20 aircraft. The same is suspected to have caused the accident of the first prototype F-20 as well.

LOC due to aircraft acceleration is not something new. In 1956, Stoll (6) published her classical work presenting tolerance curves and nomogram for grey out, black out and unconsciousness for various levels of G attained at different constant linear rates of onset. In the 50s and 60s various studies were carried out on retinal circulation during acceleration forces identifying black out and black out with fainting. However, it was only in the late 70s that Whinnery (7) identified LOC as a phenomenon separate from black out and warned pilots flying high performance aircraft that loss of consciousness was considerably more dangerous than simply an extended black out. Cases of LOC in Human Centrifuge have occurred occasionally in experimental conditions. However, these occurrences were considered in the context of centrifuge problems, with little concern relevant to operational flying. It was during 1976-78 that this problem was studied in the US by analysing video tapes of the centrifuge runs (2).

Physiological Basis

G-LOC is explained by simple fluid mechanics applied to the cardiovascular system. The mean pressure of the pump is 100 mm Hg at heart level, this being the driving force for the blood supply to brain. The height of the column of blood between heart and brain is about 30 cm, equivalent to 22 mm Hg pressure, opposing the driving force. Thus at 1 G, the brain or eye level arterial pressure is about 78 mm Hg. For every additional G applied, the eye/brain level pressure is reduced by 22 mm Hg and at around 5 G, the pressure is virtually zero, leading to black out/LOC in a relaxed individual. Physiological changes are modified by the baroreceptors, but this mechanism takes 5-12 sec to come into play.

In the normal course of events, a person will grey out, black out and eventually lose consciousness under increasing +Gz forces. However, another mechanism for LOC is by beating the reaction time of the baroreceptors. Under such rapid onset (RO) of G, a person may not have the normal prodromal symptoms of grey out and black out, and LOC may ensue quickly and unannounced. In aircraft like F-15, F-16 and Mirage-2000, it is not only the high sustained G (HSG), but also the RO HSG which predisposes a pilot to LOC.

Video studies of LOC have brought out the average duration of incapacitation to be 15.0 sec, with a range of 9 to 23 sec amongst 25 subjects (7). Following LOC, the pilot is in a state of confusion, disorientation and apathy lasting for another 5-10 sec. The LOC is usually associated with a twitch or involuntary movements of one or more extremities. There is retrograde amnesia and very few realise that there has been a missed period in the course of events.

The problem of G-LOC initially surfaced among trainee pilots and was thought to be associated with some training problem. In the USAF Air Training Command approximately two LOC episodes occurred every month during a four year review; the mean G level for LOC while flying trainer aircraft was 3.8 Gz with a range of 2.0-6.5 Gz (1). A 1983 G-LOC survey in the US reported a rate of 12% (5). LOC incidents occurred predominantly in the 5.0-8.5 G region. Many of the incidents were noted in F-4, F-15 and F-16 but most of the LOC-related fatal mishaps were in F-16 aircraft.

The following are some of the causes leading to LOC in flight:

a. Rapid onset of G.

b. Unpreparedness for the RO HSG either by the second aircrew or the aircrew himself being surprised by the manoeuvrability of the aircraft.

c. Slow response of the anti-G system.

d. Improper anti-G straining.

e. Inadvertent disconnection of G suit hose.

f. Return after a period of non-flying.

g. Fatigue.

h. Inadequate hydration and diet.

j. Poor physical state.

Except for the USAF, most other Air Forces, have not reported many incidents of LOC and hence studies are limited. USAF became aware of the LOC problem at a very early stage and the research work carried out in the US helped other countries like France, producing aircraft of similar capabilities, to be prepared for this problem. The realisation that G-LOC in aircraft does not have a medical basis in asymptomatic aircrew, has also helped USAF in their introspection of the problem (4).

Unlike black out, G-LOC is due to brain hypoxia. Concerted efforts are on for in depth studies into the G-LOC problem and means to enhance tolerance to +Gz.

