Physiological Aspects of High Altitude Flying

By Dr. med. Rainer Henn, Germany

Presented at the 10th OSTIV Congress, South Cerney (England), June 1965

In high altitude flying oxygen equipment is necessary if altitudes of more than 4,000 metres are reached. The pilot knows how to handle his oxygen system, but he should also know *why* he needs oxygen and how much. And he should know what to do when he has an incident at higher altitudes, for example when the oxygen supply is interrupted. In order to understand the necessity of oxygen supply in high altitude flying let me give you a short introduction into the physical and physiological backgrounds of hypoxia.

Dry air contains 20.94% by volume of oxygen. This relative percentage composition of the ambient air, which contains also 78% by volume of nitrogen and carbon dioxide in small amounts, does not vary appreciably within altitudes up to 20,000 meters. If the percentage of oxygen in the air is the same at sea level and at higher altitudes, why then do we need additional oxygen, already at 4,000 metres?

The quantities of gas expressed in percentages of a gas mixture have, however, little significance, for percentage represents the *relative volume* of a gas and not its *actual molecular concentration* or density. It is the latter which determines the availability of the gas—in our present case the oxygen—and this can be better expressed in terms of *partial pressure.*

For example: If we assume a total air pressure (which is the barometric pressure) at sea level of 760 mm Hg, the partial pressure of oxygen in dry air is 20.94% of 760 mm Hg, that is 159 mm Hg.

With increase in altitude the total air pressure and in the same way the partial pressure of oxygen decrease. At an altitude of 5,500 m the partial pressure of oxygen drops to one-half of the sea level value, that is about 80 mm Hg, to one-fourth—that is 40 mm Hg at 10,300 m, and to one-tenth—that is 16 mm Hg at 16,000 m.

To tell the truth, in high altitude it is not the oxygen partial pressure of the ambient atmospere which determines the degree of oxygen deficiency, but rather the oxygen partial pressure of the air in the lungs, the alveolar oxygen pressure. The composition of the air in the lungs is quite different from that of the atmosphere. It is a mixture of inspired ambient air and gases coming from the body. The latter is carbon dioxide (which is produced in the cells of the body) and water vapour, emanating from the moist walls of the alveoli, bronchi and trachea. Under normal conditions the partial pressure of carbon dioxide in the lungs is about 40 mm Hg, the partial pressure of water vapour amounts to about 47 mm Hg (at sea level).

Because of this permanent rather high content of carbon dioxyd and water vapour in the lungs — the partial pressure of both amounts to 87 mm Hg—, the oxygen partial pressure in the lungs is only about *103 mm Hg* and *not almost 160 mm Hg as in the ambient air!* For this reason the partial pressure of oxygen in the lungs decreases more rapidly than the partial pressure of the oxygen in the ambient air. This fact is very important.

At 4,000 m where already physiological disturbances caused by oxygen deficiency can occur, the atmospheric oxygen partial pressure is about 90 mm Hg, but the oxygen partial pressure in the lungs amounts only to 50 mm Hg. The corresponding values at 7,000 m are 60 mm Hg and 30 mm Hg. This alveolar oxygen partial pressure of 30 mm Hg must be regarded as critical value. A further decrease will inevitably cause severe physiological disturbances and—when remaining longer at this altitude—irreversible alterations, especially in the nervous system.

Strictly speaking, it is not the oxygen in the lungs that is important, but that which is transported with the blood to the cells of the different organs such as brain, heart, kidneys, liver and so on, to the theatre where the oxygen is consumed. Thus the *rate of decrease* of oxygen pressure—the "Sauerstoffgefälle" as we say in German—is the actual driving power in maintaining oxygen supply of the organism and keeps the metabolism running. It is easy to understand that with increasing altitude or decreasing atmospheric oxygen pressure the rate of decrease of oxygen partial pressure down to the cell level becomes less and less. For example at sea level the pressures are

in the ambient air 159 mm Hg,
↘ in the lungs 103 mm Hg,
↘ in the arteries 80 mm Hg,
↘ in the veins 35 mm Hg.

