Chapter 3

Oxygen and Respiration

THRESHOLDS OF OXYGEN REQUIREMENTS SUMMARY

<table>
<thead>
<tr>
<th>Height Range</th>
<th>Oxygen Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 10,000 ft</td>
<td>Air only</td>
</tr>
<tr>
<td>10,000 - 33,700 ft</td>
<td>Oxygen/Air mixture</td>
</tr>
<tr>
<td>33,700 - 40,000 ft</td>
<td>100% Oxygen</td>
</tr>
<tr>
<td>Above 40,000 ft</td>
<td>100% Oxygen under pressure</td>
</tr>
</tbody>
</table>

HYPOXIC HYPOXIA

The term for the effects of a shortage of oxygen is **Hypoxic Hypoxia**. This can result from a number of reasons such as extreme anaemia, asthma and meningitis. But the most important reason, as far as pilots are concerned, is altitude. Haemoglobin at sea level is approximately 97.5% saturated with oxygen. At 10,000 ft this falls to 87% and thereafter falls off rapidly so that, at 20,000 ft, the haemoglobin is only 65% saturated with oxygen. The symptoms of Hypoxia may develop slowly at lower levels or very rapidly at high altitudes.

HYPOXIC HYPOXIA SYMPTOMS

The symptoms of Hypoxic Hypoxia are:

- **Apparent Personality Change.** A change in outlook and behaviour with **euphoria** or aggression and lack of inhibitions. The very real danger of this was graphically described in 1875 by G. Tissandier after his balloon flight to 25,000 ft, which proved fatal to both his companions. The words still ring true today:

  “But soon I was keeping absolutely motionless, without suspecting that perhaps I had lost use of my movements. Towards 7,500 m. (24,606 ft.) the numbness one experiences is extraordinary. The body and the mind weaken little by little, gradually, unconsciously, without one’s knowledge. One does not suffer at all; on the contrary. One experiences an inner joy, as if it were an effect of the inundating flood of light. One becomes indifferent; one no longer thinks of the perilous situation; one rises and is happy to rise”.

- **Impaired Judgement.** Loss of self-criticism and individuals are unaware of their reduced performance. Short-term memory loss exacerbates this condition and can occur at approximately 12,000 ft.

- **Headache** (particularly if mildly hypoxic for a long period).

- **Tingling** in hands and feet.

- **Increased rate of breathing - Hyperventilation**

- **Muscular Impairment.** Finely co-ordinated movements become difficult through slow decision-making and poor fine muscular control. Handwriting becomes more and more illegible. In the late stages of hypoxia, muscular spasms and convulsions may occur.

- **Memory Impairment.** Short term memory is lost making drills difficult to complete. This starts at approximately 12,000 ft.
Visual Sensory Loss. Vision is affected early. Colour perception is reduced and peripheral vision is gradually lost. The light-sensitive cells of the eye are particularly oxygen “hungry” and a deterioration of night vision can occur at altitudes as low as 5,000 ft.

Tunnel vision develops making it necessary to make larger head movements to scan the instruments and the external environment.

Impairment of Consciousness. As Hypoxia progresses the individual’s level of consciousness drops until he/she becomes confused, then semi-conscious, and unconscious.

Cyanosis. An individual who has become Hypoxic at altitude is likely to be Cyanosed, that is the lips and fingertips under the nails will develop a blue tinge, due to much of the blood haemoglobin being in the de-oxygenated state.

Formication. The hypoxic individual may experience Formication, a creeping sensation on the skin, as of ants crawling over the body.

Unconsciousness

Death

UNLESS HE OR SHE RECEIVES OXYGEN THE INDIVIDUAL WILL DIE AND AT HIGH ALTITUDES DEATH CAN OCCUR WITHIN A FEW MINUTES.

STAGES/ZONES OF HYPOXIA

Hypoxia can be classified by stages/zones of performance decrement. The 4 stages are:

1. The Indifferent Stage/Zone GL - 10,000 ft (3,048m)
   - Dark adaption is adversely affected (can be as low as 5,000 ft).
   - Performance of new tasks may be impaired.
   - Slight increase in heart and breathing rates occurs.

2. The Compensatory Stage/Zone 10,000 ft - 15,000 ft (3,048 - 4,572m)
   - In this stage the physiological automatic responses provide some protection against hypoxia trying to maintain Homeostasis. These include:
     - increases in the respiratory volume.
     - increase in cardiac output and blood pressure.
   - However after a short time the effects of hypoxia on the CNS are perceptible causing:
     - drowsiness.
     - decreased judgement and memory.
     - difficulty in performing tasks requiring mental alertness or very small movements.
3. **The Disturbance Stage/Zone**  15,000 ft - 20,000 ft (4,572 - 6092m)

   In the Disturbance Stage/Zone, the physiological compensatory mechanisms are no longer capable of providing for adequate oxygenation of the tissues. The symptoms include:
   
   - Euphoria
   - Dizziness
   - Sleepiness
   - Headache
   - Fatigue
   - Intellectual impairment and slow thought processes
   - Memory impairment
   - Motor performance is severely impaired
   - Loss of judgement
   - ‘Greyout’ and tunnelled vision

4. **The Critical Stage/Zone**  20,000 ft - 23,000 ft (6,092 - 7010m)

   Mental performance deteriorates rapidly. Confusion and dizziness occurs within a few minutes. Total incapacitation with loss of consciousness follows with little or no warning.

