SOARING Rx

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Does Your Pulse Oximeter Mean What it Says? (Does Your Spouse?)

FAR 91.211 requires **supplemental oxygen** after 30 minutes above **12,500** feet MSL and continuously above **14,000 feet** and for pax above **15,000 feet** MSL. A pulse oximeter can show you why this requirement is in effect.

Finger pulse oximeters are mainly useful to reassure you that your oxygenation is OK (90+%), or that you should don oxygen or troubleshoot the situation (85% or below). That their readings **are often inaccurate and misleading** does *not* mean that they are useless!

Felipe enjoys flying high – to look down at mountains is always inspiring, so he's happy to have today's 15,000 ft high cloud bases. He wonders whether those FAR oxygen requirements are realistic, and how much oxygen he should really use at any particular altitude. Does his automatic Mountain High system really give him what he needs? If he keeps oxygen flow down to a minimum so the tank will last longer, can he avoid having to cut short a flight from running the tank empty? But, what's the minimum flow?

He bought a pulse oximeter and plans to answer these burning questions today. It's a bit cool, so he tucks his gloves in the side pocket where he can get at them after he's done checking out the oximeter. Field elevation is 5,000 msl – while he waits for the tow plane, he puts on the oximeter: it flickers 94, 93, 95%. He feels fine. He runs through his checklist, he gets hooked up. The tow plane tugs hard, and he's off.

Right away he realizes that keeping the oximeter on his finger is going to be hard because he has to use his hands to fly. Maybe he should have taped it in place. And the meter's numbers are always pointed away from him when he's gripping any of the controsl. When he is able to read it, he realizes that the numbers are a little hard to read in the direct sunlight under the canopy.

While thermaling up, he keeps glancing at the numbers on the oximeter. He remembers that the number should be over 90%. He's forgotten just why, but obviously it's to keep the brain functioning. In his mind his wife chuckles and says, "Will you be able to tell the difference?"

He's a little surprised that the number starts flirting with 89% even before he gets to 9000 msl! But, he feels fine, and the FARs don't require oxygen until he gets to 12,500. He will wait to turn on the oxygen. He really wants to know what his numbers will be without it, and how much and how fast they'll pick up when he turns the oxygen on.

At 12,500, the oximeter readings are hovering around 84%. The numbers fluctuate a little more than he expected. He feels fine. He's actually feeling a bit euphoric.

At 14,000, the oximeter reading often drops below 80%, and the numbers are less stable than they were. He reaches for the oxygen-system switch, then pauses. "Deep breaths should give me more oxygen – maybe I'm just not breathing enough."

He takes a series of deep breaths. Sure enough, the readings bump up, into the mid-80s. It's like descending a couple thousand feet! He notices a little shortness of breath, turns on the oxygen, and waits to feel better.

Now he's past 15,000 ft. Each time he inhales, the system gives a reassuring soft snort into his nostrils. The oximeter's readings climb above 90, and he keeps breathing deeply to see just how high he can carry the reading. This is interesting.

Flying near cloudbase and out of the sun, he gets chilly. Despite the oxygen and deep breathing, the oximeter's numbers are mostly in the 80s. He's puzzled – and a little worried. The oxygen bottle and gauge are behind him, and he can't turn far enough to read the gauge. He tries to remember the last time he filled the bottle.

After a few turns under the growing cloud, he actually begins to shiver. The dewpoint is less than 40 dF, and in the shade with the vent open to keep the canopy from getting fogged, it is definitely cool in the glider. The numbers on the oximeter are now dipping into the 70s. The oxygen cannula is still giving a little puff with each inhalation, but with these low readings, it seems that something has to be going wrong with his oxygen system.

He starts feeling a little dizzy. He gets more short of breath. A metallic taste is in his mouth. The oximeter is in the mid-70s. Something is definitely wrong! He's feeling a weird mix of euphoria and anxiety.

Doubt nourishes good sense, and he pulls the spoilers. Experiment over! On the way down, he starts to warm up. Out beyond the cloud, into the warm sun and into sink, he quickly descends toward home. There he can troubleshoot this thing on the safe, hot airport apron.

OK, what happened to Felipe?

Every electronic measuring device will display numbers if powered up. The question is, What is the relationship between reality and the displayed number? This is the main question of the science of *metrology*, the science of measurement, which really is the science of *measurement error*.

We need to avoid confusing *precision* (the number of digits after the decimal) with *accuracy* (the connection of the number to reality). Three-seconds' sober reflection is enough to realize that when the bathroom scale says 183.6, this is probably closer than the carnival shill giving cheap prizes for fooling him. However, few of us weigh a package on the bathroom scale and bother to complain at the post office when that scale differs.

With home medical care, there are three devices beside the bathroom scale that have more precision than accuracy: the blood pressure cuff, the glucose monitor, and the oximeter.

The truth about blood glucose and oximetry is that both of these instruments get less accurate when the readings are more important – lower than normal. This is because an instrument designed to detect something has a harder time finding it when there's less of it to detect.

It's the same problem faced back in the early days of AM radio: a weak signal is hard to separate from the electronic noise that's all around, so there's a lot of static with weak stations. This adds to the romance of late-night radio, but simply creates doubt about low blood sugars and oxygen levels. A low signal to noise ratio is the bane of metrologists.

Were Felipe's readings *accurate*?

