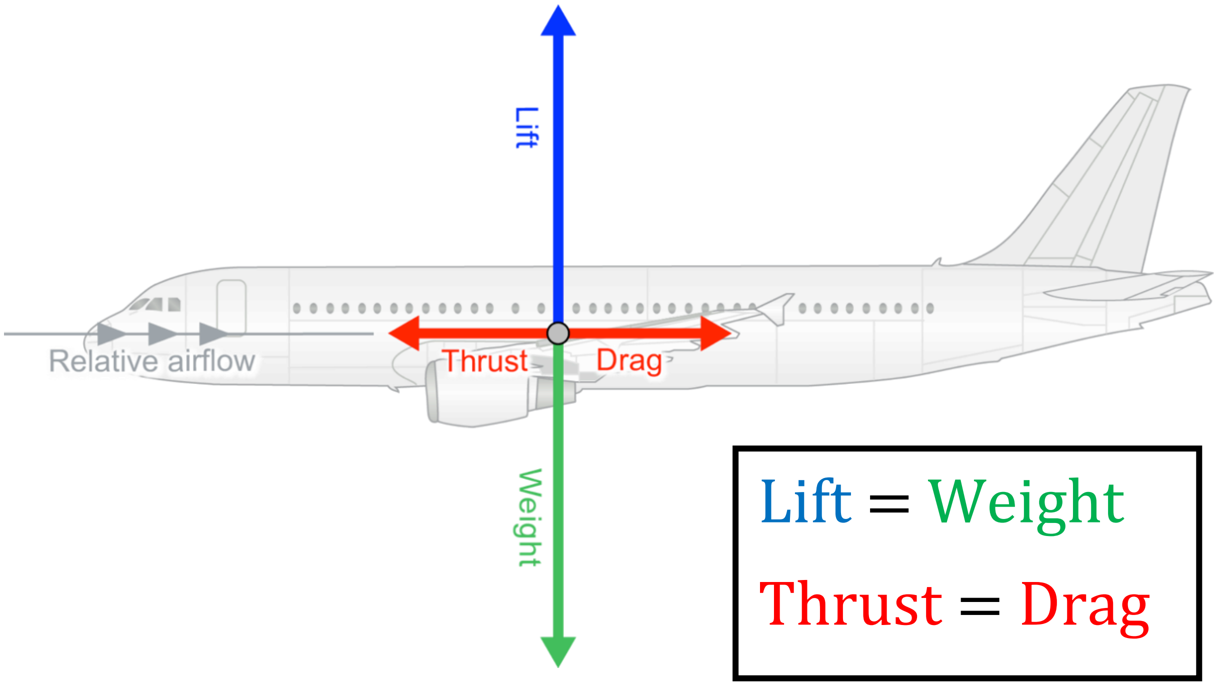
I. INTRODUCTION

1) Main Forces

An airplane, like anybody, is subject to its own WEIGHT which is attracting it to the centre of Earth. So to maintain the airplane in flight, an opposite force to the WEIGHT must exist, that is called the LIFT and will be studied in details in this lesson.

When the airplane is flying into the air, a force resisting to airplane's motion into the air and slowing it down, that force is known as DRAG and will also be seen in details. So to act again the DRAG, the airplane's engines must provide THRUST.



To understand the physics around an airplane, the environment where the airplane is operating must be studied.

