# Hypoxia, Hyperventilation, and Supplemental Oxygen Systems Introduction

**Eric Bick, Editor**

This month we are focusing on the effects of too little oxygen while flying at higher altitudes. This article will point out some fallacies of popularly held glider pilot beliefs regarding hypoxia, hyperventilation, pulse oximeters, and supplemental oxygen systems. It will also provide guidance on how to ensure you are flying at minimal risk while in the upper atmosphere, and what the danger signals are.

As background, at the 2018 SSA Convention, a presentation by Jean-Marie Clément on low-level hypoxia caught the attention of those in the audience. Data were shown that the onset of hypoxia occurs at significantly lower altitudes than the FARs mandate for supplemental oxygen use. The presentation also showed data for Mountain High EDS oxygen systems, pointing out some risks associated with it if used improperly.

This is a very important topic for glider pilots whether they fly below 10 kft consistently for short recreational flights, or exceed Class A altitudes on a regular basis for prolonged periods. Therefore, we are taking this opportunity to provide in one article that which you need to know to prevent hypoxia and its side effects, and to effectively use an EDS supplemental oxygen system.

Using input from Patrick McLaughlin, Jean-Marie Clément, and Dr. Heini Schaffner, Dr. Dan Johnson (biographies are shown following the article) has put together what I think is an extraordinary article of utmost importance to glider (and other) pilots.

If there is one message to take from this, it is: Don't mess with hypoxia and hyperventilation – they are each a different aspect of lower oxygen levels, and each is life-threatening. Learn about your oxygen system and how to use and maintain it.

As prelude to the materials being presented, there are some points that each of us has encountered during student training, and should be emphasized in annual safety reviews, and perhaps in-flight reviews regarding flying at higher altitudes (anything over 5-8 kft).

Humans, in general, are not physiologically designed to survive and thrive at high altitudes. There are levels of adaptability, but starting at 5–8 kft, the human body begins to experience a variety of symptoms, from hypoxia to hyperventilation to altitude sickness. As the altitude increases, the danger of hypoxia and hyperventilation becomes greater. Hence, we take precautions when going to higher altitudes. In the case of glider pilots, we carry supplemental oxygen onboard and use it, typically, according to the applicable regulations like CFR FARs in the U.S.A.

Once we venture into the higher altitudes, we have put our well-being, and even our lives, at greater risk due to the decreasing amount of oxygen available (not to mention the sub-zero temperatures). Hence, we start to breathe more deeply, take more rapid breaths – or use a supplemental oxygen system. Once we are at altitudes that require supplemental oxygen to avoid hypoxia, or for survival and well-being, our lives are now dependent on the use and proper functioning of that system.

The primary burden for flying safely at high altitudes lies with the pilot in command. S/he must (not should) be fully trained and vigilant regarding the system performance, its correct use, and safety of any passenger(s). This necessitates the PIC understand the equipment, onset of hypoxic and hyperventilation effects, and what to do if these effects are suspected.

Those flying routinely in wave are perhaps more aware of this than pilots that spend most of their time flying below 10 kft. To ensure a low risk, these pilots have systems and standard operating procedures (SOPs) that mitigate the risks of flying so high, and also account for the risk of a system failure or incipient malfunction. Due to the hostile nature of flying at 10-18 kft and above, even a slight degradation in equipment performance can lead to hypoxic and/or hyperventilation states for the pilot and passenger(s). These pilots know that to ignore their SOPs is to put their lives and well-being at risk.

*Soaring* magazine has previously published articles on hypoxia. The following article contains information and data that provide an extremely important update to this topic – please read and absorb … your life could depend on it.

# Hypoxia, Hyperventilation, and Supplemental Oxygen Systems

## How Each Can Kill You … or Not

**Dr. Daniel Johnson**

***Contributors***: Jean-Marie Clément, Patrick McLaughlin, Dr. Heini Schaffner

*"Lack of oxygen dulls the mind and judgment, slows the reflexes, weakens the muscles, and takes away our higher faculties. The higher one goes, the more serious are these effects. Too many people forget this exactly at a time when they should be most responsive to the danger."*

*— Charles Houston*

*(They forget, because memory itself depends on oxygen, and memory is the first to go ….)*

This article is sectioned by topic. We want to outline the pitfalls of altitude by repeatedly asking the famous sardonic question about seemingly straightforward things, "What could possibly go wrong?"

The first thing that could go wrong is our comprehension of the problem: Many pilots don't understand how to use oxygen.

The second thing is that pilots fail to test the actual effectiveness of their system with an oximeter. Your body did not read the manual. The *designed* results are probably not *your* results.

The third is that *low-altitude* oxygen will prevent fatigue and stupid mistakes (that is, mistakes that you'd not make when your brain is at peak performance).

We want to avoid *impairment*, not only *incapacitation* (which leads to funerals) – we are safest and sharpest if we avoid impairment, which is often subtle, but is sometimes durable. The oxygen regulations are based on 70-year-old science and ancient U.S. airline practice.

We can be safer than the regs require.

The rapid ascent of aircraft may bring pilots quickly to altitudes where hypoxia occurs. Many pilots have observed that subtle hypoxia causes noticeable loss of acuity, motivation, or alertness. Several hours of high altitude wave flying may create mild persistent hypoxia, with troublesome impairing symptoms that may linger for many hours. (This may be incipient *acute mountain sickness*.) Pilots may not immediately recover from inattention, fatigue, demotivation, headache, etc. after full oxygen supplementation in the air or back on the ground. We may persistently have symptoms like troubled sleep, fatigue, weakness, headache, or lassitude for up to 24 hours. Hypoxia is not merely like a car without fuel; it's like a car with contaminated fuel.

*We recommend a zero-hypoxia goal to maintain a comfortable flying experience and peak performance.*

The pilot who wants peak performance, yourself for example, will benefit from using supplemental oxygen at altitudes much lower than required by regulation. (Plan your supply accordingly.) Pilots have discovered that oxygen prevents motion sickness, fatigue, attention deficit, or headache even at low altitudes. A good and safe practice is to turn the oxygen on prior to takeoff, regardless of altitude.

