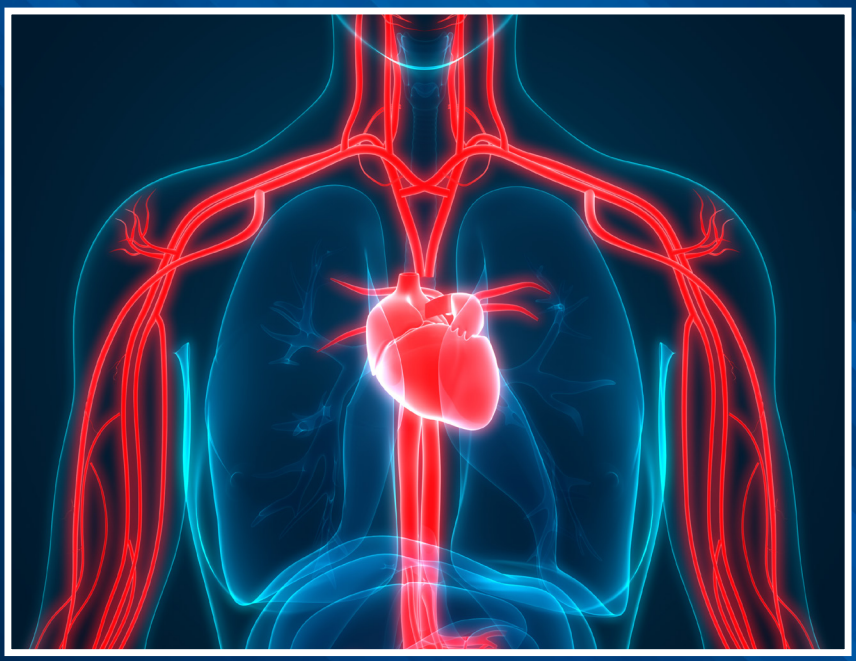
Federal Aviation Administration

Acceleration in Aviation: G-Force



Acceleration in Aviation: G-Force

Human beings are adapted to live and survive within the ever-present, accelerative force of gravity. While on earth, this is a constant, and we live and function with it from the day we are born until the day we die. As an infant learning to walk, we learn very quickly that a misstep will ultimately lead to a painful gravity-induced incident with the ground that we call "a fall."

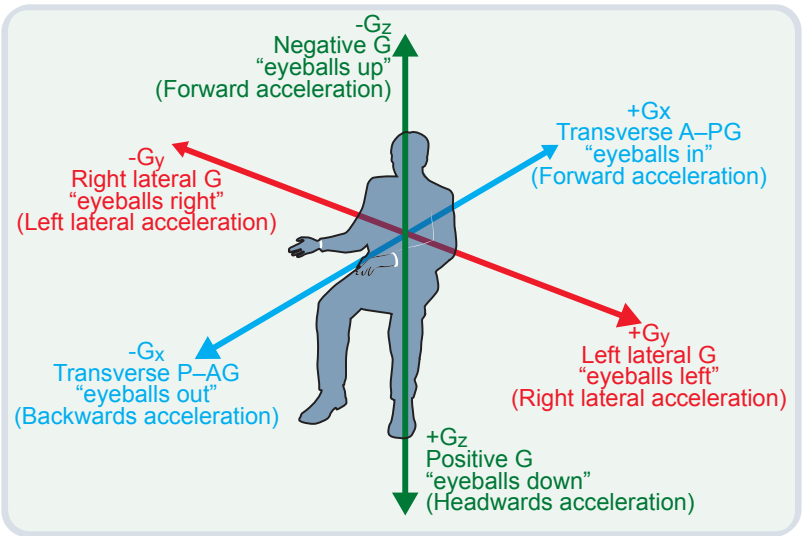
As we develop and start to solve problems, we learn that a cookie jar falling off the counter will accelerate all the way to floor with shattering results. Many hours of our youth are spent determining the results of gravity on spherical objects of various shapes and sizes to our advantage in competition. We became accustomed to gravity at the standard 1 "G-force."

When we pilot an aircraft, all that we have learned about gravity and have become comfortable with suddenly changes. Flight, in its purest definition, is overcoming gravity to ascend through the air. Just as when we were learning to walk, a primary goal of every flight should be to avoid painful, gravity-induced incidents with the ground. These encounters are called aircraft accidents and mishaps, and they can be destructive, even fatal.

What Goes Up Must Come Down

The force of gravity on earth causes a constant acceleration of 32 feet-per-second squared. An object in freefall will accelerate at an ever-increasing speed toward earth until it impacts the earth or reaches terminal velocity, the point at which the force of aerodynamic drag acting on the object overcomes the force of acceleration induced by gravity.