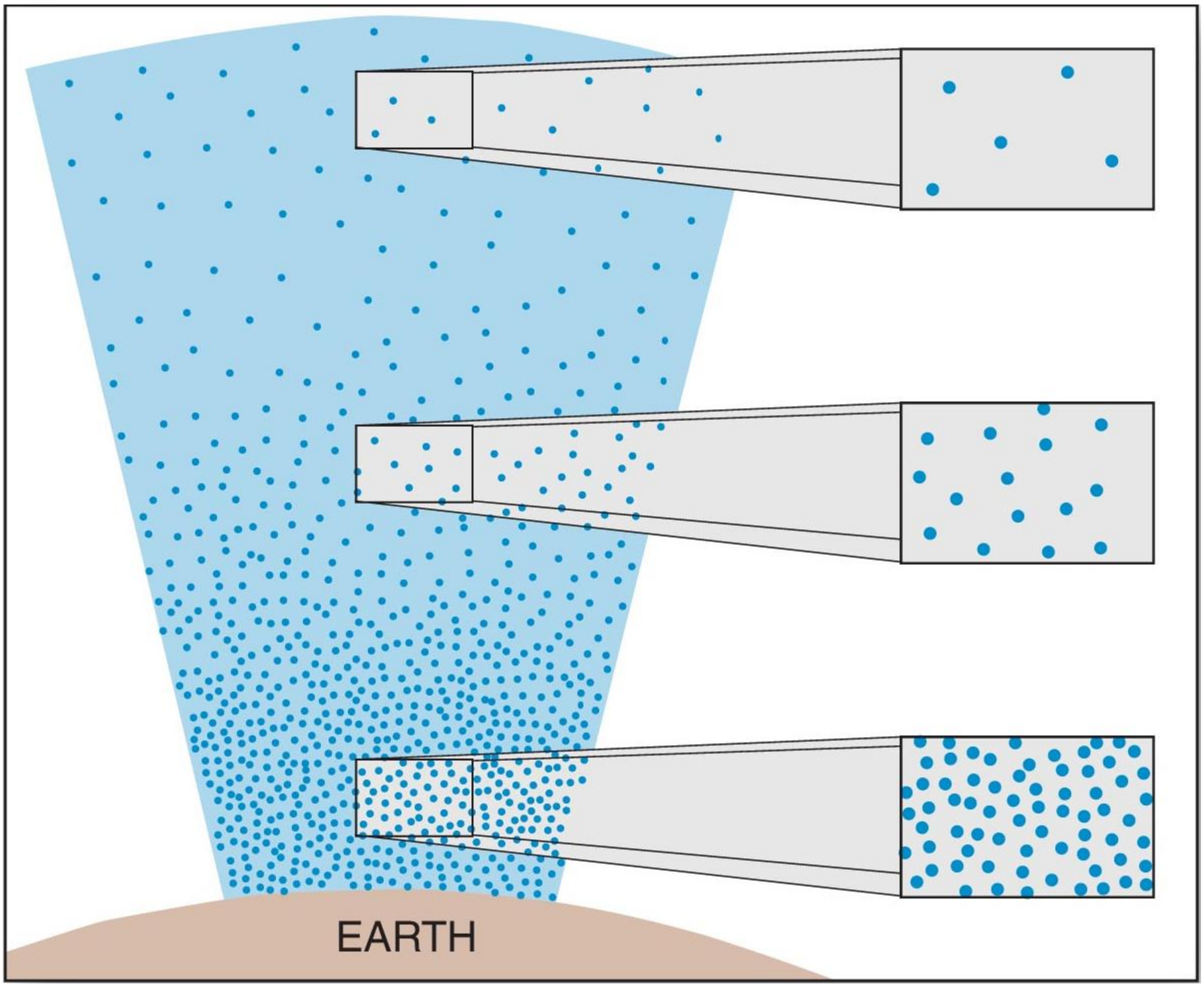
2) The Atmosphere

The atmosphere of Earth is the layer of gases, commonly known as air that surrounds the planet Earth and is retained by Earth's gravity. To understand how the aerodynamics and fluids work, the characteristics of the atmosphere must be studied.

The Air Static Pressure

Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.

The air pressure, often known as the atmospheric pressure, is simply the weight of air above the measurement point. As elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing elevation. Pressure measures force per unit area, with SI units of Pascals (1 pascal = 1 newton per square metre, 1 N/m^2)



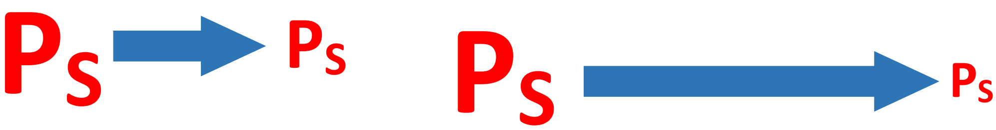
In aircraft's design and operation, the ambient atmospheric pressure is known as the **Static Pressure (P_S)**, which is simply the air pressure felt in one location.

