Physiology Clues for Pilots and Related Creatures

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This manuscript describes some essential physiologic requirements for safe glider (or powerplane) operation, and suggests simple clues pilots can use to detect their abnormal physiologic status.

http://amygdala.danlj.org/~danlj/Soaring/Clues/index.html

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1 Summary

In this essay I describe some ways you can harm yourself without meaning to, and show you some clues by which you can judge when to compensate.

First, the vestibular system (inner ear) is designed to detect change in our body's position. On the other hand, we pilots are more interested in our glider's current orientation or state with respect to airflow. I'll show you several reasons why "keeping your head on a swivel" protects you from illusions that can mess up your control coordination and wreck your ship.

The vestibular system works well, but is imprecise and is prone to certain predictable errors. Understanding the conditions in which these errors are most likely can help you avoid them.

Second, pilot physical impairment is usually subtle and insidious, and may be difficult to notice. Most important are

- fear or doubt
- fatigue
- dehydration
- hypoxia
- illness or disease[1]

Fear can completely destroy judgment and freeze rational analysis. The best antidote to fear is thorough training. Studies have shown that the pilot who has mentally rehearsed formal emergency procedures will effectively do them under stress; the pilot who is unprepared will be unable to formulate a cogent emergency plan at the instant of an emergency. Doubt is lack of confidence which may make it impossible in a moment of stress for a pilot to objectively evaluate which of several courses of action is the best.

I'll not spend any time reviewing the extensive work on the psychology of emergency decision-making, and instead focus on the inner ear and the effects of fatigue, hypoxia, and dehydration on performance.

1.1 Performance

Of the many factors affecting competence, I'll comment only on biological ones. When the Lord God made Man a living spirit, He created psychological, ethical, social, and spiritual factors; but we will assume that you and your mom pretty much worked the basics out several years ago, and you have become a competent, effective human being and later training made you a pilot.

Some of the biological factors of competence are:

- fatigue,
- hydration status,
- oxygenation,

[1] I like to distinguish "disease" from "illness" by considering a "disease" to be a condition that requires treatment, but may be completely stable and not at all bothersome with treatment; many diseases do not create any risk of decreased pilot performance. I consider "illness" to be something that *does* at least make you miserable and in other ways may physically impair performance. It's often safe to fly with a disease; it's seldom safe to fly despite illness, in this sense.

- nutritional status,
- core temperature,
- emission-control plan,
- cardiovascular conditioning & stress response,
- and others.

1.2 Fatigue

Rest, as you already know, takes several forms. You may come home from your sedentary job exhausted and rest by going for a long run. Physical and mental effort seem to produce separate types of exhaustion. Each person has a different capacity for mental or physical work, which varies over time depending on many factors. The most pervasive and subtle collection of factors is called "jet lag," which amounts to disturbed biorhythms.

1.3 Jet lag

Ideally, one should arise at the same time every day, and go to bed within about 30 minutes before and up to 1 hour after a given time (depending on your need for sleep), in order to entrain biorhythms most effectively. Changing your sleep cycle will shatter your biorhythms promptly.[2] If you stay up most of one night, you will be sleepy the next (second) day, but on the following (third) day you will lack mental and physical resilience and feel "tired" (but not sleepy), even if you sleep on your normal schedule between the second and third day. This third-day fatigue is "jet lag," and is likely to occur during any trip if the sleeping conditions are unfavorable to satisfying rest.

Chronic "jet lag" does seem to affect longevity: About 40 years ago I read a newspaper report stating that Northwest Airlines had studied its pilots, and found that the life expectancy of their trans-pacific pilots was a few years shorter than that of pilots flying only domestic routes. And a study about 15 years ago of physicians showed that those specialists such as ophthalmologists and pathologists, with no night call, lived on the average into their 80's, while those whose specialties required night call, such as general or family practice or internal medicine, died about 10 years younger.

With travel involving any significant shift of time zones, adaptation of your biorhythms requires several days, as you've noticed. Traveling west is easier than traveling east: research has demonstrated that we can cope well with a delay in bedtime, and time of arising, of up to three hours; but to "back up" only half an hour presents a similar difficulty to our systems. So our bodies adjust most smoothly if we (in traveling west) go to bed and get up three hours later each day, and if in traveling east we go to bed and get up 1/2 hour earlier each day. Ironically, this means that if we travel more than 4 time zones east, it's actually easier to adapt by going to bed three hours later each day.

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[2] Precisely, the body can adjust easily to *advancing* bedtime by three hours per day; but it can easily adjust to going to bed *earlier* by only one hour per day.

Actually to follow such a schedule rigidly is usually impossible while traveling, but understanding this principle and approximately following it can make it easier for you to adapt during and after your next trans-continental trip.

The important lesson for the pilot is that if you are able to continue "living in your home time zone" during a trip by arising at the usual zulu time daily, you will have less mental fatigue and avoid the performance degradation that comes with jet lag.

Regarding the nature of mental fatigue, little is known physiologically due to the unseemly reluctance of people to let biologists put fine metal probes into the depths of their brains. Despite this general lack of commitment to scientific progress, everyone except young children in need of a nap and college students understand that mental fatigue impairs intellectual performance. And piloting a glider is obviously an intellectual performance, if only because so little gross physical activity can take place in such a small cockpit.

If you feel tired, you ***are*** *tired: expect sub-par intellectual agility, slowed perception, and awkward judgment – and rigidly stick to the basics.*

2 Spatial Disorientation: How to Have an Accident, Confidently

Pilots do not intend to damage themselves or their aircraft, yet pilots crash. I guess that's why we call them "accidents," to differentiate them from the stupid things we *plan* on doing.

To oversimplify a whole lot, we can divide accidents into simple categories:

- the airplane is out of whack;
- the pilot is out of whack;
- somebody else whacks the pilot or his airplane;
- acts of God.

To get the theology out of the way pronto, since this is not our main subject, let me just say that, knowing God personally, I can say that not only do people ask Him to do a lot of things that He doesn't have any particular interest in doing, but also that people blame Him for a great many things He didn't do in the first place. He put us into a livable environment, gave us motor skills and a fine analog computer, some basic essential instincts, and a parenting system – really, quite enough to live prudent and safe lives if we pay attention to details.

And to get the sociology out of the way, I can also say with some authority that whatever I say here isn't going to affect the other guy one little bit, because he isn't here listening, for one thing, and neither of us can predict his behavior, for another.

And let's get the airplane thing out of the way, too. That's your responsibility, not mine. You've purchased a proper, careful annual inspection, you've researched the vagaries of your machine and its fittings, you do a careful pre-flight followed by a positive control check, and from the moment you attach the tow cable you have contingency plans for disaster in hand.

So that leaves the pilot. Hi! Here we are! That's us!

Let me say right now that not one pilot goes into an accident intending to have one. And inspecting accident records shows that some of these pilots are experienced and skillful. We expect stupid, careless, clumsy pilots to have accidents, so illogic leads us to conclude that any pilot having an accident is stupid, careless, or clumsy. If you've ever damaged an aircraft, you've felt this illogic from some of your comrades, have you not?

So our aim here is to explain some ways in which a bright, careful, skillful pilot like yourself might be surprised by an accident.

2.1 Accidents of Thinking

Frank Caron, in his Technical Soaring article on French glider accidents (V. XXIII, No, 3, July, 1999 p. 71-5)), uses James Reason's error model of cognitive errors leading to glider accidents. The breakdown is in Figure 1:

cognitive processes	accidents	fatalities	injuries
routines	37 (16%)	1 (10%)	6 (15%)
inaccurate representation of glider status	55 (23%)	7 (70%)	11 (28%)
inaccurate representation of environment	64 (27%)		9 (23%)
incorrect choice of procedure	54 (23%)	2 (20%)	10 (25%)
bad resources management	9 (4%)		
1 (3%) wrong intention	12 (5%)		
3 (8%) violations	5 (2%)		
Totals	235 (100)	10 (100)	40 (100)

Figure 1: Cognitive Errors Leading to Glider Accidents

Notice that the entries beginning with "in-" account for about three quarters of accidents and injuries and 90% of fatalities. Basically they imply, "I didn't realize exactly what was going on!" My goal here is to show you that figuring out the situation incorrectly is something we are prone to do, a design feature, not a bug. I don't believe that French pilots are basically any different than we are, even though they might like to think otherwise.

Let's take a moment right now to observe a particular peculiarity of glider accidents. They nearly all involve the ground. This is because air is relatively soft, and so for an accident to involve damaging collision with the air, some pretty spectacular weather has to occur, which scares away most of us. Such accidents have occurred, but not often.

And there are hard objects in the air, which sometimes collide with and damage gliders, but nearly all these hard objects contain brains in one form or another, and detection systems, and genuinely want to avoid each other, so such accidents are less common. I don't know what your experience has been, but every time I've had a close encounter with a bird while piloting an aircraft, the bird has been in "aggressive avoidance mode." Airplane pilots are less observant. I remember asking a macho local friend, after we both landed, "When the glider is inside and below the Pitts and both are on base for the same runway, which aircraft has the right of way?"

His answers were pretty humorous:

- "I called three miles out – didn't you hear me?" [why didn't you get out my way?]
- "I didn't hear you on the radio" [you must not have used one].
- "Well, I'm a lot faster" [why do you even bother to bring this up?]
- "I didn't get in your way" [no blood, no foul; I landed on the grass over-run before the paving began, while he was landing far ahead on the pavement].

Most glider accidents involve collision with the ground because

a. there's a lot of it;
b. earth attracts gliders to it – "ground" is what generates "gravity;"
c. glider pilots must perform their most precise maneuvers real close to the ground, e.g., the turn from base to final.

If we look carefully at the results of this study of French accidents, we'll note that "mistakes from an inaccurate representation of the situation or the status process" result in 27% of the accidents, 37% of the injuries, and 73% of the fatalities. This somewhat cryptic phrase means basically that the airman did not correctly perceive the glider's current status, condition, or position relative to the air flow or to the situation on the ground. Another phrase that says something pretty similar is "spatial disorientation." More on that later. A more instructive term might be "spatial misinterpretation."

Thus the pilot's inaccurate perceptions cause most of the fatalities and many of the accidents. Why does such inaccuracy occur? It happens not because pilots are negligent, but because our perceptions have limitations and are subject to (undetected) error.

Let's say this again, differently. Pilot error – "inaccurate representation of the situation" in Reason's rhetoric – occurs because your body and your senses are working the way they are designed to work, not because you are a dumb klutz. Well, OK, you and I might both be klutzy under some circumstances, but spatial "misinterpretation" usually occurs because your visual and vestibular senses are working just the way they are supposed to *and are prone to certain predictable errors*.

As an aside, the best way to overcome this inexactness is **practice**. If you journey to a strange gliderport or fly an unfamiliar ship, do a half-dozen pattern tows and practice landings with slightly different approaches.

In addition, I want to show you some ways that the ***normal*** operation of your senses, in *usual* flying tasks, can lead even the skilled pilot to incorrectly perceive the glider's status or its relationship to the ground. Understanding the circumstances in which this is prone to happen can help you distrust your senses at the right times, and look for confirming cues to sort out what's correct and what's real.

2.2 Accidents of Perception

First, let me mention three books that may help you study and understand the illusions leading to confident error:

Aviation Medicine and other Human Factors for Pilots, Dr. Ross L. Ewing, 3rd Int'l Edition, New Zealand Wings Limited, 1999, ISBN 0-908990-07-3 (info@nzwings.co.nz) PO Box 120, Otaki, New Zealand, tel 64-6-364-6423. This is a clear, concise text for the intelligent non-physician. Highly recommended. The retail price is USD$21.00 plus USD$2.55 postage: total USD$23.55.