Smokers, due to carbon monoxide impairment of oxygen absorption and transport, everyone past middle age, anyone who's overweight (most of us), and anyone with any kind of lung disease, should **always use oxygen beginning at 5-7 kft msl.**

Mountain-based pilots will be satisfied to use oxygen **from the ground up**. Pilots flying wave (over 6 km/20 kft) should have a ***redundant*** system, because they have only a very short time to discover and recover from an oxygen-delivery failure.

This article is not a review of oxygen delivery systems. We are going to discuss only one, the ***Mountain High EDS*** oxygen system because it is very commonly used, as it's attractive to glider pilots for its ingenious design, effectiveness, and great efficiency, saving up to 75% versus a constant-flow device. (But with 7 settings, variable flow with altitude, and greater pulsed flow when used with a mask, its actual duration is unpredictable). Yet it is complex, and not difficult to misuse or mismanage. It must be used thoughtfully, after learning how our bodies acquire oxygen, and how the EDS system is intended to work. It is not plug-and-play.

Jean-Marie Clément and Dr. Heini Schaffner began in 2008 to carefully study the *effectiveness* of their own EDS system in use. This included advising a bachelor-degree thesis at the Winterthur Engineering School of Applied Sciences (ZHAW), which unveiled the actual oxygen output of their EDS-O2D1 in their laboratory and in a hypobaric chamber. The results are detailed in the book, *Dancing with the Wind.*

Such study is important, for it allows us to understand the *actual* performance of a device as well as the *designed* performance. They went from the laboratory to the glider, where they carefully studied peripheral oxygen saturation during actual wave flights up to 28,000 ft. They found several important limitations in EDS performance and use, detailed in the book.

***Caveat***: it is impossible to test every device; deviations from expected performance could be manufacturing variability, but usually are due to neglecting maintenance, free-lancing pressure reducers or tubing, or personal characteristics. Because Clément and Schaffner's tests were done very carefully by professionals with relevant expertise, using appropriate equipment, with thoughtful analysis, we can learn much from them. Mountain High continues to make firmware changes in response to such experience, so that yesterday's outcome may not quite be tomorrow's.

**Why are we writing about high-altitude breathing?**

It's not the *amount* of oxygen in air that matters – it's the *pressure*. And it's specifically the pressure in the lungs' air-exchange sacs, the alveoli, that drives gas flow. The atmosphere is 21% oxygen at all altitudes – oxygen pressure decreases with altitude and along with that, the ability of red blood cells to adsorb it.

It's important to understand that each gas exerts its own pressure in the alveoli in proportion to the content – so oxygen itself exerts a pressure equal to 21% of total atmospheric pressure (and nitrogen 78%). The contribution of each gas is termed the "partial" pressure. It's the *partial pressure* of oxygen in your lung's alveoli – ppO2 – that keeps you alive.

Carbon dioxide is also important, and you need to understand the effects of the fact that ***carbon dioxide (partial) pressure*** in our lungs and blood decreases with altitude. This contributes to a CO2 deficit in the flight levels that may cause air hunger and other symptoms that can feel like hypoxia.

The medical term for this state of CO2 deficit is called "hyperventilation" – an unfortunate term because of the allusions that "hyper" creates. It's simply ***over***-ventilation – breathing more deeply or rapidly than required for proper CO2 pressure in the blood and tissues.

Ventilation (breathing) "blows off" carbon dioxide, which is necessary for proper acid-base balance and nerve/muscle function. Increased ventilation may also result from emotional response: delight, fear, anxiety; but the symptoms are themselves frightening and this worsens over-breathing.

***The actual pressure of oxygen and carbon dioxide in the lungs is the key to understanding***

| Altitude Ft/m | Air press mmHg | ppO2 mmHg Air=21 % | Alv pO2 mmHg on air | % sat O2 > 90% desired | Alv pCO2 > 35 best | Alv pO2 with O2=100 % | % sat O2 **100% O2** | Alv pCO2 **100% O2** |
|---|---|---|---|---|---|---|---|---|
| Sea level | 760 | 159 | **104** | 97 | 40 | 673 | 100 | 40 |
| 10k/3k | 523 | 110 | 67 | 90 | 36 | 436 | 100 | 40 |
| 20k/6.1k | 349 | 73 | 40 | **73** | 24 | 262 | 100 | 40 |
| 30k/9.1k | 226 | 47 | 18 | 24 | 24 | 139 | 99 | 40 |
| 40k/12k | 141 | 29 | | | | 58 | **84** | 36 |
| 50k/15.2k | 87 | 18 | ■ | ■ | ■ | 16 | 15 | 24 |
| | | | ■ | ■ | ■ | | | |

*Table 1: Alveolar oxygen and carbon dioxide pressure by altitude, atmosphere vs. 100% O2. (After Guyton & Hall:* Textbook of Medical Physiology*, 12th ed.)*

Key: Air press mm Hg – surrounding air pressure in millimeters of mercury
ppO2 mm Hg – the **p**art of air **p**ressure related to oxygen
Alv pO2 mm Hg – the pressure of oxygen within the lungs' air sacs, the alveoli
% sat O2 – the percentage of hemoglobin molecules fully carrying oxygen
Alv pCO2 – the pressure of carbon dioxide in the alveoli (40 is normal, < 20 is bad)
Alv pO2 with O2=100% – the max oxygen pressure possible in alveoli without a pressurized mask
% sat O2 100% O2 – the best saturation possible without a pressurized mask
Alv pCO2 – the pressure of carbon dioxide in the alveoli with 100% oxygen

Note that the blood oxygen saturation (%Sat O2), on air rapidly drops with altitude – which needs to be ***above*** ~90%. The only way to increase the alveolar *pressure* of oxygen with altitude is to increase the *proportion* of oxygen, up to 100%. With 100% oxygen it's possible to fly to almost 40,000 ft without a pressurized mask. Above about 40,000 ft, it's necessary to pressurize your mask to get the alveolar pressure of even 100% oxygen high enough to keep your brain working.