Pressure Gradient Force (PGF)

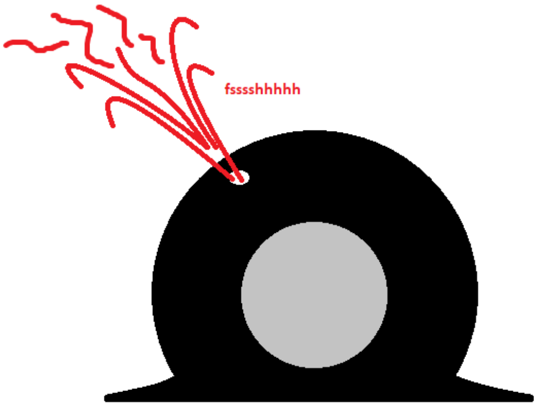
One characteristic of the Static Pressure to be known. When two points with different Static Pressure, the differential pressure will exist between those two points and a force called **Pressure Gradient Force (PGF)** will move the air molecules from the high pressure point to the low pressure point in order to equalise the static pressure.

Two major points to know regarding the PGF:

- The higher the differential pressure is, and the stronger the PGF

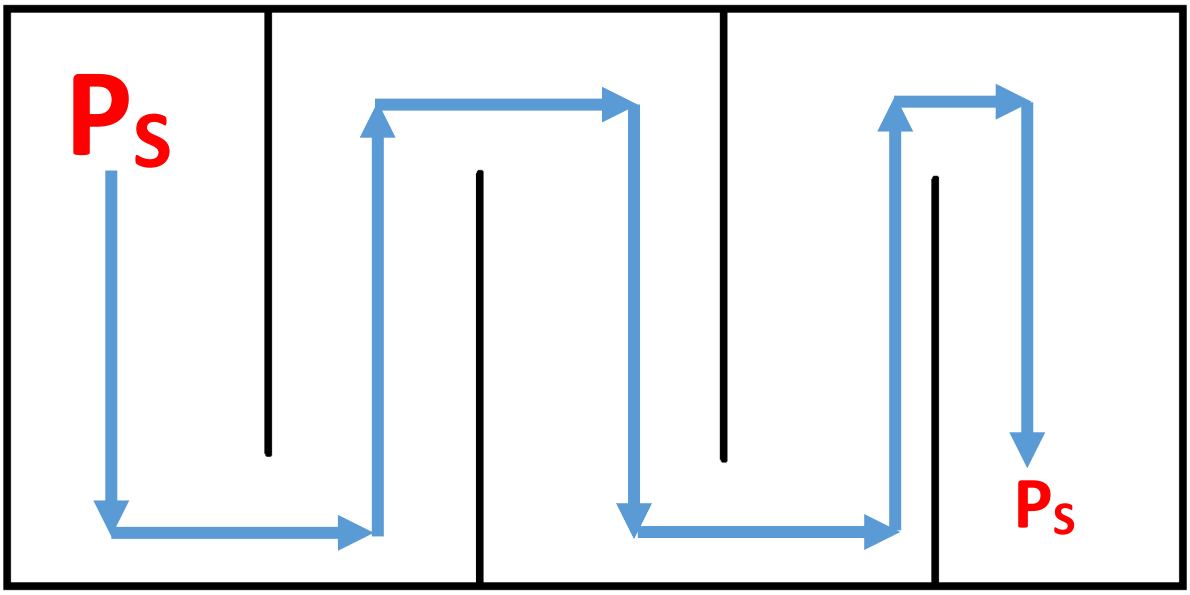


Example, the pressure in a wheel tyre is higher than the atmospheric pressure. This is why hen a tyre is burst, the air escape from it. Also, the air escaping could be heard making a "fssshhhh" sound, at the beginning the sound is strong because the differential pressure is higher and the PGF is stronger, so more air escapes. But then when tyre is almost flat, the sound is weak because the pressure in the tyre is almost equal to the atmospheric pressure and so the PGF will be weaker and less air is escaping.



Another example it's with the wind, which is simply a horizontal air motion from high pressure to low pressure area.

- The PGF will try to find a path to displace the air molecules even if physical obstruction exist.



Example, the airflow in a room with the windows open when a differential pressure exist.

