Review Article

Push-pull effect

SqnLdrPKTyagi*

ABSTRACT

The Push - Pull effect was almost unknown until the early 90s, but is today considered common during air combat manoeuvres (ACM) and ground attacks. It has already been implicated in Canadian, US Navy and US Air Force aircraft accidents. Research has revealed that even a short exposure to - Gz can significantly reduce human +Gz tolerance. The effect may contribute to Almost Loss of Consciousness (A-LOC) and G-induced loss of consciousness (G-LOC). The suggested mechanism is that the effect results in an overall reduction in bar receptor sensitivity or cardiovascular reactivity, which results in a fall in eye level BP resulting in lower +Gz tolerance.

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Acceleration 'and its effects on the body have concerned the flying community since world war I [1]. Push-pull effect (PPE) is one such entity, which has generated great interest and concern among the aviation medicine community since the last decade. Although several workers had suggested that tolerance to +Gz is reduced when preceded by 0 Gz or -Gz [2, 3, 4, 5], the term "Push-pull effect" was coined by Banks et all (1994) to describe this reduced +Gz tolerance resulting from preceding 0 Gz or -Gz stress [6, 7, 8]. Pilots of combat aircraft have perished because of this effect [9, 10]. The push-pull effect has been implicated in Canadian, US Navy and US Air Force aircraft mishaps [6, 7, 11, 12, and 13]. Some of these occurred on the weapons range during ground attacks. These mishaps have been linked to pilot physiology. Centrifuge studies have found that the stimulus of less than +1 Gz might result in a reduced +Gz tolerance, which confirmed the push-pull effect [8, 14]. PPE has not yet been investigated in India.

Emerging concept

Human subjects who participate in +Gz research in centrifuge are normally exposed to initial baseline acceleration of +lGz [6]. Flying is not limited in this manner and pilots occasionally experience +Gz, OGz or even -Gz. Aircraft occupants are frequently exposed to short duration accelerations other than +1 Gz [3]. Air turbulence, for example exposes occupants to short (up to 0.5s) exposures to ± Gz [27]. Just as coordinated

Graded Specialist, Aerospace Medicine,

I AM, IAF, Vimanapura, Bangalore - 560 017

(a) +Gz tolerance is significantly reduced in relaxed subjects when preceded by 0 Gz or negative Gz.

(b) The degree of +Gz tolerance reduction depends on the magnitude and time of the preceding negative Gz exposure.

(c) Some individuals are more susceptible to "push-pull effect' than others. Such military aircrews run an increasing risk of sudden incapacitation.

Studies have demonstrated that tolerance to +Gz decreases more when preceding Gz is relatively more negative [6, 7,17,28] and increases with increased time of exposure to preceding relative -Gz [8, 17, 28].

Given the much higher + Gz capabilities and acceleration-onset rates of some modern military aircraft, the physiological demands imposed by these aircraft and individual susceptibility, make it probable, that some military aircrew risk incapacitation due to push-pull effect. Further operational research should be aimed at assessing the risks to aircrew, understanding the relevant physiology, and developing appropriate protective strategies.

Present thinking on in-flight push-pull effect

The Push-Pull effect, almost unknown until the early [v]90s, is today considered common during air combat manoeuvres (ACM) [18] and ground attacks [20]. For instance:-

During 1 Vs 1 sortie, the aviators in high eases forward a bit to keep the "foe[1] in sight rolls over and pulls soon after zero or negative G i.e. pulls after push.

Aerobatic pilots know that pulling G after being inverted is much tougher than starting from upright flight. "Puts your light out right in the middle of the show", they did say.

Geoffrey & McCarthy (1996) [18] conducted an in flight experiment: Their relaxed G tolerance with no previous negative G was 4.85. Tolerance declined after brief, or 10 second exposures to 0 G, -1 G, & -3 G. Some of these subjects were close to G-LOC at as little as +2.8G after 10s of -3 G. Suppose one is to go from -3G to 9G (the worst possible scenario in a fighter aircraft), one probably cannot strain enough to stay awake, especially if any other factors known to reduce G tolerance (body heat or fatigue) are present [18].

In another study Geoffrey & McCarthy (1996) subjected RAF fast-jet test pilots to sorties (-3G to +6G) in an old jet fighter (57 Chevy). One unexpected qualitative remark was:-

"These 45 min trips were the most tiring things I have ever done in over 30 years of flying fighters. Seems that multiple shifts of blood north and south provoke an extreme form of fatigue".

In a study carried out in US Air Force F-15 and F-16 pilots during air combat training missions (specifically basic fighter manoeuvres and air combat manoeuvres), the HUD video tapes revealed that Push Pull Effect Manoeuveres (PPEM) were noticed in 32% of the missions [12].

Some authors consider that the need for <lGz to >lGz (push-pull effect) is limited to aircraft with low thrust to weight ratios [20]. These aircraft include training aircraft like T-38, A-7, and A-10. Mc Carthy [7] in a flight experiment conducted on the RAF Hunter T-7 aircraft used time stresses of 0G, -lGz & -3Gz for 10s. Immediately after each negative G manoeuvre, +Gz tolerance at +1G / s, as PLL was recorded verbally. They found that :-

(a) Statistically significant decrements in +Gz tolerance occurred in all pilots.