Carbon dioxide partial pressure is just as important as that of oxygen, which few know. Note the drop in the partial pressure of carbon dioxide (ppCO2) above 20,000 ft msl. CO2 is important to cognitive function. Low pCO2 cuts oxygen *delivery* to your brain in two ways:

- Its drop causes the brain's blood vessels to constrict and decrease flow by up to half.
- Its drop hinders the release of oxygen from red blood cells to your tissues.

A pCO2 of less than 20 mm Hg will make you feel hungry for air and mentally clouded, and wrongly worried about what's wrong with your oxygen system.

When the effects become incapacitating, then we are truly "hyperventilating." (More details below: Carbon Dioxide – the Outgoing Gas.)

Table 1 lays out the key parameters associated with these atmospheric effects on your physiology.

### Three Steps in Oxygen Use

**ONE**: Ventilation! We *exhale* carbon dioxide produced through metabolism of glucose and oxygen, and we *inhale* oxygen (along with nitrogen). Both the **depth** and **rate** of breathing are important. Air hunger, and respiration, is regulated by the *carbon dioxide* content of the blood and the blood's *acidity*. Only when hypoxia is severe does it influence breathing rate, and hypoxia doesn't cause air hunger.

#### *What could possibly go wrong?*

Though breathing is automatic, we stop breathing for a time during any startling or distracting event. (Attention and respiratory control share a spot in the midbrain.) Interrupted breathing can tip us into hypoxia if our supplementation is borderline.

Between 8 k and 18 kft msl (2.5-5.5 km) we subtly over-breathe in response to decreased oxygen pressure; this reduces CO2, and the respiratory center, driven chiefly by carbon dioxide, briefly shuts down breathing. This can tip us into an unconscious cycle of hypoxia with roughly half-minute intervals in which we alternate between over- and under-breathing, called *periodic respiration*.

Above 5.5 km / 18 kft, the low oxygen pressure stimulates ventilation more strongly, overcoming periodic respiration – but we still pause breathing when focusing attention and increase breathing when alarmed.

The EDS system skips every other puff of oxygen if the respiratory rate is fast (i.e., it doesn't give a puff if "requested" too soon). This skipping is a ***clue*** to the pilot that we are over-ventilating. Our response should be to consciously slow breathing, for example by counting between breaths to five or six, slowly, ***out loud*** to cause slow exhalation. This will be quickly effective if done as soon as we notice mild hyperventilation.

### Carbon dioxide – the outgoing gas

The relationship is: {***Optimal ventilation = normal oxygen supply + normal carbon dioxide level***.}. Carbon dioxide partial pressure within the air sacs of the lungs is as important as that of oxygen.

As the atmospheric pressure decreases in climb, there occurs a natural over-ventilation in response to the decreased partial pressure of oxygen, resulting in decreased carbon dioxide in the body. We may breathe either *more deeply or rapidly* than is necessary to maintain the blood's proper acid-base balance. We are not talking here about an emotional crisis! It is automatic and unconscious. Individuals are very different in the degree to which this occurs – and because this is unconscious, we can't at first know whether it's happening.

First there is increased *depth* of respiration and later increased rate. This overventilation of our lungs blows off carbon dioxide. A reduced CO2 pressure causes the blood vessels of the brain to constrict and red cells to hold back oxygen – causing brain hypoxia even if your finger oximeter is happy.

Note in Table 1 that alveolar ppCO2 is near 20 mm Hg above 20,000 ft msl simply due to decreased atmospheric pressure, and this increases the risk of hyperventilation symptoms.

Abrupt over-ventilation that brings blood ppCO2 from the normal 40 mm Hg down to 20 mm Hg (easy to do in a few minutes) will result in a 60% decrease in cerebral blood flow, with a recovery time of more than 20 minutes. This also causes the blood pH to become alkaline, causing what amounts to static in our peripheral nervous system, with numbness and tingling, especially of the mouth and fingers. As this continues, severe and uncontrollable cramping of feet and hands may occur.

Ironically, if we *feel* short of breath, we *are* over-ventilating. If we are tingly or start having uncontrollable muscle cramps in hands or feet, we are hyperventilating. The trick of putting our head in a grocery bag isn't going to work in the cockpit, so s-l-o-w d-o-w-n until you feel better. Count out loud to five or six between each breath, and you'll feel better in just a couple of minutes, but bear in mind that it may take 20 minutes of consciously slow breathing to fully correct the acid-base abnormality and recover brain blood flow.

Why so long? There are about 120 L of carbon dioxide in the body, with complex dynamics. This is a lot to replace, and it must by produced by our own metabolism. We don't have any CO2 machines to replace it. While a person can recover from severe hypoxia of 40 mm Hg in about two minutes, spontaneous recovery from hypocarbia of 10-20 mm Hg takes more than 20 minutes.

It may take several hours to recover fully from severe hyperventilation. We recommend that you descend immediately and terminate the flight promptly and safely if you experience significant symptoms of hyperventilation.

**TWO:** Red blood cell oxygen adsorption and release. The red blood cells pick up oxygen in the lungs' alveoli ("air sacs") and give it up in peripheral tissues. This straightforward process has many interesting complexities detailed in physiology textbooks.

#### *What could go wrong?*

Various diseases of the lung hinder oxygen from diffusing across the membranes of the alveoli or capillaries. Diffusing capacity can be assessed in a pulmonary lab by a pulmonary specialist.

Anemia involves having too few wheelbarrows to carry the bricks, resulting in "tissue hypoxia" – oxygen-starved brain cells – even with normal oxygen inhalation.

Acid-base disturbance of the blood (from severe exercise, infection, or hyperventilation, etc.) may hinder oxygen adsorption in the lung or release in the tissues.

