Basic Aerodynamic flow quantities   *Chapter 2*

Pressure: Is the normal force per unit area exerted on a surface due to the time rate of change of momentum of the gas molecules impacting on that surface.

P=F/A

Units:

N/m^2 , lb/ft^2 , and atm,

Density: The mass of a substance per unit volume.

ρ =m/V

Units:

kg/m^ 3 , slug/ft^3 , g/cm^3 , and lb m /ft^ 3

Specific volume: The volume per unit mass

$$\nu = \frac{1}{\rho}$$

Temperature: Is a measure of the average kinetic energy of the particles in the gas
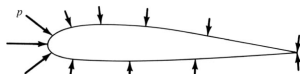
Units:

kelvin (K), degree Celsius (°C), degree Rankine (°R), and degree Fahrenheit (°F)

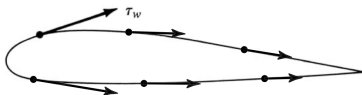Velocity: Is the distance traveled by some object per unit time

V=d/t

Forces exerted on the surface of an airplane

1. Pressure distribution on the surface. (normal to the body)

2. Shear stress (friction) on the surface. is due to the frictional effect of the fl ow "rubbing" against the surface as it moves around the body.

Equation of state for perfect gas

A perfect gas is one in which intermolecular forces are negligible. A gas in nature in which the particles are widely separated. Air at standard conditions can be readily approximated by a perfect gas.

air

$$p = \rho RT \qquad R = 287\frac{J}{(kg)(K)} = 1716\frac{ft \cdot lb}{(slug)(°R)}$$

$$\mathfrak{R} = 8314 \ J/(kg \cdot mole \ K) = 4.97 \times 10^4 \ (ft \ lb)/(slug \cdot mole \ °R)$$

$R = \mathfrak{R}/M$ where M is the molecular weight (or more properly, the molecular mass) of the gas

Anatomy of the airplane

The fuselage is the center body, where most of the usable volume of the airplane is found. The fuselage carries people, baggage, other payload, instruments, fuel, and anything else that the airplane designer puts there.

The wings are the main lift-producing components of the airplanes; the left and right wings are identified as you would see them from inside the airplane, facing forward. The internal volume of the wings can be used for such items as fuel tanks and storage of the main landing gear (the wheels and supporting struts) after the gear is retracted.

The horizontal and vertical stabilizers are located and sized so as to provide the necessary stability for the airplane in flight

Flaps and control surfaces are hinged surfaces, usually at the trailing edge (the back edge) of the wings and tail, that can be rotated up or down. The function of a flap is to increase the lift force on the airplane

The ailerons are control surfaces that control the rolling motion of the airplane around the fuselage

The elevators are control surfaces that control the nose up-and-down pitching motion

The rudder is a control surface that can turn the nose of the airplane to the right or left (called yawing)
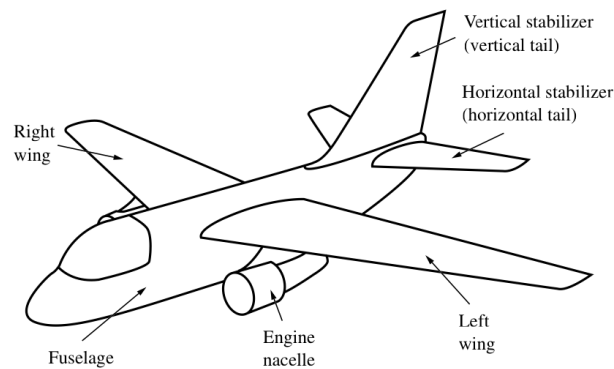

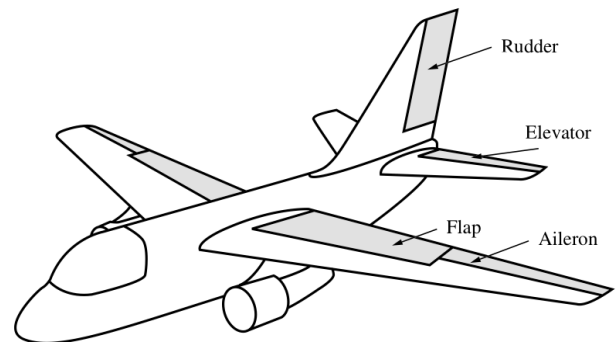Figure 2.13 Basic components of an airplane.