At 4,000 m they become
in the ambient air 90 mm Hg
↘ in the lungs 50 mm Hg
↘ in the arteries 45 mm Hg
↘ in the veins 30 mm Hg,

and at the critical altitude of 7,000 m they are
in the ambient air 60 mm Hg
↘ in the lungs 30 mm Hg
↘ in the arteries 25 mm Hg
↘ in the veins 20 mm Hg.

Derived from this, it is easy to understand that any infection or disease of the lungs, heart, blood and circulation may influence the amount of oxygen that reaches the cells, the theatre of metabolism. It is also easy to understand that an otherwise not severe sickness such as a cold, cough or influenza will, with fever present, raise the oxygen consumption considerably because of the increased metabolism.

The initial symptoms of oxygen deficiency or hypoxia are different from person to person. To some extent we can compare the initial symptoms of hypoxia with those seen after drinking alcohol. Above 4,000 m there is often a feeling of well-being, with the individual acting as though intoxicated. Swings of mood may occur, initiative, judgement, memory suffer; the reaction time is prolonged. With further ascent (still without sufficient oxygen) and decreasing air pressure, sensory and mental dullness become more and more evident. Appreciation of colours and later on acuity of vision is reduced. It follows hypacusis for sounds of high frequency and hyperacusis in the lower range. The functions of the vestibular organ suffer. Approaching the altitude of 7,000 m—which is regarded as the critical altitude in ascents without additional oxygen—consciousness is lost because of the low oxygen tension in the blood vessels or, in other words, because of the low partial pressure of oxygen which amounts only to 60 mm Hg in the ambient air or 30 mm Hg in the lungs, as we have said already. If the inspired air contains enough oxygen, so that the oxygen partial pressure is at least 90 mm Hg (which value corresponds to an altitude of about 4,000 m) symptoms of mountains sickness will not occur in a healthy person. To prevent mountain sickness we must add oxygen to the inspired gas mixture in a such percentage, that the partial pressure of oxygen amounts to about 90 mm Hg or more. When the barometric pressure drops to 90 mm Hg then we must breath *pure oxygen.* Here you see that the borderline for high altitude flying with oxygen equipment only is a barometric pressure of about 90 mm Hg which corresponds to an altitude of about 13,000 m.

Any interruption of oxygen supply in high altitudes, for example at 10,000 m, will cause symptoms of mountain sickness which appear more rapidly the higher the pilot is. The time of useful consciousness before mental dullness starts and consciousness is lost—the time of useful consciousness which is left for countermeasures such as descent with the plane by spinning or escaping by parachute is very short; at 7,500 m about 3 minutes, at 9,000 m about 80 seconds and at 12,000 m only about 20 seconds. When breathing pure oxygen before being exposed to the ambient air the time of useful consciousness is only a little longer.

Thus, in the case of an incident such as interruption of the oxygen supply at high altitudes there is only very little time to take countermeasures and to start life saving operations. Therefore everybody should know what to do beforehand. At 8,000 m for example, the duration of useful consciousness of a few minutes permits a descent with the plane by using the air brakes or by spinning because the non-dangerous zone between sea level and 4,000 m can be reached in time. The only manoevre however, at 11,000 or 12,000 m, when oxygen is interrupted, is immediate escape by parachute. An automatic parachute can *not* be used because the rate of descent is too slow. Before reaching the safe zone below 4,000 m irreversible nerve cell changes in the brain and probably death may occur. In this case reaching the normoxic zone in time is only possible by free fall to less than 4,000–5,000 m, where the parachute can be deployed. Otherwise it would involve an 8 to 10 minute descent by parachute following the escape before sufficient oxygen were available.

In conclusion, I would like to emphasize the importance of the *oxygen partial pressure* and the *time of useful consciousness* in order to prevent incidents in high altitude flying and at least leave us better equipped for facing this problem.

(Swiss Aero-Revue 2–5/1967)