SOARING Rx

BY DR. DANIEL L. JOHNSON

A Thunderstorm Commotion

"The mechanism by which this cerebral commotion came about remained elusive."
SC Stein, MD, 1988

When our head gets whacked, we might pass out. The prototypical Greek physician Hippocrates called this *commotio cerebri,* which hardly needs translation. We might also pass out for other reasons, especially sustained G forces that hinder blood flow to our brain.

Today's essay was inspired by a question from Curt Lewis: "How much G-force is needed to knock someone unconscious?"

The frustrating answer is, "It depends." It depends on the person's hydration status, on whether the extra Gs are expected, and how fast they're applied – the change in rate of acceleration (technically, a "jerk"). There is a second mechanism for unconsciousness, the percussive effect of a blow. In an aircraft incident, both may be involved.

Today's question stemmed from an incident that's instructive in many ways. We hope that these lessons will some day be published in Soaring. For now, we will only discuss loss of consciousness. Here's the medically important fragment of the story.

Waking up in Cloud

"The contest task was almost finished. I was climbing near the leading edge of a small thunderstorm's front, nearly in the blue, about 6 miles out. In my location, there was no rain or visible lightning. The clouds above seemed very benign. The lift was very strong and unusually smooth. At the top of my climb, I flew to enter the 5-mile safety finish circle with the intention of continuing on to an airport about 10 miles away that was still in the sun. I was anticipating extreme sink considering the strong 'thermal' I had been climbing in, but the strong lift continued.

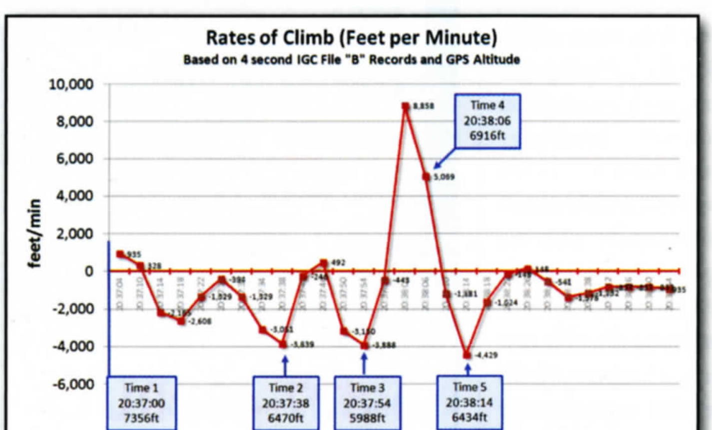
"As I dove to remain below cloud base, I encountered multiple violent, vertical, short-duration gusts that felt like the percussive hits of a metal stamping machine. The noise was like being blasted with a giant air cannon. It was a true 'pounding' unlike the more gradual G forces of aerobatics. The duration of each was less than 1/2 second. I immediately started a 180 turn to get back to the blue and found myself "coiled up" around the joystick as if trying to hold on to a rodeo bull. I was holding onto the joystick with both hands, head down, with my feet back near the stick, trying to avoid being ejected from the glider.

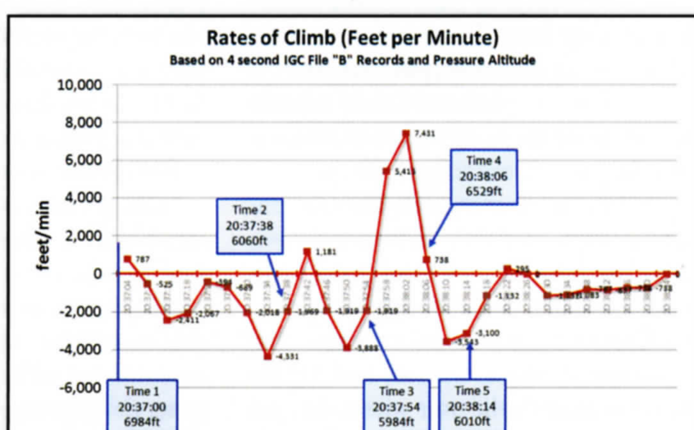
"The violence paused. I noticed there was no feedback pressure from the elevator. I feared it must have been damaged or literally broken off, and I began reviewing my bailout plan. I realized I was in the light mist of cloud base and waited to exit the bottom. When I did, the horizon was tipped almost vertical, and I was nose-up, tail-sliding out of the cloud. The elevator forces were gone because I was near zero airspeed at the top of a vertical climb. As the nose dropped and I resumed flying, the turbulence began again. It eventually subsided but the sink was so strong I abandoned my plan for the alternate and headed back to the contest site that was now in the clear only 5 miles away. During this time, I never flew in rain and never saw a lightning strike.

"Later that night I reviewed the flight log and saw a vertical climb of about 900 feet that I did not recall. I concluded that the hit that sent me vertical into the cloud had rendered me unconscious for about 8-12 seconds. I actually had regained consciousness just before I noticed the lack of force on the elevator."

The forces experienced.

