Fundamentals and Aspects of recommended Use of Pulse Oximetry in Aviation

Hypoxia is could be one of the more insidious hazards of flight. Pilots are learning in primary flight training that the higher they are flying, the less oxygen is available in the atmosphere. Additionally it is a fact that one of the effects of hypoxia is a feeling of being well. Measuring blood oxygenation level is critical to flagging hypoxia before it is too late. In non-pressurized aircrafts, the pilot will know to either use supplemental oxygen or descend to a safer altitude. In airplanes with a pressurized cabin, the pilot will be alerted to possible failures of the pressurization system (1).

> **13.3 MONITORING ON THE ROAD AND IN THE AIR**
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> **Pulse oximeters provide accurate, continuous, real-time oxygen saturation monitoring. Since they are also noninvasive, easy to use, and portable they are beneficial for monitoring in ambulances and aircraft. Both ambulances and helicopters are used for patient transport, during which vital signs need to be monitored. Altitude can cause desaturation, especially in critically ill patients. Pilots in the military are also subject to strong forces due to high acceleration, which can move blood out of the brain. These factors can cause loss of consciousness. Pulse oximeters intended for use in these types of environments are subject to special design considerations due to noise and vibration.**

(2)

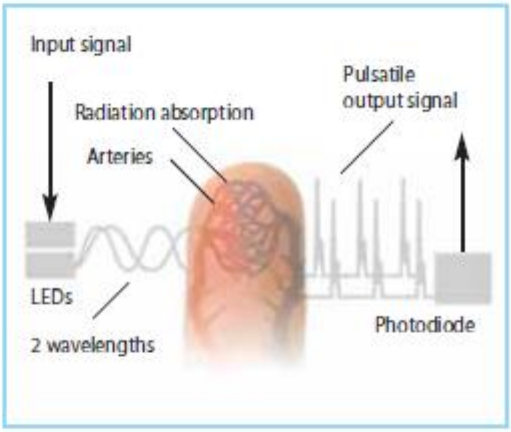
Air travel has increased steadily over the last decade, and its effect on the health of passengers has been the subject of much debate. There is a paucity of evidence on the effects of air travel on oxygen saturation in general populations. The peripheral oxygen saturation and pulse rate of 84 passengers, aged 1–78 years, were measured by pulse oximetry at round level and altitude during air travel. There was a statistically significant reduction in oxygen saturation in all passengers travelling long haul and short haul flights ($p < 0.05$). The mean [range] (SD) SpO2 for all flights at ground level was 97% [93–100] (1.33) and at cruising altitude 93% [85–98] (2.33). Fifty-four per cent of passengers had SpO2 values of 94% or less at cruising altitude. This is a value which may prompt physicians to administer supplemental oxygen in hospital patients. (3)

Until recently, the only objective guidance available to pilots concerning the use of supplemental oxygen in flight came from the Federal Aviation Regulations (3):

A pulse oximeter permits crewmembers and passengers of an aircraft to evaluate their actual need for supplemental oxygen quickly and easily. However, the FAA has not yet provided any official recommendations for the use of pulse oximetry in flight. Find enclosed the following guidelines, based on our experience in medicine and aviation. As with any such recommendation, each pilot has the obligation to become familiar with the technology and its proper use, and to interpret and adapt these guidelines to the particular situation. Some pilots and passengers will need to use supplemental oxygen at oxygen saturation levels higher than other individuals, and some may need higher oxygen flow rates than others. (3)

Principles of Operation

Pulse oximetry is based on the noninvasive measurement of the color changes that red blood cells undergo when they become oxygenated. The pulse oximeter works by transmitting a special light beam through a vascular bed of capillary blood vessels□ most commonly at a fingertip□ to evaluate the color of the red cells and calculate the degree of oxygen saturation. The units are very accurate, generally within one percent of directly measured blood oxygen levels obtained by invasive means.



