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OXYGEN IN GENERAL AVIATION

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Our metabolic engine and our aircraft engine have in common the requirement for oxygen. They also have in common the feature that neither can store oxygen.

We shall direct our attention at one table. This table, entitled "Utilizable Atmospheric Oxygen", provides us as surely with the facts of oxygen requirements in flight as do the power setting tables in specific aircraft flight manuals.

Note that at sea level, the total air pressure approximates 760 millimeters of mercury. This same total gas pressure exists within the tiny air sacs of the lungs since all of the air tubes leading from them are open and connect directly with the atmosphere.

Since the gases within these air sacs are 100 percent saturated with water vapor at a body temperature of 98.6 degrees F, a water vapor pressure of 47 mm of mercury results.

Note also that at 12,000 feet, where the total air pressure approximates 483 mm, the lung air sacs continue to contain water vapor at a pressure of 47 mm, since the water vapor saturation and body temperature remain the same.

This water vapor content of the lungs takes a proportionately larger "bite", therefore, out of the available atmospheric air at 12,000 feet, as compared to sea level. This fact, together with certain points mentioned later in this paper, explains why we begin to suffer progressively as we climb into thinner air (item: a similar situation concerning water vapor prevails with respect to aircraft engine efficiency and humidity levels. As the amount of humidity in the air increases, all other atmospheric factors remaining constant, the power deliverable by the engine decreases. People and aircraft engines have, therefore, certain features in common, in that the water vapor pressure can be critical to the function of both).

We now see that subtracting the lung air sac water vapor, we have at sea level 713 mm gas pressure remaining (consisting mostly of nitrogen and oxygen). Flying at 12,000 feet in an unpressurized aircraft, our lungs contain (minus the water vapor) a gas pressure of 436 mm.

Of these two pressures, oxygen represents roughly 20 percent, which gives us a sea level lung oxygen pressure of 143 mm and a 12,000 foot oxygen pressure of 87 mm.

Since one of the functions of the lungs is to clear the blood of carbon dioxide (the gaseous by-product of metabolism), we find that under resting conditions the lung air sacs contain 40 mm carbon dioxide pressure (the carbon dioxide is physically expelled from the lungs with each exhalation).

Let us now correct the sea level lung oxygen for the ever present carbon dioxide factor (143 minus 40) and we have an effective oxygen pressure in the lung air sacs of 103 mm.

Correcting the 12,000 foot level lung air sac oxygen pressure for carbon dioxide pressure (87 minus 40) we have remaining in the lung air sacs an oxygen pressure of 47 mm.

Here we are, then, piloting our unpressurized craft along at 12,000 feet, with a lung air sac oxygen pressure only 45 percent of that in the same air sacs at sea level (47 divided by 103 times 100).

This lowered lung air sac oxygen pressure found at 12,000 feet, provides an arterial blood oxygen saturation of 87 percent, compared to the 96 percent saturation at sea level.

It is clear from these figures, that an altitude of 12,000 feet begins to compromise the efficiency of our metabolism, and especially that of the brain, which requires a continuous irrigation of 96 percent oxygen saturated blood for peak mental function. Acceptable mental function in the

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normal individual can still be accomplished at 87 percent blood oxygen saturation (assuming that a blood hemoglobin quantity of normal or higher value exists—the red-colored chemical, hemoglobin, contained in the red blood cells, is the transporter of oxygen), but this figure approaches the marginal level. At higher altitudes, as one ascends through 14,000 feet and up, distinct impairment of mental functions occurs. This is especially true of mathematical and reasoning capabilities.

Actually, under real flight conditions, the pilot is accomplishing certain physical work above his basal rest level requirements. Hence, the arterial oxygen saturation can be even lower than that conservatively stated above. Additionally, with work above the basal level, carbon dioxide is elevated in the venous blood, and, consequently, also in the air sacs. This means that the 40 mm carbon dioxide factor can become increased, taking a further bite into the available oxygen.

The physical laws requiring us gradually to "firewall" the throttle as we gain altitude in our nonsupercharged aircraft, apply equally to our "nonsupercharged" bodies.

The solution to the engine-power problem at higher altitudes in piston light aircraft is the employment of a supercharger. The solution to the oxygen problem for occupants in these aircraft at altitudes exceeding 12,000 feet, is the use of oxygen equipment in accordance with well-established procedures, as available through the various recognized manufacturers of the aviation industry. Good portable equipment is on the market.

It is possible that in the near-future, pressurized light piston engine aircraft (with cabin pressures equivalent to 12,000 feet or less) will become available (of course, in this case, due to the possibility of rapid decompressions, emergency oxygen equipment should be available). As the cabin altitude increases, one can pass through a pressure level beyond which the venous oxygen pressure exceeds that in the air sacs, and oxygen, in effect, leaves rather than enters the body—this can occur at the 30,000 foot range of altitude.).

How much oxygen flow should a pilot use at a given altitude for a given period of time? The recommended flow rates provided by the manufacturers of oxygen equipment serve as the base line, in a fashion similar to the recommended manifold pressure and RPM settings for given altitudes to determine a certain percent horsepower. In the case of oxygen, we recommend flow rates with the specific equipment being used which insure an arterial blood oxygen saturation of 87 to 96 percent.

