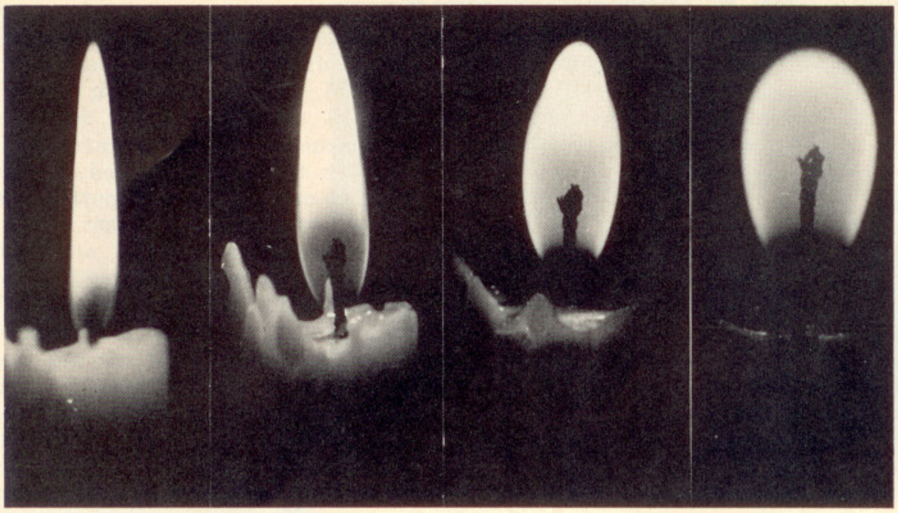

Sea level 20,000 feet 40,000 feet 58,000 feet

A candle flame changes in shape and deteriorates upon going to altitude due to the lack of oxygen. It goes out completely after a few seconds at 58,000 feet

HYPOXIA: A High-Altitude Hazard

by J. K. COLEHOUR • AOPA 33674

Decreased oxygen supply above 10,000 feet seriously affects your vision and ability to fly an airplane

Oxygen is unique among man's necessities of life. Lack of food and water can be tolerated for considerable time but oxygen lack is almost immediately apparent. While it is true that we may tolerate a 30% decrease in our oxygen supply, which we do when we fly to 10,000 feet without added oxygen, that is about the limit of how far we can safely go in cutting down on oxygen. Above that altitude things start to happen which are detrimental to our flying ability. And the unfortunate thing about it all is that the effects of hypoxia are quite subtle at first; we may be unfavorably influenced by it before we know it.

The word hypoxia is derived from the prefix "hypo" denoting deficiency of and the suffix "oxia" denoting oxygen. In medicine, hypoxia means there is a lack of oxygen in body tissues; it may result from one of several factors. In aviation it has a special meaning in that the tissue hypoxia is produced by insufficient oxygen in the inspired air. It should not be confused with the term anoxia which in its literal sense means without oxygen. Man can adapt to varying degrees of hypoxia when time is available for the adaptive processes; true anoxia is fatal in a matter of minutes.

It is unfortunate that man's vision and his brain are first affected by lack of oxygen. Impairment of vision and mental processes are probably the worst things that could happen for obvious reasons. Pilot performance in general is thus influenced. The effect of hypoxia on the pilot makes him less able to tolerate "G" forces, concentrate on instruments during IFR flights, suppress fatigue, and tolerate stress. Furthermore, it may falsely make him feel good at certain stages in the hypoxic state. That it is important is evidenced by the fact that the Navy recommends

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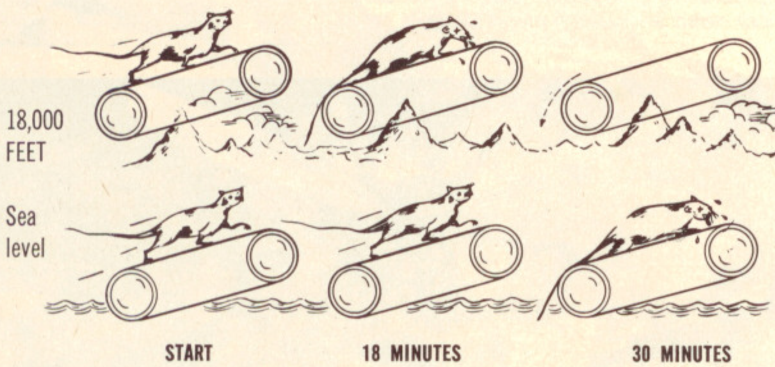