**THREE:** Circulation – the red cells have to travel from lung to periphery and back.

***What could go wrong?***

We soaring pilots now are mostly old. (Military medical aviation research has historically classified "old" as "over 40." Tough news for some of us.) The most common disease among us is *atherosclerosis*, which involves cholesterol deposits in arteries that may retard blood flow. In the leg, this risks frostbite; in the brain, this risks stroke and poor oxygen delivery. Smoking causes atherosclerosis and directly constricts arteries.

Dehydration reduces blood volume and thus g-tolerance, which reduces blood flow to the brain; cardiac and blood pressure medications also affect circulation and g-tolerance. (Your doctor is not likely to have a precise answer, but do ask about each medication.) In the worst case, pulling g's in steep turns or turbulence can cause unconsciousness.

**REGULATIONS**

FAA regulations do ***not*** a require pilots to wear a face mask in a glider or any other part-91 aircraft! Read 14 CFR 91.211 carefully, https://tinyurl.com/14CFR91-211. We are not flying commercially, and not in pressurized gliders, except for Perlan.

There ***is*** a requirement for the manufacturer of any aircraft capable of flying higher than 18,000 ft to *provide* an oxygen supply system *and a face mask* for each occupant. The only mask-wearing requirements are for commercial operation in 14 CFR 23.1447, https://tinyurl.com/14CFR23-1447. For an essay on the frustration and risk this brings, https://tinyurl.com/mask-troubles.

***What could go wrong here?***

First, pilots who misunderstand the regs may use an inadequate mask system instead of a proven cannula system and increase their hypoxia risk. Clément and Schaffner found through in-flight testing that the MH mask is ***inferior*** to the cannula in preventing hypoxia unless an F-setting is used, which reduces tank duration. They strongly recommend that the face mask not be used.

If your nose is obstructed, you *must* use a mask and *must not* use a cannula. With EDS, use the F settings, take a quality oximeter, and ***do not*** plan on flying much above 6 km / 20 kft msl. Expect higher oxygen use and shorter bottle duration.

The U.S. military and Dr. Heini Schaffner, with Jean-Marie Clément, have performed tests on the EDS system to explore its limitations.

Under a government contract to a university, an EDS cannula system was tested to 36 kft for military applications using a select group of exceptionally fit subjects. (Based on that research, MH has produced a special system for military use only.) This is exceptional performance demonstrating the use of a cannula at higher altitudes, and is *not* applicable to the glider pilot population in general or particular.

As extensively described in *Dancing with the Wind*, Dr. Schaffner initiated extensive formal testing of EDS function and effectiveness in the laboratory and in wave flights up to 20 kft; and with Clément did testing in wave flights to 28,000 ft. They discovered some important limitations of EDS function and some pitfalls that are extensively described in Chapter 12.

The upshot of their work is that you ***must*** test the effectiveness of any oxygen system you use while wearing an oximeter. Oxygen is ***not*** plug-and-play! *Buy the book and read the chapter!*

The EDS system is efficient and effective up to about 20 kft. If you expect to fly above 20 kft, you *must* have an independent backup system and have a sound understanding of high-altitude physiology. Great care is necessary. The EDS system is designed to do the right things – but it is not a stupidity antidote. It must be thoroughly understood in order to be used safely.

All oxygen-delivery systems are ***machines*** and must be respectfully used and maintained in order to be reliable. No machine adapts itself to your uniqueness.

**MONITORING**

Altitude is dangerous because our body does not have an oxygen detector: We do not hunger or thirst for oxygen, we just get stupid, and when we get stupid, our brain's stupid-detector breaks, so we *must* monitor our oxygen status.

**ONE:** Monitor supply.

Above 6 km / 20 kft, you ***must*** be able to easily see and *read* the pressure gauge of the oxygen cylinder. If you can't read the gauge, you must have a proxy, such as a perfectly reliable pressure warning with a safe margin.

**TWO:** Monitor function.

Oxygen flow gauges are readily available and can be mounted in sight, such as used with the Oxymizer™ oxygen-conserving system. (However, the EDS is not compatible with the use of the Oxymizer™ reservoir cannulas!) The EDS system nasal puff with each breath is reassuring, though the fact of a puff is not a guarantee that its duration or flow rate is sufficient, nor is a 600 psi gauge reading assurance that the flow is what *you* need.

**THREE:** Monitor effect.

There are three ways to monitor the effectiveness of our oxygen delivery.

***Brain function***. It is straightforward, in stable undistracted flight, to repeatedly perform some mildly challenging mental task such as calculating reciprocal compass/runway headings, recalling radio frequencies or ICAO abbreviations or other memorized lists. You will not notice impairment unless you are consciously testing yourself. Hearken to warnings about your function from folks who are listening to your transmissions, and have brief repeated conversations with ground personnel who can then pick up abnormal thinking or speech.

***Peripheral oxygen saturation***. Finger oximeters are available and widely used. Like any measuring device, they are not perfectly reliable. They *are* useful, but are prone to error: cold fingers, movement, sunlight, and more, are important. Just because a number is displayed does *not* guarantee it's accurate – and just because your finger has a good oxygen supply does *not* mean your brain does, because of the natural altitude-induced hyperventilation. For safety, based on manufacturer statements, assume that your oximeter is reading at least 2 points high.

Every digital measuring device shows definite numbers. This display precision deceives us about accuracy. The best medical oximeters show dashes if a pulse can't be reliably verified. Cheap fingertip oximeters show a "standard" reading while waiting for a valid signal, without giving a clue that it's in waiting mode. Don't stake your life on a $30 oximeter. Do your research and buy a Nonin, Masimo, or an equivalent alternative.

