The Denton Flyer

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Next Meeting:

The next meeting of Chapter 661 will be Saturday, 6 May, at our usual meeting place at US Aviation, 4850 Spartan Drive, on the field at KDTO, on the second floor in Classroom Bravo. The meeting will start at 1200. Our guest speaker will be our own El Presidente, Janet Patton.

Janet will talk about what it is like to pilot a Boeing 777 over the North Atlantic Ocean. As you know, she is a First Officer (A.K.A. "Number One") for American Airlines. She has been with American since the mid-1990s and flying oceanic routes over the Atlantic and Pacific Oceans since 2015. A day at work for Janet normally takes her back and forth between DFW and LHR, but she also flies into BOS, SEA, LAX, PHX, JFK, and MIA.

Come hear Janet explain NAT tracks, random routes, and ETOPS while learning to communicate via HF and CPDLC. Your Minister of Information will be the guy in the back of the room shouting, "Oh! Oh! Can we talk about grid navigation?"

Aviation Tacos and Beverages:

What do you think about those tacos? Pretty cool, huh? This month, we are adding an assortment of beverages to the menu. Our host has graciously allowed us to bring food and drink to the meeting as long as we remain well behaved and clean up after ourselves. So far, we have proven ourselves worthy of such trust. Speaking of trust, as usual, there will be that "Straight Arrow" jar, reminiscent of Air Force Regulation 30-30. Let your conscience be your guide.

Nothing About Dues:

Our senior newsletter editor, Buck Rivets, said I don't need to include a mention of chapter dues. It's May, and we are approaching the middle of the calendar year. Those responsible members have already settled their accounts. The rest of the scallywags will just have to see what happens when their Chapter 661 Secret Decoder Ring goes silent.

Supplemental Oxygen:

By Russell Erb

Editor's note: You may recall Russell's article that appeared in the March edition about "USAF Thunderbirds Smoke Oil." After producing the award-willing newsletter, "The Leading Edge" for EAA Chapter 1000 for 25 years, Russ still publishes a newsletter he calls "The Trailing Edge" (http://erbman.org/trailingedge). Russ is a graduate of the U. S. Air Force Academy and a native Texan, growing up in Arlington. He served in uniform for twenty years and now works for the USAF as a civilian employee on the faculty of the Test Pilot School at Edwards Air Force Base. This is the first installment of a three-part treatise on supplemental oxygen and why you may want to use it at lower altitudes than required by regulation. It is reprinted here with his permission:

Why You May Want to Use Supplemental Oxygen at Lower Altitudes Than Required

Hypoxia Onset Altitudes

This article is not about hypoxia, its symptoms, or how to treat it. There are plenty of resources available on those subjects. However, we will briefly discuss hypoxia as it provides background for the topic at hand.

As a pilot, you are probably familiar with the FAA rules on supplemental oxygen use, straight out of 14 CFR 91.211:

Altitude	Requirement
Below 12,500 ft	No supplemental oxygen required
Above 12,500 ft	Supplemental oxygen use required for durations greater than 30 minutes
Above 14,000 ft	Supplemental oxygen use required for crew members
Above 15,000 ft	Supplemental oxygen must be available for all passengers

You may be familiar with the US Air Force rules on supplemental oxygen use:

Altitude	Requirement
Below 10,000 feet	No supplemental oxygen required
Above 10,000 feet	Supplemental oxygen use required
25,000 feet	Maximum cabin altitude with supplemental oxygen
Above 50,000 feet	Full pressure suit required in pressurized aircraft
60,000 feet	Maximum altitude in F-22 with a partial pressure suit
Above 5,000 feet	Supplemental oxygen use recommended at night

If you go to altitude chamber training (highly recommended if you can get it), the emphasis of the training relative to the altitudes listed above is on Time of Useful Consciousness (TUC), or how long you can function in a high-altitude environment without supplemental oxygen before you go stupid or pass out. Because the TUC can get very short, the emphasis is on recognizing your hypoxia symptoms and getting on supplemental oxygen before your TUC runs out. Here is an FAA table of typical TUC, lifted directly from Wikipedia (Ref 1). Your mileage may vary.

