Part 66 Cat. B1 / B2 Module 8

BASIC AERODYNAMICS

Vilnius-2017

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8.1 PHYSICS OF THE ATMOSPHERE

Atmosphere and Basic Aerodynamics

As an aircraft operates in the air the properties of air that affect aircraft control and performance must be understood.

Air is a mixture of gases composed principally of nitrogen and oxygen. Since air is a combination of gases, it follows the laws of gases. Air is considered a fluid because it answers the definition of a fluid, namely, a substance which may be made to flow or change its shape by the application of moderate pressure. Air has weight, since something lighter than air, such as a balloon filled with helium, will rise in the air.

Air is made up of approximately 21% oxygen (O2) and 78% nitrogen (N) by volume, with the remaining 1% being made up from other gases. The ratios of the gases (21%, 78% and 1%) vary little with height although the moisture content drops with increase in altitude.

Aerodynamics is the study of the dynamics of gases, or the interaction between moving object and atmosphere causing an airflow around a body. As first a movement of a body (ship) in a water was studies, it is not a surprise that some aviation terms are the same as naval ones – rudder, water line, keel beam, speed measured in knots (nautical miles).

The understanding of basic aerodynamics – the possibility of flight, forces acting on aircraft in flight, why aircraft is designed with particular flight control systems, - is important for understanding the maintenance of aircraft systems.

As a part of physics (gas laws, fluid dynamics and propagation of sound were studied in Module 2 “Physics”) aerodynamics gives laws determining forces acting on aircraft and its behavior in interaction with atmosphere.

Temperature, Pressure and Altitude

Physically atmosphere is considered as a fluid of changing density, pressure and temperature. According to temperature changes with the height above the sea level atmosphere is divided into troposphere, stratosphere, mesosphere and thermosphere (**Fig. 1-1**).

As altitude increases, up to 30,000 feet (about 10 000 m), the temperature, pressure and density of the air decrease. This region is known as the TROPOSPHERE and the upper boundary is the TROPOPAUSE.

Being minimal (about -60°C) at tropopause it rises up to -10°C at stratopause, and then decreases to the altitude of about 80-85 kilometers (mesopause).

These changes in temperature are very interesting as it is known the temperature of cosmic background is $-455°F\ or - 273K$, but measurement show it depends on place of measurement – being in shadow or not.

