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TITLE

A NEW UNDERSTANDING OF THE EFFECTS OF +G

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A New Understanding of the Effects of +G

ABSTRACT

G-induced loss of consciousness (G-LOC) remains a killer in aviation. A vector quantity usually expressed as "G," acceleration stress is experienced by aircraft occupants whenever the aircraft changes speed or direction. Any increase in the magnitude of this vector is termed increased positive Gz (+Gz). Under increased +Gz, blood pressure at head level can decrease to the point that blood flow in the brain stops. When blood flow stops, brain function is possible for only several seconds before G-LOC occurs. When G-LOC occurs to a pilot in control of an aircraft, the result is often catastrophic. A significant amount of flying involves +Gz following relative -Gz. Reduced +Gz tolerance following relative -Gz has been demonstrated. A loss of +Gz tolerance was termed the "push-pull effect." This effect has been found causal in at least two aircraft accidents. The role of +Gz time-history in determining +G tolerance should be understood by all pilots and those involved in design. Protective systems and strategies must be designed to account for the preceding baseline, particularly in an era of advanced technolgy aircraft designed to perform complex acceleration profiles. Through education and technology development, human and aircraft losses due to G-LOC can be prevented.

RÉSUMÉ

La perte de conscience engendrée par les forces G (G-LOC) demeure toujours un élément meurtrier en aviation. Une quantité vectorielle que l'on exprime en général par le vocable "G", le stress relié à l'accélération est subi par les occupants d'un aéronef chaque fois que celui-ci change de vitesse ou de cap. Toute augmentation de l'ordre de grandeur de ce vecteur se nomme augmentation de Gz positif (+Gz). Sous +Gz accru, la pression sanguine vers la tête peut diminuer à tel point que le sang ne puisse plus se rendre au cerveau. Si le sang arrête de circuler, le cerveau fonctionne seulement quelques secondes avant la perte de conscience (G-LOC). Si c'est le cas pour un pilote d'aéronef, il résulte souvent une catastrophe. Un pilote qui vole souvent peut subir le +Gz à la suite d'un -Gz relatif.

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ABOUT "G"

G-induced loss of consciousness (G-LOC) remains a killer in aviation. Despite protective strategies that include advanced g-suits and the anti-g strain maneuvre (AGSM), the military still reports aviation accidents that result from G-LOC. While the incidence of G-LOC in civil aviation is unknown, aerobatic pilots experience the effects of G, and accidents involving G-LOC are occasionally reported. It is likely that incidents of G-LOC are under-reported due to difficulty obtaining proof following fatal accidents.

Pilots are subjected to many stresses in flight, among them acceleration stress. A vector quantity usually expressed as "G" (1G = acceleration in ft/s^2 ÷ 32.2 ft/s^2), acceleration stress is experienced by aircraft occupants whenever the aircraft changes speed or direction. While G can occur in any direction, the most physiologically significant G occurs when the aircraft changes direction in pitch, directing G along the vertical axis of a seated occupant. This form of G is termed Gz. Humans on Earth experience +1 Gz when standing or sitting vertically at rest. Any increase in the magnitude of this vector is termed increased positive Gz (+Gz). When the Gz-vector is reversed from +Gz — for example, during sustained inverted flight — negative Gz occurs (-Gz). Zero G, which occurs in space, can also occur in flight, and is the absence of acceleration, including the effect of gravity. However, zero Gz — that is, the absence of G in the vertical direction — occurs while lying horizontal to the Earth's surface, thereby removing any component of gravity from the vertical axis. A new term, "relative -Gz" refers to Gz that is relatively negative to gravity (+1 Gz).

PHYSIOLOGY OF GZ

When exposed to increased +Gz, the weight of all human tissues increases in proportion to the increased +Gz. An accumulation of body fluids occurs in the lower, distensible areas of the body due to the increased weight of the fluid column. Deprived of blood volume in the upper body as a result of lower body accumulation of fluids, decreased blood pressure is experienced at head level. As +Gz continues to increase, blood pressure at head level can decrease to the point that blood flow in the brain stops. When blood flow stops, brain function is possible for only several seconds before G-LOC occurs. The heart and vascular system will attempt to increase blood flow in the brain through

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Il a été démontré qu'il y avait une tolérance réduite au +Gz à la suite d'un -Gz relatif. Une perte de tolérance à +Gz a été désignée "effet symétrique" (push-pull). On a conclu que cet effet était la cause d'au moins deux accidents d'aéronefs. Le rôle de la relation durée-antécédents +Gz dans le calcul de la tolérance au +Gz doit être compris par tous les pilotes et les concepteurs d'aéronefs. Il faut donc concevoir des systèmes et stratégies de protection afin de tenir compte du minimum ci-haut, surtout dans notre ère où il existe des aéronefs à technologie de pointe conçus pour exécuter des profils d'accélération très complexes. On peut donc prévenir les pertes de personnes et d'aéronefs dues aux forces G-LOC par le perfectionnement de l'enseignement et de la technologie.

increased heart rate, increased heart contraction, and constriction of vessels. However, these responses can be overwhelmed. Blood flow then stops at head level, brain function stops, and G-LOC occurs. When G-LOC occurs to a pilot in control of an aircraft, the result is often catastrophic.