(b) Decrements increased with both amplitude and time of exposure to zero or negative G.

(c) Relaxed G tolerance with no proceeding -Gz stress, declined significantly after this exposure.

The effect may contribute to Almost loss of Consciousness (A-LOC). McGowan (1997) has reported that aviators more frequently experience "Almost loss of consciousness" or A-LOC, rather than G-LOC [21]. Aviators more frequently report brief and variable episodes of confusion, amnesia, apathy, loss of situational awareness, or weakness or twitching of hands during actual air combat manoeuvres characterized by rapid G-transients, relatively low G-levels of short durations, and less than 1G flight.

Mechanism

Push-pull effect results in an overall reduction in bar receptor sensitivity or cardiovascular reactivity [22], which results in a fall in eye level BP resulting in lower +Gz tolerance. Goodman and colleagues successfully used a tilt table to simulate the PPE [7]. Their findings and others [6, 20] showed that during head down tilt (HDT) less than +lGz causes head-ward shift of blood which leads to reflexogenic bradycardia & vasodilatation in response to increased BP at the carotid sinus. +Gz pal oat (head up tilt) causes foot ward shift of blood and retarded cardiovascular response leading to decrease eye level blood pressure as there was a delay in sympathic drive during +Gz following -Gz. This may be one of the mechanisms of PPE.

In 1995. Doe and colleagues [26] in their experiment on dogs demonstrated that parasympathetically mediated vasodilatation is a more rapid process than sympathetically mediated vasoconstriction. This difference in parasympathetic-*;. —pr.re::; response times could be true for humans too and this further explains the occurrence of push pull effect

Recently [23] Zhange et al used head down tilt 90 degrees, followed by bead up tilt (HUP) 90 degrees and measured cerebral blood flow through left middle cerebral artery using a transcranial Doppler, a device used commonly in acceleration research [24]. During their simulation of PPE, the results indicate that during HDT cerebral vasoconstriction occurs in response to the elevated perfusion pressure to maintain cerebral blood flow, and during subsequent HUP the increased resistance of the cerebral blood vessel remained at the higher level for about 20 s, and may have worsened the cerebral perfusion from exposure to +Gz. This and other experiments [6,7] suggest that reflexogenic peripheral vasodilatation during -Gz might occur in response to elevated pressure on the carotid sinus, and auto regulated cerebral vasoconstriction might occur in response to increased cerebral perfusion pressure changes. Then, there is a delay in sympathetic drive and recovery of the cerebral vessel states during subsequent -i-Gz. The blood pressure and heart rate reduce very quickly under the influence of negative Gz but recover very slowly when positive Gz is rapidly applied [15] thus both peripheral vasodilatation and cerebral vasoconstriction might contribute to the decreased G tolerance to PPE.

Studies in three axis Dynamic Environment Simulator (DES) at Wright Patterson base revealed that progressive nausea resulted in autonomic stimulation that reduced +Gz tolerance [22]. However, even in absence of nausea, decrease in +Gz tolerance occurred probably because of push pull effect.

Prevention

How to prevent push-pull effect? Combat edge (CE) / Advance Technology Anti-G Suit (ATAGS) will not be a cure. CE+ATAGs can increase relaxed G tolerance of a pilot to over 8G. But if the pilot has gone to less than 1G for even a few seconds a near maximal strain will still be necessary at as little as 4-5 G [18,4]. And one cannot use vision loss as a cue. Negative and positive G transitions are more demanding because of the transient effects of cardiovascular responses. Therefore, timing is a critical element in the effective use of protective manoeuvres under pull-push conditions [25].

Aero medical / Operational significance

Push-pull effect is a potent threat to flight safety. It can significantly lower Gz tolerance & contribute to A-LOC & G-LOC (sudden in-flight incapacitation), leading to aircraft mishaps.

The effect can compromise mission effectiveness especially weapons delivery during ground attacks.

Repeated -Gz and +GZ transients can cause fatigue, a potent threat to flight safety.

The effect imposes additional physical work on the pilot. If the pilot has gone to less than 1G for even a few seconds, a near maximal strain will be necessary at as little as 4-5 G. If a pilot has to go from 3G to 9G (the worst possible scenario in a fighter aircraft), he may not be able to maintain consciousness even with maximal strain.

In-flight studies have shown that a proper anti-G straining manoeuvre and / or G-suit inflation only partially counters PPE [28]. The timing of protective manoeuvres are critical to effectively counter push-pull effect, therefore, need for better training of aircrew in AGSM.

Limitation of centrifuges for simulating push-pull effect : The existing centrifuges can easily simulate +G. Some have yaw, pitch, & roll capability, but most centrifuges cannot simulate more than - 1.8G. To simulate push-pull effect a multi-axial dynamic environment simulator (DES) is needed.

Some individuals are more susceptible to PPE than others [6] which means that a susceptible pilot has greater risk of incapacitation from the effect.

Conclusion

PPE has important implications for flight safety. The problem of push-pull effect on one hand and the constantly increasing G capability of future generation high performance fighters on the other, has further complicated the Gz research. Fatal air crashes have been attributed to PPE. Further research is required to be carried out in a modern centrifuge which can simulate all three axes. Designing adequate protection for pilots will require understanding the mechanisms of PPE [27].

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