In April 2007 Blue Angels pilot Lieutenant Commander Kevin Davis went down in his F/A-18 Hornet during a maneuver in an air show held over Marine Corps Air Station Beaufort, South Carolina. He was killed in the crash, and the ensuing investigation led officials to conclude that Lieutenant Commander Davis had suffered a blackout due to a brief loss in “situational awareness” while pulling his aircraft into a particularly tight turn.

In other words, it was not the aircraft, but Lieutenant Commander Davis’ physiological response, that probably led to his fatal crash.

The greatest limiting factor in military combat aircraft is the pilot. Today’s planes fly faster, higher, and farther than ever before, yet the human body still has maximum force and endurance thresholds that cannot be increased. One of the body’s most critical deficiencies is its inability to tolerate high inertial forces, or G-forces. These are the acceleration or deceleration forces that the body experiences when its path of motion changes. Fortunately, the body is capable of adapting to G-forces—to a point.

The New Science of Speed

The first documented air incident that was attributed to G-forces occurred in 1918, when the pilot of a Sopwith Triplane passed out in a tight turn. At the time these forces were not well understood, primarily because they had never before been experienced. Pilots such as Lieutenant Commander Davis face far more extreme “G-loads” than those pioneering pilots.
Witnesses reported seeing Davis’ jet appear to sink too low following a tight, high-speed turn and ultimately crash into the tree line. The 15 January 2008 Pensacola News Journal reported on the investigation of the event and cited the cause of the accident from the Judge Advocate General Manual Investigation report: “LCDR Davis’ failure to perform a proper anti-G straining maneuver resulted in him suffering possible physiological effects that contributed to his loss of situational awareness of his rate of descent and ultimately a controlled flight into the terrain.”

What does “anti-G straining maneuver” mean? In the plainest terms, it involves simply performing flexing exercises during a high-G episode to prevent blood from pooling in the legs and keep it moving to the brain.

G-forces refers to the force acting on an object that resists change to motion and is related to the normal pull of gravity on the body. Thus, 1 G equals the force one would feel on a constant trajectory without any change in speed; 2 Gs equals the feeling of double the force of gravity, and so on. Gs can be either positive or negative. Positive Gs are experienced when the change in motion relative to the body is upward, and negative Gs are experienced when the change in relative motion is downward. While every aviator’s body is different, G-forces affect the same physiological systems in everyone, and therefore there are roughly defined limits to their tolerance.

With the onset of a higher-than-normal G-force, a well-documented chain of physiological events occurs in the body. If the load is experienced in the positive direction, one’s body feels like the force of gravity pulling down on it is increasing. This increased force pulls blood from the upper body and causes it to pool in the legs. The lack of blood and oxygen to the brain results in very serious physical consequences if the load is experienced for more than an instant.

**The First Sign**

The first indication of an unsafe G-load is known as a brown- or gray-out. In this case, the aviator’s vision loses its color capacity. If the force or duration of the G-load is increased, a loss of peripheral vision called tunnel vision occurs. If the loading or duration continues to increase, a blackout occurs. In a blackout, the aviator remains conscious and has full control of his other functions, but completely loses his sight. This may have happened to Lieutenant Commander Davis before he crashed.

The last stage of the human body’s reaction to G-forces is called gravity-induced loss of consciousness, or G-LOC. This stage occurs if the initial force or the total duration of the force is greater than that of the blackout stage. This is an extremely dangerous situation as it requires an average of 15 seconds to recover consciousness and also results in another 15 to 30 seconds of disorientation. To have a jet aircraft out of control for that length of time nearly always results in a crash.

By contrast to the positive, downward G-forces, an aviator can also experience negative Gs, in which the body feels gravity being reversed, or being pulled upward. During negative Gs, blood is forced into the head, causing a “red-out.” This increase in pressure can rupture capillaries in the eyes and face and can be extremely painful. The body can tolerate many more positive than negative Gs, with the average, unaided person experiencing G-LOC at 5 Gs. A trained pilot can withstand up to 9 Gs for a short period before G-LOC. However, regardless of training, a pilot will “red-out” after only 2.5–3 negative Gs. This disparity has a significant impact on how a plane is flown.