Protective Methods

The object of the G protective methods and devices is to enable the crew to exploit the capabilities of his weapon system fully. The methods can be grouped as under :-

a. Personal Protection

- Anti-G straining manoeuvres
- Role of exercise training

b. Hardware Programmes

- Anti-G system (Valve and Suit)
- Anti-G hose and connectors
- Positive pressure breathing
- High G cockpit (Tilt back seat)
- Light weight helmets
- Automatic recovery systems

Personal Protection

Anti-G straining manoeuvres (AGSM), variations of which are code named as M1, L1 or M2, have been practised by pilots flying the older generation aircraft. Though the concept is not new, the full potential of AGSM has been realised only recently. Today, a well coordinated and timely straining manoeuvre is considered as the single most important factor in improving G tolerance. Many quite emphatically state that the ultimate factor limiting sustained G tolerance is failure to maintain adequate blood supply to brain as a result of the inability to maintain the performance of the straining manoeuvre. Repeated straining is tiresome to the pilots. Once fatigue ensues, the manoeuvres monopolise attention at the time of combat, head movements become difficult and the muscular relaxation which follows reduces G tolerance. It is in this light that many of the Air Forces abroad have adopted training and exercise programmes for the aircrew.

Physical conditioning programmes to improve the strength and stamina of the aircrew are receiving world wide attention. It is apparent from many studies that though each individual has his own inherent resistance to G, regulated exercise training can improve not only the G threshold but also the ability to withstand the stress better without getting fatigued early. There has been a lot of discussion on the relative merits of the different physical fitness programmes. Individuals engaged in endurance running or athletic training are generally found to have lower G tolerance than average. Yet, the improved cardiovascular tone helps an individual to withstand better the stresses involved in high G flying. If the negative value of lowered blood pressure in aerobic training can be offset by exercise to provide voluntary increase in blood pressure during G manoeuvres, a total benefit would accrue to the high G aviator. It is under this philosophy that the idea of providing upper body weight training gained favour very rapidly. Regardless of the doubts of this philosophy, it was always agreed that such a training programme would certainly do no harm. Today, with many Air Forces having adopted the exercising programmes, there is little doubt over the benefits of training. The schedules are designed to be an optimal combination of strength and endurance training with regard to intensity, frequency and duration, the emphasis being on exercising and building up of abdominal, upper torso and neck muscles. Surveys on individuals following the exercise programmes have shown a high degree of acceptability amongst aircrew who have not only reported an increase in G tolerance without fatiguing but also a feeling of being more fit.

In conjunction with weight training, aerobic training in the form of jogging or playing squash/tennis twice or thrice a week is carried out. The recommendation is that these exercises be carried out for 20 - 30 min on days alternating with weight training. Running distance should not exceed 3 miles per day.

Hardware Programmes

Anti-G System: This is the old and reliable system serving the aircrew for many years. The anti-G suit and the peak pressures provided by the valves are near optimum and provide a protection of 1.2 to 1.5 G. However well it may have served, the inadequacy of the conventional anti-G valve has been brought to light by the rapid G onset capability of the modern fighter aircraft. The valve has an initial lag of 1 to 1.5 sec and the total time for the build up of peak pressure is long. This is obviously not enough for an aircraft where high peak accelerations are reached in 2 sec or less. A number of new design anti-G valves have been developed some of which are already in use while others are undergoing trials. The main advantage is the high flow characteristics of the valves which allow peak pressures to be reached in less than 2 sec. In other words, the peak pressures supplied to the anti-G suit follow the G rise time closely. Some of the valves have the added feature of providing ready pressure or pre-inflation of the anti-G suits. A combination of high flow ready pressure (HFRP) is claimed to have an advantage of 1.0 G over the conventional valve. A variety of improved anti-G valves are coming to the forefront, the published reports of flight test results of which are awaited. Some of them are the electronic valve, the servo-controlled valve, the 'bang bang' solenoid valve and the synchronised external pulsation (SEP)-controlled valve. The anti-G suit may have very little to offer in terms of modifications for improvement, but what has caught the attention is the need to integrate it with the garment that may be required for nuclear, biological and chemical warfare.