First, the forces could have been very large. Air is incompressible below the speed of sound, so big changes in speed of vertical turbulence, at high speed, will hit an aircraft hard. This is a strong aircraft: the designer of the Genesis, Jim Marske, told me in a phone conversation that the Genesis had been tested to 19G. By coincidence, before Col John Stapp's work after WWII, it was thought that 18G would be fatal. Stapp proved this wrong by surviving 46.2 Gs in December, 1954, accelerating to 632 mph in 5 seconds, then stopping in 1 second. He was sometimes injured during his runs, but regained almost-normal vision within days after this run, his last, and lived until 89.





The graphics with this column are the work of John DeRosa, who has analyzed the GPS log of this flight. This GPS record, with data at 4-second intervals, shows altitude changes of about 300 meters (900 ft), with rates of climb changing, maximally, from a 4-second mean of -20m/sec (-65ft/sec = -44 mph) to a mean of +38m/sec (+123 ft/sec = 83 mph) in 12 seconds, back to -18m/sec (-60 ft/sec = -41 mph) in 8 seconds, then back to +2m/sec (+5 ft/sec = 3 mph) in 12 sec.

These are not John Stapp numbers, but involve some big whacks. The largest change in velocity is 127 mph within 3 tics of the GPS record. Since he gained 900 ft altitude during this time, the reversal of direction – the acceleration – must have occurred, as the pilot suspects, in less than a couple of seconds. This is highway-crash territory.

Damage

Both glider and pilot were annoyingly damaged but not crippled. The wing-root sealing tape was split from trailing edge to spar. A flat lead counterweight in the aft fuselage was bent 45 degrees, the fenestrated metal landing-gear linkage was bent, preventing from being locked when extended, and the canopy pins were bent, without the pilot's head having struck it. This is evidence of severe acceleration, not of impact. It was the wheel not wanting change from 44 mph downwards to 83 mph upwards (inertia) that bent the linkage arm.

The pilot had weeks of severe soreness of his upper chest, where his chin would have struck it when his head was thrown forward. He had weeks of neck and upper-back muscle pain from traumatically stretched muscles – the classic "whiplash" injury. Auto crash videos – when the car is hit only once and not tossed about in turbulence – show the crash dummy's head bouncing around atop the neck. This is hard on the ligaments and muscles of the neck and shoulders, as many of you probably know from experience.

Why did he lose consciousness?

Specifically, I don't know; but I've got this column to write, and the possibilities seem interesting. In any case, he *did* lose consciousness. The question is just how this may have happened.

First, the likely G forces, both positive and negative, were clearly well beyond what's needed to cause people to pass out in gentler situations such as aerobatics and centrifuges. Gradual changes of as little as -2G to +3 G have caused loss of consciousness in some people, and +5 G causes most people to pass out in a few seconds. Trained jet-fighter and aerobatic pilots with G-suits can endure +9 G.

Second, he seems to have whacked his chin on his chest, which might have been enough of a blow to KO him, in the street-fighter sense.

Third, it is not actually necessary to be struck on the head to be knocked out, or to have a concussion (headache, dizziness, mental or emotional dysfunction). Force (pressure waves) can be transmitted through the neck to the brain from the abdomen and thorax. In this situation, the pilot seems to have taken the biggest hit while bent over, holding onto the stick. In this posture, internal pressure is increased, and a sharp jerk (change in G force) will amplify this.

Research 30-50 years ago showed that rapidly tipping the head from one side to the other in a fraction of a second, without an external blow, could (depending on the speed at which the head was tipped and stopped) cause brief or prolonged coma, or fatal brain injury. In other words, the head only needs to move and stop quickly to knock a person out. It doesn't take a whack.

A little history

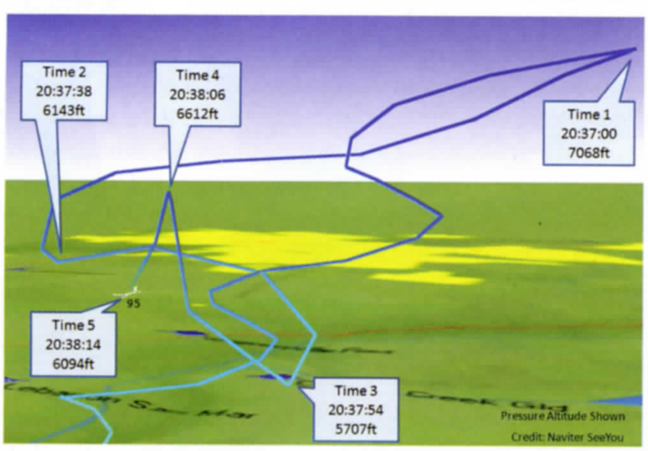
Apparently, the first article about pilots losing consciousness was published in 1920 by Dr.H. Head in Britain. He described 'fainting in the air' in WWI aircraft. Experiments showed that these blackouts "lasted about 20 seconds" and occurred when 4.5-4.6G were reached vertically. So we see that pilots began blacking out as soon as airplanes had to be flown aggressively. Such blackouts are due to decreased blood flow to the eyes and brain.