## OXYGEN DELIVERY

The remainder of this essay is focused on some specific aspects of the Mountain High **E**lectronic **D**elivery **S**ystem, invented in 1991 by Patrick McLaughlin, an embedded developer by profession and *de facto* pulmonary physiologist for his company – and pilot. MH has demonstrated it to provide sufficient flows for healthy lean people. Yet it does not know your medical status, is not artificially intelligent, nor can it read your mind – you have to provide the intelligence!

### EDS function

The essence is that a constant-flow system wastes most of the oxygen; EDS pulses what's needed when we inhale. EDS detects the small drop in pressure within the nostrils as a breath begins and gives a little puff of oxygen at 15 L/min for up to ½ second, depending on pressure altitude. (See Figure 1.)

The idea is straightforward. Yet like so many things that seem easy, the path goes over a tall hill and involves some nuances.

***What could go wrong here?***

### Oxygen supply

If the cylinder is empty, nothing helps. (Some of us have put the aircraft away without closing the bottle.) The maximum pressure available from U.S. suppliers is about 2,300 lb/sq-in (nominally 2,000 psi). Special suppliers offer higher pressures.

Beginning a flight with a cylinder other than full is suitable only to prevent low-altitude mild hypoxia. (See figure 2 for an example of flow change with decreasing bottle pressure reserve.)

EDS produces less than maximal flow when the cylinder is < 600 psi. ***If using full capacity of your cylinder is important, install two different regulators in cascaded series, e.g. 2,000 to 60 psi plus 60 to 20 psi, available at MH and at other suppliers.***

### Electricity

EDS single-place units are battery powered with 2 AA alkaline batteries (3 AAs for 2-place units) and will operate for ~100 hr with a fresh set of DURACELL ULTRA alkaline batteries under normal operation. Batteries should be replaced at least annually. The newer 2-place EDS O2D2-2G units have optional external power – a special cord fits a standard USB slot and expects 5V @ 2.4A.

***What could go wrong here?***

- Obviously, dead batteries will yield no action. Weak batteries are worse, because they may die when they're most needed in flight.
- There are three low-battery levels: a silent red flash each second means that about 4 hours of function remain. Two silent red flashes each second means that less than an hour remains. At least get below 12,500! This low-battery detector is specifically calibrated for alkaline cells. It does not give a timely warning with lithium cells because of their abrupt voltage drop.
- Alkaline batteries rejuvenate somewhat with rest. Don't be fooled: this may allow the unit to boot but will not endure through flight.
- If the batteries are found to be too low during power-on self-test, the unit will lock out functionality.
- ***Wave flying***. Alkaline batteries

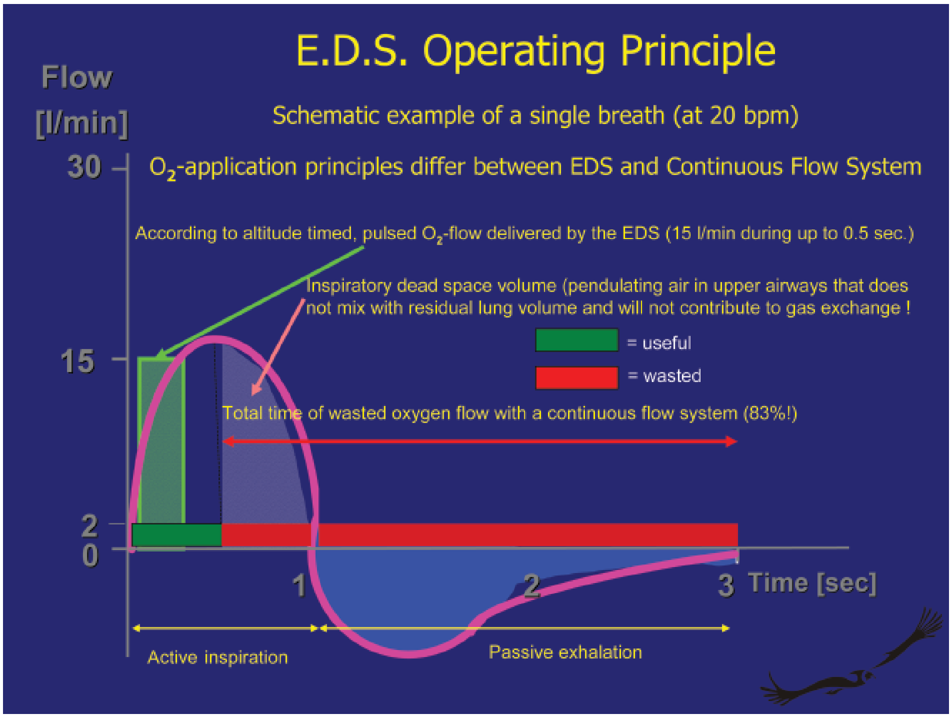


*Figure 1: EDS O2 flow — Dr. Heini Schaffner; Dancing with the Wind, p 270.*

perform poorly below -20° C / -4° F. Lithium batteries may still have some life at -40. But if you plan to fly in a cockpit that is below zero with EDS, buy the 2-place O2D2-G2 system and plug it into ship's power with its USB adapter.

**Regulator**

The EDS must be used with its own XCR regulator or an inline stepdown regulator-equalizer combination to provide the pressures for which the EDS delivery unit is designed. (See https://tinyurl.com/MH-Regulator-spec.) Note that in Figure 2 oxygen flow drops off significantly below 600 psi. This may be fine for low altitudes, but for flights above about 13,000 ft / 4,00 m msl, the bottle really should be full at takeoff to ensure adequate reserve.

***What could go wrong?***

Other than possibly wrecking the internal EDS sensors or creating an unsealed solenoid valve with excessive pressure, flow will be wrong.

In addition, removing tubing and letting it live independently, open, in the cockpit or hangar, will allow moisture, dirt, and insects to find a home. When the EDS is later reconnected and gas applied, whatever debris found its way into the open tubes gets pushed into the unit and blocks a narrow place.

**Tubing**

Mountain High supplies tubing of proper material, length, and diameter.