Figure 1
Rats trained to run on the treadmill at sea level tire out in a much shorter time when taken to altitude because of hypoxia

Hypoxia

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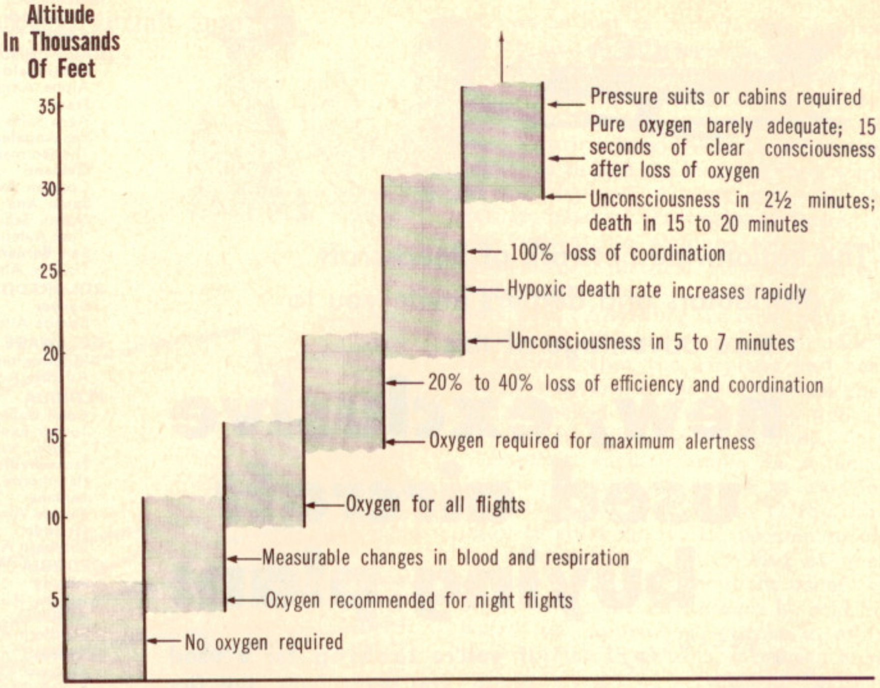
oxygen for its pilots on night flights above 5,000 feet and for all jet flights from the ground up.

What are the other effects of hypoxia besides those on mental and visual processes? Any other metabolic processes requiring oxygen would be affected if the amount inspired went below our minimum needs. The burning of food for production of energy would be one, but in this case the deficiency would not be very noticeable. Muscular action is very much handicapped by lack of oxygen; but our pilot would hardly be aware of this since his muscular function is light in sitting position. Those of us who have taken an auto ride to the top of a mountain and then tried to run a foot race are well aware of it.

Recently we conducted an experiment designed to quantitate muscular deficiency under hypoxic conditions. White rats were used for the purpose. A group of 40 of the animals were selected for uniformity and trained to run on an inclined plane treadmill. After all had become equally proficient at prolonged running, each was weighed, certain blood tests were made and then the group was divided into halves. One group was kept at sea level as the control group, and the others were taken to 18,000 feet in a low pressure chamber. The rate of ascent was 1,000 feet per minute. The animals became very hypoxic. They were exercised on the treadmill as before but their performance deteriorated considerably. While their mates on the ground could run a total of 30 minutes per day, the altitude rats were completely exhausted after 18 minutes running. See Figure 1.

In order to show that the animals could adapt to altitude the test was continued for several weeks. They were put on the treadmill twice a day and encouraged to run until they were completely tired out. The chamber was maintained at 18,000 feet, night and day. As time went on, their ability to run increased and after a four week period their average running ability was as good as those at sea level. The changes that had taken place are involved in what we call adaptation to altitude. The adaptation is similar but not the same as the complete adjustment that certain peoples who have lived at altitude for generations have made.

The Inca Indians of Peru are examples of peoples who were completely adapted to altitude. They were excellent specimens physiologically and could work and perform in athletic events surprisingly well although their living abodes were as high as 18,000 feet. The most important part of their adaptation was that their systems could more efficiently extract oxygen from their inspired air. This is always accompanied by an increase in the number of red cells in the circulating blood. This type of adaptation does not apply in aviation. A considerable portion of



Man's oxygen requirements and the effect of the lack of oxygen at various altitudes

FIGURE 2

each day would have to be spent at altitude for an aviator to have a significant degree of adaptation.