Anti-G Hose and Connector: Various surveys and investigations of G-LOC incidents have brought out that the bayonnet connection between the anti-G hose of the aircraft and the connector of the anti-G suit sometimes becomes loose or totally disconnected during rapidly built up G. This has prompted modification of the anti-G connectors and improved varieties are now being made available. These, along with frequent checks on the part of the aviator, should eliminate future occurrences of such incidents.

Positive Pressure Breathing (PPB): This method of improving G tolerance has been on the cards for quite some time now. A number of centrifuge studies have proved its efficiency beyond doubt. The principle is akin to that of the anti-G straining manoeuvre where the intrathoracic pressure is raised artificially. However, in this case the pressure is raised passively (without straining) through additional pressure in the breathing mixture. Its main advantages over AGSM are that it is far less fatiguing, the cardiovascular recovery is much quicker, and it eliminates the counter-productive possibility of a wrongly done M1 manoeuvre.

The crux of the hardware requirement is a G-sensitive oxygen regulator which would give the pre-requisite additional pressure automatically after 'cutting in' at a particular level of G. The USAF is in the process of flight testing one such regulator to prove its operational suitability. The features of that regulator are initiation of PPB at 4 G, provision of 12 mm Hg/G upto 9 G, maximum pressure of 60 mm Hg at 9 G and chest counterpressure equal to PPB pressure.

For Indian conditions, where the heat load in the cockpit is high, 30 mm Hg additional pressure would be more realistic as this could be tolerated without additional counter-pressure garments. The remaining increase in intrathoracic pressure could be brought about by 25-50% of the straining manoeuvre.

Tilt Back Seat and Leg Elevation: The idea of converting +Gz into a load vector transverse to the body is nothing new. It is well known that +Gx is much better tolerated than accelerations along the longitudinal axis of the body. The essential element in a high G cockpit would therefore be a reclined or a tilt back seat. It has also been established that to obtain any appreciable gain in G threshold (about 0.5 G), the seat has to be reclined by at least 45 deg from the vertical. In order to gain 1 G, a tilt back of about 55 deg is required while increments of 2 and 3 G are obtained at 69 deg and 74 deg recline respectively. Transferring this information into the high G cockpit is by no means simple. The degree of recline of the seat would be restricted by so many ergonomic considerations as well as the operational configuration of the aircraft. The designers, of course, are still at it. The most favoured design still is the articulated reclined seat which can be selected through a side hand controller to a high G position in combat, upright position in cruise or on ground and an automatic upright position during ejection. Irrespective of the degree of G protection offered, any increase in incline along with leg elevation would increase the comfort and reduce fatigue in a high G environment.

Light Weight Helmet: Cervical pain or 'neck catches' are often reported amongst aviators flying the high G aircraft. The incidence is fairly high even amongst our own aircrew flying these kind of aircraft. Though these incidents are often due to unavoidable and sometimes avoidable head movements during combat manoeuvring, the weight and comfort of the helmet has a significant role to play. The emphasis now is on making the helmets as light as possible and make them as individual fits for comfort. The role of strengthening the neck muscles through isotonic exercises is also stressed.

Automatic Recovery Systems: Autorecovery of the aircraft in the event of G-LOC of a pilot is indeed a novel idea. It is based on the assumption that even with the best protection provided to the aviator there still exists a possibility of experiencing a G-LOC. If the aircraft could be designed to accomplish an acute recovery, the pilot and the aircraft could still be saved. R&D programmes have been initiated by the US with the approach of initiating auto-recovery based on a set altitude clearance, or integrating the G-LOC recovery with a ground proximity warning system. The current modification suggested for the F-16 auto pilot system is that wings would roll level and pull up to 5 G to return to the set altitude whenever the aircraft sensed that it was below the floor altitude set by the pilot. We should be hearing more on the auto-recovery systems in the near future.

Conclusion

It is evident that no single protective method would be adequate in combating the high G stress in a modern fighter aircraft. Newer methods are being employed and the older ones are being improved upon. Ultimately, it will have to be a combination of techniques that will be employed. The results of a number of studies (3) have shown that combining of protection techniques show an additive effect and any one method in no way interferes or diminishes the effectiveness of the other.

References

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