Atmosphere

1 Overview

The performance of aircraft, spacecraft and their engines depend on atmosphere in which they operate, primarily **density and viscosity**. Density and viscosity are functions of **altitude**:

1. Density (ρ) varies with pressure (p) and temperature (T)
2. Viscosity (μ) varies only with temperature (T)

2 Standard Atmosphere

The standard atmosphere is defined from **Perfect Gas Law:**

$$p = \rho R T \tag{1}$$

There are four units of temperature:

1. Celsius (^oC)
2. Fahrenheit (^oF)
3. Rankine (R)
4. Kelvin (K)

And their conversions are listed below:

$$^oF = (^oC \times \frac{9}{5}) + 32 \tag{2}$$

$$R = (^oF) + 459.7 \tag{3}$$

$$K = (^oC) + 273.15 \tag{4}$$

To simplify the problem, the atmosphere can be regarded as **homogeneous** gas of **uniform composition** that satisfies the perfect gas law. Established by International Civil Aviation Organization (ICAO), the **standard sea level properties**:

$$g_0 = 32.17\ ft/s^2 = 9.806\ m/s^2 \tag{5}$$

$$p_0 = 2116.2\ lb/ft^2 = 1.013 \times 10^5\ N/m^2 \tag{6}$$

$$T_0 = 59\,^oF = 518.7\,R = 15^oC = 288.2\,K \tag{7}$$

$$\rho_0 = 0.002377\ slugs/ft^3 = 1.225\,kg/m^3 \tag{8}$$

3 Variation with Altitude

3.1 Regions of the Atmosphere

Normally atmosphere could be divided into four regions (from low to high):

1. Troposphere
2. Stratosphere
3. Ionosphere
4. Exosphere-rarefield

The characteristics of each region are shown below:

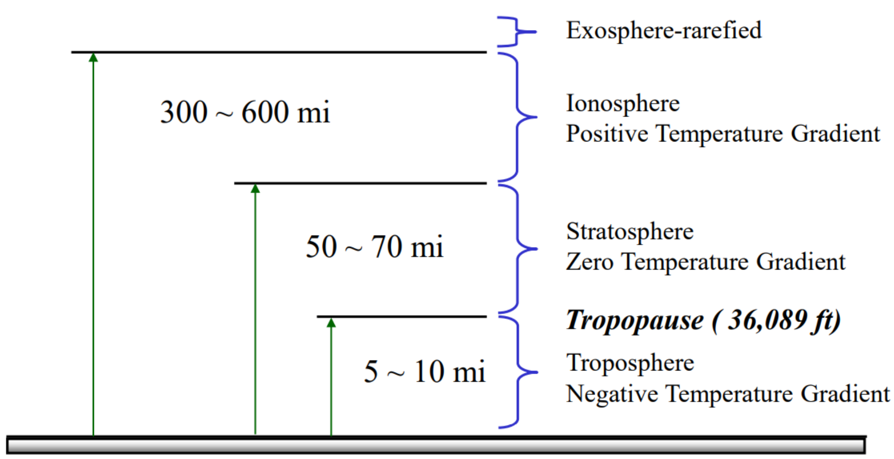

Figure 1: Regions of Atmosphere

For aircraft, only **troposphere** and **stratosphere** are important.

3.2 Variations under Tropopause

Below Tropopause, we assume there is a **constant drop** of temperature from **sea level** to altitude:

$$T = T_1 + a(h - h_1) \tag{9}$$

Here a is the **lapse rate**, with the unit of $^oF/ft$:

$$a = -0.00356616 \tag{10}$$

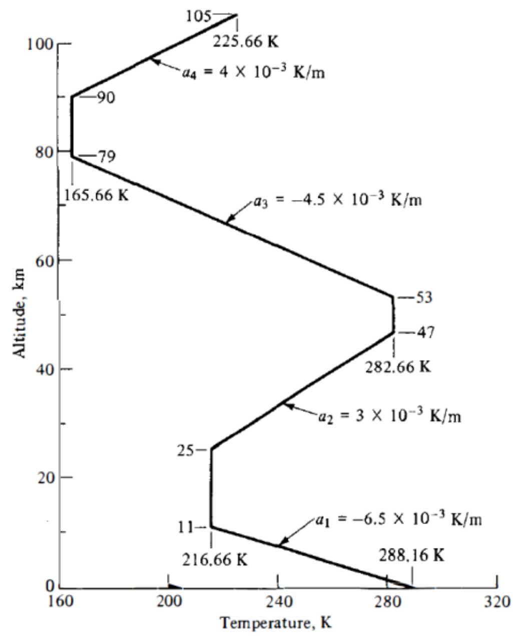

Figure 2: Temperature Variation

T_1 and h_1 are the reference values. At sea level, we have $T_1 = T_0$ and $h_1 = 0$. **Below Tropopause**, we have the following relations:

$$\frac{T}{T_0} = \theta = 1 + \frac{a}{T_0}h = 1 - 6.875 \times 10^{-6}h \tag{11}$$

$$\frac{p}{p_0} = \delta = \theta^{\frac{g}{aR}} = \theta^{5.2561} \tag{12}$$

$$\frac{\rho}{\rho_0} = \sigma = \theta^{\frac{g}{aR}-1} = \theta^{4.2561} \tag{13}$$

3.3 Variations above Tropopause

Above tropopause, the standard temperature is assumed **constant** and equal to $-69.7\ ^oF$. Then, we have the following relations (relative to standard sea level values):

$$\frac{p}{p_0} = 0.2234 \exp\left[-\frac{h - 36089}{20806.7}\right] \tag{14}$$

$$\frac{\rho}{\rho_0} = 0.2971 \exp\left[-\frac{h - 36089}{20806.7}\right] \tag{15}$$

4 Types of Airspeed

4.1 Indicated Airspeed (IAS)

IAS is the direct reading from the **airspeed indicator**. This represents the aircraft's speed **through the air**, may not be its speed **across the ground**.

4.2 Calibrated Airspeed (CAS)

CAS is the indicated airspeed corrected for **instrument position and instrument error**. This is a function of each unique and **the position of its pitot tube**. There is direct reading of CAS! The pilot must refer to the operating handbook for a table for that particular aircraft.

4.3 True Airspeed (TAS)

Because an airspeed indicator is **calibrated for standard sea level conditions**, when the airplane is flying at altitude, the airspeed is not correctly reflected. The amount of error is a function of temperature and altitude.