G-LOC

G-LOC, Could it happen to you?
Source: aeromedical.org
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G-LOC, pronounced 'Gee-Lock' (as in half a horse and something you put a key into), is an abbreviated term meaning G-induced Loss of Consciousness. The letter 'G' representing the acceleration being experienced, for example the 1 G experienced while we stand still on the ground or the 2G of a 60 degree banked turn. The 'G' that we wish to discuss in this article is technically termed '+Gz' and occurs when the body is accelerated in the headwords direction. It is also called 'positive G' and, somewhat confusingly, 'Eyeballs down G' supposedly indicating the direction in which your eyeballs tend to move when experiencing +Gz acceleration. Standing still on the ground causes our body to experience +1 Gz, due to the earth's gravitational attraction, while the steep 60 degrees banked, turn subjects us to +2Gz, and conversely an outside loop may expose us to -3 or -4Gz, being opposite in direction to +Gz.

The human being, essentially a terrestrial animal, is designed to eke out life in a +1 Gz environment punctuated by occasional short bursts of increased +Gz as we run, jump, or fall. We are not engineered to tolerate the prolonged, increased +Gz acceleration of aircraft manoeuvring. To do this we must practice regularly, make strenuous physical effort, and occasionally employ mechanical aids. Even then our tolerance to +Gz is only marginally increased.

The basic mechanism of G-LOC is not too difficult to understand. The brain and eyes require Oxygen and Sugar (Glucose) to function properly, they both have a very small store of sugar and virtually no stored Oxygen. A constant supply of both these nutrients, via the bloodstream, is necessary for normal brain and eye function. Blood is constantly pumped to the head, against gravity, by the heart. This arrangement works well until the body is exposed to increase +Gz which force the blood away from the head, no matter how hard the heart may work. If the +Gz is of sufficient intensity for a long enough time, little or no blood flow reaches the head, the eyes and brain exhaust their limited Sugar and Oxygen supplies and cease to function.

Thus we suffer 'G. Induced Loss of Consciousness'. This is a somewhat simplistic explanation but it wouldn't be fair to inflict a detailed description upon you as you'd require substantial Medical and Physiological understanding to make any sense of it. For example, a more correct Aviation Medical definition of G-LOC is "a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of cerebral blood circulation caused by increased G force".

Historical
G-LOC is not merely a product of our modern age with fighter aircraft manoeuvring at several hundred knots and sustaining up to +12Gz. G-LOC has been with us almost as long as man has been trying anything more adventurous than Straight and Level in his heavier than air flying machines. An article, first published in 1919, by a Dr. Head describes the problem of G-LOC accurately but uses the name 'fainting in the air'. This article documents G-LOC in aircraft such as the Sopwith Camel, Sopwith Triplane, and DeHaviland. Prior to 1920 experiments had been performed in aircraft and it was know that G-LOC "lasted about 20 seconds" and occurred with 4.5-4.6 G was reached.
During the 1920s contestants in the Pulitzer and Schneider trophy races were documented as suffering G-LOC and the closely related phenomena of greyout and blackout (discussed below) during the fast turns required in these events. It was during this period that straining manoeuvres were found to enhance a pilot's G-tolerance.

Prior to, and during the Second World War G-LOC slowly became better recognized within the Aviation community. Efforts were made to gain a greater understanding of the problem and to reduce its incidence and effect upon aircrew. It was during this period that the 'G-Suit', so common in modern military aircraft, was invented. Aircraft seat position, aircrew general health, aircrew experience and currency were also identified as factors influencing the ability to tolerate G. During this period G-LOC was becoming increasingly recognized as a possible cause for a number of fatal aircraft crashes. Extensive research, aimed at detailed investigation of G-LOC, was being carried out in the USA, Britain, and Germany using Human Centrifuges.

After WWII these centrifuge studies continued for several years and then interest seemed to fall off and research into G-LOC remained relatively dormant for about twenty years. Perhaps it was felt that G-suit technology and the anti-G straining manoeuvre were adequate to protect the pilots of the future. Interest in the subject of G-LOC re-emerged in the 1970s as higher performance aircraft continued to evolve. It was almost as if the subject was being reinvented in 1978 when the article "Loss of Consciousness during Air Combat Manoeuvring" was published in the USA. At this time G-LOC was thought only to be a problem with the higher performance aircraft such as the F-15 and F-16 but later an aircrew survey demonstrated that it also occurred in lower performance military aircraft.

