2 Flight Physiology

2.1 The Atmosphere

Most of our flying takes place within the troposphere, which extends from the surface of the earth to 25 000 ft at the poles and to 55 000 ft at the equator.

The composition of the atmosphere (see fig. HP 2.1) is constant up to the tropopause and consists of 78% nitrogen, 21% oxygen and 1% other gases (which include argon, carbon dioxide, neon, hydrogen, and ozone). The volume percentage of gases, in ambient air, remains constant with altitude.

The International Standard Atmosphere (ISA)
Pressure at sea level 1013.25 hPa (mb)  
760 mmHg  
29.92 inHg

Temperature +15°C

Fig. HP 2.2 shows the reduction of atmospheric pressure with the increase of altitude in thousands of feet - the rate of pressure change being greater the closer to the earth.

Fig. HP 2.1 Composition of the air throughout the Troposphere

Fig. HP 2.2 Atmospheric pressure levels

- 33500 ft = 1/4 atmospheric pressure = 250 hPa
- 26500 ft = 1/3 atmospheric pressure = 350 hPa
- 18000 ft = 1/2 atmospheric pressure = 500 hPa
- 8000 ft = 3/4 atmospheric pressure = 750 hPa
Sea level = 1013 hPa
2.2 The Gas Laws

As atmospheric air is a mixture of gases, it is subject to established laws, which govern volume, pressure, temperature and density. Students are expected to remember the formulae and the relevance of the laws to flight operations.

**Boyle’s Law**
Providing the temperature is constant, the volume of a gas is inversely proportional to its pressure (at moderate temperatures). Or to put it another way, as pressure increases, volume will decrease.

\[
\frac{P_1}{P_2} = \frac{V_2}{V_1} \quad \text{or} \quad P \alpha \frac{1}{V}
\]

**Relevance to flight**
Otic, gastro-intestinal tract barotraumas and aerodontalgia. These are conditions in which gas expansion within confined areas causes pain. Otic barotrauma affects the inner ear, aerodontalgia applies to the teeth and gastrointestinal tract barotrauma applies to the stomach and intestines.

**Charles’ Law**
The volume of a fixed mass of gas held at a constant pressure varies directly with absolute temperature. As temperature increases, volume also increases.

\[
\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{or} \quad V \alpha T
\]

**General Gas Equation**
This is a combination of Boyle’s law and Charles’ law and also includes mass (m). Should the volume and mass be held constant then pressure will vary directly with temperature.

\[
\frac{PV}{mT} = \text{constant, or} \quad \frac{P_1V_1}{mT_1} = \frac{P_2V_2}{mT_2}
\]

**Relevance to flight**
Variations in pressure readings on supplemental oxygen cylinders, at different ambient temperatures. The mass of oxygen remains the same within the cylinder, but the indicated pressure changes with changes in temperature.

**Dalton’s Law**
The total pressure of the gas mixture is equal to the sum of the partial pressures.

\[
P_t = \text{ppGas}_1 + \text{ppGas}_2 + \ldots + \text{ppGas}_n
\]

**Relevance to flight**
Consider the air. The Nitrogen, Oxygen and other gases all exert their own partial pressures within the mixture. As altitude increases, total atmospheric pressure decreases, and the partial pressures of the constituents of air will decrease. As the partial pressure of oxygen in the ambient air decreases it becomes more difficult for oxygen to transfer from the lungs to the blood.
**Henry’s Law**
At equilibrium, the amount of gas dissolved in a liquid is proportional to the pressure of the same gas above the liquid.

**Relevance to flight**
The risk of Decompression Sickness (DCS) at higher altitudes (see paragraph 2.10).

**Fick’s Law**
The rate of gas transfer through a tissue is proportional to the difference between the partial pressures of the gas on the two sides of the tissue and also proportional to the transfer area, but inversely proportional to the tissue thickness.

**Relevance to flight**
Breathing: the diffusion of oxygen from the lungs into the bloodstream, and of carbon dioxide from the bloodstream to the lungs.

**2.3 Altitude and Height**
Altitude is defined as the elevation above mean sea level.

Since atmospheric pressure varies over the surface of the earth, a forecast is made of the pressure in a given region for a given time period, in order for pilots to set the correct altimeter pressure datum. This datum is known as regional QNH and is available for the current and next hour. Pilots should update the regional pressure datum as they transit regional boundaries.

Aerodrome QNH is used as the datum pressure when aircraft are flying in the vicinity of an aerodrome.

Above a certain altitude, which is called “Transition Altitude”, the standard pressure setting (1013.25 hPa) is used as the datum pressure setting and vertical distance is referred to as “Flight Level (FL)”.

When descending into an airfield, the standard pressure setting is replaced by aerodrome QNH, which is set on the altimeter when passing the “Transition Level”.

Height is defined as the vertical distance of an aircraft above the surface.

The atmospheric pressure at the airfield datum is called QFE. An aircraft when taking off or landing at an airfield with the correct QFE set should indicate zero feet on its altimeter. Consider the relationships shown in *fig. HP 2.3.*

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**Fig. HP 2.3** Relationships of pressure settings and height gained
2.4 Metabolism, Respiration and Circulation

Our functioning and growth require energy. This energy is supplied by our metabolism. Metabolism is the sum of all the chemical and physical changes that take place within the body.