Picture: Principles of Operation (4)

The pulse oximeter requires light transmission to work. The unit is slipped over the finger so that the light source shines through the part of the finger that is covered by the fingernail. Although pulse oximeters will generally work on most fingers, they will work dramatically better if the fingernail is not covered with nail polish¾ especially dark pigmented nail polish. Pulse oximeter readings can generally be relied upon when the instrument's *perfusion indicator* is "in the green" and the displayed pulse rate is accurate. To double-check that the oximeter is receiving good data, take your pulse manually and compare it with the pulse readout on the oximeter. If the two are close, you can be relatively confident that the instrument's oxygen saturation reading will be accurate (see pictures below).

Finger pulse oximeter

Handheld pulse oximeter with fingerclip sensor

An important limitation of pulse oximetry is that **it cannot detect or measure carbon monoxide (CO) poisoning.** This is because when CO binds to the hemoglobin in a red blood cell, the cell turns bright red in color, just as it does when it binds with oxygen. Consequently, you could literally be dying of CO poisoning and the pulse oximeter would show normal oxygen saturation readings. Consequently, the use of a sensitive, accurate, digital-readout **CO detector** is strongly recommended.

Normal And Tolerated O_2 Saturation Readings

When using a pulse oximeter, what blood oxygen saturation level is considered normal? The answer varies from one individual to another, and depends on lots of factors, including age, cardiopulmonary conditioning, and altitude acclimatization. However, as a general guideline, the following pulse oximeter readings can be considered normal:

Altitude (MSL)	O_2 Saturation
Sea Level	95-100%
10,000'	88-93%
13,000'	83-88%
16,000'	75-80%
20,000'	70-75%

During flight, this distinction between normal and tolerated is all-important. For instance, flying at 12,000 feet, a pilot may have an oxygen saturation of 85% -- which is absolutely normal for that altitude -- but that may not be tolerated very well by the pilot, who could easily develop cognitive (thinking) difficulties that affects his ability to comprehend a clearance, calculate fuel consumption, or respond thoughtfully to an emergency.

Besides altitude, there are other factors which will lower oxygen saturation, such as the congestion associated with a cold, insufficiently deep breathing (which can occur with overweight people in sitting positions), underlying lung conditions such as asthma, tobacco abuse (which also causes carbon monoxide poisoning), and something we have discovered just recently: *periodic breathing*.

Periodic breathing is an unconscious response to altitude where a person will breathe deeply for several breaths, then progressively start breathing more and more shallowly until he may actually stop breathing altogether for a few seconds (apnea), after which breathing becomes increasingly deep, and the cycle repeats. During the shallow breaths, oxygen saturation may drop substantially, and then rebound during the deep breaths. This can be observed clearly as rhythmic oscillations of pulse oximeter readings occurring several times per minute. The antidote is to make a conscious effort to breathe slowly, deeply, and regularly.

When Should Supplemental Oxygen Be Used?

Since there is no official recommendations for using pulse oximeter readings in flight, I have developed the following basic guidelines:

- **To avoid physical and cognitive impairment, always use supplemental oxygen in flight whenever your oxygen saturation drops 10 percentage points below normal for your home altitude.**
- **Most people will feel better and have less fatigue if they start using supplemental oxygen when their oxygen saturation drops 5 percentage points below their normal home altitude saturation.**

Note that these guidelines do not relieve the pilot from the regulatory requirement to comply with the 12,500- and 14,000-foot requirements of FAR 91.211. However, in most cases and for most individuals, adherence to the guidelines will result in using supplemental oxygen at lower altitudes than dictated by the FAR.

If you have an oxygen system that permits manual adjustment of flow rates, the pulse oximeter may be used to adjust oxygen flow to provide the desired saturation. However, it's important to understand that initiating oxygen use or adjusting oxygen flow will take 15 to 30 seconds before the effect shows up on the oximeter reading. That's how long it takes for the additional oxygen to enter the lungs, oxygenate the blood in the pulmonary blood vessels, pass through the heart, flow to the fingertip, and be measured by the oximeter. The effects of deep breathing (which also increases oxygen saturation) is also subject to this delay before it shows up on the instrument.