Dynamic Pressure (Q)

When an object is in motion, it has a **Kinetic Energy (E_K)**. It is defined as the work needed to accelerate a body of a given mass (m) from rest to its stated velocity (V). Having gained this energy during its acceleration, the body maintains this kinetic energy unless its speed changes. The standard unit (SI) of kinetic energy is the **joule (J).**

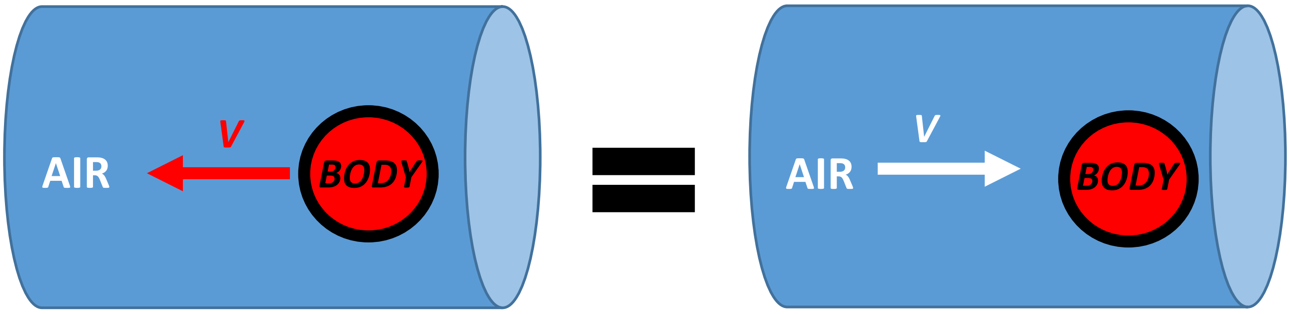
$$E_K = ½.m.V^2$$

When measuring the Kinetic Energy of a fluid (gas or liquid), **we speak about Dynamic pressure (Q)**, which is the increase in a moving fluid's pressure over its static value due to motion.

Since the air is a fluid, so we measure its Dynamic Pressure when in motion. One parameter must be changed, indeed for a fluid we don't use its mass (m) but the density (ρ) which is its mass per unit volume.

$$Q = ½.\rho.V^2$$

When a body is moving onto the air a given velocity (V), the Dynamic Pressure of the air is the same as the air where traveling toward that body at that velocity (V)



Temperature

It is a proportional measure of the average kinetic energy (agitation) of the random motions of the constituent particles of matter (such as atoms and molecules) in a system. The higher the agitation and the higher the temperature. Do not confuse temperature with heat, heat is the transfer of energy from the particles.

Different scale exist to measure the temperature

Degree Celsius (°C)
The Celsius scale is a temperature scale used by the International System of Units (SI). As an SI derived unit, it is used by all countries except the United States and Liberia. It is named after the Swedish astronomer Anders Celsius (1701–1744), who developed a similar temperature scale. The degree Celsius (symbol: °C) can refer to a specific temperature on the Celsius scale or a unit to indicate a difference between two temperatures or an uncertainty. Before being renamed to honor Anders Celsius in 1948, the unit was called centigrade, from the Latin centum, which means 100, and gradus, which means steps.

Before 1954, the Celsius scale was based on 0 °C for the freezing point of water and 100 °C for the boiling point of water at 1 atm pressure.

Degree Fahrenheit (°F)
The Fahrenheit scale is a temperature scale based on one proposed in 1724 by Dutch–German–Polish physicist Daniel Gabriel Fahrenheit (1686–1736).[1] It uses the degree Fahrenheit (symbol: °F) as the unit. Several accounts of how he originally defined his scale exist. The lower defining point, 0 °F, was established as the temperature of a solution of brine made from equal parts of ice, water and salt (ammonium chloride).[2] Further limits were established as the melting point of ice (32 °F) and his best estimate of the average human body temperature (96 °F, about 2.6 °F less than the modern value due to a later redefinition of the scale)