Metabolism involves the breakdown of carbohydrates (e.g. glucose), proteins and fats from food with the aid of oxygen, resulting in the liberation of energy. This process also produces waste products - carbon dioxide and water.

The process is represented by the following formula:

\[
\text{Carbohydrates} + \text{Proteins} + \text{Fats} + \text{O}_2 \rightarrow \text{Energy} + \text{CO}_2 + \text{H}_2\text{O}
\]

The oxygen needed for our metabolism is extracted from the air we inhale. Within the lungs, oxygen enters the bloodstream by a process called diffusion (see Fick's law), to be distributed to the body organs and tissues. With each exhalation, we dispose of carbon dioxide, the waste product of our bodily processes.

The exchange of gases between the body and the atmosphere in the lungs is termed external respiration and the actual oxidation process in the cells liberating energy is termed internal respiration.

2.5 The Respiratory System

Respiration is the act of breathing. Ventilation means supplying the blood with oxygen and removing carbon dioxide from the body.

2.5.1 The Lungs

The lungs are internal organs. Yet they are, uniquely, constantly exposed to our external environment and are a direct interface with the world outside. With each breath, a host of alien substances enter our bodies such as pollens, dust, viruses, bacteria, smoke and radon.

The lungs, with their tiny air sacs called alveoli, have sometimes been simplistically compared to sponges. They are actually far more complex than many other organs. The heart, for example, is a relatively uncomplicated muscular pump designed, with one-way mechanical valves, for one purpose: to keep the bloodstream flowing in one direction. The lungs must play multiple roles - supplier of oxygen, remover of wastes and toxins.

They contain dozens of distinct types of cells, each with its special tasks and abilities. Some scavenge foreign matter. Others, equipped with delicate, hair-like cilia, sweep the mucous membranes lining the smallest air passages. Some act on substances crucial to blood pressure control, or serve as sentries to spot invading agents of infection. The roles of many others remain mysteries, posing challenges to researchers.
2.5.2 Breathing
Breathing is the process of exchanging respiratory gases, whereby oxygen is extracted from the ambient air and transported to the cells and carbon dioxide is removed.

The normal breathing rate is 10-15 breaths per minute at rest and 40-45 at maximum exercise.

Air is breathed in through the nose (See fig. HP 2.4) where it is filtered, moistened and warmed, and passes on to the lungs via the trachea and bronchi. Each bronchus divides into a number of bronchioles, which in turn end in thin walled sacs called alveoli. It is these millions of alveoli that form the lung tissue. The thin walls of these sacs are surrounded by thin-walled blood carrying vessels called capillaries and it is here that oxygen is diffused into the bloodstream. The oxygen attaches itself to the haemoglobin of the red blood cells and is transported to the body tissues that require it. Deoxygenated (oxygen-poor but CO2-rich), blood returns from the tissues to the heart and is pumped to the lungs via the pulmonary artery. The lungs relieve the blood of its burden of waste and return a refreshed, oxygen-rich stream of blood to the heart through the pulmonary vein, see Fig. HP 2.6.

2.5.3 Lung Volumes
Total lung capacity is the total volume of gas that can be held in the lungs at the end of a maximum inspiration. The total lung capacity for an average healthy person is about 6.0 litres, see fig. HP 2.5.
The volume of gas inhaled and expelled from the lungs during normal quiet respiration is called the tidal volume and is about \( \frac{1}{2} \) litre.

During normal breathing the volume of gas in the lung is about half the total lung capacity. At the end of normal expiration the volume of gas remaining in the lung, known as functional residual capacity, is around 2.4 litres.

It is possible after normal expiration to expel a further volume of gas but even then there will remain a residual amount of gas in the lungs. This remaining amount is called residual volume and amounts to about 1.2 litres.

The difference between the total lung capacity and residual volume is 4.8 litres. This is termed vital capacity. It is the difference between maximum inspiration and maximum expiration. It is measured at the pilot’s medical examination.

2.6 The Circulatory System

The circulatory system, driven by the heart, is responsible for circulating blood around the body.

*Fig. HP 2.6* shows how oxygenated (\( \text{O}_2 \)-rich and \( \text{CO}_2 \)-poor) blood, which is bright red in colour, is carried from the lungs via the pulmonary vein (1) into the left atrium of the heart (2). It then passes through a one way valve into the left ventricle (3) from which it is pumped under pressure via the aorta (4) into the main arteries.

Via the arterioles (smaller arteries) the oxygenated blood reaches the capillaries.

Capillaries are the smallest blood vessels and are where gaseous diffusion takes place. This can either be within the lungs where the capillaries aid transfer of oxygen from the air, or within the body tissues, where oxygen is removed from the blood and used to create energy by the oxidation of carbohydrates.

Deoxygenated blood (\( \text{O}_2 \)-poor and \( \text{CO}_2 \)-rich), which is dark red in colour, is returned from the capillaries within the body tissues and organs by the veins to the right atrium (5) of the heart and then passes through another one way valve into the right