Acceleration is described in units of the force called "Gs." A pilot in a steep turn may experience forces of acceleration equivalent to many times the force of gravity. This is especially true in military fighter jets and high-performance, aerobatic aircraft where the acceleration forces may be as high as 9 Gs. Air race pilots in a tight pylon turn also experience high G-forces, but the important thing to remember is that any aircraft operated in a maximum-performance profile will subject the pilot to acceleration that is greater than the 1 G acceleration encountered on the ground. Pilots need to understand this in to successfully master flying.



Adapted from Ernsting J, Nicolson AN, and Rainford DJ. Aviation Medicine, (3rd ed) Butterworth–Heinemann, Oxford, 1999.

Types of Acceleration

There are three types of acceleration. These types are Linear, Radial, and Angular Acceleration.

Linear Acceleration, reflects a change of speed in a straight line. This type of acceleration occurs during take-off, landing, or in level flight when a throttle setting i s changed.

Radial Acceleration, is the result of a change in direction such as when a pilot performs a sharp turn, pushes over into a dive, or pulls out of a dive.

Angular Acceleration, results from a simultaneous change in both speed and direction, which happens in spins and climbing turns.

G Forces

During flight, a pilot may experience a combination of these accelerations as a result of input to the flight controls. These accelerations induce G-forces on the body that may be described as Gx, Gy, and Gz.

Gx is described as force acting on the body from chest to back; +Gx is experienced, for example, during the take-off roll as the throttle is advanced. This is the force that pushes the pilot back into the seat as the aircraft accelerates.

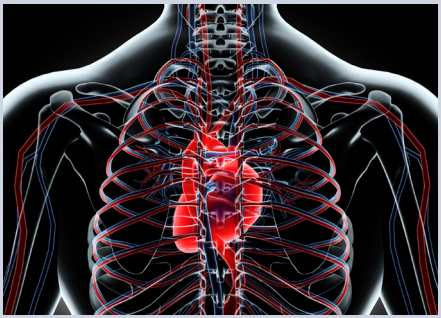
-Gx is described as force from back to chest, and it is encountered during landing as the throttle is closed. This force pushes the pilot forward into the shoulder strap. Naval pilots flying from aircraft carriers feel the extremes of this type of G force. During a catapult launch, the aircraft accelerates to 160-plus mph in just under two seconds. During landing, the aircraft will decelerate to a complete stop in just a few feet. Carrier pilots have adapted and successfully functioned with these extreme Gs for decades.

Gy is a lateral force that acts from shoulder to shoulder, and it is encountered during aileron rolls. Aerobatic pilots routinely encounter this type of G force and can still safely and precisely maneuver their aircraft.

Gz is a gravitational force that is applied to the vertical axis of the body. If it is experienced from head to foot, it is termed (positive) +Gz. This happens when a pilot pulls out of a dive or pulls into an inside loop. -Gz (negative) travels from foot to head, and it is experienced when a pilot pushes over into a dive.

Physiological Effects of High G Forces

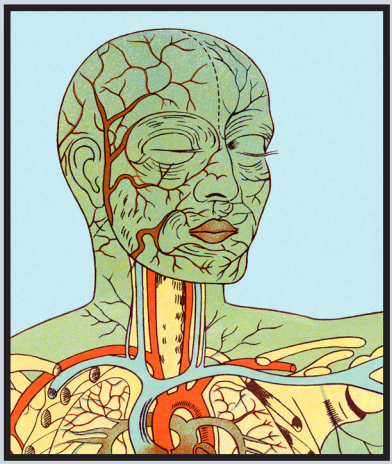
Human beings are adapted for life at 1 G on the surface of the earth. In the aviation environment, any maneuver has the potential to expose the human body to more than 1+ Gz of acceleration force. This can be particularly hazardous for pilots in the Gz axis. This is a G force that acts from head to toe in the case of +Gz and from toe to head in the case of -Gz. As an aircraft enters into a high-speed, coordinated turn or begins the pullout from a steep dive, the pilot experiences +Gz. The heart and cardiovascular system must respond quickly to G acceleration to keep blood flowing to the brain and maintain consciousness. Physiological response to +Gz causes the heart to beat harder and faster with an increased vascular tone to keep the blood flowing “northward” toward the head.



If the physiologic response of the heart and vascular system does not keep pace with the rapid onset of the G forces, pilot performance will be degraded to the point where unconsciousness and inability to pilot the aircraft may ensue.