Pressure Altitude	TUC (normal ascent)	TUC (rapid decompression)
FL180 (18,000 ft; 5,500 m)	20 to 30 minutes	10 to 15 minutes
FL220 (22,000 ft; 6,700 m)	10 minutes	5 minutes
FL250 (25,000 ft; 7,600 m)	3 to 5 minutes	1.5 to 3.5 minutes
FL280 (28,000 ft; 8,550 m)	2.5 to 3 minutes	1.25 to 1.5 minutes
FL300 (30,000 ft; 9,150 m)	1 to 2 minutes	30 to 60 seconds
FL350 (35,000 ft; 10,650 m)	30 secs to 1 minute	15 to 30 seconds
FL400 (40,000 ft; 12,200 m)	15 to 20 seconds	7 to 10 seconds
FL430 (43,000 ft; 13,100 m)	9 to 12 seconds	5 to 6 seconds
FL500 (50,000 ft; 15,250 m)	8 to 10 seconds	5 seconds

At 10,000 feet a reduced ability to learn new tasks can be measured (Ref 2). Additionally, a person who normally lives at sea level who finds themselves at 10,000 feet pressure altitude for an extended period of time (such as 12 hours or more) will eventually reach a blood oxygen saturation of around 84%, which is generally accepted as qualifying as "clinical hypoxia." Long exposures at higher pressure altitudes rapidly get worse (Ref 3).

Thus, the Air Force set the requirement for supplemental oxygen use at a cabin altitude above 10,000 feet. The Air Force has one advantage while mandating supplemental oxygen use. All of its aircraft intended to operate above 10,000 feet either have pressurized cabins (such that the cabin altitude never exceeds 10,000 feet) or the aircraft are equipped with supplemental oxygen systems. The last Air Force aircraft I know of that did not have a pressurized cockpit but was expected to operate above 10,000 feet was the Cessna T-37. In the T-37 the aircrew wore helmets with oxygen masks, and supplemental oxygen was supplied through a regulator.

However, many general aviation aircraft are not pressurized, do not have supplemental oxygen systems, and yet operate at altitudes just above 10,000 feet. The body has some spare capacity to operate at an acceptably degraded state slightly above 10,000 feet (Ref 3). Thus, the FAA allows for operations up to 12,500 feet without supplemental oxygen, and over 12,500 feet (but below 14,000 feet) for no more than 30 minutes. One possibly apocryphal tale states that these limits were set because it was possible for unpressurized commercial airliners, such as the DC-3, to cross the Rocky Mountains through certain passes without violating these rules, thus allowing the airlines to avoid the cost of installing oxygen systems in non-pressurized aircraft. Whether this story is true or not, it is possible to cross the Rocky Mountains without supplemental oxygen without violating the FAA regulations.

The altitudes for supplemental oxygen use are set assuming an individual with a healthy respiratory system. Those with asthma or other respiratory issues may notice hypoxia symptoms at lower altitudes. One person I know with asthma starts to feel the effects above 5,000 feet.

So, while very important, your altitude chamber training would lead you to believe that the sole purpose of supplementary oxygen use is to extend your Time of Useful Consciousness to longer than necessary to complete your flight. That is certainly one reason, but just like Yoda said, "there is another."

The Experiment That Started All This

Back in 2002, Gary Aldrich and I were flying in Gary's Cessna 180 "Fightin' Skywagon" to Oshkosh for AirVenture. On our first day we flew from Fox Field (KWJF) to Hays Kansas (KHYS). To get there, we had to fly over Colorado through the Cumbres Pass (V368) and La Veta Pass (V83-210). Both of these passes can be flown VFR without exceeding 12,500 feet, but not much lower. After flying all day without supplemental oxygen with one leg at 11,500 feet, at dinner that night we realized that we were both very fatigued, like we had been mountain climbing all day, even though it seemed to us that all we did all day was to sit. We did that at the office all day and still felt good enough to have a full evening of activities. How could sitting all day be so fatiguing?