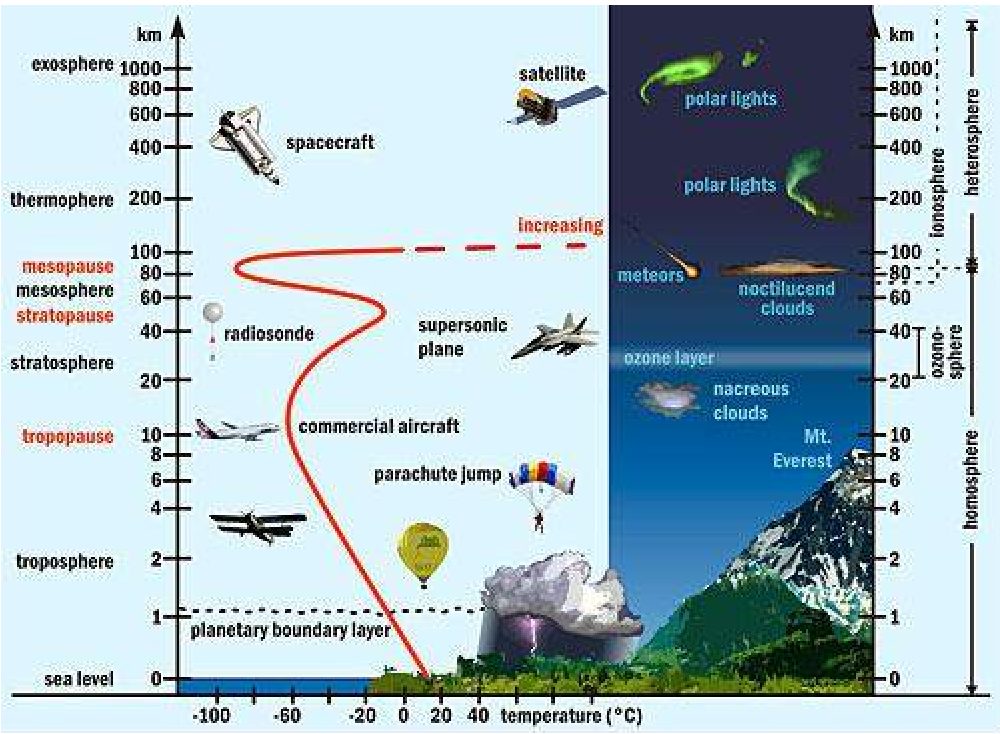

Figure 1-1. Atmospheric Regions & Relationship

More exactly the changes in temperature from sea level up to tropopause are presented on **Fig. 1-2**. Really the change in temperature from the sea level up to tropopause is almost linear and gives the values of 6.5°C for each 1 000 meters or 3.6°F per each 1 000 feet. This is called the standard (or average) laps rate.

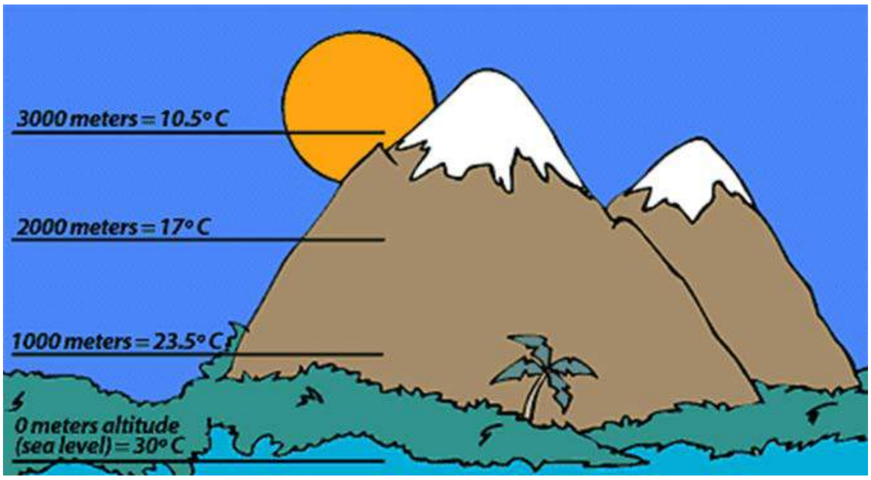

Figure 1-2. Changes in temperature with altitude

If a 1-in. square column of air extending from sea level to the "top" of the atmosphere could be weighed, it would be found to weigh about 14.7 lbs. Thus, atmospheric pressure at sea level is 14.7 PSI (pounds per square inch). However, pounds per square inch are rather a crude unit for the measurement of a light substance such as air. Therefore, atmospheric pressure is usually measured in terms of inches of mercury (**Fig. 1-3**) when measured with a mercury barometer or SI units.

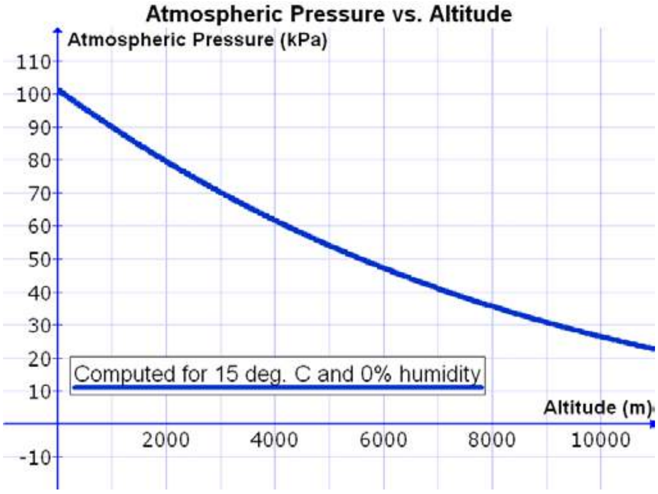

Figure 1-5. Atmospheric pressure and attitude relationship

The relation between different units is as follows:

29.92 in Hg = 1 atm = 14.7 psi = 1013.2 hPa = 760 mm Hg = 1.013 bar

The last unit is that meteorologists use.

Density

Density is a term that means weight per unit volume. Since air is a mixture of gases, it can be compressed. If the air in one container is under one-half as much pressure as the air in another identical container, the air under the greater pressure weighs twice as much as that in the container under lower pressure. The air under greater pressure is twice as dense as that in the other container. For equal weights of air, that which is under the greater pressure occupies only half the volume of that under half the pressure.