Examination of the oxygen content in aircraft cabins during long-distance flights and control of blood gases under appropriate conditions in the high-altitude climate simulation system (4)

Particularly in intercontinental flights altitudes of 10,000 meters to 13 000 meters are preference. For materials and thus to save fuel is in long-distance flights by lowering the cabin pressure to 565 mmHg, which corresponds to an altitude of 2438 m or 8000 ft.. above sea level equivalent, reduces the transmural pressure. The occurring at this ambient pressure slight hypoxia can already trigger disorders: Decrease in capacity of visual faculty during night , drowsiness, judgment weakness. Therefore, it is extremely important that the oxygen supply is not lowered additionally to reduced pressure caused by a recirculation based reduction content of oxygen. Measurements in different planes of various airlines revealed even at crowded transatlantic flights always showed an oxygen content of 20.9%. Despite rising fuel prices it seems that airlines do currently not skimp on fresh air throughput in their aeroplanes.

The effect of reduced oxygen supply to the oxygen balance of passengers was measured in the high altitude air conditioning simulation system of the Flight Medical Institute of the German Luftwaffe Königsbrück at Dresden, Germany, on 15 women aged 26-70 years (51.8 ± 14.0 years) and 15 men aged 26 to 85 years (57.7 ± 16.6 years). Measurements were made by blood gas analysis and pulse oximetry of the hemoglobin saturation. Additionally, a blood count has been made and temperature was measured at the same finger where the pulse oximetry measurement was done. The entire test person group was brought from an altitude of 250 ft.

(local altitude) at altitudes of 6,000 ft. and 8,000 ft. In addition 10 participants were assigned in heights of 10 000 ft. and 12 000 ft. Each height the test persons were ascending exposed for a time interval of about 30 minutes.

The results out of the test series can be summarized as following: The arterial oxygen tension follows the height linear: $PO_2 = -0.003 \times \text{height ft.} + 80$. In local level of PO_2 follows age: $PO_2 = -0.418 \times \text{age} + 97.3$ ($r = -0.674$; $p < 0.0001$). At 8000 ft. the relationship is somewhat flatter: $PO_2 = -0.24 \times \text{age} + 67.7$ ($r = -0.651$; $p < 0.0001$). Maybe older people respond slightly more to the waste arterial oxygen pressure than younger people do. The PO_2 negatively correlated with body mass index (at 250 ft.: $r = -0.683$; $p < 0.0001$). The PCO_2 rises aged slightly (at 250 ft.: $r = 0.446$; $0.01 < P < 0.02$), but he falls with increasing altitude a little bit at almost all test persons as a sign of a slight hyperventilation.

Comparing the measurement results of the pulse oximetry measurement on women with those of men, it is conspicuous that the values of women on average are slightly higher. The pulse oximetry measured oxygen saturation is similarly, as the PO_2 depending on height and pressure, however the temperature at the measuring finger and the hematocrit value affect the negatively measurement results. This shows why under otherwise identical conditions the pulse oximetry saturation values are slightly higher in women. Since the pulse oximetry saturation values usually are calculated 2% to 5% higher than the values from blood gas analysis, values below 90%, as they may occur by elderly persons already in heights of 8000ft., are construed as quite serious indicators of hypoxia. In any way “sea level” values lower than **93 %** of SpO_2 can be, in combination with other risk factors, an indication not to fly.

<u>Literature:</u>

Comments and collection of literature; Günther C. Glatte, Scientific Author, June 2019

(1) Joanna B Ruchala, MD, Application of Pulse Oxymetry

(2) S. Humphreys, R. Deyermond, I. Bali, M. Stevenson and J. P. H. Fee,
The effect of high altitude commercial air travel on oxygen saturation

(3) This is an expanded version of Brent Blue's, MD ad Senior Aviation Medical Examiner, article that appeared in the FAA's "Federal Air Surgeon's Bulletin" which was sent to all Aviation Medical Examiners.

(4) Free translation of “7. Summary” of the dissertation by Frank Neuwirth:
Examination of the oxygen content in aircraft cabins during long-distance flights and control of blood gases under appropriate conditions in the high-altitude climate simulation system