Figure 2.14 Control surfaces and flaps.

① A Boeing 747-8 is flying 600 mph at steady level flight at an altitude where the ambient temperature is 391°R and the pressure altitude is 35,830 ft. The lift generated is 900,000 lb, and the wing area is 554 m².

a) What is the lift coefficient?
b) If the lift to drag ratio is 18, how much thrust is produced by each engine?

Given:
$V = 600$ mph
$T = 391°R$
$h_p = 35,830$ ft
$L = 900,000$ lb
$S = 554$ m² ←
$\frac{L}{D} = 18$

$600 \frac{mi}{h} \cdot \frac{5280 ft}{1 mi} \cdot \frac{1 h}{60 \cdot 60} = 880 ft/s$

$554 \, m^2 \cdot \frac{(1 ft)^2}{(0.3048 \, m)^2} = 5963.21 ft^2$

Equations:

$L = \frac{1}{2} \rho V^2 S c_L$

$c_L = \frac{2L}{\rho V^2 S}$

$P = \rho R T \qquad \rho = \frac{P}{RT}$

$\frac{P - P_1}{P_1 - P_2} = \frac{h - h_1}{h_1 - h_2}$

$P = \left(\frac{h - h_1}{h_1 - h_2}\right)(P_1 - P_2) + P_1$

$P = \frac{35,830 - 35,500}{35,500 - 36,000} \left(4.8762\times10^2 - 4.7612\times10^2 \right) + 4.8762 \times 10^2$

$\boxed{P = 4.80 \times 10^2 \, lb/ft^2}$

$\rho = \frac{4.80 \times 10^2}{1716 \cdot 391} = 0.000715 \, slugs/ft^3$

$c_L = 2 \cdot \frac{900,000}{0.000715 \cdot 880^2 \cdot 5963.21} \qquad \boxed{= 0.545156}$

b) $L = W \qquad \frac{L}{D} = 18 \qquad D = \frac{L}{18} = \frac{900,000}{18}$
   $D = T$

   $D = 50000 \, lb$

Teach engine $\dfrac{D}{4} = \dfrac{50\,000}{4} = \boxed{,250\,016 \text{ per engine}}$

CHAPTER 3

ALTITUDE: 6 DIFFERENT

ABSOLUTE: FROM CORE OF EARTH $[h_a]$ $h_a = h_G + r_{earth}$
        (VERY HELPFUL FOR SPACE)

GEOMETRIC: GEOMETRIC HEIGHT ABOVE SEA LEVEL $[h_G]$

GEOPOTENTIAL: $h = \dfrac{r}{r + h_G} h_G$

* **FOR PRESSURE, DENSITY & TEMPERATURE ALT. IF YOU ARE FLYING AT AN ALT. & THE T, P, ρ @ THAT ALT. THAT IS STANDARD FOR A GIVEN ALT. THAT WOULD BE YOUR T, P, ρ ALTITUDE ACCORDINGLY** *

> FOR CALCULATIONS MOVING FURTHER IN ATMOSPHERE, YOU HAVE TO TAKE INTO ACCOUNT THE VARIATION IN GRAVITY.
>
> $$g = g_0 \left(\frac{r}{h_a}\right) = g_0 \left(\frac{r}{r + h_G}\right)^2$$

EX: YOU ARE FLYING AT A GIVEN ALTITUDE AND THE PRESSURE READS 6.16×10^4 N/m² WHICH FROM APP. A WE SEE CORRESPONDS TO THE PRESSURE AT 4km. THEREFORE YOU ARE FLYING AT A PRESSURE ALT. OF 4km.

HYDROSTATIC EQUATION:

$$dP = -\rho g \, dh_G$$

* APPLIES TO ANY FLUID OF DENSITY ρ.
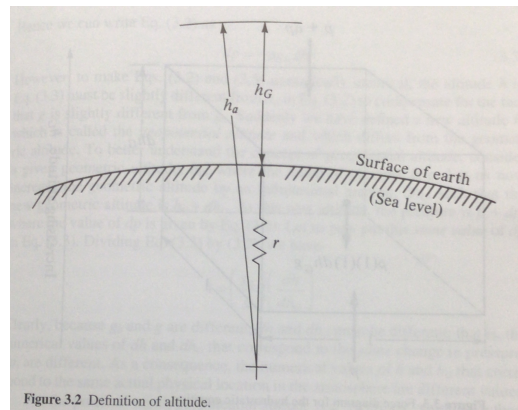→ USED TO DERIVE OUR STANDARD ALTITUDE RELATIONS.