**FACTORS DETERMINING THE SEVERITY OF AND THE SUSCEPTIBILITY TO HYPOXIC HYPOXIA**

The most important factors in determining an individual’s likelihood of becoming Hypoxic are:

- **Altitude.** The greater the altitude the greater the degree of Hypoxia and the more rapid the onset and progression.
- **Time.** The longer the time exposed to high altitude the greater will be the effect.
- **Exercise (Workload).** Exercise increases the demand for oxygen and hence increases the degree of Hypoxia. Even the smallest of physical exertion will significantly reduce the time of useful consciousness.
- **Extremes of Temperature.** Extremes of heat or cold place a heavy demand upon the circulatory adjustments which the body has to make, and thus lower the tolerance to hypoxia. At low temperatures we shiver in order to maintain body temperature, thus increasing the demand for oxygen and so increasing the state of Hypoxia.
- **Illness and Fatigue.** Both increase the energy demands of the body and lower the threshold for Hypoxia symptoms.
- **Alcohol/Drugs.** Alcohol affects metabolism and causes Histotoxic Hypoxia, thus reducing the tolerance to Hypoxic hypoxia. Many other drugs have adverse effects on the brain function which may lead to Hypoxia as altitude tolerance decreases.
ANAEMIC HYPOXIA

Anaemic Hypoxia is caused by the inability of the blood to carry oxygen and may be due to a medical condition (anaemia) or to carbon monoxide poisoning both of which have been discussed in Chapter 2.

Smoking and Anaemic Hypoxia
Smoking produces carbon monoxide which is inhaled. As the haemoglobin in the red blood cells has a much greater affinity to this carbon monoxide than to oxygen it reduces the availability of haemoglobin to transport oxygen. Heavy smoking produces 8% - 10% carboxyhaemoglobin in the blood. A regular smoker will start to suffer from hypoxia approximately 4,000 ft - 5,000 ft below that of a non-smoker.

The importance of aircrew being able to recognise Hypoxia cannot be overstated.

Treatment of Hypoxia
Knowledge of the signs and symptoms and early identification of the problem will allow the correct drills to be carried out before anyone is placed in jeopardy but it is important that these drills are well learnt and easily accomplished.

Principally:

- Provide Oxygen.
- Descend to a level where atmospheric oxygen is present in sufficient quantities to meet the body’s needs or to Minimum Safe Altitude (MSA), whichever is the higher.

Aircrew must familiarise themselves with the appropriate oxygen drills for the aircraft they are flying before venturing above an altitude at which Hypoxia can occur (above 10,000 ft).

Prevention of Hypoxia
Some of the factors predisposing to Hypoxia are unavoidable risks of flying; others can be reduced by good personal habits and forethought. Some pointers are:

- When anticipating flying above 10,000 ft ensure that a serviceable supplementary supply of oxygen is available and that the correct method of use is known.
- Ensure that passengers are correctly briefed.
- If you smoke - stop.
- Fly only if you are 100% fit and you are not taking any medication or drugs.
- Ensure that cabin heaters are thoroughly checked and serviceable. If used, ensure that fresh air is also brought into the cabin.
TIME OF USEFUL CONSCIOUSNESS (TUC)

This is the time available to a pilot to recognise the development of Hypoxia and do something about it. It is not the time to unconsciousness but the shorter time from a reduction in adequate oxygen until a specific degree of impairment, generally taken to be the point when the individual can no longer take steps to help him/herself.

The time will depend on the individual, and will be affected by any or all of the following:

- Individual fitness
- Workload
- Smoking
- Overweight or Obesity
- Decompression is progressive or explosive

The average times of useful consciousness at various altitudes are set out in the following table.

TIMES OF USEFUL CONSCIOUSNESS AT VARIOUS ALTITUDES

<table>
<thead>
<tr>
<th>ALTITUDE (ft)</th>
<th>Progressive decompression</th>
<th>Rapid Decompression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sitting</td>
<td>Moderate Activity</td>
</tr>
<tr>
<td>18,000</td>
<td>About 40 min.</td>
<td>About 30 min.</td>
</tr>
<tr>
<td>20,000</td>
<td>10 min</td>
<td>5 min.</td>
</tr>
<tr>
<td>25,000</td>
<td>5 min.</td>
<td>3 min.</td>
</tr>
<tr>
<td>30,000</td>
<td>1.5 min.</td>
<td>45 sec.</td>
</tr>
<tr>
<td>35,000</td>
<td>45 sec.</td>
<td>30 sec.</td>
</tr>
<tr>
<td>40,000</td>
<td>25 sec.</td>
<td>18 sec.</td>
</tr>
<tr>
<td>43,000</td>
<td>18 sec.</td>
<td>12 sec.</td>
</tr>
</tbody>
</table>