Another effect of hypoxia at 10,000 feet that few of us are aware of is the slight increase in the rate of breathing which automatically takes place. At 12,000 feet the increase should be definitely noticeable. The effect of the increase in rate of breathing is that more volume of air is moved in and out of the lungs per minute although it is less dense than sea-level air. In other words, although there are less molecules of oxygen per single volume of inspiration, the fact that more total volume is passed through makes it possible for our systems to pick up as much oxygen as at sea level. Here again the body extracts the necessary gas more efficiently. This compensation is adequate up to 10,000 or 12,000 feet but above that altitude it is not adequate. The various effects of lack of oxygen at altitude are shown in Figure 2.

Regulation of respiratory rate under hypoxic conditions is not a simple matter. Although our breathing moves more air in and out of our bodies in order to pick up more oxygen molecules, there are conflicting effects from this process. Carbon dioxide is involved in two ways. It must be continuously removed from our systems because it is continuously produced and at the same time the amount in our blood and tissue must be held within certain limits. Adverse effects will be produced if these requirements are not met. Carbon dioxide (CO_2) regulates respiratory rate through the respiratory center in the brain. When the CO_2 content of the blood becomes too high the respiratory rate increases; when the content is too low, the rate decreases. The more rapid breathing we have talked about decreases blood CO_2 to lower than normal levels and the respiratory center slows the breathing rate. Thus, our pilot at 12,000 feet increases his respiratory rate to increase his oxygen supply but removes CO_2 from his system too rapidly which tends to depress his respiratory rate. It is at this point that there is conflict and the system starts to fail. If we go to higher altitudes the detrimental effects become more pronounced.

The effects of hypoxia are mediated by other influences on the respiratory system. Noxious gases and carbon monoxide (CO) in particular intensify the detrimental effects of hypoxia. CO in our inspired air prevents our red blood cells from carrying their normal oxygen load from the lungs to the various parts of the body. Our systems can compensate for this at sea level so that when we are exposed to low concentrations for short periods nothing happens. If we ride to work on a cold winter morning with car windows shut and exhaust fumes containing CO seep into the car the oxygen carrying ability of our blood will decrease depending on how much of the gas gets into the car. We have observed this amount to be as much as 15% or 20%. Even smoking can have the same effect but usually not over 6% or 8%. Fortunately amounts greater than those we have specified are accompanied by headache, nausea and other noticeable effects so that the one affected realizes that something is wrong; he gets out in the fresh air and the situation is rapidly remedied. CO poisoning has recognizable signs but hypoxia does not.

But let us consider our pilot at 12,000 feet or above. He is operating at the upper limit that his system will permit due to hypoxia. If carbon monoxide is introduced into the cabin at this point it may well reduce his own "service ceiling" rather rapidly. The effects of hypoxia and carbon monoxide are cumulative because both make it impossible for body tissues to receive their normal amount of oxygen. The importance of tight exhaust systems and firewalls can not be overemphasized. Cabin pressures usually are slightly below outside pressures and therefore leakage is to the inside rather than to the outside. Exhaust fumes that flow over cabin surfaces tend to seep inside.

The writer knows of one case where part of the fairing behind the firewall was lost in flight. The occupants of the aircraft became aware that something was wrong physiologically so they landed. Blood samples were taken immediately and showed 35% saturation with carbon monoxide. It is very probable that continued flight for another few minutes would have resulted in loss of consciousness.

Modern civilian aircraft are being equipped with more powerful engines, performance is increased and altitude flight is easier to attain. Before we choose our cruising altitude greater than 10,000 feet let us remember the risk of hypoxia. It gives no warning except to those trained in its detection; recovery is always questionable because our mental facilities are first affected. Carbon monoxide not only from exhaust fume leakage into the aircraft but also from smoking can hasten incapacitation from hypoxia. Oxygen at altitude is the cheapest insurance you can buy.

END

THE AUTHOR

J. K. Colehour (AOPA 33674), author of "Hypoxia: A High-Altitude Hazard," is research biochemist with the U.S. Naval Aviation Medical Center at Pensacola, Fla. He holds a master of science degree. Flying is one of his favorite hobbies; he has held a pilot license for 12 years, soloing at Dallas, Tex., in 1946. It was not long after receiving his private license that Colehour became an AOPA member, and has remained one since 1947. He is the proud owner of a Luscombe and does quite a bit of cross-country flying in it.

Opinions or conclusions contained in this article are those of the author and are not to be construed as necessarily reflecting the view or endorsement of the Navy Department.