***What could go wrong with tubing!?!***

When two pilots each have an EDS unit (O2D1) supplied from one tank, the tubing to each EDS unit must be exactly the same length, or the pilot with the shorter tubing will steal flow if they inhale simultaneously.

In addition, only one EDS O2D1 can be serviced with the standard 4 mm dia. tubing, no more than 1.5 m / 5 ft from the regulator.

The best way to service two O2D1 units in a dual-place aircraft is for each to have its own tube, of *identical length and diameter,* from the regulator, using MH 'Y' split-kits to attach them to the one regulator as close to the outlet fitting as possible. Otherwise the inspiratory pressure drop from each unit will create a delivery issue with the other.

You should use **6** mm dia. tubing with the O2D**2** at distances up to and over one meter – if some debris should get into the inlet tubing and restrict the flow a bit, it would be quite a bit less significant than with 4 mm dia. tubing.

*Why not borrow an oxygen cannula from your uncle* with lung disease who's on oxygen? Medical tips are so much more soft and comfortable …. *Here's why not:*

First, EDS requires stiff tubing so that the subtle pressure drop of inspiration is accurately transmitted. Medical cannulas are made for use in clinical environments for a short period of time. The softness is from the plasticizers, which leach out and the tubing becomes brittle.

Medical pulse-conserving oxygen dispensers are calibrated to a particular cannula, are flow-regulated, and are designed for a patient sitting upright. Some ambulatory medical oxygen conserving devices have unique cannulas that have a separate tube for each nostril. Pilots who've tried these cannulas are mystified that their EDS unit no longer works.

In addition, each maker of oxygen systems has carefully selected the cannula, tubing type, and length for use with their delivery system. EDS units are built and calibrated for proper delivery while using MH tubing. If you change the tubing, you'll change the flow.

*The pilot may not fit the cannula.*

Clément and Schaffner discovered that a tall pilot had to pinch his nose around the cannula to get proper response from the EDS because his nostrils were large and a sufficient inspiratory pressure drop did not occur.

MH now supplies *two* cannulas with each system, standard for most people and flared for those of us with large nostrils. Try each, in turn, to see which delivers puffs more reliably.

*I'd like to use the Oxymizer™ moustache reservoir cannula to further con-*

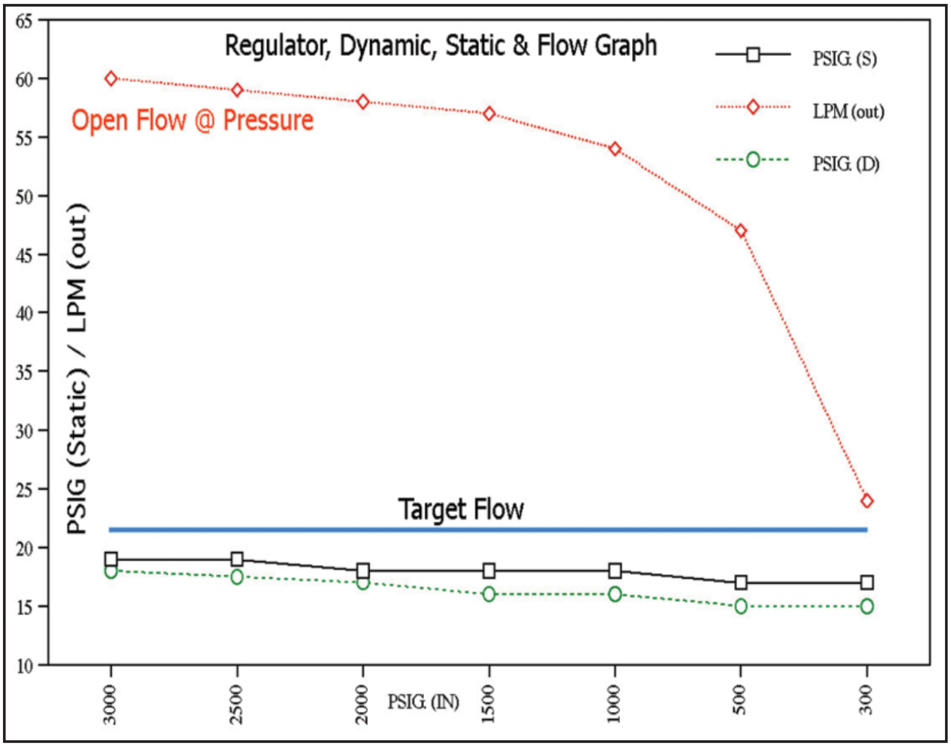


*Figure 2: Cannula flow vs. tank pressure. (Courtesy Mountain High.)*

*serve oxygen.*

Ted Nelson was the first to design a calibrated flowmeter and the Oxymizer™ conserving cannula. This was revolutionary at the time. When used and worn correctly, it reduced the needed flow of oxygen at 10,000 ft. by well over 50%.

Adding an Oxymizer™ cannula to your EDS will not conserve even more oxygen, rather, it will deprive you of it because the accumulating reservoir of this cannula confuses the breath sensor in the EDS and the dynamic benefit of a sharp pulse is lost.

***Cannula orientation***

The flat tab rests on your ***philtrum (that narrow vertical groove in the middle of the lip)***. The prongs should follow the curve of the nasal channels. If the tab points up, the prongs' opening may touch the inside of your nose and hinder detection of the inspiratory pressure drop and the EDS will miss many of your breathing events, increasing the chance for hypoxia, and will become uncomfortable. (Having said that, your faithful editor has to use the cannula upside down due to personal intra-nasal anatomy.)

***Preflight check***

Think about the effect of head movement on the tubing: after placing the prongs in your nostrils,

– Put the selector switch on N, ensure that normal quiet inhalations trigger a puff (may occur with alternate breaths on the ground).

– Turn your head fully from side to side, and up and down, to ensure that this does not dislodge the nasal prongs.