Figure 3.2 Definition of altitude.

STANDARD ATMOSPHERE:

 — VARIATION OF T W/ ALT.

STANDARD S.L. VALUES

$P_s = 1.01325 \times 10^5$ N/m² $= 2116.12$ lb/ft²

$\rho_s = 1.2250$ kg/m³ $= 0.002377$ slug/ft³

$T_s = 288.16$ K $= 518.69$ °R

Figure 3.4 Temperature distribution in the standard atmosphere.
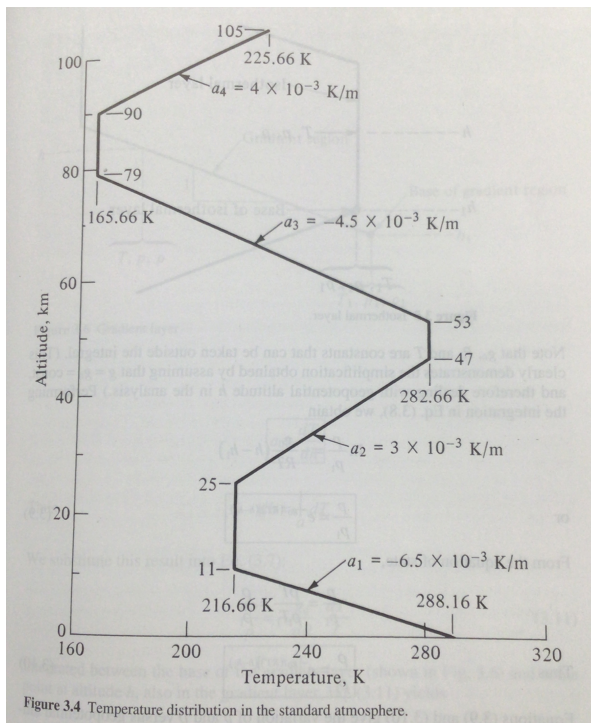
$$\frac{P}{P_1} = \exp\left(-\left[g_0/(RT)\right](h-h_1)\right) \qquad \boxed{3.9}$$

$$\frac{\rho}{\rho_1} = \exp\left(-\left[-g_0/(RT)\right](h-h_1)\right) \qquad \boxed{3.10}$$

$a \equiv \dfrac{dT}{dh}$: SLOPE IN GRADIENT REGIONS

CAN SOLVE w/ GIVEN VALUES

$$\rightarrow \quad a = \frac{T_2 - T_1}{h_2 - h_1}$$

$$\frac{P}{P_1} = \left(\frac{T}{T_1}\right)^{-g_0/(aR)} \qquad \boxed{3.12}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-\{[g_0/(aR)]+1\}} \qquad \boxed{3.13}$$

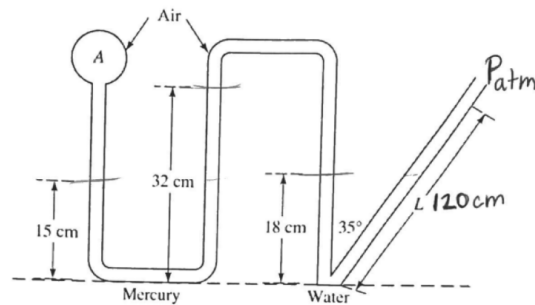$$T = T_1 + a(h - h_1) \qquad \boxed{3.14}$$
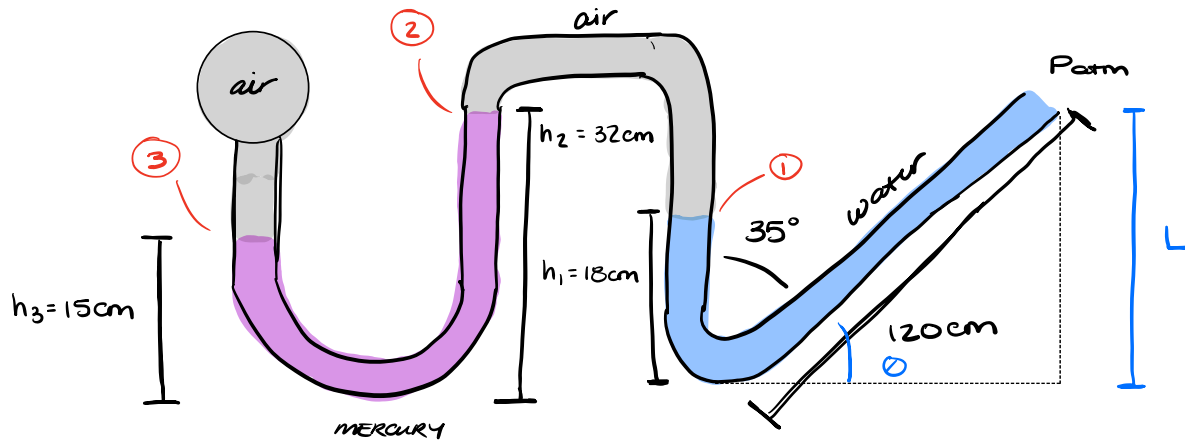
MANOMETER PROBLEM :

