# HYPOXIA, OXYGEN AND PULSE OXIMETRY

Take a deep breath. Exhale. Now relax. It's amazing. That conscious replenishing of the air in your lungs is something your body has been doing automatically throughout your life. About 20% of each breath comprises essential life-giving oxygen. Once inside the lungs, the oxygen rapidly crosses a thin membrane and is absorbed by hemoglobin—the "red" in the blood cells—for distribution to all the body tissues.

The heart pumps this bright red blood throughout the body, transporting oxygen to tissue cells in order to create energy in a process called metabolism. As the blood flows past each cell, oxygen is absorbed. At the same time, carbon dioxide, a byproduct of metabolism, is removed. The dark red blood containing carbon dioxide flows back to the lungs where an exchange for a fresh supply of oxygen takes place.

**Causes of Hypoxia**

Whether we are sleeping, thinking or active, every organ in the body requires more or less oxygen depending upon the degree of activity taking place. The deficiency of usable oxygen, or the inability to take advantage of the oxygen that is present, is a condition known as "hypoxia." Although all tissues in the body eventually succumb to hypoxia, the brain is by far the most sensitive to a mild oxygen deficit.

The effects of hypoxia range from subtle to deadly, particularly in situations where sound judgement, reasoning and physical coordination are required. Like alcohol, the person affected will not likely notice the symptoms of mild hypoxia. As the severity of hypoxia increases the symptoms grow worse: headache, difficulty concentrating, visual problems, heavy breathing (hyperventilation), poor aircraft control, and ultimately loss of consciousness and death.

Hypoxia can result from a number of causes. If, for example, the flow of blood to the tissues is restricted and oxygen is blocked from the cells, "stagnant hypoxia" occurs. The tingling associated with a foot "falling asleep" after sitting in a cramped position results from stagnant hypoxia. The high G-induced loss of consciousness is caused by the inability of blood to reach the level of the brain.

Anemia is a condition where the oxygen-carrying capacity of the blood itself is reduced. Known as "hypemic hypoxia," this situation could result from a low hemoglobin count. Since hemoglobin is the body's oxygen transportation mechanism, reduced amounts of oxygen reach each cell. Hypemic hypoxia also occurs when carbon monoxide is present, since hemoglobin has a far greater affinity for carbon monoxide than oxygen. Although sufficient oxygen may be available, carbon monoxide replaces it in the blood.

Not only does carbon monoxide prevent oxygen from reaching the cells, it is also a metabolic poison, compromising the cell's ability to utilize oxygen. A condition known as "histotoxic hypoxia" results. Someone suffering from the effects of severe carbon monoxide poisoning may not quickly recover when the source of carbon monoxide is removed and oxygen is supplied.

One final manifestation of hypoxia, particularly important to aviators results from the decreasing amounts of oxygen available on ascent in the atmosphere. This deficiency is known as "hypoxic hypoxia" or "altitude hypoxia."

**Altitude Hypoxia**

Whether sampled at sea level or miles above the Earth, the percentage composition of the atmosphere remains the same—approximately 78% nitrogen, 21% oxygen and 1% inert gases. As one takes off and climbs higher in an unpressurized aircraft, an increasingly greater oxygen deficit will be experienced. Reduced atmospheric pressure results in fewer molecules per volume in the air we breathe. Therefore, each lung full of air at altitude contains less oxygen. This reduced oxygen supply will eventually result in the symptoms of hypoxia.


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The body, however, has several coping mechanisms. First, the rate and depth of breathing increase in order to deliver more oxygen to the lungs. Then, the pulse rate increases as the heart pumps blood faster in order to increase the delivery of oxygen to the tissues. There is a limit, however, on how far these adaptations can be taken, and eventually, supplemental oxygen will be required to make up for the deficit. The most important question for the pilot: “At what altitude will I need supplemental oxygen?”

The answer will depend on several factors that will vary for each individual depending upon whether the person is a smoker or non-smoker, male or female, whether flying during the day or night, one’s physical condition, and, perhaps, even piloting experience and stress level.

Studies performed at the FAA’S Civil Aeromedical Institute, have shown that pilots flying in unpressurized airplanes at altitudes between 8,000 and 12,000 feet without supplemental oxygen, make more procedural errors than pilots who are well oxygenated. Pilots not receiving oxygen at altitude also made more errors on descent and approach because the effects of hypoxia at altitude have residual impact later on; a sort of “hypoxia hangover.”

**Oxygen Saturation**

Since oxygen comprises about 21% of the atmosphere, when surface air pressure is 30 inches of mercury, oxygen will contribute 6 inches of “partial pressure.” At 18,000 feet, where atmospheric pressure is 15 inches, the “oxygen partial pressure” is 3 inches. At that altitude, the body will be receiving only one-half of the amount of oxygen required for optimum performance.