EFFECTIVE PERFORMANCE TIME (EPT)

Effective Performance Time is always within and shorter than TUC. Its quantification, however, is not possible since it will depend upon the individual, the task in hand, physiological and mental stress, altitude and the circumstances involved. It is highly variable and individualistic. Above 40,000 ft the EPT is approximately 5-6 seconds.
HYPERVERTILATION

Hyperventilation can be defined as lung ventilation in excess of the body’s needs and denotes an over-riding of the normal automatic control of breathing by the brain. Simply, hyperventilation is over-breathing. That is breathing in excess of the ventilation required to remove carbon dioxide. Over-breathing induces a reduction in the carbon dioxide and thus decreases the carbonic acid balance of the blood. This disturbance of the acid balance has a number of effects, the major one being that haemoglobin gives up its oxygen readily only in an acid medium.

Hypoxia does cause hyperventilation but it is far from the only cause. Anxiety, motion sickness, shock, vibration, heat, high G-forces, pressure breathing can all bring on the symptoms of Hyperventilation. A high standard of training breeds confidence and decreases the chances of confronting unusual and stressful situations and is, without doubt, the best means of preventing hyperventilation in aircrew.

An anxious passenger boarding an aircraft must be closely watched since hyperventilation may take place even whilst still on the ground.

SYMPTOMS OF HYPERVERTILATION

- Dizziness and a feeling of unreality.
- Tingling. Especially in the extremities and lips.
- Visual Disturbances. Blurred, tunnelling and clouding vision.
- Hot or cold sensations. These may alternate in time and vary as to parts of the body affected.
- Anxiety. Thus establishing a vicious circle.
- Loss of muscular co-ordination and impaired performance.
- Increased heart rate.
- Spasms. Just prior to unconsciousness, the muscles of the hands, fingers and feet may go into spasm.
- Loss of Consciousness. Hyperventilation can lead to collapse but thereafter the body’s automatic system will restore the normal respiration rate and the individual will recover.

Treatment of Hyperventilation

The classic way to treat a patient suffering from Hyperventilation is to make him/her breathe into a paper bag. The sufferer is then forced to inhale the carbon-dioxide that has been exhaled. The immediate effect of this is to increase the carbonic acid level to its norm and the brain consequently reduces the breathing rate.

The symptoms can, in themselves, be alarming. In all cases try to calm the patient and encourage her/him to slow down the rate of breathing.
HYPOXIA or HYPERVENTILATION?

The natural reaction to a shortage of oxygen is for the body to try to obtain more air by breathing faster and deeper. The hypoxic individual may Hyperventilate in an effort to get more oxygen, but this is of little value when in an environment of low ambient pressure.

In flight it can be difficult to distinguish the symptoms of Hypoxia and Hyperventilation. The appropriate response of pilots must be to assume the worst and if they are at an altitude where Hypoxia is a possibility they must take that to be the cause and carry out their Hypoxia drills. If symptoms occur at an altitude at which Hypoxia is not a consideration (below 10,000 ft) they should regulate the rate and depth of breathing to restore the normal acid/base balance of the blood and alleviate the symptoms. When flying below 10,000 ft significant symptoms of hypoxia are unlikely and hyperventilation may be assumed.

DO NOT ASSUME HYPERVENTILATION IF IT COULD BE HYPOXIA

HYPERVENTILATION - AFTER UNCONSCIOUSNESS - RECOVERY

HYPOXIA - AFTER UNCONSCIOUSNESS - DEATH

CABIN PRESSURISATION

Cabin pressurisation systems ensure that the effective altitude to which the occupants are actually exposed is much lower than the altitude at which the aircraft is flying. Ideally the cabin should be maintained at sea level but this is impractical because of aircraft weight and fuselage strength limitations.

The pressurisation of a commercial airliner flying at 30,000 ft produces an internal cabin pressure equivalent to about 6,000 ft with a maximum of 8,000 ft. The pressure differential across the aircraft skin is normally designed not to exceed 8-9 p.s.i. The rate of change of cabin pressure is restricted to 500 ft/min in the ascent and 300 ft/min in the descent to minimise passenger discomfort due to the pressure equalization limitations of the middle ear.

CABIN DECOMPRESSION

Loss of cabin pressurisation can occur in flight. The rate of loss may be slow, with the crew recognising the problem and making appropriate height reductions before the passengers are aware of anything amiss. Very occasionally there is rapid decompression perhaps due to the loss of a window or door, or a failure in the fuselage.

Occupants, crew and passengers, will rapidly be exposed to the full rigours of high altitude: Hypoxia, Cold, Decompression sickness. Oxygen can be supplied to all occupants but for only a limited period.

THE AIRCRAFT MUST RAPIDLY DESCEND TO 10,000 ft OR MSA WHICHEVER IS THE HIGHER

In cases of rapid decompression the altitude of the cabin may actually rise to above the pressure altitude. The Venturi effect of air passing over the fuselage can suck air out of the cabin; this can make up to 5,000 ft difference in pressure terms.