For the next Oshkosh trip (2004), we flew from Fox Field (KWJF) to Casper Wyoming (KCPR). This route would require similar high-altitude legs around 11,500 feet, mainly over the Provo River from Provo to Heber City Utah. This time Gary directed me to buy my own cannula so we could try using his oxygen system. This time we used the oxygen at altitudes below the required 12,500 feet, and when we arrived at Casper, we felt no more fatigued than after a day at the office. This was sufficient anecdotal evidence that supplemental oxygen could be useful at altitudes below where it is required.

Altitude Induced Fatigue is a Thing

So now we had reason to believe it was useful to use supplemental oxygen at altitudes below where it is required to ensure "Useful Consciousness," but for years I have been trying to understand why. After all, sitting in my desk chair at a pressure altitude of 2300 feet doesn't *feel* any different than sitting in an airplane seat at 9500 feet, but clearly something is going on.

We are about to start talking about human physiology, and I will admit that I am not an Aerospace Physiologist, nor do I play one on TV. I did do well in my biology classes, but to make sure I had the details correct I consulted with the USAF TPS Staff Aerospace Physiologist (Ref 3).

At any given moment, the cells in your body have a certain demand for oxygen for metabolism. This demand depends on what you are doing. If you are sitting watching the pregame festivities for the Super Bowl and eating my wife Tuki's yummy food, you don't need very much oxygen. However, if you are at Mountain Valley airport pushing a glider out to the runway or running inside to get a replacement yaw string, your demand for oxygen will be higher.

We all know how we get more oxygen to our cells when exercising. Exercise increases the metabolic demand of the cells. The blood needs to flow faster while (ideally) maintaining the same blood oxygen saturation (percentage of arterial red blood cells carrying oxygen) to supply the increased demand. Our heart rate gets faster (increase in rate) and the stroke volume increases (increase in volume) which pushes the oxygenated blood to the cells faster to keep up with the increased demand. Now that the blood flow has increased, the flow of oxygen in the lungs into the blood must increase to keep the blood oxygen saturation the same. To accomplish an increased flow of oxygen, our breathing gets deeper (increase in volume) and more rapid (increase in rate).

Our bodies (when functioning properly) have an absolutely wonderful control system to manage the blood pumping and breathing right to the minimum level required to meet the oxygen demand. If you exercise hard enough to overwhelm the ability of the heart and lungs to supply the required amount of oxygen, then you go into oxygen debt. However, if your oxygen demand remains within the capability of the heart and lungs, the body's control system will ensure that the effort required for blood pumping and breathing stays at the minimum required. This is because blood pumping and breathing both require muscular work, and this work consumes your energy supplies and contributes to overall fatigue, just like that muscular work you used to walk that 10K.

So, we understand that if we exert ourselves, that will cause increased effort to deliver more oxygen to the cells. "But I thought we were going to talk about why I get tired just sitting in the airplane, not from walking that 10K with Stormy and Mary." That's right, we are. The difference is that your body's demand for oxygen isn't that much different between sitting in your office chair and sitting in your airplane, but your body's ability to deliver that oxygen is different.

For oxygen to be absorbed into the bloodstream in the lung's alveoli, the pressure of the oxygen in the lungs must be higher than the pressure of the oxygen in the bloodstream. More specifically, the partial pressure of oxygen in the lungs must be greater than the partial pressure of oxygen in the bloodstream. Partial pressure is the pressure of a gas in a mixture as if it alone occupied the entire volume of the mixture at the same temperature (Ref 4). In the case of oxygen, the partial pressure is about 20% that of atmospheric pressure, because air is 20% oxygen by volume. Because the partial pressure of oxygen in the lungs is greater than that in the bloodstream, the oxygen is "pushed" into the blood and latches on to some waiting hemoglobin. (Likewise, the partial pressure of carbon dioxide in the bloodstream is higher than the partial pressure of carbon dioxide in the lungs, so the carbon dioxide is pushed out of the bloodstream.)