**Flying Flat**

Is it easier to deal with G-forces while flying vertically or horizontally? Much of the data here has dealt with a G-load in the vertical plane, given that most aviators in a dogfight are required to change altitude rapidly. Human physiology, however, has the lowest tolerance to increased Gs in that direction. G-forces that are experienced in the horizontal plane have relatively little effect on the body. This holds true up to loads of around 40 Gs (though this is substantially a greater G-load than any plane can handle, and would make the structural integrity the limiting factor—and render the experiment moot).

The space shuttle exploits horizontal versus vertical G-loads. It orients astronauts in the prone position at takeoff, so that they can accelerate the vehicle to orbital velocity while remaining conscious. An earlier experimental effort to reduce the effects of vertical G-forces had less success. In 1945 Northrop unveiled the XP-79B flying wing fighter aircraft, also known as the “Flying Ram,” which the pilot flew while prone. After a series of unsuccessful tests, it ended on the scrap heap.

How to get around the risks of pulling Gs? Given that technology has and will continue to outpace the human body’s capacity to adapt, it’s unsurprising that physiology has turned out to be aviation’s greatest limiting factor. But there are some natural and artificial ways for military aviators to increase their vertical G-load tolerance.

**Stay in Shape? Or Take Up Smoking**

A common natural technique is the Anti-G Straining Maneuver, which Lieutenant Commander Davis is thought not to have used prior to his crash. The current Navy variant is known as the “Hook” maneuver—an adaptation of the Air Force’s L-1 maneuver. The Navy version...
involves a three-second tensing of major muscle groups in the legs, arms and lower abdomen, combined with a 0.5-second period of quick short breaths. The current technique involves closing the glottis (the space between the vocal chords) during the strain. Students are taught to say the word “hook” or “hic” as they begin to strain to ensure a completely closed throat during the maneuver. The Hook gives the pilot a little over 1 G of tolerance.

A more controversial natural technique involves the aviator’s physical fitness. Logic says that an aviator must be in good health and strong enough to withstand the straining necessary to combat increased G-loads. But this is only true to a certain extent. A 1980s Air Force study found that athletes with endurance training handled G-loads poorly because their heart rate and blood pressure were too low to provide the requisite blood to the brain. Another study suggested that short female aviators who smoke displayed the highest natural G tolerance. The female’s naturally higher G-tolerance may have been caused by the shorter distance that the heart had to pump the blood to the brain, and elevated blood pressure due to smoking. A reasonable alternative for tall, nonsmoking males would be to adopt a weight training program that focuses on the core muscles and the legs to increase the effectiveness of their Hook maneuver.

The G-Suit, Then and Now

The G-suit, in one form or another, has been around for a long time. The earliest contrivance consisted of a water-filled coverall invented by Dr. Wilbur Franks in 1939. A version of the Franks suit was first fielded by British aviators in World War II. The modern G-suit consists of a series of pneumatic bladders that inflate during high-G flight, in order to force blood from the legs to the brain. It’s capable of allowing aviators slightly more than 1 G of additional tolerance. In addition to the suits, some aircraft have forced breathing systems to decrease the amount of effort necessary to fly at high-Gs for a prolonged period of time.

Some flying techniques are designed to modify the G-load. Since negative vertical Gs are much less tolerable than positive vertical Gs, some maneuvers can be used, such as inverted flight, to transpose the negative Gs into positive ones. Since G-forces are experienced relative to the change in direction of motion, rolling the aircraft 180 degrees will give an inverse G feeling. This technique is used in the split-s maneuver, as opposed to a normal, turning descent. An upright, turning descent would not be able to be executed as dynamically as the split-s because of the negative Gs involved.

Ultimately, there is just so much an aviator can do to reduce the effects of G-forces in flight—maneuvers like inverted flight, to transpose negative Gs to positive ones, performing the Hook, or strapping into his G-suit. Barring a radical change in the ways planes are designed, the most difficult stress that aviators will have to overcome will be either positive or negative Gs in the vertical plane. The current maximum force that a body can stand remains only about 9 positive and 3 negative Gs. No matter how much faster, higher, and farther the planes can fly, the pilot’s still only human.

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