Hemoglobin, however, has such a tremendous affinity for oxygen that it is able to hold onto oxygen even when its partial pressure falls, up to a point. This is analogous to a turbocharged engine that maintains a constant manifold pressure up to the critical altitude. Hemoglobin is the body’s own turbocharger, and we speak about the percentage of hemoglobin that is “saturated” with oxygen. This is the amount of oxygen the blood is actually carrying compared to the maximum amount it could carry (100%), expressed as a percentage called the “oxy-hemoglobin saturation.”

At sea level, normal blood oxygen saturation is 97-99%. At 5,000 feet, it might drop to 95% and at 10,000 feet perhaps to 90%. These figures vary significantly between individuals and may even change in the same person over time. At some altitude near 10,000 feet, the body’s ability to compensate for the oxygen deficit is compromised and oxygen saturation will fall precipitously into the 80% level or below. Serious hypoxic symptoms will result unless supplemental oxygen is provided.

**Supplemental Oxygen**

Using a facemask or nasal cannula in conjunction with an aviation oxygen tank and flow meter, one can eliminate the oxygen deficit and continue to perform normally at altitude. Nasal cannulas are approved for use up to 18,000 feet and are more comfortable and economical in oxygen use than a mask. Its drawbacks include lower inspired oxygen concentrations that are somewhat unpredictable due to dilution with cabin air, especially if the pilot is a mouth-breather.

At 18,000 feet, where the oxygen partial pressure is three inches, the inhaled oxygen must be increased from 20% to 30% to obtain the oxygen equivalent of an altitude of 8,000 feet. This will demand a high flow of oxygen if using a nasal cannula. Masks provide a greater safety margin by allowing inspired oxygen concentrations up to 60% when high flow rates are supplied. At a cabin altitude of 25,000 feet, a 50% oxygen concentration equates to an oxygen altitude of 2,500 feet.

Oxygen delivery systems come with various types of flow controls. The flow meter calibrated in thousands of feet is a useful device to control oxygen flow. But beware, merely setting the small ball in the meter to your altitude may provide you with an inadequate supply of oxygen.


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## Pulse Oximetry

Fortunately, there is an affordable way for pilots to measure their own blood oxy-hemoglobin saturation level and accurately gauge the need for supplemental oxygen. A device called a "pulse oximeter," used for years in hospitals, is available to pilots. The pulse oximeter slips onto your fingertip and measures saturation by shining red and infrared light through the tissue. It also displays pulse rate, and accuracy is within 2%. The smallest model, the Nonin FlightStat®, is a compact, 2-ounce device.

With the pulse oximeter it will become evident that supplemental oxygen is needed at altitudes lower than those required by the Federal Aviation Regulations. It is a good idea to consider oxygen for flights above 5,000 feet at night and above 8,000 feet during the day. If oxygen use is anticipated, place the nasal cannula or face mask on and start the oxygen flow when climbing through 5,000 feet. Initially, set the flow to the altitude to which you will be climbing and check your oxygen saturation after level-off. If your reading is below 92-93%, increase the flow until the desired reading is obtained. Check your blood oxygen saturation at 10-15-minute intervals during the flight to determine if your oxygen flow is sufficient. At night, or during flights that are stressful such as in IFR conditions, increase the oxygen flow until a saturation of 94-95% is achieved. Since workload is heaviest during the descent and approach, especially during the night IFR, remain on oxygen until you are on the ground.

If your system is equipped with an adjustable flow meter, you will most likely require a flow rate that is higher than indicated for your altitude, which will mean a consumption rate greater than predicted by the manufacturer. Therefore, check your oxygen supply as frequently as you check your fuel gauges, keeping in mind that tank depletion, disconnects and inadvertent shutdowns are possible.

Also keep in mind that regardless of the numbers, if at anytime you do not feel right at altitude, turn on the oxygen supply. If your symptoms improve, remain on oxygen. If they don't, land as soon as possible. Since the pulse oximeter cannot detect carbon monoxide you may be suffering from carbon monoxide poisoning, which even high oxygen flows won't eliminate.

## Summary

The use of supplemental oxygen as specified by the FAR's simply does not afford sufficient protection from hypoxia; it can occur at lower altitudes. Manufacturer's suggested oxygen flow and duration may not be reliable and do not take into account individual variations. Furthermore, personal susceptibility to hypoxia is not considered. Oxygen usage needs to be custom-tailored to each individual pilot, and the pulse oximeter provides the only objective means to do this—providing valuable information to pilots who fly above 5,000 feet.

Although there is much more to learn about how hypoxia affects pilot performance, there is nothing to lose by maintaining near normal oxygen levels when flying at altitude. In fact, any effort to increase the margin of safety is well placed because hypoxia is insidious and deadly. It is a silent killer that leaves no trace.

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