$$°F = °C \times 1{,}8 + 32 \quad \text{or} \quad °F = °C \times (9/5) + 32$$

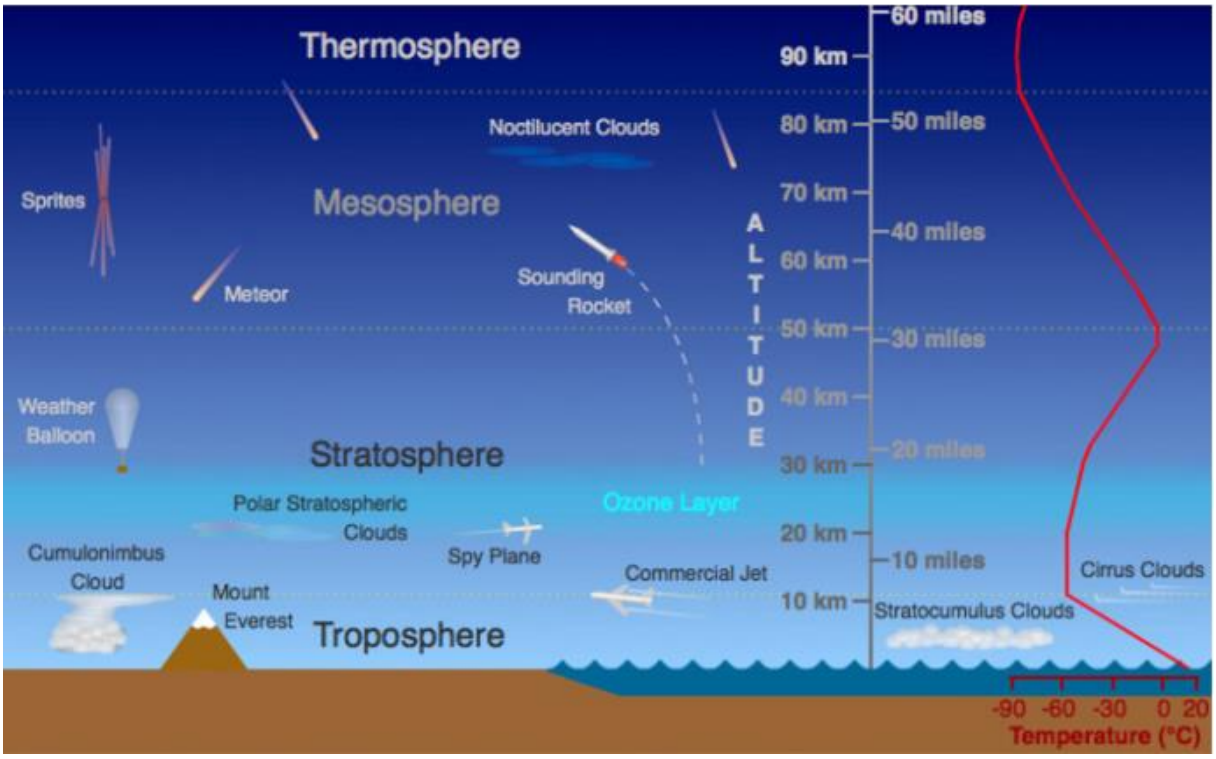
Kelvin (K)
The Kelvin scale is an absolute thermodynamic temperature scale using as its null point absolute zero, the temperature at which all thermal motion ceases in the classical description of thermodynamics (least or no agitation). The kelvin (symbol: K) is the base unit of temperature in the International System of Units (SI).

The Kelvin scale is named after the Belfast-born, Glasgow University engineer and physicist William Thomson, 1st Baron Kelvin (1824–1907), who wrote of the need for an "absolute thermometric scale". Unlike the degree Fahrenheit and degree Celsius, the kelvin is not referred to or written as a degree. The kelvin is the primary unit of temperature measurement in the physical sciences, but is often used in conjunction with the degree Celsius, which has the same magnitude. The definition implies that absolute zero (0 K) is equivalent to −273.15°C