**YOU: (What could possibly go wrong with *me*?)**

Clément and Schaffner extensively recorded oxygen saturation while flying wave. They discovered that many typical pilot activities interrupt breathing and can cause transient severe hypoxia.

First, any event that strongly focuses pilot attention may cause unconscious breath-holding for up to 30 or 45 seconds, which can quickly drop oxygen saturation into the 70% range. Stressful peaks in flying can also trigger shallow or chaotic breathing that randomly triggers the EDS, causing hypoxia.

Episodic patterns of periodic breathing ("Cheyne-Stokes") have been observed in all their investigated pilots above 8 kft. The usual, regular respirations are replaced with clusters of subconscious over-breathing (hyperventilation), followed either by absent or (less often) shallow breathing. This results in variations of blood O2 saturation up to 12% in flight, discovered post-flight in review of continuous recording. (This is a reason to use a recording "wristwatch" oximeter, and download the record after flight, to see whether unrecognized hypoxia occurred.)

They observed one troublesome incident of slight but continuous coughing at 25 kft msl – the pilot could not inhale effectively to trigger the EDS and could not speak. He turned the

## The Invention of the Mountain High Electronic Delivery System

Patrick McLaughlin

I wanted a system that automatically adjusted the delivery of oxygen with altitude, was small enough to be taken up in a hang glider, and affordable to pilots. This idea kept rattling around starting in the mid-1980s, until I read a paper by Brian Teip, et al, about anticipatory oxygen delivery methods that decreased wasted flow by 75% while still achieving a target saturation. From this I realized that to use sensing diaphragms to detect breathing and a pressure sensor to track pressure altitude was feasible. It would be so radically different from the norm that I feared it may not be accepted.

Pilots then were taught that an aviator's oxygen system, capable of working at high altitudes, must have a large vacuum-cleaner sized hose connected to a smelly face mask that made you sound like Darth Vader, a large regulator, and a SCUBA-sized tank. The complexity, size, and weight of the system and the complexity of cockpit management, as well as its unaffordability, deterred pilots from using oxygen.

After patiently working to create reliable and inexpensive breathing-sensor technology, I designed, built, and test-flew the first EDS in 1991. It looked more like a Walkman than an aviator's oxygen system, with novel small tubes, black box, and cannula.

I feared that pilots would be skeptical of its small size and strange appearance and not give it a chance. However, I knew it was a very good solution for these missions. It seemed realistic that only perhaps a hundred or so, globally, would see this. Holy Moon Rocks(!) I was quite wrong, as this technology is now being used globally in fixed and rotor wing and soaring flight every day.

I produced about 50 units, advertised in Soaring magazine, and released it as the EDS Model A1 in 1992. A glider pilot, Bill Hill, was one of my first customers. He purchased one, flew with it, understood and liked it, and then wrote an article about it for the magazine (https://tinyurl.com/bhill-EDS.) Soon after, I realized that Mountain High E&S Co., est. 1985, was busy enough to put me to work full time for a while. The business grew slowly, the technology evolved, and we added a spectrum of support items.

We are now in the fifth generation of the EDS. The most satisfying thing is that we now have about 15 families earning a paycheck.

EDS down to N when he meant to turn it up to F to increase flow. Hypoxia then caused tunnel vision and stupor, though he could hear. Fortunately, the other pilot was alert to trouble and took control. The hypoxia may have impaired his cough reflex; at any event he stopped coughing and recovered.

Other "minor" activities were also seen to cause moderate hypoxia: eating, drinking, talking to each other or ATC, and pushing to urinate.

**Conclusions:**

1. Understand that flight in Class A airspace, especially above 20 kft/6 km, is life-threatening territory for both hypoxia and hypothermia, and neither comes with an idiot light. Prepare intelligently.

a. Have backup oxygen, with confirmed function, up there.

b. Take off with less than a full tank only if you don't really need O2.

2. Hyperventilation is *important* – it causes tissue hypoxia. Expect subconscious hyperventilation above 10 kft / 3 km, increasing with altitude.

a. If you feel air hunger, you're most likely hyperventilating.

b. Then count out loud to six slowly between breaths until the air hunger diminishes.

3. Use oxygen above 5 kft / 1.5 km msl for peak performance, minimum stupidity.

4. Buy an excellent, proven oxygen system and ***read the manual***, memorizing the bold print.

a. Where the manual confuses you, email a question to the manufacturer and follow up with an actual telephone call to ensure understanding.

b. Review the manual when you break the equipment out of storage after a layoff.

5. Test every aspect of your oxygen system on the ground – and ***use fresh batteries***.

***6. Use an oximeter*** to measure the effectiveness of your system ***for yourself***, but thoughtfully, understanding its failure modes (cold fingers, motion,

# GOAL: Safe oxygenation –

## *Should you use an oximeter?*

*Yes, truly. There is no other way to test your system's effectiveness.* If your system works as designed, you may feel that you don't "need" one. If you become hypoxic, you may not function well enough to understand what it's saying. They are prone to particular errors. Yet we recommend that every pilot flying a non-pressurized aircraft above 6 km / 20k ft msl should use a quality oximeter. (The life you save may be your own ….)

Though imperfect, they are *useful* – especially for intermittent use, to determine whether flow rates are correct for yourself in the conditions you are flying into, and whether your system has been configured properly. A recording oximeter can allow you to discover incidents that might have caused unnoticed hypoxia while flying.

Pulse oximeters work by shining two colors of light into an area of tissue with known blood perfusion. They measure the ratio of the reflection over the absorption of the two colors by the tissue. They should constantly calibrate against the ratio between the surge of reflected light caused by each pulse and the intervening quiescent flow, to produce a valid reading.

Inexpensive oximeters are neither as reliable nor as accurate. Nonin was the first and remains the standard; Masimo appears equivalent. Manufacturers claim their readings are +/- 2% or +/- 3% in the range of 70-100% saturation. This means that when the oximeter reads precisely 87%, your actual blood oxygen saturation is probably in the range of 84- 90% for the less accurate, 85-89% for the more accurate – in the best laboratory conditions, which your cockpit is not!