When we go up in altitude, the atmospheric pressure decreases and thus the partial pressure of oxygen decreases. Because the partial pressure of atmospheric oxygen is less, but the partial pressure of bloodstream oxygen is the same, the difference (or gradient) between them is reduced. When the gradient is reduced, the amount of force "pushing" the oxygen into the bloodstream is reduced, **so less oxygen gets into the bloodstream**, reducing the blood oxygen saturation. Herein lies the big problem.

The demand of the body cells for oxygen has not changed, so the required mass flow of oxygen needs to remain the same. Mass flow is given by the continuity equation

$$\dot{m} = \rho A V$$

which says that the mass flow can be calculated as the product of density, cross sectional area, and velocity. In our example, we will assume the cross-sectional area of the arteries stays the same. Because less oxygen was absorbed into the bloodstream (because of the lowered partial pressure of oxygen in the atmosphere), the blood oxygen saturation (represented by density (ρ)) is reduced. If the density of oxygen is reduced, then the only way to maintain the required mass flow is to increase the velocity. That is, if fewer red blood cells are carrying oxygen molecules, then they need to be pumped faster such that the same number of oxygen molecules are pumped by the cell as at lower altitudes. This increase in blood flow comes from a faster heart beat (higher frequency) and an increase in heart stroke volume (higher volume).

Once again, because the blood flow rate has increased, the rate of oxygen absorption in the lungs must increase to maintain whatever blood oxygen saturation is possible. This is accomplished by breathing deeper (more oxygen available in the lungs) and by breathing faster (bringing in more oxygen per minute).

So, when less partial pressure of oxygen is available to the body, the body responds by pumping what it has faster so that the cells still see the same amount of oxygen, and by breathing deeper to capture more oxygen to maintain the blood oxygen saturation. All of this extra breathing and blood pumping takes energy, and **this leads to the additional fatigue caused by flying at high altitude**.

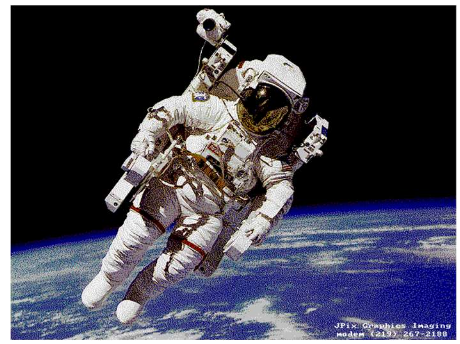
The real kicker to this problem is that this additional workload goes mostly unnoticed by the conscious brain, so you don't realize you are working harder. Generally, you won't notice a difference unless you are at least at 10,000 feet, and then only if you are doing mild exertion, such as walking up a hill. However, your body actually starts trying to compensate for the reduction in available oxygen at altitudes as low as 4500 feet. Remember the recommendation to use supplemental oxygen above 5000 feet at night for better vision? The eyes are perhaps the most sensitive organs in your body to a reduction in available oxygen, and the reduction of oxygen even at this low altitude reduces the cones' ability to detect colors.

Thus, avoiding Altitude Induced Fatigue is the best reason for using oxygen at lower altitudes than required by the FAA, especially if you don't like feeling tired. I generally use oxygen starting at around 9500 feet, and sometimes even lower.

Increasing the Partial Pressure of Oxygen Available in the Lungs

So how do we increase the partial pressure of oxygen available in the lungs? No, it doesn't require attaching a hose to your face and inflating you like a party balloon. The key is that we need to increase the partial pressure of oxygen, not the overall pressure of gases in the lungs. To increase the partial pressure of oxygen in the inspired gases we must increase the percentage of oxygen in the mixture of gases. This can be done as simply as just adding pure oxygen to air, which will increase the percentage of oxygen in the mixture above 20 per cent.