And two textbooks, written for physicians, but understandable to the educated layman:

Human Factors in Aviation, Earl L. Wiener and David C. Nagel, eds., Academic Press, 1988, ISBN 0-12-750031-6 (www.apnet.com/), especially Chapters 4, The Human Senses in Flight, by Herschel W. Leibowitz, and 9, Human Error in Aviation Operations, by David C. Nagel.

Fundamentals of Aerospace Medicine, second ed., Roy L. DeHart, ed., Williams & Wilkins, 1996, ISBN 0-683-02396-9 (www.wwilkins.com), especially Chapter 11, Spatial Orientation in Flight, by Kent K. Gillingham and Fred H. Previc.

Second, let me emphasize that, even if we understand intellectually the perceptual illusions to which we pilots are prone, to realize in the cockpit that "something is wrong" is very different from correctly analyzing *what* is wrong and even that is well short of *acting correctly* and doing this *in time to avoid bonking the ground.*

Third, it is important to realize that in severe turbulence or when doing aerobatics, it is possible for your brain to become so discombobulated that it is not even possible to read your instruments: this is called "nystagmus," and prevents your eyes from focusing on your instruments to read them and to understand what they are trying to tell you or from focusing on the ground to understand your orientation. This is rare, but has killed pilots, especially fighter pilots in real or practice air combat.

Sometimes these illusions are dismissed by glider pilots as unlikely to happen, for textbooks present them as problems that plague instrument-airplane pilots, who are continually functioning in conditions of reduced visibility or absent visual cues. But they can and do affect glider pilots, only somewhat differently in visual conditions; and we need to remember that glider pilots do sometimes fly in cloud in other countries; and even in visual flight conditions, that haze, smoke, dust, unexpected cloud formation, dirt on the canopy, rain and dusk can significantly degrade outside visual references, sometimes at inconvenient moments.

Canadian Air Force studies have shown that *24%* of accidents in *VFR* conditions in fixed-wing aircraft are related to *spatial disorientation*. Note that's *visual* conditions, not instrument conditions. A special study of Canadian Air Force rotorcraft accidents that occurred when pilots were using night vision goggles in VFR conditions revealed that *48%* were related to spatial disorientation. The simple lesson here is that even in VFR conditions, any degradation of visual conditions doubles the accident rate. This impresses me. It throws out the old notion that spatial disorientation is for IFR pilots.

Let's stop for a bit to discuss the functional anatomy involved: the inner ear and the eyes. "Seat-of-the-pants" flying, which dominates soaring and gliding, requires fine coordination of the vestibular system, chiefly involving the "inner ear," and the eyes.

The inner ear has three interconnected parts: the cochlea, which parses sound into discrete frequencies; the semicircular canals, which detect rotation in three axes, and the otolith apparatus – the utricle and saccule – which detects gravity and linear acceleration.

The key to understanding the inner ear is that it detects *change*, not the status quo. That is, it detects not whether you are turning, but whether the *rate of turn* has changed. It detects not whether you are moving or still, but whether your speed has changed; not whether you are floating through space, but whether you got kicked in the rump.

The sensations of the inner ear are linked within the brain and cross-checked against perceptions of neck position and visual perception, to build a composite of your relationship to space, time, gravity, and the cockpit. Each of these parts – and the brain itself – is susceptible to predictable errors, to inherent limits, to disease, to degradation from fatigue and dehydration, and to aging.

When these systems are working well, pilots can do amazing feats of skill and precision; the problem is that pilots are often unaware of subtle degradation, or underestimate more severe degradation of these perceptual systems. Understanding the way they work and the illusions we are susceptible to, and adapting our flying intelligently, can help us avoid catastrophe.

Next, the eye: it has two visual functions:
- *ambient* vision and
- *central* vision.

Ambient vision is most important in maintaining spatial orientation through detecting patterns and movement through peripheral vision. If you doubt this, try flying your glider while looking through a pair of paper tubes. Glue a pair of toilet-paper tubes to the front of your sunglasses. Only with a safety pilot!

Focal vision is most important in object recognition through processing of fine detail. It is not as important as ambient vision in keeping track of where you are in space. Ambient vision knows you're in a bank; focal vision knows the cloud up ahead has a tight bottom.

Let's catalog the illusions of perception one by one, briefly.

2.3 Visual Illusions

Shape constancy. We expect all runways to have similar trapezoidal shape when we're on final. Larger or smaller runways look nearer or further than they "really" are, compared to the runway we're most used to; an upsloping or downsloping runway likewise looks nearer or further, respectively, than it really is. This illusion has led to numerous overshoot or undershoot accidents, and it's not an easy one to overcome, especially when the strange runway is almost like the one at home.

Size constancy. Size is the main clue to distance beyond the 15-foot range of binocular vision; we tend to flare high over a big runway and low over a narrow one. A runway that slopes down makes us feel low, so we tend to get high; one that slopes up makes us feel high, and we tend to get too low. Some accidents have been caused by pilots overcompensating for these illusions.

Aerial Perspective. Haze, fog, or rain, may obscure distant landmarks that would otherwise give clues to distance. Mountain valleys provide false convergence clues that can easily delude us. Flight in and around steeply-sloped mountain valleys is particularly fraught with illusions of perspective from the sloping terrain. It's safe to *assume* that things are not as they seem: watch your airspeed indicator and and look continually for visual clues for correct orientation such as level cloud bases.

Absent focal cues. Smooth water and fresh snow are the classic examples; glider pilots do not normally land on these surfaces, but have done so by not realizing how close they really are. The lack of texture makes it nearly impossible to judge distance either through texture gradient (the usual mechanism past 15 ft) or through binocular fusion (within 15 ft).

Absent ambient clues. A gust front has been approaching, and you begin to transition to flare just as it crosses the airport boundary and puts you into a turbulent dust cloud. Or you have lingered too long in wave, and the evening is well along before your final glide takes you over the darkening airport. You of course have no landing light, and the asphalt is just a well between the glowing runway lights. Or you are between thermals on a hazy day, and you notice a small, blurry insect stuck on your canopy, which you suddenly realize is another aircraft. An aircraft on a collision course does not appear to move against the canopy! A clue is that the bug does not grow!

Vection illusion. A fancy name for something we've all experienced. You are in your car, waiting at a stoplight on an upsloping road. You sense your car beginning to creep forward; you jam your foot on the brake to keep from hitting the bumper of the car ahead; nothing happens. The car next to you continues to creep backwards...

You are thermaling at a comfortably high altitude, in a 45-degree bank. The glider pivots around its center of gravity, the inside wing sweeping back across the terrain as you make tiny little turns; later, having failed to make a low save over the factory next to the airport, you turn from base to final at 200 ft agl. Despite your aggressive 45-degree bank, the glider makes huge turns, pivoting around some point in the far distance, and seems to skid across the ground as it speeds across the terrain. You make an S-turn back to line up with the runway, keep the spoilers tucked in, and hope no one is there to admire your performance.

There are three vection illusions described in this flight. Two are opposite angular-vection illusions; one well above the pivot altitude, one well below it. The angular-vection illusion in which we feel that we are failing to turn sharply when low, below the pivot altitude, contributes to over-ruddered, skidding turns and to spins on the turn to final. The vection illusion of greater speed when low over the ground may contribute to inappropriate slowing and to the stall that permits the spin.

False Horizon. You are flying in wave, with lovely lenticular clouds sloping up and away to your left. Your yaw string keeps drifting off to the left across the canopy. What's happening? The lenticular forms a false horizon that your ambient vision keeps trying to use. Or you enter a canyon toward an off-field landing, and overshoot the stub of straight road you had chosen for an off-field landing, realizing too late that the canyon floor only seemed to be level, and was actually sloping subtly away. Your buddy was in a similar situation, only snagged the sagebrush on the way in, landing short because the upsloping floor looked level.

False stabilization. When you are busy inside the cockpit, checking charts or programming your GPS or final glide calculator, ambient as well as focal vision may begin to depend on the stable cues of the cockpit and canopy. Lack of clouds or other outside cues may mean that there's nothing to contradict the false impression of stability. You look up from your map to find the yaw string streaming crosswise across the canopy and the right wing down thirty degrees.

2.4 Vestibular illusions

Vestibular illusions are much more important in instrument flying than in visual flight, but even in visual flight conditions can lead to seriously uncoordinated flight and can significantly delay our recognition of dangerous attitudes. If you fly gliders in cloud, understanding these illusions is important to safety.

Somatogyral illusion. The semicircular canals sense only *change* in rotation, and the illusion is two-fold: when rotation begins, the rotation is properly sensed, but when steady rotation is maintained, such as with proper thermaling technique, in about ten seconds the sense of rotation vanishes, even though the turn continues. This is the first illusion; the second illusion is of false rotation in the opposite direction when the turn is stopped. Often the *Barany chair* is used to demonstrate these illusions. This illusion is prominent in instrument flight, but not in visual flight because visual cues are overriding. The famous *graveyard spiral* is a product of the somatogyral (somato = body; gyro = turn) illusion, and occurs because the pilot "corrects" for the false sensation of turning that is provoked by stopping the initial, unintended, turn. This results in a gradual turn in the opposite direction; the descent occurs because the pilot reflexively seeks to keep the vertical G-force the same as in level flight. This is what killed John F. Kennedy, Jr. – in VFR weather.

Oculogyral illusion. During the somatogyral illusion, an isolated object seen at a distance will seem to be moving with the falsely perceived turn. As this involves the eyes, it's called "oculo." This may cause the instrument panel to appear to briefly move when it should not. This illusion is an interesting curiosity, but I don't know that it has any special significance except to alert the pilot to the simultaneous, more subtle and more hazardous somatogyral illusion

The Coriolis illusion. This one is important for glider pilots. Here's the scenario: your body is turning at a steady rate, long enough – ten to fifteen seconds – for the fluid motion to become stable within the semicircular canal which is in line with that plane of rotation. Then you raise or lower your head. A different semicircular canal is abruptly lined up with the fluid flow, and suddenly the fluid is flowing through *another* semicircular canal, creating a sudden, strong sensation of turning in a *different* direction. You instinctively respond to that sense, causing the glider to change attitude to "correct" the illusion.

Does this happen? Of course, it does. It takes only about 10 seconds for the fluid flow to stabilize in a semicircular canal. How long do you remain established in a stable banked turn? Longer, sometimes for many minutes when thermaling, but even in a turn from one pattern leg to another the duration is longer than that.

What happens? You are in a stable banked turn, looking ahead, and...

- you look down to check a chart, or
- you look up to check traffic above you in the gaggle.

We are all well advised to keep track of the traffic around us. "Keep your head on a swivel," is the byword. But checking for overhead traffic is clearly dangerous if you've kept your attention forward continuously for as long as ten seconds. And looking down at your checklist or charts, flap handle or gear lever, likewise.

Remember, the key to this illusion is having your head's posture stable for more than ten seconds. Continual head movement helps protect against this illusion. In addition, one must have one's head stable at just the right angle – actually cocked downward slightly – in order to experience it most vividly. There are clearly accidents in which this illusion has been a factor.

Here's an example of how this works, from a 1998 accident, reported in the December, 1998, and February, 1999, *Soaring Magazine* (quotations are from those articles):

2.5 Coriolis Illusion Damages Glider Pilot

The pilot of the glider was circling above a ridge searching for lift, and circling beneath a 1-34 in hopes of sharing a thermal. In a report describing how he broke his glider and himself, the key sentence is, "...not finding any lift under the 1-34, he craned his head back to look directly overhead to center beneath the other glider." We'll assume that he was making left turns, although the direction is immaterial except to make the analysis clear.