Figure 7: Inclined manometer.

Question 8

Consider the inclined manometer in Fig. 7 filled with Mercury ($\rho_{Hg} = 13,600 kg/m^3$) and water ($\rho_{H_2O} = 1000 kg/m^3$). The system is open to 1 atm (101,325 Pa) air ($\rho_{air} = 1.225 kg/m^3$) on the right side. If $L = 120cm$, what is the air pressure in container A?

Solution:

$$p_A - \rho_{Hg}g(0.32 - 0.15) + \rho_{air}g(0.32 - 0.18) - \rho_{H_2O}g(1.20\sin55° - 0.18) = p_{atm} \qquad (34)$$

$$\Rightarrow p_A = 131.8 \text{ kPa}$$

GIVEN :

$$\rho_{Hg} = 13,600 \ kg/m^3$$

$$\rho_{H2O} = 1,000 \ kg/m^3$$

$$\rho_{air} = 1.225 \ kg/m^3$$

$$L = ?$$

$$P_{atm} = 1 \ atm = 101,325 \ Pa$$

$$\theta = 90° - 35° = 55°$$
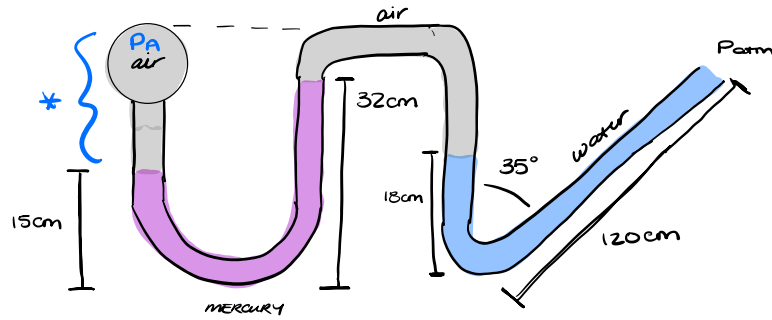
$$L = 1.2 \sin(55) = 0.983m$$

$$\Delta P = \rho g \Delta h$$

* ASSUMING
IN EQUILIBRIUM
& THAT PRESSURE
IN TANK IS SAME
AS PRESSURE OF AIR IN
TUBE: $P_3 = P_A$

START:

$$P_1 - P_{atm} = -\rho g \Delta h \qquad \rightarrow \Delta h = (h_1 - h)$$

$$* \ h = L$$

$$P_1 - P_{atm} = -\rho_{H2O} \ g \ (h_1 - h)$$

$$P_1 = -\rho_{H2O} \ g (h_1 - h) + P_{atm}$$

$$P_1 = -(1000 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(0.18m - 0.983m) + 101325 Pa$$

$$P_1 = 109202.43 \ Pa$$

$$P_2 - P_1 = -\rho_{air} g \Delta h \qquad \rightarrow \Delta h = (h_2 - h_1)$$

$$P_2 - P_1 = -(1.225 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(0.32 - 0.18)$$

$$P_2 = -(1.225 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(0.32m - 0.018m) + 109202.43 Pa$$

$$P_2 = 109,200.7476$$

$$P_3 - P_2 = -\rho_{Hg} g \Delta h \rightarrow \Delta h = (h_3 - h_2)$$

$$P_3 = -(13,600 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(0.15 - 0.32) + 109,200.7476 \ Pa$$

$$\boxed{P_3 = 131,881.4676 \ Pa = P_{atm}}$$