One of the first indications of impending disaster may be a progressive loss of vision as the aircraft enters the maneuver. The eyes are extremely sensitive to low blood flow, and if the vascular system cannot keep up with the onset of Gs, the retina will not be supplied with adequate blood. As arterial pressure in the eye falls below that needed for the retina, the pilot may notice a loss of peripheral vision (tunnel vision), which may then be followed by progressive degradation to a smaller visual field (gun barrel vision), which in turn may be quickly followed by Gray Out and Blackout of the visual fields. If the rapid onset of G forces continues, the end result may be G-induced loss of consciousness (GLOC). In this condition, unless the aircraft has sufficient altitude for the pilot to back off the Gs and recover vision and/or consciousness, the result can be tragic. This has been the cause of far too many military and civilian aviation fatalities.

The symptoms that result from high G exposure are dependent on the rate of onset of the acceleration. When the onset is gradual (about 0.1 G per sec.), visual symptoms precede GLOC. If the onset is rapid (1 G per second or more), GLOC can occur without visual warning.



While the effects of +Gz can be profound, the human body is even less well equipped to handle -Gz, which is described as a foot-to-head force and is encountered when a pilot pushes over into a dive or enters an outside loop. Under -Gz, the blood is prevented from flowing back down the jugular veins into the heart, but the arterial blood flow to the head is enhanced. Once again, the retina of the eye is extremely sensitive, and the visual effect is a loss of vision due to “Red Out.” If the pilot does not back off the control pressure, loss of consciousness will ensue in short order because the blood does not flow through the brain. To survive in an aviation environment, pilots must respect the laws of acceleration.

OK….What Does This Mean to Me?

Any aircraft, civilian or military, can expose the pilot, crew, and passengers to forces in excess of 1 G. During steep turns and unusual attitude recovery, civil aviation pilots can experience high G forces that may take them by surprise unless they are prepared. Subsequently, all aviators need to understand what makes their body more resistant to the effects of G acceleration. Conversely, aviators need to understand those conditions that will make their body more susceptible to the effects of G forces. The bottom line is that G tolerance for each individual aviator

may fluctuate from day to day, and this can lead to disastrous consequences in flight. This is one of the reasons that military pilots do a "G warm-up" maneuver prior to flying high-performance aircraft, it allows them to assess their own body and how well they will be able to tolerate the high -G environment.

The Bad Things

G tolerance is degraded as a result of dehydration, fatigue, hunger, and medications, which are often associated with a social event. With the "Big Four" above, the aviator may experience severe symptoms of G exposure at much less than the customary level. Lack of physical conditioning and a sedentary lifestyle can also degrade G tolerance and increase the aviator's susceptibility. Also, once again, smoking and flying do not mix. Individuals who smoke have diminished performance at high altitude and high-G environments. Flying is difficult, do not make it harder by needlessly abusing your body.

The Good Things

Most civilian aircraft are not equipped to handle G-protective clothing, a "G suit." However, there are other things that can be done to enhance aviator performance in the high-G environment. A well-rested, hydrated, and fit aviator will physically be able to withstand higher G forces. When an aviator is well hydrated, there is more circulating volume in the blood stream, and it is easier for the heart to keep the brain perfused with oxygenated blood.

A regular program of conditioning that includes a mix of aerobic exercise coupled with resistance weight training will increase an aviator's resistance to the effects of Gs. (All exercise programs should be physician-approved prior to the initiation of training.) Training that is only aerobic in nature (jogging and swimming, for example) may lower the aviator's heart rate to the point where is does not accelerate fast enough to compensate for the effects of Gs. The combination of aerobic and resistance weight training enhances the response to G forces and adds a layer of protection that is not present in aerobic conditioning alone.

The Anti-G Straining Maneuver

Another technique for dealing with G forces is the anti -G straining maneuver. This is a physical technique where the aviator pushes air out of the lungs against a closed glottis, while simultaneously contracting the muscles in the calves, thighs, and shoulders. This resistance inhibits the blood from flowing away from the brain, and it simultaneously increases the pressure in the carotid arteries. This maneuver is practiced by military pilots, and it can increase G-tolerance. To avoid injury, however, it should not be attempted at 1 G with 100% effort.

Respect

Aviators need to respect G acceleration just as they respect other aspects of flight. Proper flight planning will take a number of things into account, such as weather, fuel, distance, and time. A smart aviator will also include consideration of the G forces for the aircraft and all aboard when it comes to flight planning. A healthy respect, training, and planning will help to avoid possible encounters with the ground.

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