However, just adding oxygen only works up to a certain altitude. At 35,000 feet pressure altitude, the ambient pressure is roughly equal to the partial pressure of oxygen at about 8,000 feet pressure altitude. Thus, at 35,000 feet pressure altitude, the mixture of breathing gases must be 100 per cent oxygen just to get the required partial pressure of oxygen for proper respiration. I have heard less informed sources state that the pressure inside an astronaut's space suit while on a spacewalk is equivalent to being at 35,000 feet. While strictly true, they leave out that the gas mixture inside the space suit is 100 per cent oxygen, so it is nothing like standing on top of Mount Everest, where the oxygen is only 20 per cent.



Flying above a cabin altitude of 40,000 feet does actually require inflating you like a balloon with 100 per cent oxygen at a pressure higher than the air pressure surrounding you. This is called "pressure breathing" and it is extremely exhausting and dangerous. The danger comes about because your breathing process is reversed. In normal breathing, you use muscular exertion to draw air into the lungs. Relaxing the chest pushes the air out of the lungs. Under pressure breathing, relaxing causes the lungs to fill with air. To exhale, muscular exertion (like blowing hard to inflate a balloon or pool toy) is required. The body's control system does not understand this, and it requires conscious effort just to breath. Relaxation will cause you to suffocate with inflated lungs.

The other option to increase the partial pressure of oxygen available is to inflate the airplane with air, which is usually referred to as pressurization. Most pressurized aircraft can only pressurize to a particular difference above the outside air pressure because of leaks or structural strength. Thus, above some critical altitude, the cabin pressure of a pressurized airplane will start to reduce as altitude is increased. Most airliners only pressurize the cabin to about 8,000 feet pressure altitude. This is sufficiently low that most people will not significantly notice the effects. Pressurizing to a lower altitude requires more bleed air from the engines, which reduces the thrust, which requires an increase in fuel flow to compensate. Additionally, higher pressure will put more stress on the structure of the fuselage, causing it to fatigue and crack quicker. If you've ever felt fatigued after a long flight in an airliner, even though you were just sitting there, refer to the discussion above. An altitude of 8,000 feet is sufficient for you to start feeling Altitude Induced Fatigue, especially after six or more hours.

Military fighters and bombers don't over pressurize for another reason besides structural airframe weight. An ejection at high altitude would clearly fit the definition of a rapid decompression. The likelihood of suffering decompression sickness (DCS, also known as "The Bends") is increased as the amount of pressure change is increased. It is quite possible that an aircraft at 50,000 feet pressure altitude might have a cabin pressure as high as 25,000 feet, the maximum allowed without pressurization. The aircrew remain fully oxygenated because they are breathing from a demand regulator with a sealed mask. A rapid decompression from 25,000 feet pressure altitude to 50,000 feet pressure altitude is much less jarring to the physiological system than going from 8,000 feet to 50,000 feet. This is not as big of a problem for airliners, as a small hole won't depressurize that fast. A hole big enough to cause a rapid decompression in an airliner is going to be big enough to cause even bigger problems. Aloha Airlines Flight 243 comes to mind.

Acclimatization to Lower Atmospheric Pressure

Yes, there are people living in La Paz Bolivia (elevation 11,942 feet) who don't seem to be passing out on a regular basis. When I moved from Texas to Colorado, I felt kind of krappy for a while but eventually felt better. Another compensation available to the body when exposed to a lower partial pressure of oxygen for an extended period of time is to increase the number of red blood cells in the bloodstream. This doesn't happen overnight, though. It actually takes about six months. More blood cells to carry oxygen helps with increasing the amount of oxygen in the blood at the same blood oxygen saturation. Of course, when you then move back to Texas, over the next six months your body slowly reduces the number of red blood cells by not replacing them as fast as they are removed because it has no need to maintain that many red blood cells.

A popular thing with athletes is to spend a few weeks at high altitude, thinking it will improve their endurance. The Arizona Cardinals go to Spring Training for about three weeks in Flagstaff AZ (elevation 6,910 feet), then return to Phoenix. This brief time does not really increase the oxygen capacity (VO_2) of the players. At most, it teaches them to push through the discomfort and pain of oxygen debt to allow temporary bursts of increased output.

How Can I Detect Early Onset Hypoxia?