Physiologically, the important point is that this pilot, an experienced and competent fellow pilot, was in an established banked turn at the moment he needed to look vertically. This would require him to throw his head back **and** turn it to the right.

If he had been in the turn for as much as 15 seconds (probable, given that this was thermaling flight), his vestibular system (semicircular canals and otolith organs) would have stabilized.

When a pilot in a stable turn turns his head to the outside and tips it back, an inevitable, strong sensation is created of banking more steeply and diving.

When this pilot looked directly overhead, his visual references to the cockpit and to the ground were dramatically changed and diminished. Technically, this is "degradation of visual referents," which predisposes to motion illusions.

To maintain a **sense** of remaining in a stable turn, he would have to pull back on the stick and bank toward level. He would have been strongly motivated to obey the seat of his pants by his sense that he was close to the ridge. Whether he was 300 feet as he thought or 955 feet as his GPS readout indicated, is not material; the point is that if the ridge "felt" close, the pilot would have been more motivated to maintain coordinated-feeling flight than if he had been comfortably high.

It is important to realize that these illusions **feel right**. There is no confusion until something happens to contradict the illusion. To continue, "At that point, he indicated that he might have become disoriented, causing the stick to be pulled back excessively, and for the ship to skid. It immediately went into a spin." Well, this is the language of someone who was surprised, who is looking back at the awful fact that a spin happened and trying to understand the cause. It does not say, "The pilot said he became confused." It is the pilot acknowledging that, because the spin happened, the aircraft could not have been in the safe attitude he felt it to be in and which he was trying to maintain.

In this particular case the pilot was flying a glider which doesn't give much warning - buffet or shudder - of a stall, so he had no opportunity to perceive the illusion that injured him until the stall was fully developed.

I hope you do not think, just because this pilot crashed, that he was incompetent, poorly trained, careless, negligent, or indulging in deliberate risky thrill-seeking. In fact, the articles cite several signs of careful planning for possible disaster and awareness of its possibility. The fact is that someone just as careful and skilled as you, could, while intending to be extremely careful, experience exactly the same type of motion illusion and crash, with the same humiliation, the same raised eyebrows, the same adverse presumptions about pilot judgment and skill.

Now let's turn to another key fact in this incident. The GPS data from the flight was analyzed. The pilot says, "The data shows that I was flying straight and level for approximately 1 minute after making the 180-degree turn in which I craned my head back to look up at the 1-34....So, the spin developed from some other reason rather than my distraction with the 1-34."

The GPS data proves that the pilot did respond "appropriately" to his vestibular sense, and did level out and straighten while looking up at the 1-34; the physiologic point is that during this time he would have **felt** as though he was continuing in a stable turn. If he had **not** had illusion, his vestibular system would not be functioning properly.

Got that, guys and gals? The illusion is **inevitable**. It occurs because the system is **working**. It occurs because cross-checks (visual referents, tactile referents) are **diminished**. Everything **feels right**. Suddenly something happens that shouldn't - a stall - and the pilot must quickly re-orient. We hope. What about recognition and recovery?

As the airplane quits flying, the pilot's vestibular system is continuing to function normally, sending wrong information to his cerebral cortex about the glider's motion, interfering with his ability to recognize and recover from the spin. From the pilot's point of view, something has happened, suddenly and unexpectedly.

He turns back to look "out the front window," and the message this head movement sends to his cortex is that the glider has pitched up and banked to the right. Meanwhile, the actual movement of the glider has been to pitch his head down, and to turn it to the right or to further to the left, depending on the spin rotation - or perhaps the glider is not rotating; his head movement has only given him the sensation of a spin and the glider is actually in a deep stall. In this case, it will feel right to apply opposite rudder, which will actually cause a spin.

Let's step aside from the vestibular illusions: please realize that this is not a training session, where we expect a spin for learning purposes. All the pilot knows at first is that the controls are slack and the world is cockeyed. Has he had a mid-air with an unseen glider? Has the elevator disconnected? It will take time to sort this out, time that may not be available, given the alacrity and enthusiasm with which gravity operates.

Now holding in mind that such a situation developed because of motion illusions, what will overcome the illusion? Only a stable visual reference. This may not appear until the spin is fully developed, nose down and dropping. Prior to this, the sense of rotation may be either exaggerated or wrong, and the pilot has no clue (more precisely, has inadequate clues) that this perception is wrong.

Is this sufficiently clear? ***There are circumstances in which a stall-spin is inevitable***, and ***there are particular conditions under which even a superb pilot will be genuinely incapacitated from recognizing the pitch of the aircraft and its direction of rotation during those few seconds in which recovery is aerodynamically possible***. These circumstances can arise in the **normal** conduct of glider operations: thermaling "low" over ridges or during approach to landing.

Back to our story. The pilot concludes, "So, the spin developed from some other reason rather than my distraction with the 1-34." He's exactly right. Is it clear to you now what the "other reason" probably was?

This sentence contains a common misconception: that it is "distraction" that is the problem. It is not. We must "attend to many cues," as the psychologists say, throughout flight, especially in traffic. Every "cue" distracts from every other, and we don't know in advance which "cue" may hide the teeth that bite us.

The problem occurs due to **head movement in turns after holding it stable for 10 to 15 seconds**. Head movement, in a turn, **always** creates a vestibular illusion. This illusion is usually over-ridden by redundant correct sensations, chiefly visual ones. Unfortunately, to avoid all risk of this illusion means not turning the head: not checking for traffic, not checking ground reference points when landing, not visually checking for flap, spoiler, and gear-handle positions, not checking charts. Impossible. But another way to decrease susceptibility is *not to hold the head still* for more than a few seconds, so that the vestibular fluids never quite stabilize. This is more realistic: *Keep your head on a swivel*, as pilots have been told for decades for other reasons.

2.6 Coriolis Illusion Kills Jet Pilot

Another crash illustrates the risk of checking charts in the pattern.

A fighter was observed by a flight surgeon to be approaching a landing in the early night. Just as it finished the turn to base, he saw the cockpit interior light go on. Then the wings rolled up to vertical, the nose dropped, and the fighter crashed, killing the pilot. What happened? It was the coriolis illusion again.

The flight surgeon knew the fighter's cockpit layout, and realized that when this light came on that the pilot was looking at a board located downward and to his right. To look downward and to the right at the completion of a stable turn to the left, creates the illusion of pitching up and leveling off. Thus the pilot, with his eyes in the cockpit and off the instruments, followed the "seat of his pants" into dropping the nose and rolling to the left.

During the post-crash investigation he explained this mechanism, but the base commander would not believe him, and said, "You can't be right. There must have been a problem with the aircraft. I'll go out and do the same maneuver myself and show you it won't cause an accident."

The flight surgeon, pretty confident that he'd learned physiology correctly, said, "Only if you take a safety pilot!"

That model of fighter is available as a two-holer; one was on base, and so the challenge was on.

The commander flew the pattern, at night and in vfr conditions as during the accident, and simply looked down and to the right at the chart as he completed the turn to base. The safety pilot recovered the aircraft less than 100 feet off the ground. QED.

A glass slipper can fall out of the sky from base or final just about as quickly as a jet. It's not only warplanes that carry charts, that have controls down and to the side at which we may wish to look. Don't do it. Keep your eyes out of the cockpit during pattern turns. Use peripheral vision to locate the spoilers and the gear lever, and move your eyes, not your head. Use feel to check their position and make sure they're locked.

2.7 Gravity Magnifies Tilt

Somatogravic illusion. This is an important illusion that can cause slow airspeed on final. (Yes, "gravic" relates to gravity.) This illusion is caused by a properly functioning otolith organ, which senses gravity and linear acceleration.

Here's the deal: a forward acceleration and a tilting backward cause exactly the same change in the otolith; a slowing and a tipping forward also cause identical response. Which one seems actually to be happening depends on your brain properly integrating vestibular signals with visual cues.

You are on final in your glider. You sense you are high, and apply full spoiler. This slows the glider abruptly, and the deceleration causes a signal from the otolith organ, "Nose-down pitch change!" Ground references are not fixed – they're flowing backwards past the nose – so they don't correct the impression readily. If you simply react confidently to this sensation with a nose-up pitch change, your airspeed will diminish and you may quickly develop excessive sink.

You say, "Wait a minute, I can ***see*** the nose pitching down!" Sorry, pal; that's a related illusion, the ***oculogravic*** illusion. The false sense from our vestibular system causes us to "see" what we feel, and momentarily prevents our vision from correcting the false sensation.

You are taking a winch or autotow launch. As you transition to climb, there's a surge of acceleration as well as a dramatic increase in nose-up pitch. The acceleration greatly magnifies the sensation of nose-up pitch change, and if you fly by the seat of your pants you will level off prematurely. The antidote is to discipline yourself to look out at the wing angle and at the airspeed indicator instead of what feels right.

This illusion is a special danger to airplane pilots taking off into IFR or night skies. Many accidents have involved such an airplane flying through the fog or the night into the ground, just a few miles from the airport. Acceleration during the ten seconds after takeoff from 100 to 130 knots creates only a 1.01 G gravitoinertial force, but gives the unsuspecting pilot the sense of a nine-degree nose-up pitch attitude. As single-engine aircraft typically climb at about 6 degrees, a seat of the pants correction yields a three degree descent, exactly a normal instrument final-approach slope.

You can imagine the special danger in taking off at night or in fog from an aircraft carrier, with the dramatic, 3 to 5 G acceleration of a catapult, and the false sensation of nose-high pitch can last for 30 seconds or more after the acceleration slows. This has caused pilots to nose down into the ocean.

This illusion can also lead to a form of graveyard spiral. If the pilot maintains a sensation of constant G force while failing to perceive a slow roll, the only way to maintain the proper G force is with a descending turn. In 1978, a Boeing 747 left Bombay at night, taking off over the dark sea under high overcast. The flight data recorders indicated that the pilot, flying at night by the seat of his pants instead of his instruments (which he misperceived to be malfunctioning), maintained a constant G force of 1.0 +/- 0.1, as if he were in a 10-12 degree climb; he actually leveled off as an unperceived turn began and then descended in a spiral, crashing almost inverted.

2.8 Gravity and Gliding Accidents

Inversion illusion ("Sub-Gravity"). In its extreme form, from which this illusion has received its textbook name, the pilot feels the aircraft has pitched upward and over on its back. The classic situation happens when a jet fighter abruptly levels from a steep climb and accelerates, especially in turbulence. The vestibular system sends the message, "Hey, you're tumbling over on your back!" and the pilot instinctively puts the stick full forward. The resulting acceleration doesn't make the illusion any weaker! The result may be a vertical dive into the ground, which is always down there somewhere.

This is a dangerous illusion for glider pilots, for whom it evolves differently than in this textbook depiction. The illusion for glider pilots is of a dramatic nose-up pitch change (rather than actual inversion), which occurs because of a sudden nose-down transition and acceleration, producing less than 1 G on the pilot's body, a forward rotation, and some degree of forward acceleration. Forward acceleration is not essential to the illusion, but magnifies it greatly. Thus, both the semicircular canals and the otolith organ participate in the illusion, which can be very powerful and has killed quite a few pilots.

Derek Piggott has thoroughly analyzed this illusion in his monograph, ***Sub-Gravity Sensations** and Gliding Accidents* (1994, published by the author). He does not explain the physiologic operation of the vestibular system in this phenomenon (it is complex), but he describes the situations well in which it arises, and shows exactly what pilots do in response to these situations. He has observed that this illusion is more likely to occur in low-G situations.