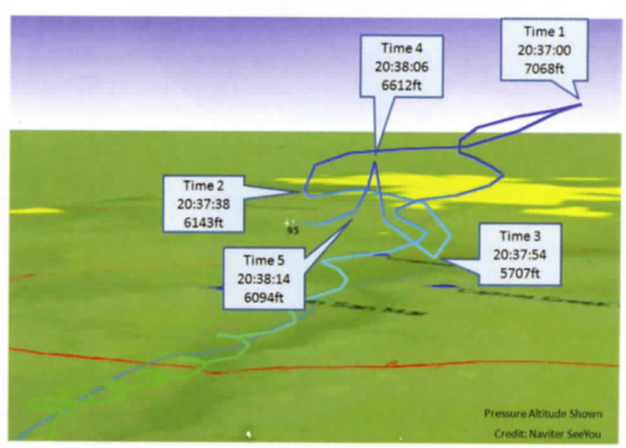
While G-tolerance varies with posture (stopping abruptly is best done in reverse), if the G load is high and the onset is brief (e.g., more than +6G/sec), unconsciousness occurs within a second or two. The individual quickly passes from full alertness to unconsciousness with no warning symptoms such as faintness or graying out.

With sustained acceleration of 4.5 to 6 G consciousness comes on progressively in about 5 seconds, and with this about half of people have seizure-like movements. Confusion typically occurs after regaining consciousness.

Why do we go unconscious?

The brain is an electrical organ that is highly active metabolically. It will globally dysfunction – fail entirely to work – if its electrical state is disrupted or if its metabolic needs are not met. ☛





Metabolically the brain needs oxygen and glucose. These are supplied by flowing blood, and they migrate from blood vessel to brain cell partly through the pressure gradient that exists between artery and tissue. This gives us four main mechanisms of failing to provide metabolic needs: lack of glucose (diabetic hypoglycemia), lack of oxygen (asphyxia), lack of pressure (hypotension) and lack of flow (cardiac arrest, arterial obstruction). Only asphyxia (slow onset, with altitude, or rapid onset, at altitude with O2 system failure) and low pressure (pulling Gs) normally affects pilots. Usually we can anticipate these and avoid the problem.

The classic whole-brain electrical disruption is the epileptic seizure, in which there's an area of the brain that's abnormally prone to spontaneous electrical activity, which may spread or generalize through the whole brain. This causes the classic "grand mal" or generalized seizure. If the abnormal electrical activity remains focal, we call it a seizure with "partial" symptoms, which may involve anything the brain is capable of doing.

A physical blow can cause muscle or nerve membranes to depolarize electrically. This is the reason the "precordial thump" sometimes is used in cardiac arrest. A blow is a pressure wave – so any whack or jerk that's strong enough to depolarize nerves in the brain or brainstem can cause generalized dysfunction, sometimes with "seizure-like activity."

We do not completely understand consciousness, so any physiologic analysis of unconsciousness must be incomplete. In any case, we know that sleep is a normal state of unconsciousness. Sleep and alertness involve fairly complex processes that are, fortunately for me, beyond the scope of this essay, because I'm no expert. The structures involved in sleep, and awakening are located in the upper brainstem; and we do know that shock or injury to the brainstem is especially likely to disturb consciousness, much more than shock to the brain (the cerebrum). If you want to explore this, search for "neuroanatomy of sleep."

All the complexity aside, it is well known that *accelerating* the head *without any impact* will cause loss of consciousness. Whether this is brief (seconds to minutes) or prolonged (hours to days) depends on the severity of the acceleration and whether physical damage is done to the brain or to the brainstem.

Thus, for our pilot, it's quite likely that the severe G loads caused by the turbulence themselves knocked him out. This seems more likely than the mechanism of decreased blood flow because loss of blood flow causes graying out (medically, *pre-syncope*) that, though brief, is almost always remembered.

A great deal of research has been done on such head injuries. The physical damage to brain tissue may involve tearing and leakage of small or large blood vessels, but whether or not blood vessels are damaged, the nerve fibers may be torn or stretched ("*diffuse axonal injury*"). This results in some of the symptoms of concussion and if severe, can lead to post-traumatic dementia. In general, it is true that if any bleeding is seen on magnetic resonance imaging after head trauma, there will be a test-detectable cognitive loss. (And an increased risk of seizures. Such a pilot should not fly again, the FAA believes, until seizure-free for five years after injury. An ex-airline pilot I care for had his first seizure about 15 years after being concussed playing high-school hockey.)

What are today's lessons?

Give thunderstorms a wide berth, eh?

References:

Martin Voshell. High Acceleration and the Human Body. November 28, 2004 csel.eng.ohio-state.edu/voshell/gforce.pdf

KV Kumar. Issues on Human Acceleration Tolerance. NASA Technical Memorandum 104753. 1992. ntrs.nasa.gov/archive/

Nick T. Spark. The Story of John Paul Stapp. http://www.ejectionsite.com/stapp.htm

Acknowledgments:

Curt Lewis, for the question and the story; John DeRosa, for the analysis and lovely graphics; Peter Saundby, for thoughtful comments.

Archive

An archive of these columns is located at www.danlj.org/~danlj/Soaring/Soaring Rx/