First, what was the quality of his oximeter?

If you search the Internet, you'll see them offered from about \$25 to about \$250. The over-\$200 meter is a Nonin pulse oximeter, the first and the gold standard. Are you paying mostly for the name? Or do you get what you pay for in the inexpensive meters? I've never found research comparing them. The most useful page I found by Googling site:squidoo.com "Finger Pulse Oximeter Reviews" (Nonin's competitive meter is the Nonin GO2 for \$88 with an LCD display that reads fine in direct sunlight without reading glasses.)

This web page shows that 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!

As an aside, given that oximeters are reasonably accurate only to 70% saturation makes it hazardous to the "guinea pig" to go lower than that in testing, so ethics prevent manufacturers from using volunteers to calibrate their units to a lower level.

Second, what were the conditions of measurement?

He was mostly using this in bright sunlight. Sunlight can "overpower" the unit's own spectrophotometric light source. Some models have better shielding than others.

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

He moved his hands a lot in flight as is normal, and when he got cold he shivered. Simple fidgeting degrades the accuracy of these units significantly, with saturation numbers dropping by 5-20% (that is, with a true O2 saturation of 95%, the meter may read 75-90%). Some professional units are specifically designed to mathematically filter out the effects of tremor. I couldn't determine whether any fingertip units do.

A reason that tremor degrades accuracy is that these things are *pulse* oximeters – measurement is limited to the *pulsatile* light transmission, to eliminate the absorption by bone, skin, tissues, and skin pigment.

A challenge is to differentiate between the pulsation of a wobble and a heartbeat: what's the difference mathematically? Some oximeters have more successful algorithms than others. In any case, bodily movement can quickly drop the "measured" saturation.

This month's jargon treat: *The device is a spectrophotometer that measures absorption of light at 660 nm and 940 nm. At 660 nm, deoxyHgb absorbs 10x as much light as oxyHgb; at 940 nm, deoxyHgb absorbs less light than oxyHgb. The oximeter estimates functional Hgb by comparing amounts of oxy and deoxy Hgb; a fast Fourier transform generates Fourier spectral peaks, representing the pulse, the pulse harmonics, noise artifact, and any noise and artifact harmonics.* (Jargon courtesy of Respiratory Care, January, 2002, Vol 47 No. 1, p. 59)

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. The fingertip's blood can easily be different from that of the blood flowing through the brain. The oxygenation of the finger is only interesting insofar as it serves as a proxy for our brain. As we begin to cool, but before we ever feel cold, arterial blood supply to fingers and toes becomes constricted. In some people, veins dilate. Arterial constriction means there's less pulsing blood to measure. Venous pooling, if it occurs, means that more of the blood available for measurement is desaturated.

If the fingers are cool or cold, we simply can't take the finger reading as an indication of what the brain is getting, and it's falsely low.

It's also easy to get a falsely high reading. The most important cause of this is carbon monoxide. Real Men don't soar with engines running, but this matters for smokers, tow pilots, and touring motorgliders. In smokers, up to about 10% of hemoglobin in the bloodstream may be locked to carbon monoxide, which is useless for oxygen transport. This condition would be read by the oximeter as 10% desaturated and 90% saturated. This falsely raises oximeter saturation readings. When the tow pilot prangs the prop, perhaps the crack in the exhaust bracket is the real cause.

Last, let's consider the effects of hyperventilating. (See the December, 2011 edition of Soaring Rx for details.) Hyperventilation increases peripheral oxygenation while *decreasing* brain oxygenation. At 14k msl, your saturation should be about 85%. If you hyperventilate, you can bring your oximeter reading up to 96% – but your *brain* oxygen saturation falls to about 55%, which rather decreases your ability to be an interesting, well-rounded, skilled pilot with really good judgment. Philipe was feeling hypoxia-induced euphoria when he intentionally hyperventilated to raise his oximeter reading.

Then there are the annoying symptoms of hyperventilation, most important shortness of breath. Ultimately, this is what drove Felipe home. A good decision, but avoidable if he'd known How Things Work. Playing around with hyperventilation, plus the several factors leading to an erroneously low pulse oximeter reading, led him to suspect that a perfectly good oxygen system had malfunctioned in some mysterious and unknowable way.

Since it's the brain we're most concerned with, why measure saturation in the finger at all? Purely for convenience. We pass on better sites because we can see the meter more easily (unless you're one of those special mothers who can see her own ears).

The truth is that finger pulse oximeters are mainly useful to reassure you that your oxygenation is OK (90+%), or that you should don oxygen or troubleshoot the situation (85% or below). That they are not extremely accurate does *not* mean that they are useless!

FAR Sec. 91.211 ***Supplemental oxygen****. (a) General. No person may operate a civil aircraft of U.S. registry – (1) At cabin pressure altitudes above 12,500 feet (MSL) up to and including 14,000 feet (MSL) unless the required minimum flight crew is provided with and uses supplemental oxygen for that part of the flight at those altitudes that is of more than* ***30 minutes*** *duration; (2) At cabin pressure altitudes above* ***14,000 feet*** *(MSL) unless the required minimum flight crew is provided with and uses supplemental oxygen during the entire flight time at those altitudes; and (3) At cabin pressure altitudes above* ***15,000 feet*** *(MSL) unless each occupant of the aircraft is provided with supplemental oxygen.*

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