Piggott also shows vividly that fright or panic may completely mask corrective sensory information, "locking" the pilot into the illusion.

And he does us a service in observing that the susceptibility of pilots to this illusion, and the degree of panic they experience, differ greatly between individuals. He suggests an approach to training that identifies susceptible individuals and prepares them to responds to the illusion.

The situations in which this illusion occurs in gliders are less dramatic than in fighters but not less dangerous. First, consider those situations in which you the pilot might make an abrupt nose-down pitch change; in all such situations the glider will either accelerate or stop slowing (which are equivalent to our otolith organ).

- Recovery from a cable break during a steep winch or autotow launch.
- Abrupt recovery from a stall.
- Abrupt nose-down pitch in turbulence and wind shear.
- Pilot-induced strong pitch oscillations.
- Any time the stick is abruptly put well forward.

2.9 G-excess effect

This illusion's physiologic origin is complicated, but a simple explanation will give you the idea. If you tilt your head while sitting in a chair on the ground, your vestibular organs correctly estimate the degree of tilt. However, if you are sitting in a seat in an aircraft that is banked or swooping and tilt your head, the excess G force magnifies the amount of sensed tilt. In a 45-degree bank, our usual attitude, the turn's 1.5 G introduces a 5 to 10 degree error in perceived bank when we tilt our head to look outside to check traffic or terrain. The bank seems to level when we look to the inside of the turn. If we react instinctively to this, as skilled and experience pilots tend to do, the yaw string will be adrift when we look back. Not a problem unless slow speed or turbulence puts you at the edge of stall, at which point an incipient spin could develop. Perhaps you looked out because you're in a gaggle. You see where I'm leading. Has this caused mid-air collisions? I don't know. It clearly has caused accidents in attack aircraft, for example, when the pilot looks outside at the opponent during a 5-G tight turn.

2.10 The elevator illusion

Because the utricle is not exactly horizontal, vertical acceleration causes a sensation of tilting. To go up in an elevator causes a sensation of both climbing and tipping backward; to go down in an elevator causes a sensation of descending and tipping forward.

So when you fly into a strong thermal, the aerodynamic pitch-up that occurs is magnified falsely by the elevator illusion; and when you fly into strong sink, the nose-down pitch change feels greater than it actually is.

And if you level off abruptly during a descent, there is an immediate, erroneous feeling that you raised the nose too much. In fact, if pilots close their eyes immediately after leveling off, they resume a descent at about 2/3 of their previous descent rate.

2.11 The Leans

Everyone who has ever flown in actual instrument conditions has experienced the leans – the persistent sense that the aircraft is turning when the instruments say it is not. As you know, this sense can be powerful and persistent. And the leans are not due to any single vestibular or visual illusion, but can be caused by many different stimuli. They contribute to erratic and uncoordinated flying, and for glider pilots are a factor chiefly in cloud flying.

2.12 Spatial Disorientation

It is very important that you understand that "spatial disorientation" does *not* mean "totally discombobulated." It means that you have misinterpreted the glider's attitude, speed, or position with respect to other ships or the ground, *however slightly*. This is why would I prefer we would speak of "spatial misinterpretation," but the terminology is frozen in tradition.

Spatial disorientation may affect us in three ways:

I - unrecognized. Of course, at first it is always unrecognized. That's what "dis-" is all about. But fortunately you have flight instruments and eyes, and a multitude of sensory inputs. So pretty soon you realize that maybe your sensations aren't accurately representing the real world.

But knowing "something" is wrong is far different from correctly analyzing *what* is wrong and acting accurately and confidently and expeditiously based on this analysis while your instincts are shouting "NO!"

II - recognized. You have both recognized that something is amiss and have correctly analyzed what the error is. Now we hope that you have the training and skill – and altitude – to recover.

III - incapacitating. We must acknowledge that disorientation can truly be incapacitating. In its most severe form nystagmus develops, and the pilot's eyes are unable to focus or fixate on the visual cues that will permit reorientation. Panic or fear may cloud reason, delaying recognition or hindering analysis. Or we may fly into bad visual conditions in which re-orientation is difficult or impossible. In the end, incapacitation only lasts until we strike the ground...

2.13 Dynamics of Disorientation

Visual dominance and Vestibular suppression. Normally visual cues dominate our interpretation of our orientation in space, and vestibular cues are relatively suppressed. Disorientation occurs when visual cues are reduced, vague, or ambiguous; or when, due to unusual aircraft movements, vestibular sensations become obtrusively strong. It's important for us each to acknowledge within our selves that our bodies, functioning normally, can produce subtle or powerful false sensations that seem right and valid. These illusions can best be recognized by understanding what they are and looking for them.

Opportunism refers to the tendency of either the visual or vestibular system to "opportunistically" – reflexively, without conscious decision – fill a void in the welter of information that maintains spatial orientation. This is a powerful tendency that operates without regard to whether the opportunism provides a more correct sensation than other simultaneous sensations.

Fixation refers to what happens when the pilot begins to concentrate on one object to the exclusion of others. This typically happens when something is going wrong; the neophyte glider pilot may fixate on the yaw string in order to maintain coordination, on the vario to verify lift, or on the airspeed indicator to ensure against variation. Less often a pilot will fixate on traffic, clouds, or ground objects.

Fixation is a special danger because this stops head movement and increases the pilot's susceptibility to vestibular illusion when head movement resumes.

2.14 Motion Sickness

Motion sickness is a different sort of malfunction of the vestibular system than the illusions we've discussed. This can occur from turning movements, such as thermaling or riding a merry-go-round. The strongest, most persistent motion sickness comes from sub-gravity sensations such as weightlessness.

The important lesson for soaring pilots is to admit to ourselves that motion sickness degrades our flying skills and judgment, and to respond to it by getting out of the sky.

3 Water Balance: We're Soup

Though Scripture does not point this out, when the Lord God formed Man out of the dust of the earth, He added water, most likely before breathing the Breath of Life into his nostrils, as the nostrils would otherwise not have held together. Since then, the American Heart Association has wrapped its hands tightly around jurisdiction of mouth-to-mouth resuscitation, but has not required of God that He annually re-certify to maintain His competence.

Hundreds of eminent biologists have devoted entire careers to working in windowless laboratories to prove in tiny detail the exact manner in which we are constructed of various solutes in a water solvent, combined in an elaborate framework of enzymatically-controlled reactants. While we are thankful for their detail, which makes modern medicine possible, among other blessings like chicken soup and fried eggs, we can boil down the requirements for optimal functioning of the organism to just a few elements:

- Solvent: Water, in the right amount.
- Solute: Electrolytes, in proper proportion.
- Reactants: Fuel in various forms, ideally delicious.
- Electrons: Oxygen is our electron donor, for oxidative metabolism.
- Temperature: The proper ambient temperature is maintained, subject to foolish interference, by oxidation of fuel, homeostatic mechanisms, insulation, and a nice fireplace.

3.1 Hydration Status

The fact that we're about 85% solvent does not signify the extent of the problem we face in maintaining optimal hydration status. The important facts are that our expired air is fully humidified, that we are required to make a certain amount of urine daily, and are covered with millions of pores, each containing a little water pump that is more responsive to our core temperature than to our hydration status. We are little more than elaborately leaky sponges that must be saturated with water to function well.

The bottom line is that we must steadily consume beverages in order to keep the inhabitant of the sponge – ourselves – happy and well coordinated; exactly what we consume and how we manage our relationship to the energy status of our environment determines how successful we are in maintaining our performance status. More simply, *dehydration hinders brain function, overhydration is inconvenient, but safer.*

Having said this, I do need to caution you that overhydration can be taken too far: it's not only that you might flood the cockpit; your kidneys can get rid of extra water only so fast. Under normal circumstances your kidneys and sweat glands can get rid of water faster than your stomach and intestines can absorb it. But sometimes folks develop "defective water excretion" on account of disease or medication, and then excess water can accumulate, diluting the solute and eventually hindering brain function. This causes irrationality, hallucinations, or even seizures (convulsions). This is called "water intoxication," a bad name because it's much more subtle than drunkenness and very difficult to recognize in ourselves or others.

3.2 Volume status

Hydration and fluid volume are related but different features of the water-management problem.

- "Hydration" refers to how much water is in the soup;
- "volume" refers to how much soup there is.

This is important to the pilot and to the walker, because volume is what maintains blood pressure, and without blood pressure we faint. If you become ***dehydrated***, your blood volume contracts and you will tend to grey out when pulling g's, but you can quickly restore this volume with water. If you become *volume depleted*, you must replace solute (salts, essentially) as well as water in order to restore blood volume. This is what made Gatorade a household word. But if Gatorade were the only way to restore electrolytes they would not have to promote it. (In fact, Gatorade contains too much salt.)

There are a number of things you can do to make management of your fluid balance easier and yourself a safer pilot.

First, look for and recognize the signs in your body of proper fluid balance. *Mental mistakes and incoordination are **late signs**, not early signs, of dehydration.* **Thirst** is the best clue you have: *if you are thirsty, drink.* Thirst is very imprecise; runners, for example, think they are drinking about ten times as much water as they actually are. On the other hand, people get in serious trouble only when they don't respond to thirst or are forbidden access to water, such as by macho football or wrestling coaches.

It is impossible to know exactly how much water and salt you are losing. You can measure your urine easily, although no one does, but we can't measure sweat, especially the part that evaporates. On the other hand, it *is* possible to estimate your total water loss during any period of time. All you need is a reliable (not necessarily accurate) scale. A pint is a pound; a liter is a kilogram. With an empty bladder, weigh yourself before flight, and weigh yourself afterward. If you have lost weight, you have failed to maintain normal hydration. If you have gained weight, you have overhydrated (probably by taking in salt and water). Loss of more than 3% to 5% of your body weight is associated with performance impairment. Three percent for a 120-pound woman is 3.6 pounds; for a 210-pound man, it's 6.3 pounds.

If you have experienced dehydration, you will be aware of other, more subtle symptoms that are partly specific to yourself.

Overhydration is mostly inconvenience: In a normal, 70-kg healthy human, the kidneys are able to get rid of about 16 ml (.5 ounce) of extra water per minute. In other words, if conditions are cool and you are not working hard, you should not drink more than 2 pints of fluid (1 quart, 1 liter) an hour above your losses. If you are working hard in hot conditions, up to 16 liters a day of sweat can be lost; this is more than one can keep up with by drinking. Eventually you'll weaken and lie down to drink...

Frequent urination is a clue to overhydration. If we consume extra water, our kidneys begin excreting it in about 15 minutes, and are fully ramped up in about 45. After the body has adapted to having too much water, it takes about four hours to revert to water conservation, so that if you overhydrate and then stop drinking, you may become mildly dehydrated while you shift into water-conservation mode. It's just another reason to listen to your body's hints in order to stay reasonably well hydrated and avoid extremes.

3.3 Water Balance

We ooze water: our sweat glands are never quite completely at rest, our kidneys are obligated to make at least some urine to rid us of soluble wastes, our exhaled breath is completely saturated with water, our nose may run, we may weep. We're unaware of this constant water loss; physiologists call it "insensible loss." We're pretty well aware of making pee, and this plus the sweat that doesn't evaporate are the "sensible" losses.

We need to replace the sensible plus the insensible losses in order to maintain proper water balance and hydration. This is a guessing game, because we can't measure sweat, and can't even estimate it when it evaporates quickly in a dry, hot climate; and we don't bother to measure urine volumes, as this would provoke gossip.