The last 15, or so, years have seen a growing interest in the subject of G-LOC and other aircrew problems due to prolonged acceleration. During this period centrifuge studies have expanded our knowledge base on the subject and several new methods of enhancing G-tolerance have been identified. An airman's tolerance to G seems to be improved if he breathes 100% oxygen, if he is 'Pressure Breathing' and if he is aerobically fit. While a reasonable level of aerobic fitness is desirable for effective aircrew performance there is some evidence that those people who are extremely fit, with a low resting pulse, may actually have a slightly reduced G-tolerance.

The studies into G-LOC have, from their beginnings, concentrated on the higher performance aircraft of the times (Today the Sopwith Camel or Triplane may not seem terribly high performance, but in 1916 they were at the fore-front of fighter technology) and has, therefore, tended to be primarily a military concern. G-LOC can, and does, occur in lower performance, propeller driven aircraft in this day and age. In the last twelve months alone there have been two observed cases of G-LOC in RAAF pilots flying CT-4 trainer aircraft, which are propeller driven and limited to operating between +5.5Gz and -1.8Gz.

The CT-4's performance envelope is nothing dramatic and is certainly less than that of many of the civilian utility and aerobatic craft that we might fly. The Drifter 503 (An Ultralight) is rated from +5 to -3Gz while the Cessna 152 'Aerobat' is rated from +6.0 to -3.0Gz, not that I'd like to try either of these at their extremes. The Bellanca 8KCAB 'Decathlon' is rated from +6.0 to -5.0Gz. The Pitts S-2A and S1, although rated from +6.0 to -3.0Gz, commonly operate between +9Gz and -9Gz, and are probably capable of +10Gz to -10Gz without structural failure.
Considering these performance parameters it should be readily apparent to us all that we could easily suffer G-LOC in our aviation pursuits.

What happens?
As a pilot pulls G they will feel their weight increasing as the seat pushes up hard against their bottom. Head and arm movements will feel cumbersome and awkward due to the increased weight.
If the G onset is gradual the next thing noticed may be a dulling of vision which may be more prominent at the periphery of the visual fields, the so-called 'Greyout' phenomenon. Greyout is due to a fall in the amount of blood reaching the eye. The pilot's peripheral vision actually starts to deteriorate as soon as the stick starts to come back towards their lap and by the time they notices any 'tunneling', 75% of the visual field is already gone.
If the G continues to increase 'Blackout' may follow. Blackout is a complete loss of vision due to no blood getting to the eye. The pilot is not unconscious at this time, in fact RAF pilots training for the Schneider trophy in the mid 1920s became quite adept at pulling just enough G to blackout but not lose consciousness, maintaining control of their aircraft by 'feel'.

Should the G continue to increase and the pilot's tolerance be exceeded loss of consciousness will promptly occur. This loss of consciousness may be associated with jerking, 'flail' movements of the head and arms. If the G remains high the pilot will remain unconscious and could, conceivably, suffer brain death.

Usually, however, the G is relaxed upon the commencement of G-LOC. Once the G has returned to +1 Gz the pilot will remain unconscious for a period, usually around 15 seconds, and then begin to revive. During this brief 'wake up' period, usually another 15-30 seconds, there is often extreme confusion. Upon reviving fully the pilot often suffers a complete memory loss of the event. After an episode of G-LOC a variety of psychological responses may occur, including disorientation, unreliability, anxiety, fear, embarrassment and a 'give up' attitude.

A notable variation on the above occurs when the G rate of onset is high (for example +6Gz per second) exceeding the pilot's G tolerance within a second or two. If the G rises quickly and then remains high the pilot will quickly pass from full capability to complete unconsciousness with no warning visual symptoms.
The loss of memory, mentioned above, is particularly concerning as it leaves the pilot totally unaware that they have been unconscious and may provide them with a false perception of how well they can cope with G.

G-Tolerance
Centrifuge and Flying studies have identified man's tolerance to +Gz with reasonable accuracy. Figure 1 is a +Gz v. Time graph demonstrating the tolerance to +Gz of relaxed subjects not using any G-protection device or manoeuvre.
The area above and to the right of the solid black curve represents the +Gz and Time at which unconsciousness (on average) occurs. The area between this curve and the grey curve is the region of visual disturbances (greyout and blackout) without loss of consciousness. Below and to the left of the grey curve is the +Gz/Time zone where no visual symptoms or G-LOC occur in the average, unprotected person.
The line 'C' on figure 1 represents a gradual onset of +Gz at a rate of around 0.5G per second and shows that visual symptoms are likely after about 5 seconds and Loss of
Consciousness about 1 second later at +4Gz. Line D shows a slower rate of +Gz onset, in this case visual symptoms will occur after 16 seconds (+4Gz) and G-LOC will intervene after 22 seconds when the acceleration will be +5Gz. Rapid onset of sustained +Gz, as shown in line B will result in G-LOC after about 4 seconds without any warning visual symptoms. However, very rapid onset +Gz that is not sustained at a high level, line A, may well result in no visual disturbances or G-LOC. This last feature is what saves many of our unlimited aerobatic pilots from suffering G-LOC more often, although they pull substantial G they do so for only very short periods.