One way you can detect hypoxia is by going to the altitude chamber and learning what your hypoxia symptoms are. Of course, that's not available to everyone, and by the time you feel your symptoms it's really later than you had wished it would be.

Fortunately, there is instrumentation available! Remember the last time you went to the doctor and somebody clipped a thing over one of your fingertips and then wrote down some cryptic numbers? Well, the little electronic marvel that revolutionized medical care has applications in the cockpit too. Best of all, they're dirt cheap! Do a search for "pulse oximeter" and you will be presented with hundreds of choices. At the time of this writing, I saw one on Amazon for as little as $16.

Pulse Oximeter

This magic little battery powered device will tell you your current pulse rate (PR_{bpm}) and your blood oxygen saturation (SpO_2%).

How does this non-invasive magic happen? Inside the device on one side are two LEDs. One is colored red and the other is colored infrared. On the other side of the device is a photocell which can detect red light and infrared light. If you put your finger over a flashlight, you know that some light will pass through your finger. When the light comes out of your finger, it tends to look red, because all of the other color wavelengths were absorbed based on the colors of your tissues. Using this idea to advantage, the key principle at play is that red blood cells with oxygen (oxygenated) and red blood cells without oxygen (deoxygenated) are different colors, both in the visible spectrum and the infrared spectrum. As such, oxygenated cells absorb different amounts of red and infrared light when compared to deoxygenated cells. Deoxygenated blood (venous) is not colored "blue" like all of those diagrams in your biology book imply, but it is a different color than oxygenated blood.

"Okay, Spectrum Absorption Boy," you're probably thinking, "how do you separate that out from the absorption by bones, skin, fat, and the little guys who open and close the capillaries (Ref 5)?" The red and infrared absorption caused by those things remains constant, but the absorption caused by the blood cells pulses, because of, well, your pulse. The microprocessor in the oximeter ignores the constant part of the signal and focuses on the pulsing part. By counting the pulses, it can tell you your pulse rate (frequency). By looking at the intensity of the colors of light received and comparing it with the known intensity without a finger, the microprocessor can do some maths and figure out what percentage of the red blood cells are carrying oxygen.

For a more complete explanation of how a pulse oximeter works, watch the Technology Connections video at https://youtu.be/4pZZ5AEEmek (Ref 6). While no one will publish what blood oxygen saturation values "should" be (because it varies person to person), it seems generally accepted that while sitting at rest, values from 100% down to about 95% are generally okay. Another generally accepted value is if you see 90% or less in flight you really need to take action—either get on supplemental oxygen or descend.

For those of you competitive types out there (You know who you are!), you'll just have to be satisfied with 99% SpO_2%, because most pulse oximeters only have two characters on the display and thus can't display "100%".

One last faulty indication to be aware of—red blood cells bonded to carbon monoxide (CO) are the exact same color as they are when bonded to oxygen molecules. As such, the pulse oximeter can't tell the difference between carbon monoxide and oxygen, so it won't work as a carbon monoxide detector. You'll need a separate device for that.

References

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2. Physiological hazards of flight at high altitude https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(03)15059-3/fulltext
3. Discussions with Lt Col Matt "Spider" Taranto, USAF Test Pilot School Staff Aerospace Physiologist
4. "Partial Pressure", Wikipedia https://en.wikipedia.org/wiki/Partial_pressure ,
5. Hemo The Magnificent https://youtu.be/08QDu2pGtkc?t=2240
6. "Pulse Oximeters; An Amazing Use of Light", Technology Connections https://youtu.be/4pZZ5AEEmek ,

Be sure to watch for the second installment of this treatise where Russ explains the choices of supplemental oxygen systems that you could use to equip your airplane.

Coffin Races

First, let me say this project is not dead. (Oh yes! Pun definitely intended!) It is merely somewhat comatose at the moment. The next step is to generate some drawings of concepts that we may develop into the aforementioned E-Racer. We should be able to provide a glimpse of the selected concept in the next edition of this newsletter. That's my story and I am stickin' to it.