3.4 Clues: Thirst

Fortunately we have this little gizmo built into our brain, the *osmostat*, that detects when we've lost water and generates an appetite called "thirst." If you're overloaded with water, there's no thirst; if you lack water, you gradually get more and more thirsty. You'll seldom get dehydrated if you drink water when thirsty.

Can we be fooled? Yes, we can. Glad you asked. First, a dry mouth often accompanies thirst, so in very dry air, those of us who are mouth-breathers due to stress, allergies or colds get dry mouths long before we need water. And folks taking medications that cause dry mouth – none of which you should take prior to flight – are rarely tricked by this into a condition of water intoxication. For this reason elderly people with defective salivary secretion sometimes become seriously over-hydrated, especially in the northern states in winter. But dehydration does result in thick spit, so this is a clue unless you're a dedicated mouth-breather.

Also, when it's very hot ***and*** you're working very hard – before or after a flight, perhaps, but probably not during one – thirst is delayed. So thirst does not perfectly reflect our hydration status and water needs, but it is a reliable clue you can use to decide to drink. People get in trouble from water deficits only when they don't have or aren't allowed access to water when thirsty.

Thirst is a fairly reliable guide to dehydration, but responds late to volume depletion. An injured person who bleeds heavily becomes intensely thirsty, but we don't like to wait for this degree of volume depletion before re-hydrating. The more sensitive part of your thirst mechanism detects dehydration – the relative excess of sodium in the blood that accompanies water loss – and generates a thirst sensation.

One reason that "thirst" is unreliable in adults is that we have learned to suppress our visceral sensations and functions. It's worth getting reacquainted with what thirst really is by experiencing it, and watching it go away with drinking. Hunger, thirst, and dry mouth are all closely related, but in my experience can be differentiated adequately.

If you eat excess salt, you become thirsty until you take in enough water to restore a normal electrolyte balance (normal osmolality), and you are in a state of *volume excess* until your kidneys dispose of the extra salt.

Moral: *if you're thirsty, drink. If you're sweating, drink. If you feel hot, drink.* Trust your body on this.

3.5 What to Drink

Water works well. It's what you need, unless you've been exercising hard. With vigorous exercise in hot weather, it may be impossible to keep up with fluid and electrolyte loss by drinking. But while pushing your glider to the line may qualify as "hard," glider flying is mostly just "hot," and only while you're low. If we have good weather, as soon as we find lift we can get into the air-conditioned heights. So water is sufficient to preserve volume most of the time.

But there are alternatives to water, especially after the flight. Let's briefly review a few. Let's call fluids that are equivalent to water, "beverages."

Milk: Milk is *food*, not "hydration," as it contains a lot of salt (sodium, actually). With 125 mg sodium per 1-cup serving (290 mEq per liter), it is nearly "isotonic" with body fluids. So it will replace "volume" but will not make up a water deficit. It tastes good, a cold glass feels refreshing, but don't try to hydrate with it. Milk is not a beverage as we've defined it here.

Coffee: Caffeine is a diuretic, meaning that all caffeinated beverages, including coffee, tea, and soda get rid of most of the fluid in which you drink it. "Decaf" coffee is ***not*** caffeine-free, but contains 17-25% as much caffeine as regular coffee. Caffeinated drinks are stimulants, not "beverages."

Pop: Before flight, the fizz will fill your stomach with carbon dioxide gas just before you take flight. Gas expands at altitude. If you have any trouble burping this up, you will get bloated or airsick.

Many soft drinks have quite a bit of sodium, even though they no longer are made with "soda." Sodium, in large amounts is a diuretic. This is not a concern if you've been sweating heavily, as you may need the sodium.

Sport drinks: These are divided into high-sodium (Gatorade) and medium-sodium/high-potassium versions. Gatorade has 110 mg sodium per 8 oz, about half as much as milk, and a lot more than is needed. Extra sodium just increases the amount of urine you have to make.

Other sport drinks have about 50 mg sodium per 8 oz, a better level for most people. But they do have about 50 mg potassium also. If you have kidney disease and have been warned by your doctor to reduce potassium, or if you have high blood pressure and take a "potassium-sparing diuretic," you should avoid these.

Juice: Fruit juices contain sugar and moderate amounts of potassium. Because of this, they aren't quite as effective as water, and do have some food value. The electrolytes in juice are not as precisely measured as sport drinks. But fruit juices ***are*** beverages that can replace water.

Tomato juice and V8 juice are *very salty*, are *not* fruit juices, and should not be used for hydration.

3.6 Sweat

Sweat (sudoresis, diaphoresis, or perspiration) is a clue to the success of your hydration efforts and the aggressiveness with which you need to hydrate. Whether you are acclimated influences what type of solution you should use to rehydrate.

Sweating is annoying and inconvenient. It runs onto our glasses and down our chin. When we close the canopy, it condenses and fogs both it and our glasses. It corrodes metal. And it makes us itch. We're grateful when it stops. Unfortunately this gratitude may be misplaced, as on a hot day sweating may stop (or seem to stop because it's diminished) simply because the tank is low.

So on a hot day, *to sweat is a sign that you're well hydrated*. And *if you feel a little warm and are not sweating, you're getting in trouble!*

You lose a little salt along with sweat, especially when sweating profusely or if you, like me, spend a lot of time in an air- conditioned office and have not become acclimated to heat. Acclimatization involves several slow adjustments of our physiology, one of which is for the sweat glands to conserve salt. On a dry, warm day, when sweat evaporates rapidly, the non-acclimated person will get a little crusty from the salt left behind, and the dog will be happier when he licks your hand.

A non-acclimatized person's sweat is about 0.3% salt. (Blood is 0.9% salt.) After 3 or 4 days of continual exposure to heat, a person's sweat is about 0.03% salt – 1/10th as salty – and the acclimatized person is able to produce a greater volume of sweat as well. So the non-acclimatized person shouldn't eat a low-sodium diet while acclimatizing. In these days of air-conditioned cars and offices and homes, nearly every pilot is non-acclimatized. And acclimatization is lost in just two days.

When sweat is salty, you lose volume, not just water. You may not get normally thirsty because the osmolality of your blood changes little, and instead you simply feel worn out. Which you might expect at the end of a long flight anyway, and fail to realize that your chief need is not sleep or rest but a long draught. The amounts of salt actually lost by a person who's not acclimated is small – there's no need to eat potato chips and corned beef or bologna.

The sweat of an acclimated person, or the person sweating slightly, is not very salty. Thirst tends to occur more appropriately, and the chief effect of such sweating is dehydration. But in acclimatized people thirst is actually delayed, for unkown reasons, until about 3% dehydration occurs.

In addition, if people try to keep ahead of sweating by drinking water avidly, their stomach tends not to empty properly, and they just get bloated or nauseated. It's better to wait for a little thirst, perhaps an hour or two.

So if you are thirsty, drink water. If you are drenched with sweat or your skin is getting crusty, drink sport drinks or have some chips with your water. Or dilute tomato juice of V8 half and half with water.

Our bodies lose about 50 ml/hr of sweat as an obligatory minimal amount; just enough, I suppose, to keep the pumps in shape and the pores open. On a hot day and with vigorous physical activity up to 1600 ml/hr can be produced. That's right, folks. 1.6 liters/hour. Fortunately piloting aircraft is not a vigorous physical activity, but sometimes it's quite a warm one. So bear this range in mind.

Now, let's combine this with the fact that the kidneys can't get rid of more than 16 ml of extra water each minute (.9 liter/hr). This implies that 2.5 liters of fluid per hour should be a reasonable upper limit for fluid consumption in hot weather. This is about a pint every 12 minutes, more than the stomach can absorb. I recommend that you measure what you bring or buy so that, in hot weather, you have a couple of liters for every hour you will be working in hot conditions, and then respond to your thirst.

What is the minimum water consumption? We must replace the water vapor lost in breath and obligatory sweating, and the kidneys must excrete a minimal amount of waste solute that must be carried out with water. Altogether, this is somewhere between 750 and 1000 ml daily: three to four cups of water a day.

Beyond this, we must replace what's lost in sweat, and the difficulty of accurately estimating this has led to all sorts of anxiety, mostly about other people, and various oversimplified rules on how much fluid pilots should drink. I repeat my advice: have more water available, in some form, than you think you'll need, and let thirst be your guide.

Leeway

Sometimes people talk as if staying properly hydrated is difficult. The reality is that not only do we have thirst to protect us from ignorance, we also have the luxury of very adaptable kidneys. Ignoring sweating, we can survive in vibrant good health on .5 to 20 liters of water daily, a huge range. There's lots of leeway, and you really aren't likely to get in trouble unless you skimp on your water supply and become unable to slake your thirst.

3.7 Water conservation

Your body does have several ways in which it tries to conserve water. The most obvious is that all body secretions diminish as you dry up. *One clue of mild dehydration, for example, is whether you need to take a sip of your beverage in order to chew your toast comfortably*. Ardent spit production means you're well hydrated.

The colon, an emissions-control device, has as one of its main functions the removal of water from its contents. It receives twenty liters a day of watery post-digestion fluid, nearly all the nutrients removed, and reabsorbs the water and most of the electrolytes. Cholera prevents this reabsorption, and causes death in hours through volume depletion. (And as it causes loss of water in excess of sodium is associated with weakness more than thirst.) "Food poisoning" and other causes of diarrhea are conditions in which actually the colon is not working rather than being overactive.

One clear sign of dehydration is firm stools. In my part of the country, hot weather arrives in June. People don't hydrate until they start sweating or feel hot and thirsty. But before that happens, the weather turns comfortably warm and they perspire insensibly. They don't get dehydrated or volume depleted because the colon faithfully extracts every last drop of water from the stool to protect life. The first firm clue that the weather has turned warm comes the next morning when they try to expel the brick that was manufactured to prevent thirst. For the pilot this provides an annoying check regarding whether, on the average, your hydration attempts have been adequate. *If your stools are soft, your water balance is OK; if they are firm, drink more, not harder*.

Your kidneys are designed to regulate blood volume. It is their job to get rid of extra stuff and conserve scarce stuff. Sometimes water is the "extra stuff" and sometimes it's the scarce stuff. Healthy kidneys can conserve water to the extent of making only about 1/4 liter of urine daily or can get rid of extra by making about 20 liters a day.

A biological mystery not yet solved is the origin and purpose of *urochrome*, the chemical that makes urine yellow. As a constant amount of this stuff is made, the intensity of color varies with how concentrated the urine is. This provides another clue to the success of your hydration efforts: *if your urine is dark yellow, drink harder; if it is pale, you're doing fine*. The kidneys react very quickly to your volume status, so if you pee just before a flight you can judge immediately whether you've hydrated well enough.

4 Diuresis

There are several ways in which pilots make it hard for themselves to stay hydrated. These all involve "diuresis" of one kind or another. Diuresis is the process of making extra urine. Physicians produce diuresis deliberately when medical conditions hinder the kidneys from getting rid of extra salt or water. Pilots produce diuresis unintentionally, a problem only when the main goal is to conserve water, and a nuisance if no waste-disposal plans have been made for a long flight.

4.1 Sugar

For most pilots, sugar is not a problem, and medical certification is difficult for diabetics. But if you are, especially you who are and don't know it, or you who think their diabetes is mild and requires little attention, listen up.