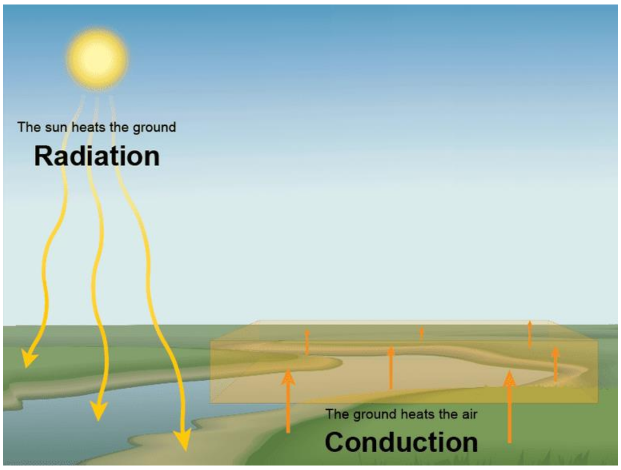
$$K = °C + 273{,}15$$

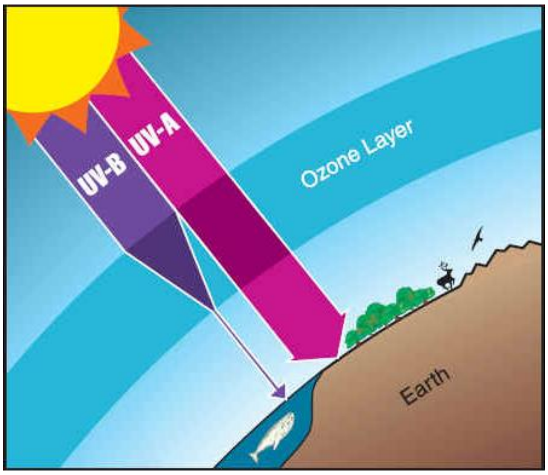
The temperature in the atmosphere
The global temperature in the atmosphere is either rising or dropping through different layers of the atmosphere. When the temperature tendency variation change, it marks the beginning of a new layer.

In this chapter, only the first two layers from the Earth’s surface are important to understand the fundamentals, the **troposphere** and the **stratosphere**, there where the civil aviation operate. The other layers will be seen Meteorology Chapter.



When the sun's radius reach the Earth's surface, this latter will warm by absorbing the sun's radiation (UV-A) and become a source of heat. Meaning that, the temperature is the highest at the ground and so the temperature will decreases with height an average of 2°C per 1000 ft. However at an altitude between 20km and 30km, there is a layer composed with trioxygene or Ozone (O_3). The oxygen molecules have the particularity to absorb the sun's radiation (UV-B), so the Ozone layer is now also a source of heat and will warm up the surrounding air.





This means that the temperature will drop with increasing height from the surface, and then it will cease dropping and remain constant until it starts to rise again.

The first layer where the temperature drops is called the **troposphere**, it has an average thickness of 11km height (at the mid-latitude) and it's where the main meteorological activities and general aviation operations are located.

Then, the layer where the temperature ceases to drop and remain constant is called the **tropopause**, and it's where most of the airliners airplanes operates.

Finally, the layer where the temperature starts to increase again is called the **stratosphere**, it's the fighter jet and all supersonic flight operates, and its average location is between 12km and 50km from the Earth's surface.

Density

The **density**, or more precisely, the **volumetric mass density**, of a substance is its mass per unit volume. The symbol most often used for density is ρ (the lower case Greek letter *rho*). Mathematically, density is defined as mass (m) divided by volume (V)

$$\boldsymbol{\rho = \frac{m}{V}}$$

In general, density can be changed by changing either the pressure or the temperature. Increasing the pressure always increases the density of a material, because more molecules will be found in the same volume. Increasing the temperature generally decreases the density, when the molecules are agitated they are far from each other and so less molecules for the same volume.

In the troposphere, with increasing altitude the pressure decreases which decreases the air density, although the temperature decreases also which increases the air density. However the density decreases with increasing the altitude, because in contrast, the density of gases is strongly affected by pressure. The density of an ideal gas is

$$\boldsymbol{\rho = \frac{M.P}{R.T}}$$

Where M is the molar mass, P is the pressure, R is the universal gas constant, and T is the absolute temperature. This means that the density of an ideal gas can be doubled by doubling the pressure, or by halving the absolute temperature.

International Standard Atmosphere (ISA)

The International Standard Atmosphere (ISA) is an atmospheric model of how the pressure, temperature, density, and viscosity of the Earth's atmosphere change over a wide range of altitudes or elevations. It has been established to provide a common reference for temperature and pressure and consists of tables of values at various altitudes, plus some formulas by which those values were derived.

The International Civil Aviation Organization (ICAO) published their "ICAO Standard Atmosphere" as Doc 7488-CD in 1993. It has the same model as the ISA, but extends the altitude coverage to 80 km (262,500 feet).

Aviation standards and flying rules are based on the International Standard Atmosphere. Airspeed indicators are calibrated on the assumption that they are operating at sea level in the International Standard Atmosphere where the air density is 1.225 kg/m^3.

Some of the values defined by ICAO are:

At Sea Level:

T°= +15°C (or +59°F)

Pressure= 1013.25mb or 1013.25hPa (or 29.92inHg)

ρ= 1.225 kg/m^3

Environmental Lapse Rate (ELR) = -2°C/+1000ft (or -0.65°C/+100m)

Pressure Lapse Rate= -1hPa/+27ft

The Tropopause:

Located at altitude: 11km or 36000ft

T°= -56.5°C

Density:

The air density **at 20,000 ft is ½ of the sea-level** value and at **40,000 ft is only ¼ of the sea-level** value.