RESEARCH

G-LOC was first identified as a problem during the First World War when pilots reported "fainting in the air" during recovery from steep dives. Early flight-based research began in the 1920s, but significant understanding did not occur until laboratory work began in the mid-1930s. The primary research tool used for these early studies was the human centrifuge. Initially very crude in design and construction, these devices soon evolved into powerful, high-velocity devices capable of exploring the physiological effects of +Gz. Subsequent research during the Second World War defined the field of acceleration physiology and led to the design and development of anti-G-suits. An effective countermeasure, the basic G-suit design has remained unchanged until recently. The Franks Mark VI G-suit produced in 1944 is shown in **Figure 1a**. A current G-suit worn by operational fighter pilots is shown in **Figure 1b**. A more advanced G-suit is now in flight test evaluation.

Pilots are taught that +Gz tolerance depends on:

- magnitude of +Gz;
- period of time exposed to high +Gz; and
- rate of onset to high +Gz.

The science that led to these lessons on +Gz evolved during approximately 10,000 studies conducted on human centrifuges. -Gz tolerance has been considered in about 30 studies. Missing until recently was consideration of both factors together — that is, +Gz tolerance when exposure to +Gz follows relative -Gz.

A significant amount of flying involves +Gz following relative -Gz. Aerobatic flying can result in transitions from -Gz to +Gz. Turbulence, experienced to some degree on almost

Figure 1a.
Franks Mark VI G-suit (1944).

every flight, can cause various magnitudes of relative -Gz for up to 0.5 seconds or longer, followed usually by brief exposures to subsequent +Gz. During routine training aerobatics, inverted flight results in -1 Gz for up to 15 seconds in most aircraft, followed by at least +1 Gz on recovery. Maneuvres such as the split-S usually start with 0 Gz, or fractional -Gz or +Gz during the roll-in, followed by up to +3 to +4 Gz during recovery. In the military, air combat maneuvering, test flying, terrain-following flight, and emergency evasion can produce extreme swings in -Gz to +Gz accelerations.

THE "PUSH-PULL EFFECT"

The potential for reduced +Gz following relative -Gz led to research. The results of early work have now been reported, and led to a new understanding of the role of Gz time-history as a determinant of +Gz tolerance. In a study conducted at the U.S. Navy laboratory in Pensacola,

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Figure 1b.
Current Canadian Forces G-suit worn by CF-18 pilots.

Florida, it was demonstrated that +Gz-tolerance is significantly reduced by preceding zero- or -Gz, and that this reduced tolerance is more profound with increased -Gz and increased time of exposure to -Gz. The **average** +Gz tolerance loss among the 12 volunteers was 1.3 G in the worst condition (going from -2 to +2.25 Gz). However, some individuals did far worse. When going from -1 Gz to +2.25 Gz, one subject lost nearly 4 G of tolerance. This loss of +Gz tolerance due to preceding relative -Gz was termed the "push-pull effect."[1,2]

Has the push-pull effect caused aircraft accidents? Almost certainly, although direct evidence is difficult to obtain. U.S. civil aviation, through the investigative functions of the FAA, has implicated push-pull type maneuvres in some accidents. The push-pull effect has recently been implicated as the cause of two military fighter accidents. Several other military accidents appear to have involved this effect. There is speculation that the push-pull effect may be a hazard in high-speed, nap-of-the-earth attack helicopter flights or low-level weapons deliveries. Many mishaps in this mission environment remain unexplained.

NEW UNDERSTANDING

The role of +Gz time-history in determining +G tolerance should be understood by all pilots and those involved in design. What happens physiologically? Under relative -Gz, the heart rate slows quickly and the vessels in the body dilate in an attempt to lower the increased blood pressure in the head. When subsequent +Gz occurs, the heart rate and dilated vessels are comparatively slow to recover. As +Gz increases, the diminished blood pressure at head level is not immediately countered by the heart and vessels, and G-LOC can result much sooner. To the earlier three determinants of +Gz tolerance taught to pilots should now be added:

- starting Gz baseline, or time-history.

CONCLUSIONS

Protective systems and strategies must be designed to account for the preceding baseline, particularly in an era of advanced technolgy aircraft designed to perform complex acceleration profiles. One approach in development involves the design of a flexible pneumatic pressure schedule for G-suits that accounts for increased periods of susceptibility based on a time-history analysis. Another is an educational training video that is attempting to impart this new understanding of acceleration to all military aircrew.* Through education and technology development, human and aircraft losses due to G-LOC can be prevented.

REFERENCES

[1]Banks, R.D., Grisset, J.D., Turnipseed, G.T., Saunders, P.L., and Rupert, A.H. (1994). "The Push-Pull Effect," *Aviat. Space Environ. Med.*, 65:699–704.

[2]Banks, R.D., Grisset, J.D., Saunders, P.L., and Mateczun, A.J. (1995). "The Effects of Varying Time Exposure to -Gz on Subsequent Decreased +Gz Physiological Tolerance (Push-Pull Effect)," *Aviat. Space Environ. Med.*, 66:723–7.

*The Canadian Forces Directorate of Flight Safety has created a training video for pilots called *The Push-Pull Effect.* Copies may be obtained through Capt. Jim Hatton, Director of Flight Safety, Air Command Headquarters, Westwin, Manitoba R3J OTO.

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