Sugar in the blood above a certain amount, which is different for everyone, spills into the urine. The level at which sugar begins to "spill" is called the "renal threshold." This can be fairly close to normal, as low as 150 mg/dl. This is significant because a normal *fasting* blood sugar is 70 - 110 mg/dl, and a normal after-meal blood sugar is up to about 150 (some would say 180). A person can have mild diabetes with no symptoms at all, and even a normal fasting blood sugar, and after eating (or more significantly, after over-eating) can run the blood sugar up to 250 mg/dl or more and have it stay there for hours.

When sugar spills into the urine, it creates an "osmotic gradient" that pulls water into the urine (or hinders its reabsorption). This results in excess loss of water. As the water is lost through an osmotic process, you feel thirst as a result and drink more water, so generally people are able to maintain their blood volume easily. But it does require that you drink a lot more water than might otherwise seem reasonable and sufficient, possibly a problem during a long flight in a warm cockpit on a hot day.

And people age, people who haven't had diabetes but might have older relatives who have had it, people who might be a little more portly than they used to be or intended to become. These folks, not you or me, but some other folks, might develop diabetes without ever being aware that it is happening, without ever feeling badly. It can sneak up on a person, just as old age tends to do. Think about it.

While we're thinking about sugar, let me mention that it sometimes causes fatigue. Everyone handles sugar a little differently, and if you happen to be one of those folks susceptible to "hypoglycemia," it's worth thinking about. If you fast, your blood sugar drops gradually. Some folks run through their stored sugar – liver glycogen – faster than others; other folks (more often the portly ones) tend to have higher than desirable levels of insulin hanging around, which hinders release of glucose from storage.

The result, in either case, is fatigue, usually coupled with hunger, or perhaps shakiness or weakness. If you happen to be unlucky enough to have diabetes, either known or undiscovered (most people with adult-onset diabetes don't know it), the hyperglycemia that follows a hearty meal can last two to four hours, and itself can bring about a sense of fatigue and subtly impairs cognition.

4.2 Caffeine

Caffeine is, plain and simple, "a diuretic to the kidneys" as the Doane's Pills ads used to say. It is relatively harmless, it is a useful stimulant, but it *is* a diuretic, and if you drink it, you will get rid through your kidney most of the beverage in which it is imbibed.

The moral here is, *if you don't want to be inconvenienced by copious urination during a long flight, don't drink caffeinated beverages before flight*. And if you are trying to hydrate on a warm day, either avoid caffeinated beverages or double the amount you might otherwise drink.

Soda is the source of caffeine by which you might be caught unawares. In my area, for example, Barq's root beer is caffeinated, but Barq's diet root beer is not. The only clue is the fine print on the label. In addition, the word "soda" is contracted from "sodium," the cation of table salt. See "salt," page 2.

And "de-caf" coffee is not caffeine free. Depending on how it's brewed, decaf has 16-25% as much caffeine as a cup of regular coffee. Less, but not none.

4.3 Alcohol

Well, none of us would ever drink alcohol before flying any more than we would take a sleeping pill before flying. But I mention it in this list because of its effect on post-flight hydration. Alcohol is a diuretic. *If you drink alcoholic beverages while you are re- hydrating, you must over-hydrate in order to compensate for the diuresis.*

As long as we're on the topic, let me remind you that last night's party will affect today's flight. Modest alcohol use – 1 to 3 ounces for a man, 1 or 2 for a woman – is not likely to cause trouble. But alcohol's metabolites, chiefly aldehydes, stick around for many hours, well into the next day, and do cause fatigue, decreased tolerance to metabolic stresses like hypoxia, and decreased performance. So if you're in the least bit hung over, don't do a task.

4.4 Water

This is a surprise, isn't it? Water is a diuretic? Here's how:

Mark McMurray, eager to avoid the dangers of dehydration, avidly and steadily drinks water in various forms. His stools are soft, his mouth moist, he sweats easily, his urine is as pale as water and he's hourly in the rest room or irrigating a bush.

What Mark doesn't know is that his kidneys must establish an osmotic gradient within their substance, that body water conservation requires a metabolic and hormonal shift that requires an hour or more to become complete. By keeping himself in a persistently over-hydrated state he causes himself no injury, but after a few days puts himself in a situation in which his biological momentum is entirely in the direction of getting rid of excess water, requiring that he continue to drink ardently. And if he runs out of water, he'll have to become somewhat volume depleted in order for his kidneys and endocrine system to shift quickly into water-conservation mode.

So the risk to Mark is small, but by over-hydrating he does make adjustment a little harder when he makes that off-field landing and begins working to conserve his water supply. *Better that he should keep a little color in his urine by not hydrating quite so single- mindedly*. Remember what we said about water intoxication up above, page two

4.5 Salt

Americans love salt! Restauranteurs and food processors love it even more, because salt enhances flavor, and flavor sells food.

This is a problem for the pilot trying to hydrate because the kidneys are obligated to get rid of excess solute. If they do not, our obligation to preserve osmotic balance (via thirst) causes hypervolemia. Not a big problem to the healthy young pilot, but possibly a troublesome one to the older pilot with a gristly heart and stiff arteries. Excess volume for these folks can cause high blood pressure, swollen ankles, and even pulmonary edema.

Even for a healthy young pilot, excess salt can take two or three days to dissipate. Meanwhile you're drinking extra water to maintain normal osmolality and peeing twice as much as usual to get rid of the excess salt (obligatory solute excretion, if you care to know).

Other solutes can contribute to this problem, but salt is the main one. The average American consumes about 10 grams of sodium daily; the minimum daily requirement is more like 10 milligrams. It's hard to follow a diet, even with diligent effort, containing less that 2 grams. So sodium deficiency is definitely not one of our worries. As we've observed earlier, water follows salt, so if we get faint from excessive sweating, eating a little salty food and drinking water guarantees that we'll restore lost volume.

But how is salt a diuretic? Well, extra salt ***must*** be gotten rid of. And the body uses water to carry away this salt. The brick that you passed while on the commode this morning was almost salt-free, I'm sorry to say. So for every dollop of extra salt that you eat, you must also excrete an aliquot of water that you might have otherwise used as sweat to keep yourself cool or to make spit to keep your mouth moist, or to keep mucus moist so that the inside of your nose doesn't crust up.

The summary is that *eating extra salt causes extra urination, an inconvenience during flight; it wastes water (as urine) that might be better spent as sweat.* It thus creates a requirement that you drink extra water, making it harder to hydrate adequately just as caffeine does.

Conclusion: you're best off avoiding salty food unless you, the non- acclimated pilot, have been sweating heavily. Salt creates a need for excess water that is swiftly excreted to get rid of the extra salt and it does nothing to protect your hydration status.

4.6 What to drink?

In a nutshell, **water** is the best beverage. It doesn't contain anything detrimental or unnecessary.

Juices have extra sugar, which is fine if you need the nutrition, and have potassium, which may help solve the electrolyte problem.

Soda pop may contain *sodium*, which decreases its effectiveness as hydration, though it might help replenish volume. And it contains carbon dioxide, which may result in a lot of bloating or burping aloft, and may magnify the nausea of motion sickness. Not a good choice, don't you think?

Milk is nutrition, not effective hydration because the sodium content is relatively high – nearly the same as blood.

Soup is rarely useful for hydration; canned soups are very salty, and most soups made in restaurants are essentially brine. If you make your own, without salty foods or salt, then the liquid might add to your hydration status.

Beer and other alcoholic beverages should never be used before flight because alcohol degrades brain performance; after flight their diuretic effect will delay effective rehydration. First quench your thirst with water; then relax with wine or beer.

4.7 Fatigue as a Clue

Fatigue is one of those symptoms that drives doctors crazy, because everything causes fatigue. Here's the deal. The important causes of fatigue to the pilot are:
- hypoxia
- dehydration
- volume depletion
- hypoglycemia
- (hyperglycemia)
- exhaustion

The message is simple: if you're feeling tired, think very seriously about getting out of the sky. Real men know when to quit. Then try to fix it. Check out the obvious:
- Is your oxygen system working? If you're between 8,000 and 12,000 ft msl without O_2 (5000 ft msl or above if you're a smoker), consider hypoxia as a possible cause of your fatigue.
- Are you even a little thirsty? Take a drink of water, to make sure you aren't dehydrated.
- Eat a snack. Calories provide fuel, and the electrolytes in food, plus water, provide *volume*.

5 Cockpit Waste Management

Unless something *really* scary happens, the only waste disposal problem in the cockpit, besides power-bar wrappers, is likely to be what to do with the urine created by your vigorous hydration-work.

For some reason, women have in general just gone ahead and pragmatically solved the problem for themselves while men have endlessly debated techniques. The solutions have been characteristically interesting. A bottle is a favorite; peeing uphill can be a challenge, the cap may leak or be knocked off, and the occasional pilot forgets to stow and zip after landing. One pilot famously finished his 6-hour flight by unbuckling to pee and afterward did a celebratory loop. He did this badly, pulling some negative g's at the top and falling out through his canopy, presumably with his pee-bottle close behind, thus discovering his own pilot impairment: he'd not re-fastened his seat belt. The bottle did not have a parachute, but the pilot did, which is why we know the story.

I heard of a doctor, a soaring pilot, who apparently catheterized himself and wore a leg bag that was not quite hidden by his Bermuda shorts. I have not heard of any copy-cats.

The condom catheter (or Texas catheter) is a favorite with some pilots, as it's non-invasive. A leg bag can be connected, or the tubing can be led outdoors. The risk with these is of course plumbing leaks, disconnections and fractures. There was a story in *Soaring* magazine, *Pilots, Planes and Privies*, in June, 1999 (pages 16ff) about a pilot who used one of these, the tubing kinked, and when he could hold back no longer, the condom filled and then exploded in the cockpit. These things do happen...

Darth Vader prefers one-quart baggies (I presume they're zip-lock – twisties might be a challenge in contest conditions) which come back unless very full. Those are used to bomb competitors. No word on any missing hikers...

A recent fad has been a relief tube led out through the gear-well door. Apparently this is satisfactory to many airmen. One potential problem is that urine is very corrosive; another is that it acquires a characteristic aroma as it ages. No word about style points from the mechanics doing the gear maintenance, or whether there's an aroma- surcharge; no word from pilots on what they do when their dilute, well-hydrated urine ices up on wave flights. Urine is a strong salt solution, and most of us do not spray brine deliberately on the working parts of our aircraft. For those who like this idea, we merely note here that such a tube can be connected either to a condom cath or a funnel.

Sporty's sells the **Brief Relief**, a disposable urinal bag containing a chemical that instantly gels urine so that it won't spill. This is manufactured by American Innotek, Inc., Escondido CA 92029, phone 760-741-6600.

The astronauts and many women pilots have discovered a very efficient solution that requires no engineering at all: **adult diapers**, or nappies in the British Empire. As you might surmise, under weightless conditions urine does not fall into the bottle, and furthermore tends to break up and aerosolize. This being hard on fellow astronauts and integrated circuits, the answer is to not let it escape at all.

Adult "briefs" are available for $12-18 for 18-22 diapers. If you hydrate well, I recommend the "overnight" model. No caps, no tubes, no catheters, and no leakage unless your production is truly stupendous. They keep you damp but not wet, and are easy to remove. They fit invisibly under normal clothes (cycling shorts and chinos excepted). They do get a bit clammy in warm weather, and may chafe on the walk out after an off-field landing. My own experience is that when I wear a diaper the urinary sphincter tightens up mysteriously, guaranteeing a dry flight.

6 Oxygen

There are many reasons we need oxygen, but only one is continuously important to the pilot aloft in an aircraft: without lots of it, our brain does not work right.

An example of how subtle and insidious hypoxemia can be was published in the January, 2000, *ASRS Reporter* (See http://asrs.arc.nasa.gov/).

