ACCELERATION STRESS - DESIGN CONSIDERATIONS

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Manoeuvring capabilities of the new generation tactical fighters are substantially greater than those available with the current operational systems. New high thrust-to-weight, lightly loaded designs will be capable of sustained load factor performance well in excess of current designs throughout the flight envelope. Performance inherent in these designs is becoming a challenge to the pilot's ability to use his aeroplane to maximum capability. High magnitude accelerations for prolonged durations with rapid rates of onset and rapidly changing profiles may well take the aircrew to limits beyond their tolerance during air combat manoeuvres (ACM). Reports are already available on G-induced loss of consciousness (G-LOC) in some modern fighter aircraft of the West. This development has refocussed attention on the design and development of protective equipment and methods to safeguard the operator. The prospect of an '8 G man' in control of a '10 G aircraft' has to be faced. It must be remembered that the pilot has not only to survive the high G but has also to perform optimally in that environment.

G Tolerance : Present Status and Future Requirements

The relaxed G tolerance of Indian fighter aircrew population has been found to range from 3.6 to 5.0 G with a mean of 4.3 G at an onset rate of 1.0 G per sec. With the present anti-G system providing additional protection of 1.2 to 1.5 G, a peak value of 6.0 G is well within tolerable limits. Over and above this, 1 G could be gained through a well performed straining manoeuvre for a short duration. Slightly higher peaks for a second or two are tolerated without much detriment. This has been actually ascertained by analysing various G profiles of the present generation aircraft. Higher magnitude acceleration of longer duration with rapid rates of onset expected in the later generation aircraft would be a different cup of tea. A large amount of work has already gone on and is still being pursued to find additional methods of protection of man in the high G environment. The thrust has been towards the design of a high G cockpit and artificial methods of improving G tolerance.

High G Cockpit : Design Considerations

The essential element of a high acceleration cockpit is a reclined or tilt back seat. Maximum load factor tolerances can be realised through application of the load vector transverse to the body. It has been established that the G thresholds increase with the increase in tilt back from the vertical and are directly proportional to the reciprocal of the vertical distance between the eye and the haemodynamic indifference point. The slower rates of onset lead to higher thresholds. There is no difference in the protection offered by anti-G suits at various tilts. Also there is little or no gain in G threshold till a tilt of about 45 deg from vertical is obtained. In order to raise tolerance by 1.0 G from that obtained in a conventional seat, a back angle of 55 to 58 deg would be required, whilst increments of 2.0 G and 3.0 G require back angles of 69 deg and 74 deg respectively. Transferring this information into this high G cockpit would not only mean the design of an optimum reclined seat but also the design of the total cockpit for accommodation, control and display location and the ejection system and clearances in the ejection path. It has been determined that the maximum usable seat back angle (with respect to the aircraft vertical axis) is 65 deg which caters for substantial pilot protection (almost 2.0 G) and allows integration within the cockpit retaining vision, reach and adequate instrument panel space.

The high acceleration cockpit provides a new design consideration in the evolution of helmet display systems. The present systems are designed for a pilot sitting in the upright position where his head is not supported and head movement not restricted. The requirement during high accelerations is supported head mobility. A logical approach would be to add mobility features into the head rest. Additionally, the CRT and projection optics could be carried in the head rest mechanism thus reducing the helmet weight. In other words, it would mean head rest sight and display systems rather than helmet mounted sight and displays.

Positive Pressure Breathing (PPB) in High G Environment

It is well known that increased intrathoracic pressure is directly transmitted to the large blood vessels and raises the mean arterial pressure between the heart and the eyes. If the intrathoracic pressure is raised passively (without straining) through additional pressure in the breathing mixture, a similar rise in the arterial pressure could be achieved to raise G tolerance. Not only is this method less fatiguing than the straining method, but the recovery of the cardiovascular system is much quicker. A number of studies on PPB and G tolerance have been conducted on the centrifuge. Table I shows the increase in peripheral light loss (PLL) thresholds over the unprotected state with various levels of PPB. These figures have been obtained with the subjects wearing counter pressure garments. The best protection is afforded at 45 mm PPB (2.2 G). At higher levels of PPB, G protection comes down because of sheer discomfort and fatigue. A maximum of 30 mm Hg PPB seems most plausible in the