Although various studies provide slightly different figures for G-LOC most show that it tends to occur at around +4.5Gz in the unprotected individual, but may occur at anywhere between +2Gz and +6.5Gz. Aircrew have suffered G-LOC at +2 Gz, which is the G-loading during a steep, balanced, 60 degree angle of bank, turn. It is also important to note that although G-LOC is often preceded by visual symptoms this is not always the case.

The duration of a period of G-LOC also varies, after the G returns to +1 Gz, but usually the period of complete incapacitation lasts around 15 seconds and is followed by another 15, or so, seconds of relative incapacitation. Periods of up to 3 minutes incapacitation have been observed.

**Prevention of G-LOC**

The only fool proof way of avoiding G-LOC is to 'Pull No G', though it’s doubtful that anyone who has read this far is at all interested in maintaining straight and level on terra firma.

The next easiest way or reducing your risk of G-LOC is to remain current and practiced at pulling G. After a spell away from flying and G your tolerance will have reduced appreciably as discovered by the RAFF pilot in Reference 8. So if you haven’t flown aero’s for a month or so it would be wiser to spend some time dual or ease into manoeuvres for a few flights before going 'all out'.

As it does with every aspect of aviation your general health plays an important role in your tolerance of +Gz. Any illness even a minor 'cold' or 'Gastro' will reduce your G-tolerance significantly. Adequate rest is essential to maintain a maximal G-tolerance. Similarly any medication has the potential to reduce this tolerance, you should consult your DAME (Designated Aviation Medical Examiner) if you’re taking any medication and flying. Non-illegal drugs such as alcohol and caffeine can also have a detrimental effect of G-tolerance.

Aircraft seat angle can also have a profound effect on the pilot's G-tolerance. The USAF F-16 has it's seat reclined 30 degrees and the Soviet Su-25M 35 degrees each giving about 1G added protection while still allowing good visibility. A seat reclined to about 80 degrees allows a pilot to easily sustain 15G but this is of little practical use as such a position impairs forward, and downwards, visibility.

Anaerobic fitness, especially involving abdominal and biceps muscles, improves G-tolerance. The duration of High G Tolerance can be extended 53% by an aggressive anaerobic weight programme. There is considerable debate, and a lot of ongoing research, into the relative merits of aerobic and anaerobic fitness in the protection against G-LOC. Your DAME should be able to provide further advice on fitness (Anaerobic and Aerobic) training.
There are a number of Anti-G Straining Manoeuvres (AGSM), including the Valsalva, M-1, and L-1 manoeuvres, that can be used to increase your G-tolerance. A properly performed AGSM can enhance a pilot's G-tolerance by around +3Gz. Most of the AGSMs involve isometric muscle contraction and regulated breathing routines. Description of each manoeuvre is too involved for this article, consult your DAME or an experienced colleague for instruction. Correct instruction, training, and lots of practice are essential for the correct performance of an AGSM. An incorrectly performed AGSM is useless.

G-suits are almost solely used by military pilots and enhance G-tolerance by 1.5 - 2.0G. A G-suit is essentially a series of balloons within a pair of trousers. When the G forces increase a valve is activated and pumps these balloons full of air. The pressure of the filled balloons, squeezing the legs and abdomen, reduces the amount of blood that is forced away from the head into the legs by the G hence improving G-tolerance. G-suits are uncomfortable, hot, and ugly but a necessary component of the fighter pilot's wardrobe.

There is apparently evidence emerging that the breathing of 100% Oxygen affords some minimal G-protection. It seems reasonable that by increasing the amount of Oxygen stored in your body's tissues you would increase your time of consciousness under G but we've been unable to find any research articles confirming this. Pressure Breathing is another method of enhancing G-tolerance being assessed by Air Forces around the world. Breathing Oxygen under pressure increases the pressure within your chest and literally pushes more blood up towards your head. Pressure breathing, like the G-suit, is unlikely to be routinely used, in the foreseeable future, to G-protect civilian aviators.