> While at FL250 on an IFR flight plan, I could hear the oxygen escaping and thought the regulator had not sealed on the portable tank behind the passenger seat. As I had changed tanks within the past 15 minutes, I attempted to tighten the regulator, but to no avail. I recognized hypoxia coming on, pulled power back, disconnected the autopilot, and lost consciousness. I became conscious at 17,000 feet. The plane was descending and in a bank. I leveled the plane and declared an emergency and told the controller I had lost my oxygen supply and had lost consciousness. I landed at the nearest airport, [where] I saw that the line to the regulator had come off.

The obvious teaching points of this experience:

- Hypoxic incapacitation develops very rapidly when supplementation is lost.
- Hypoxia must be *recognized* before incapacitation occurs: time is short, folks!
- This pilot used the "benign spiral mode" for a safe descent while unconscious, by disconnecting the autopilot and throttling back.
- How does your own ship behave when you release the controls?
- Would you remember quickly to configure your ship for this mode if you sensed incapacitation coming?

In late 1999, the golfer Payne Stewart left Florida in his LearJet and crashed in South Dakota. Reports are clear that there was no response from the crew to ATC's transmissions and no activity to manipulate the airplane's controls, as it flew in a straight line until the fuel was exhausted. The only thing that could have caused the rapid and complete simultaneous incapacitation of pilots and passengers in this aircraft is hypoxia, as carbon monoxide is not available to the cabin pressurization and ventilation system of this jet.

More often the impairment of hypoxia is incomplete, and early hypoxia is unrecognizable.

Some pilots think that their skills are so well honed that they can fly automatically. Well, that's almost true, but the "automatic" stuff is located in cerebellar and cerebral memory, and that's your brain, my friend. Without oxygen its pilot light goes out, and you start doing clumsy and dumb things – unfortunately without feeling either dumb or clumsy.

We all know that the higher we fly, the less oxygen is available. We could spend a couple of pages happily exploring the physics of the atmosphere and why the FAA regulations are too strict and why they're not strict enough. But before we do that, there's something more important to bring up.

The oxygen in the air around you may not be available to your brain.

That is, you may be happily flying around without oxygen at 12,499 feet, blissfully unaware that your brain has only as much oxygen as you'd expect it to have at 18,000 feet. (Just to pick some numbers arbitrarily.)

This is true because the oxygen in the air you breathe must somehow be *delivered* to your brain. There are a number of physical conditions that can impede this delivery; you may not be aware that you have one of these conditions, or you may underestimate the importance of one you do have. If you're not sure, talk to a doctor who understands your disease and altitude issues.

Let's get technical for a couple of paragraphs and simply list the fences that oxygen has to cross in order to fuel your brain's fires.

1. *Your lips or nose*. Seems tautological, doesn't it? But here's your first chance not to get the oxygen you think you're getting: You have hayfever or a cold; your nose is stuffy; you've become a mouth-breather for awhile. We don our oxygen canula as usual. What do we do? We put it across our stiff upper lip, the little prongs tickling our nose hairs. The oxygen goes where? Why, it wanders around our face instead of flowing in as we breathe, and perhaps a little of it will be entrained with the air rushing into our mouth...if there's no draft in the cockpit.

2. We assume, since this an essay on human physiology, that *the equipment* is actually delivering oxygen, that the bottle is full enough, the regulator is on, there's no frozen spit or dew in the line and no kinks, and so on. But your physiology does need this stuff to be working, or you may not have any physiology afterward. It's worth checking to be sure.

3. *Your mouth, throat, and trachea* we assume are working. Diseases of the major airways that would hinder oxygen delivery would pretty much motivate you to go to hospital; flying would be the last thing on your mind, so we can dispense with a whole list of things.

4. *Your lungs* are another matter. Folks with asthma or other chronic lung or heart disease might feel just fine on the ground, but could discover at altitude just why the doctor seemed too interested. Here's the deal: Your lungs do two things:

- *Ventilation*: Air must move in and out as with bellows, in sufficient volume to exchange fresh air for (pardon the expression) dead air. Asthma, pneumonia, emphysema, and the like hinder the lung's bellows function.

- Gas Exchange: After fresh air is brought in, gases must diffuse across the membranes that separate blood from air in the alveolus, the terminal air sacs that are the business part of the lung. Diseases that thicken these membranes hinder oxygenation of the blood. Also, diseases that cause uneven ventilation of the lung cause some blood not to become oxygenated as it flows through. In either case, a person who feels fine on the ground will discover they have inadequate reserve at altitude.

5. *Blood* abnormalities may hinder oxygen from being delivered to the tissues where it is actually used in energy production.

- Anemia: Anemia is a shortage of hemoglobin, the chemical that transports oxygen from lung to tissue. Hemoglobin is packaged in red cells. These are freighters for oxygen. If you don't have enough buses, you can't get the tourists to the museum. If you have anemia, oxygen delivery to your tissues is hindered no matter how much oxygen is flowing through that nasal canula.

- Carbon Monoxide: Glider pilots don't have to worry about carbon monoxide (CO), of course. Except for motorgliders. Or the ride to the airport in that old car. Or flying tow. Or that heater in the camper where you slept last night. Carbon monoxide binds almost irreversibly to hemoglobin, preventing a portion of red blood cells from carrying any oxygen at all. This has exactly the same effect as anemia. It can take days for the carbon monoxide to completely leach out of your red cells. We all know that carbon monoxide exposure can be fatal or incapacitating; subthreshold exposure, without symptoms, can severely decrease altitude tolerance: exposure you're unaware of, too small to cause headache, can decrease your altitude tolerance by half. Carbon monoxide poisoning is just a form of hypoxia, one that can't be "fixed" by going to a lower altitude.

- Smoking: Smokers of tobacco usually have carbon monoxide levels of 3 to 7 per cent, enough to reduce altitude tolerance significantly, and the hundreds of organic chemicals in cigaret smoke have other effects on vascular dynamics. The retina is especially dependent on oxygen: night vision deteriorates above 8000 ft normally, but as low as 5000 ft in smokers.

Smokers have, on the average, about a 10% decrease in delivery of oxygen to tissues, and the effects of a single cigaret last for an hour, not counting the carbon monoxide, which is retained for days.

Also, nicotine has a sedative effect; nicotine withdrawal enhances anxiety, so a cigaret smoker who is aloft a long time is more susceptible to hyperventilation and other anxiety-related problems.

6. *Oxygen release*: Oxygen must be released from red blood cells and diffuse into tissues. There are few conditions that hinder the diffusion of oxygen from red blood cells to tissues, but several things can hinder cells from releasing oxygen properly. Most importantly, when the blood Ph becomes alkaline – called "alkalosis" – this hinders the release of oxygen to body tissues. Hyperventilation produces alkalosis, so hyperventilation will cause hypoxia to occur at a lower altitude than you might expect. (See *Hyperventilation*, page two, below.)

7. *The atmosphere*. Only after we've made sure that our supplemental oxygen system works well, and our body's gas exchange systems are functioning, does it make sense to worry about altitude.

6.1 The atmosphere and hypoxia

"Hypoxia" means "low oxygen." If *your cells* lack oxygen, we say *you* are hypoxic, meaning that oxygen is failing to get into cells such as your brain cells for some reason. Sometimes this is because you are in a *hypoxic environment*, usually high altitude. *Hypoxemia* includes the root "heme," meaning "blood;" if the oxygen content of your blood is low, you are *hypoxemic*. This is just to be pedantic and precise about terms, so if I misuse them below you can snicker or send me a tart letter.

The only organ that matters while soaring, as far as oxygenation goes, is your brain. The glider is the only soaring bird with a removable brain, and we'd not like you to take yours out of commission while still aloft. High altitudes are a low-oxygen environment because the "partial pressure" of oxygen – the fraction of atmospheric pressure that represents oxygen – decreases with altitude. As the amount of oxygen available to our brain cells decreases, they don't work as well.

Brain efficiency decreases *gradually* with altitude. There ***is*** an on- off switch, called "consciousness," but decreased performance begins as low as 5000 ft msl, and there's a long gradual slide before we wink out somewhere above 20,000 ft msl. As I read the literature, night vision declines first, then complex problem-solving such as mental arithmetic, then procedural mistakes begin to occur, then judgment declines.

The sensation of shortness of breath is caused by many things, but not by lack of oxygen. Anything that makes the lungs stiff causes us to feel short of breath, and exercise or excitement do, too. But slowly decreasing the oxygen level in your blood is just like putting a frog in a pan of cold water over a fire. It's comfortable until the end. This is probably why the crew and passengers in Payne Stewart's jet never had a clue something was wrong.

There ***are*** symptoms of hypoxia that precede unconsciousness, but they are subtle and vary considerably between persons. In order to recognize hypoxia, you must try it out yourself and see what your own symptoms are. As you'll discover, the symptoms of hypoxia and hyperventilation (page 2) are very similar.

6.2 Hypoxic symptoms

A symptom is something you ***notice*** about your body. Although night vision is reduced by 10% at 5000 ft msl and by 28% at 10,000 ft msl (3000 M), in nonsmokers,[3] we don't notice this happening, because we don't have anything to which we can compare our vision. Cognitive symptoms – slow or erroneous thinking – begins when our arterial blood is about 87% saturated with oxygen. Incapacitation is likely if the saturation falls below about 65%. The actual point of incapacitation varies considerably between people, and real men don't admit they're incapacitated at any point short of being comatose. But your ability to add and subtract goes away long before you lose your grip on the control stick or see the horizon tilt crazily...

6.3 Clues you can Use

Here's where you're on your own to experiment. The symptoms of mild hypoxia are so subtle and differ so much from one person to another that you must simply go up without oxygen and see how you feel. Yet at moderate altitudes without oxygen (the exact range depends on acclimatization and individuality) our brains simply aren't in fine tune. Your mind isn't as nimble at 14,000 msl as are at sea level.

Tiredness or poor night vision develop at altitudes of 5000 or 6000 feet msl, but these aren't reliable clues to hypoxia. The safe way to do discover your own symptoms is with a ride in an

[3] Smokers have reduced night vision even at sea level. Sorry about that.

altitude chamber. Judgment and fine motor control are impaired when the blood O_2 saturation is below about 85% in the healthy, unacclimatized pilot. It's judgment that matters most at this point. Hypoxia is a little like getting smashed: the bystanders are much more clear about who is impaired and by how much than the drunk.

At 14,000 or 16,000 msl, fine motor control is less important, as at altitude in smooth weather piloting an aircraft is about as demanding as sitting in front of your TV twiddling the remote. But navigating and complex strategic decisions are different matters entirely.

A ride in a pressure chamber is the safest way to find out how to detect your own symptoms of hypoxia. Another way is to fly dual with a pilot who has oxygen. Headache, nausea, dizziness, sleepiness, or fatigue are common symptoms. Some pilots repeatedly calculate compass bearings as a check on mental function, with the very logical theory that if you can mentally subtract 170 from 340 without hesitation, the brain is at least working well enough to navigate.

Altitude	Atmosphere	O_2 Pressure	Blood O_2 Saturation
Sea level	760 mm Hg	160 mm Hg	98%
5000 ft msl	624 mm Hg	131 mm Hg	94%
10,000 ft msl	523 mm Hg	110 mm Hg	87%
FL 180	404 mm Hg	85 mm Hg	72%
with 30% O_2	121 mm Hg		91%
(This is about the best a canula can do)			

Figure 2: Partial Pressure of Oxygen and Hemoglobin Saturation With Altitude

6.4 How Much Oxygen is Enough?

Good question. The answer is, "enough is enough." Enough, that is, to keep your brain working satisfactorily.