Table I. Influence of Positive Pressure Breathing on +Gz Tolerance

PPB mm Hg	+Gz TOLERANCE Control	With PPB	Increase in G tolerance
15	6.5	6.9	0.4
30	6.3	8.1	1.8
45	6.4	8.6	2.2
60	6.6	8.3	1.7

aircraft, the additional pressure being provided by the oxygen regulator. Up to this level it is not necessary to have counter pressure garments and is more realistic for our kind of environments where the heat load in the cockpit is high. Wearing a pressure garment like the pressure jerkin would only add to the total heat load. However, the protection offered by the same amount of PPB comes down when unprotected by the pressure garment. This of course is being investigated further but the fact remains that PPB could well replace the more tiring M1/L1 manoeuvres. From the design point of view, the requirement is of a G sensitive oxygen regulator which would give the pre-requisite additional pressure automatically after 'cutting in' at a particular level of G.

The Anti-G System and New Design Anti-G Valves

The conventional anti-G system consisting of the anti-G suit and the anti-G valve gives an additional protection of 1.2 to 1.5 G at the normal setting. The protection provided is dependent on two variables - the amount of counter pressure provided and the surface area covered by the bladders. Studies have shown that the surface area covered by existing anti-G suits is near optimum both from the protection as well as comfort point of view. The pressures provided by various anti-G valves vary from 1.0 to 1.5 psi depending on the type and setting. The later generation aircraft have not only higher peak pressures but also higher rates of flow. However, the anti-G valves now used for pressurising the anti-G suits during acceleration operate too slowly for the rapid G onset capability of the modern fighter aircraft. In the present generation anti-G valve, there is an initial lag and a slow phase of pressure build up and the total time for build up of peak pressure is long. This is obviously inadequate in an aircraft where high peak G is reached in 2 sec or less. A new design anti-G valve of the kind developed for the F-15, F-16 series would be more suitable. It has the features of providing a ready pressure or pre-inflation of the anti-G suit as well as higher rates of flow during the actual G manoeuvres. The ready pressure in the suit at 1.0 G (about 0.2 psi) reduces the air volume required to pressurise the suit by 60% during onset of G. This in combination with higher flow rates during G obviates the lag, and peak pressures are able to follow the G rise time. An anti-G valve with pre-inflation and rapid flow characteristics is expected to give protection 1.0 G higher than the conventional one.

A recently developed servo controlled anti-G valve is reported in literature. The servo controlled valve depends for its action upon the amplified voltage difference between the output of an accelerometer, which senses G and a pressure transducer which senses the pressure inflating the bladders. The amplifier gain is adjusted to maintain a maximum loop stability and a minimum pressure lag. The protection claimed by such a valve is about 2.0 G.

Combination of Protective Techniques under High G

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 studied and the older ones are being improved upon. However, it will ultimately be a combination of two or more suitable techniques that will be utilised by the aircrew. A number of studies have shown that a combination of various techniques give protection equal to or a little more than the sum of the individual protection of each technique. There have been no indications in any study that the combined effect has been less than additive or that any one G protective method interferes with or somehow diminishes the effectiveness of another employed at the same time.

Exercise Training

Though this does not strictly fall into the category of design criteria for a modern aircraft, it has a direct bearing on the individuals performing in a high G environment. In fact exercise training has become a firm curriculum in some of the countries already using the high capability aircraft. Though each individual has his own inherent resistance to G loading, a regulated exercise training can improve not only the threshold of G tolerance but also the ability to withstand the stress better without getting fatigued easily. The emphasis is on exercising and building up of the muscles of upper torso, neck and arm rather than endurance or athletic training. Person with a stronger upper body withstands the repeated straining manoeuvres with less fatigue. The denser vascular bed in the musculature in the upper part of the body allows lesser pooling in lower parts and stronger neck muscles give good support to the vasculature in that area.