**Who gets G-LOC?**

Simple! Anyone who pulls G could suffer G-LOC. Anyone who gets G-LOC loses control of their aircraft. Anyone who loses control of their aircraft could crash. Crashing aircraft is a health hazard. Although most of the research into G-LOC has had a military bias the problem is most certainly not isolated to high performance military jets. The G pulled in a simple Cessna 152 aerobat during initial aerobatic training is sufficient to induce G-LOC. There is even potential for G-LOC in Ultralight aircraft.

You are not immune! No-one is too good or too experienced to suffer G-LOC! Even unlimited aerobatic competition pilots who've been "doing' it for years" are not immune to G-LOC, the fact that their G is usually of quite short duration may offer them some protection but never immunity. G-LOC is not a sign of weakness or lack of 'The Right Stuff', it's a perfectly normal reaction to the abnormal environment of flight.

**What can I do?**

You've already taken the single most important step in preventing G-LOC, you've increased your awareness of the problem. If you are aware of the possibilities of G-LOC in flight you will be more able to avoid it's clutches. Aim to understand the problem and think about it every time you're flying G.

Maintain good physical and mental health. Flying is no fun when you're in anything but tip-top condition, in fact it can be downright dangerous. If you have any doubts consult your DAME for advice. Don't take drugs, any drugs, without clearing they with your DAME.
Stay reasonably fit. Don’t fly when you’re tired.
Maintain a good currency with your flying. A long break from pulling G reduces your tolerance significantly. If you haven’t pulled G for a while ease yourself back into it. Keep your harness tight. The support of a wide tight abdominal strap may offer a small amount of G-protection, via a mechanism similar to that of a G-suit. This factor was brought to our attention during discussion with an Australian Aerobatic Club competition pilot and although we have no documentary evidence to support it, it does not seem an unreasonable practice.

If your flying involves regular G-loadings or high-G, practice and perfect one of the Anti-G Straining Manoeuvres. A good AGSM may mean the difference between G-LOC and successfully completing that ‘vertical 8’ you’ve been working one.

Good health, a healthy awareness, currency, and a well practiced AGSM should provide adequate G-protection for your aerobatic flying. If you’re thinking of buying an F/A-18 or F-16 we suggest that you also get a serviceable G-suit and learn to pressure breathe. Whenever you have any doubts consult your DAME or talk to sensible, more experienced colleagues.

Other G-related problems
'Greyout’ is caused by +Gz and involves a reduction in your vision, especially around the edges. The world really does look as if you're looking at it from the inside of a dark tunnel. It happens because there is insufficient blood reaching the eye due to the G-loading. If you experience greyout ease off, you’re not far from G-LOC. Prevention is the same as for G-LOC.

'Blackout’ is the next step on from greyout when your eyes cease to function altogether. You remain conscious but can only see blackness. Blackout occurs when no blood reaches the eyes and they exhaust their limited store of sugar and Oxygen. Blackout means that you are very close to G-LOC and should reduce the G-loading. Prevention is the same as for G-LOC.

'Redout’ is caused by excessive -Gz and can occur during manoeuvres such as outside loops. When you Redout you lose your vision and can only see red. Some Medical Books state that redout is due to excess blood rushing to your head and eyes, while Neil Williams believes it is due to your lower eyelid being pulled up to cover your eyes by the negative G loading. Excessive negative G also causes discomfort of the face and eyes as they become engorged by blood and body fluid forced into the head by the G.

Bruising can be caused by excessive positive or negative G. The blood is pushed into the vessels with so much force that the vessel walls break. This often occurs on the forehead and in the whites of the eyes in people not used to pulling negative G and can also affect the legs and buttocks when +Gz is pulled. Also tight harnesses can cause bruising during a grueling aerobatic session. Even the experts are not immune a evidenced by the bruising of the Russian pilot after he flew his Su-26M to clinch the World Champion Title in 1986 (and Canada, 1988, from memory). He did, apparently, pull from +12Gz to -12Gz.
Conclusion
G-Induced Loss of Consciousness can, and does, occur in propeller driven aircraft. G-Induced Loss of Consciousness could happen to any of us if we’re not careful.

The loss of memory that often occurs during G-LOC is particularly concerning as it leaves the pilot totally unaware that they have been unconscious and may provide them with a false perception of how well they can cope with G.

Awareness about G-LOC is, probably, the single most important factor in it’s avoidance. Good health, fitness, currency, experience, and a well practiced Anti-G Straining Manoeuvre will all help increase a pilot's G-tolerance.

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