FAR's require the pilot of an unpressurized aircraft to use oxygen above 12,500 feet MSL "for that part of the flight exceeding 30 minutes" and to use oxygen continuously above 14,000 feet. At 14,000 ft the pilot's blood oxygen saturation would be around 80% without oxygen, well below the level at which cognitive function fades. This regulation makes sense as you've already seen.

If you often fly above 10,000 ft msl, consider buying a pulse oximeter, which measures blood oxygen saturation through the skin. The *Nonin Onyx* is a little black block that gently embraces the end of a finger and continuously reads your saturation. It is reliable as long as your fingers are warm. It's not expensive considering that it could save your life when you are not certain if your oxygen system is actually delivering as it should. It's about $350 at medical supply houses, and uses two AAA batteries. It comes with a neck lanyard.

Despite the fact that a healthy person is unlikely to become impaired by hypoxia below 10,000 ft, the smoker who has taken a cold tablet for a stuffy nose, who is getting chilly, who may have tipped a few last night, or the pilot with a heart or lung condition, is susceptible to hypoxia at a much lower altitude.

If you're flying dual, keep an eye on each other. Hypoxia, like drunkenness, is easier to recognize in others than in ourselves.

6.5 Hyperventilation

What causes hyperventilation? Not neurosis, but emotional stimulation of any kind. Hyperventilation occurs reflexively with fear, excitement, intense physical activity, etc. Many events in a glider can cause emotional arousal, either euphoric or aversive: all cause some degree of hyperventilation.

Increased carbon dioxide in the blood is the strongest stimulus to breathing. This is what creates the powerful drive to get to fresh air that we begin to feel in an unventilated small room. Ironically, the brain's carbon dioxide detector has a reversal point: if your blood's carbon dioxide content falls quite low, this causes you to feel extremely short of breath. It is this that exacerbates hyperventilation and makes overcoming it extremely difficult when it is severe. This is not merely a psychological effect, it is physiologic.

Our bodies are a complex chemical soup, dependent on millions of continuous catalyzed chemical reactions. The catalysts – enzymes – are dependent on exact control of temperature and pH. Cells die if the pH is below 7.0 or above 7.8; but believe me, you'll feel very ill if it's below 7.3 or above 7.6; piloting an aircraft won't seem fun.

Your body uses CO_2, in the form of $[HCO_3]^-$ as a buffer to regulate pH. When we breathe either more deeply or more rapidly than necessary – hyperventilate – we blow off CO_2, getting rid of this buffer and quickly making the blood alkaline (raising the pH).

Your body's respiratory center reflexively overventilates under any conditions of physical or psychological stress: excitement, fear, anxiety, euphoria, or anger; and also hypoxia, vibration, heat, or illness. This is not something you can necessarily decide not to do.

Fortunately, most hyperventilation is not severe or disabling, and often it's appropriate, such as during illness or before or during intense exertion. But it's seldom needed in a cockpit, as we're strapped in with little opportunity to actually exercise. Unfortunately, there's no warning that your respiratory center is about to hit the reversal point, beyond which hyperventilation becomes self-perpetuating.

At altitude, we've got an extra problem: if the hyperventilation is due to hypoxia, the alkalosis it causes hinders release of oxygen from red blood cells in the tissues, also worsening the hypoxia.

Worst case scenario for the pilot, then is to be at 18,000 msl with a silently failing oxygen system, and hyperventilation that is unrecognized until severe shortness of breath and knifelike muscle spasms in the arms and hands, calves and feet make proper control manipulation difficult. The home remedy – putting a paper bag over your face and breathing into it – is not something we expect the pilot in command to reach right out for.

The chief symptom is shortness of breath. There is really no physiologic reason whatever for a healthy pilot, sitting in a cockpit, to become short of breath. QED, if you feel shortness of breath while piloting an aircraft, *you are hyperventilating*. Other symptoms include tingling sensations of the lips, tongue, mouth, finger, or toes; incoordination, dizziness, lightheadedness, headache, subtle and strange visual distortions, or muscle twitching.

The solution, since we don't want to put a paper bag over our head, is breath-holding. Simply hold your breath for a few seconds over and over again, check and turn up your oxygen, and descend if possible. If you do have a paper bag, hold it over your nose and mouth and rebreathe your air for ten to twenty minutes, until all the symptoms are gone completely.

7 Temperature homeostasis

We are mammals; we are homeotherms. Biologically this means that our enzymes are designed to work best at about 37^{o} C (99^{o} F). If our body goes much above or below this temperature, the chemical reactions that keep us going simply don't work well. Body temperatures above 42^{o} (108^{o} F) are usually fatal or disabling. We can survive cold temperatures much better than warm ones, but rarely can function well below about 31^{o} (88^{o} F).

Mountain soaring is a particular challenge because the flight may start in hot, dry conditions and proceed fairly quickly to cold, high altitudes near cloud base. If the cloud base is reached, the ambient temperature will be at the dewpoint, which may be 5^{o} C (41^{o} F) or less in dry desert conditions.

The sweat that formed at low altitudes to save us from disabling hyperthermia becomes dangerous there, for its evaporation accelerates our body's cooling, and wet clothing conducts heat away. Little physical activity is possible in the cockpit that might generate extra warmth through muscle metabolism.

Abnormal body temperatures slow thinking and impair judgment just as insidiously and just as surely as fatigue or hypoxia or dehydration; and of course all four factors may commonly combine during a single extended task. Concentrated attention to the basics and disciplined adherence to procedural flying can save you from serious or impulsive errors in judgment or technique at these times.

*The cardinal warning signal of impending hypothermia is **shivering***. Shivering begins at a body temperature of about 93^{o} F. or about 34^{o} C. If you begin shivering, it's time to descend to *much* warmer air, and to plan a landing. If you are shivering, count on half an hour to an hour to warm up even if you can quickly get into ambient temperatures above 85^{o} F. The fastest cure for hypothermia is a nice bath at 100-110^{o} F, not available in any glider or at most glider ports.

Temperature management in mountain soaring requires flexibility in managing clothing. *Your greatest site of heat loss is your head, especially if balding.* In hot conditions, ventilate your scalp and provide a breeze across it; in cold conditions cover it. *The second greatest site of heat loss is the front side of your trunk, especially the area of your breastbone*. A lightly insulated jacket that can be easily kept open in warm air on the ground and quickly closed at cool altitudes will provide maximum flexibility. Some pilots have a dark windbreaker which they don backwards in flight when it gets cold.

Your hands and feet are relatively unimportant in managing your temperature except in extreme conditions, but can get distractingly painful. *The chief meaning of cold hands or feet is as a signal that you will become hypothermic if you don't take action to conserve heat better.* If you can't do that, land, or play at a warmer altitude.

Clues you can use.

If your hands or feet get cold, your body is struggling to stay warm. Get warmer somehow or go home. If you begin to shiver, **abort the flight** as soon as possible by getting into warm conditions. It will take you up to half an hour to warm up satisfactorily after you stop shivering even if you jump into a hot bath (This is the fastest, most effective treatment for hypothermia: it should be not warmer than 43^{o} C (110^{o} F).)

8 Other Factors

8.1 Altitude Illness

You probably think of the **bends** as something that doesn't belong in an essay for pilots. It's something scuba divers have to worry about, not pilots. Well, there's a grain of truth in most misconceptions: if you're a diver, you are far more likely to get the bends if you fly soon after diving. As a rule of thumb, wait 24 hours before flying either as a passenger or pilot, after diving. If your dive has been deeper than 35 meters (120 ft), or if you will be above 8000 ft during flight, wait 48 hours.

But you can get bent flying even if you're not a diver, if you go high enough, fast enough. There is a small but real risk of the bends any time you go above FL18, and a definite risk about FL25 (25,000 ft msl). It's not the altitude alone, but the rate of ascent that creates the risk. All the cases of the bends that I know of have been from ascents above 30,000 ft in strong wave conditions.

Every glider pilot flying wave should consider "the bends" as a real risk when the wave is strong and deep. There are two useful steps you can take to reduce this risk. One is to take off from a mountain airport rather than a low-altitude field, to provide some preliminary decompression. Another is to make "decompression stops" in really good wave, to ensure there is time for nitrogen to escape from body tissues. I have not been able to find specific recommendations regarding safe rates of climb at altitude comparable to diving charts. (Sorry.)

8.2 Conditioning

Maintaining some degree of cardiovascular conditioning through regular exercise is useful, not only in walking out for help after a landout, but also provides for a better response to stress in the cockpit. The deconditioned pilot reacts physically to stress with higher blood pressure, more rapid heart rate, and a greater degree of hyperventilation than the pilot who is conditioned. This is not an essay on conditioning, so I'll just suggest that you should at least take an hour-long walk thrice weekly.

8.3 Disease

The effects of specific diseases, and of non-disease conditions such as intestinal gas, are sometimes very important to flying safety, but each of these would require an essay in itself. The important principle is that if you have any medical condition, you should educate yourself on its nature just as avidly as you educate yourself about the flight characteristics of your ship. By doing this you will be able to recognize signs of impending performance degradation or incapacitation and avoid risky flight.

8.4 Actinic damage

Sunburn, corneal light injury, and the delayed effects of sun exposure are important to glider pilots. They affect comfort more than performance, so I will add material on these topics only if I get inspired, which I am not at the moment. Diffuse sunburn is characteristically associated with *hypothermia* during the 12 - 24 hours following exposure, due to the dilated blood vessels in sunburned skin radiating heat to one's surroundings. It is possible that exposure to intense light contributes to macular degeneration, but this is unproven.

9 Medical Self-Certification

Airman medical certificates are not required for pilots of gliders, motorgliders, and hot air balloons (nor for ultralights, which are unregulated).

There has long been a tradition in the soaring community that glider pilots may "self-certify" their medical qualification. This terminology, "self-certification" may be based on discussions between the DOT and SSA, but there has been no such process required by the FAR's, either before or since 1997, when Part 67, *Medical Standards and Certification*, was last changed.

Here's our legal status:

1. No medical certification is required for pilots of gliders or hot air balloons, either "self" or "official."

2. The concerns of the public, Congress, the DOT, and the FAA regarding pilot health can be summed up simply:

- The main requirement regarding illness is that the pilot not have any condition that carries a risk of **sudden in-flight incapacitation**. The basic requirement concerning physical capacity is that the pilot be able to safely manipulate the controls, and have the vision, hearing, intellectual capacity, and judgment to operate the craft with proper skill.

3. Pilots are required to use good judgment at all times regarding whether their present health interferes with safety:

   FAR 61.53 Prohibition on operations during medical deficiency.

   (b) Operations that do not require a medical certificate. For operations provided for in Section 61.23(b) [Operations not requiring a medical certificate] of this part, a person shall not act as pilot in command, or in any other capacity as a required pilot flight crewmember, while that person knows or has reason to know of any medical condition that would make the person unable to operate the aircraft in a safe manner.

4. There is no record of the DOT ever having taken an enforcement action against the pilot of a glider or hot air balloon for flying with a medical deficiency.

5. There is no record of any litigation against a pilot who had a crash or other accident in which the health or physical incapacitation of the pilot was an issue.

We conclude that soaring and hot-air balloon pilots have done a satisfactory job of recognizing their health limitations. And we can conclude that pilots of these types of aircraft need not be anxious about the possibility of a health-related legal problem. In any event, the burden of proof is on the "enforcer."

Physiology Clues for Pilots and Related Creatures

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