We recommend you consider a recording wrist oximeter. It uses a small finger probe and a wristwatch device. It displays the current pulse and saturation after being touched, and is not easily read in sunlight. Post-flight analysis is useful to identify undetected incidents of hypoxia.

***What can delude this instrument?***

- Sunlight can "overpower" the unit's own spectrophotometric light source. Some models have better shielding than others.

- Pigmented skin yields lower saturation readings when actual values are in the 80% range.

- Fidgeting degrades their accuracy by 5-20% (that is, with a true O2 saturation of 95%, the meter may read 75-90%). It's the pilot's *job* to continually fidget with the controls!

- The oximeter is measuring the oxygenation of the blood in the *fingertip*. What really matters is the oxygenation of the blood flowing through the *brain*.

- Hyperventilation constricts brain arteries but not finger arteries.

- Cold fingers have low blood flow, so readings will be low. Only measure warm fingers. Yes, this is a problem for wave flights! (Consider using a "claw" bicycling mitten to keep the fingers warm, protect the finger probe from being dislodged, and allow pinch with thumb and first fingers.)

- Carbon monoxide, dear smokers, *falsely elevates* saturation readings due the color of carboxyhemoglobin.

***References*: Pulse oximetry**, https://tinyurl.com/PulsOx1 and **Pulse oximetry: fundamentals and technology update,** https://preview.tinyurl.com/PulsOx2, are technical reviews of oximetry that are worth reading. There are no reviews of the quality of specific oximeters.

sunlight, etc.)

a. If you buy a cheap one, also check your life and liability insurance coverage so your heirs won't be burdened financially.

b. Keep your oxygen pressure gauge in sight.

If you feel foggy mentally, you're probably hypoxic.

OK, now have safe thrills!

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**About the Author:**

**Daniel Johnson, MD, FACP, ex-Sr. AME**

Dr. Dan Johnson, an internist for 40 years and aviation medical examiner for 32, hung up his boots at the end of 2017 and is taking his first sabbatical since he was 16.

He lives in the remote reaches of the west coast of Wisconsin, where some people are confused whether they belong to Minnesota, and he has come, blinking, out of the medical cave.

He's been a pilot since age 16, active since 45; he's a mediocre soaring pilot and owns an old Ventus Cm and an older Mooney 231, and is older than both laid end-to-end.

He has spoken to and written for pilots for 25 years on aeromedical factors, and wrote the monthly "Soaring Rx" column in *Soaring* magazine from April, 2011 through March, 2016, when he laid that aside because the rest of life had become much too busy.

Now that he has no real responsibilities, he is finally free to go soaring on the good days – so what did he do? He agreed to spend half the summer in el Calafate helping the delightful Perlan folks in some way.

**About the contributors:**
**Jean-Marie Clément**

Jean-Marie Clement is a French engineer and soaring pilot whose first flight was at 14. He joined the French national junior soaring team in 1963 and became a CFI in 1964.

His first degree was in fluid dynamics and aerodynamics. He worked with Prof. Piero Morelli at the Turin Polytechnic Institute in development of the superior KMX TE probe in 1972, making the first demonstration of acceleration on TE compensation.

His second degree was in paper manufacturing, in which his father was also involved, and this became his career, while aerodynamics remained an enthusiasm.

He was active in hang gliding beginning in 1975 and co-founded the Italian Hang Gliding Federation, and designed and built a series of improved Rogallo wings, which he used to win the Italian Standard Class championship in 1977.

In 1982, he resumed gliding and achieved first place at the World Cup at Vinon, and in that year flew the first 1000-km flight in the Alps. After this flight, he applied engineering principles to arrive at an understanding of wave and dynamic soaring.

With the French team, he won the European championship in 1988 at Issoudun and the French Open in 1989 at Fayence.

Beginning in 1992, he focused on long-distance flights, with the first declared-goal 1000 km flight in Italy. Beginning in 2000, he set several more distance records in Europe, including a 3-turnpoint flight of 1064 km in the Pyrénées and in 2001 an out-and-return of 1014 km from Varese across the Alps.

In 2002, he began flying in Patagonia, setting more records, including the first 2,000 km out-and-return in November, 2003. Since 2002, he has organized annually a scientific gliding expedition to Patagonia.

His book, *Dancing with the Wind*, is a distillation of his long experience with successful wave soaring.

In total, he has set 27 French records and 6 World records in soaring.

**Heini Schaffner, MD**

Heini Schaffner, MD, is a Swiss alpine glider pilot since 1961 (3,500 hr gliding and 150 hr powered flight) and has been a clinical anesthesiologist for 39 years. He has been checked out in 35 different types of gliders and has worked in 80 different hospitals (to obtain more gliding opportunities ...), and besides hard work, he has flown all over the world as an accompanying physician on repatriating MedEvacs. Today he is the proud owner of a two-seater Arcus M that occasionally serves as his "flying research lab."

Although he never sought an appointment as an AME, nonetheless he annually attended for 30 years week-long advanced refresher courses for French and twice for German AMEs, held at the National Gliding Centre (CNVV) in St. Auban, SE-France. His special medical interest was neuroanesthesia, and since retirement, he has focused on high altitude medicine, ingenious oxygen dispensing devices for gliders, and particularly the impairing effects of subtle, but sustained hypoxia during daylong alpine and cross-country flights. This led to propagating his unofficial concept of "zero hypoxia" in flight as a basic prerequisite to good airmanship. Two widespread PDFs (in German) further explain this concept and made him a popular speaker and "eye-opener" in gliding clubs and instructor refresher courses.

**Patrick McLaughlin**

Patrick is the inventor of the oxygen Electronic Delivery System, founder of Mountain High, and is currently the Director of Research and Development at Mountain High. How the EDS system came about is described in the side bar "The Invention of the Mountain High Electronic Delivery System."