Let us be cognizant, then, of one salient fact: the brain is our governing body during flight, our master organ. It consists of nerve cells which, unlike other types of cells (for example: muscle cells, liver cells or bone cells), cannot function more than about fifteen seconds without oxygen. As a matter of fact, as the arterial blood oxygen saturation level falls from the usual 96 percent to 90 percent and then to 87 percent, the efficiency of brain function begins to fall as measured by objective psychophysiologic tests.

There is a wide individual variation in susceptibility to hypoxia, since individuals vary in their blood vascular efficiency and other biologic characteristics. However, all persons begin to deteriorate in alertness and mental efficiency to some degree above 12,000 feet in the absence of supplemental oxygen, and here lies, therefore, the crux of the matter. Incidentally, air traffic controllers have witnessed pilots suffering from hypoxia (example: slurred speech) between 12,000 and 14,000 feet, who were unaware of their hypoxic state. Daily exposures to these altitudes during flights does not produce adaption to high altitude.

As a general rule, it would be wise to use supplemental oxygen above 12,000 feet, and it should be an invariable companion above 14,000 feet in unpressurized aircraft. It is well to remember the advisability of providing passengers with poor circulatory conditions (arteriosclerosis, heart disease, etc.), or with poor lung function (asthma, emphysema, chronic bronchitis, etc.), with supplemental oxygen beginning at about 8,000 feet, depending upon the severity of the condition and duration of the flight. A physician should be consulted on specific cases.

Of course, from the operational standpoint, there is little percentage in cruising a nonsupercharged aircraft at altitudes above 14,000 feet. The lower engine efficiency, coupled with the high angle of attack and the slow cruising speed, plus the time and fuel consumed in climbing to this altitude, conspire to keep most of the light present-day aircraft in the lower altitudes.

As previously mentioned, this picture will change with the more general availability of supercharged light aircraft, and it is our responsibility to foster and promote, through education, an effective and safe mounting of these higher altitudes.

At CARI, through our Physiological Training Support Service and utilizing a modern altitude chamber complex, private and business pilots are being given oxygen equipment training and altitude effect demonstrations. Each individual can determine his own tolerance to hypoxia (low oxygen) in this one day course. Proper breathing is taught, especially the means of avoiding overbreathing (hyperventilation) which can result in uncontrollable muscle spasms (due to too much loss from the body of carbon dioxide with the blood becoming too alkaline in character).

Already, CARI has provided indoctrination as part of the FAA's public safety education program to many private and business pilots, aviation medical examiners, and commercial pilots of such companies as Mooney, Cessna, Aero Commander, Piper and Beech. The result will be a safer tomorrow in the upper atmosphere. We also provide for civilian physiological training at various Air Force installations around the country.

We would be remiss if we did not mention certain factors which aggravate the effects of thinner air on the individual.

Such conditions as anemias, emphysema (weakened lungs due to premature aging, asthma, etc.), and illnesses accompanied by fever, can lower the individual pilot's tolerance to altitude.

In addition, fatigue, alcohol, antihistamines, and heavy smoking (with inhalation), also lower altitude tolerance. Carbon monoxide is one of the most subtle and vicious factors in lowering altitude tolerance, since it binds with the blood far more tightly than oxygen, and, in effect, diminishes the total quantity of circulating blood capable of carrying oxygen. Carbon monoxide poisoning mimics anemia, therefore.

All persons deteriorate as they ascend in altitude. Some, especially those in poor physical condition (as not infrequently found in the business-man pilot population), deteriorate in performance far more rapidly than others. As a general statement, night vision deteriorates in all persons beginning at about 5,000 feet altitude in the absence of supplemental oxygen. Symptoms of oxygen deficiency begin in a subtle fashion, and are frequently unrecognized by the individual with no direct experience in the matter.

The non-physically conditioned person deteriorates faster at high altitudes, because his body demands more blood flow per unit of metabolic increase resulting from the work stress of altitude, and, being in poor physical condition, he cannot deliver as efficiently the required blood flow.

The frequency of mistakes begins to increase above 12,000 feet, and mental clarity definitely becomes clouded. Since the subjective evaluation of one's own performance is compromised under these circumstances, there is a tendency to believe one is performing better than is really the case. Euphoria develops at 16,000 to 20,000 feet, and all seems wonderful, in spite of the fact that the speech may be slurred, the motions sluggish and uncoordinated, and the computations of time and distance inaccurate. An objective sign of hypoxia at these upper altitudes is the change in color of the finger nails from pink to gray.

We are tempted to relate here the half dozen or so recent tragic experiences of those who came to grief in light aircraft through lack of knowledge about and respect for the brain's oxygen requirement.

We shall not do so because our table entitled "Utilizable Atmospheric Oxygen" speaks for itself.

Let us then be certain that we ourselves, as well as our flight colleagues, acquire and bring to bear the requisite knowledge in our next great adventure in light aircraft: flight into the higher altitudes.

UTILIZABLE ATMOSPHERIC OXYGEN

	Sea Level	*12,000 feet*
Available Atmospheric Air Pressure	760 mm Mercury	483 mm Mercury
Lung Air Sac Water Vapor	−47	−47
Pressure of Remaining Lung Gases	713	436
Oxygen Portion (20%)	x0.20	x0.20
Oxygen Pressure in Air Sac	143	87
Minus Air Sac Carbon Dioxide	40	40
Oxygen Pressure in Lung Air Sacs	103 mm Mercury	47 mm Mercury
Provides Arterial Blood Oxygen % of	96%	87%