The density of gases is governed by the following rules (gas Laws studied previously in M2 Physics):

- Density varies in direct proportion with the pressure (under constant temp);
- Density varies inversely with the temperature (under constant pressure).

Thus, air at high altitudes is less dense than air at low altitudes (**Fig. 1-4**), and a mass of hot air is less dense than a mass of cool air. Changes in density affect the aerodynamic performance of aircraft. With the same horsepower, turbine aircraft can fly faster at a high altitude where the density is low than at a low altitude where the density is great. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit volume.

Humidity

Humidity is the amount of water vapor in the air. The maximum amount of water vapor that air can hold varies with the temperature. The higher the temperature of the air, the more water vapor it can absorb. By itself, water vapor weighs approximately five-eighths as much as an equal amount of perfectly dry air. The last fact is due to difference in water (H_2O) and main air components (N_2 and

O_2) molecular weights. H_2O molecule molecular weight is 18 whereas N_2 molecular weight – 28 (~78% of air), and O_2 molecular weight – 32 (~20% of air). Therefore, when air contains water vapor it is not as heavy as air containing no moisture.

Assuming that the temperature and pressure remain the same, the density of the air varies inversely with the humidity. On damp days the air density is less than on dry days. For this reason, an aircraft requires a longer runway for takeoff on damp days than it does on dry days.

Absolute Humidity

The number of grams of water vapor per 1 m^3 of the atmosphere.

Relative Humidity and the Dew Point

Existing water vapor pressure of the atmosphere, expressed as a percentage of the saturated water vapor pressure at the same temperature.

Air temperature drops as we rise in altitude above the surface. At some point the air temp drops to the dew point of the air at which point the water vapor in the air condenses into liquid water, and this water we see condensed onto specs of dust in the air makes up the clouds. All air contains some amount of water vapor, varying from just a fraction of a percent (by weight) for cold dry desert air, on up to some 3% for hot steaming jungles.

As the properties of air and water vapor are essentially independent, the property of the water – water vapor equilibrium (**Fig. 1-6**) at various temperatures is of great importance, but not the properties of the air.

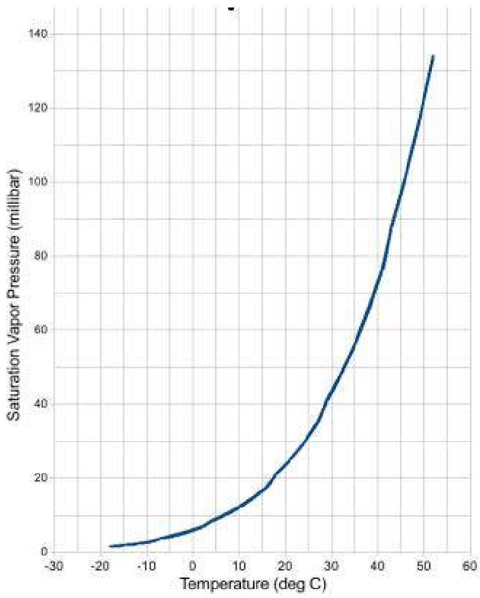

Figure 1-6. Air – saturation vapor pressure (According to The Engineering ToolBox)

Having a jar of dry air, and poured some water into the bottom of it, water molecules on the surface will evaporate from the surface and periodically condense back into the surface until it reaches some equilibrium value where evaporation and condensation is equal. At that point the air in the jar will

8.2. AERODYNAMICS

In addition to definition given in sub-module 8.1 aerodynamics as the science describing body's movement in an air. Thus it is a branch of dynamics which deals with the motion of air and other gases, with the forces acting upon an object in motion through the air, or with an object which is stationary in a current of air. In effect, in aviation aerodynamics is concerned with three distinct parts. These parts may be defined as the aircraft, the relative wind, and the atmosphere.

Airfoils

An airfoil is a surface designed to obtain a desirable reaction from the air through which it moves. Thus, we can say that any part of the aircraft which converts air resistance into a force useful for flight is an airfoil. The blades of a propeller are so designed that when they rotate, their shape and position cause a higher pressure to be built up behind them than in front of them so that they will pull the aircraft forward. The model of a wing (**Fig. 2-1**) gives an excellent example of streamlines around airfoil.

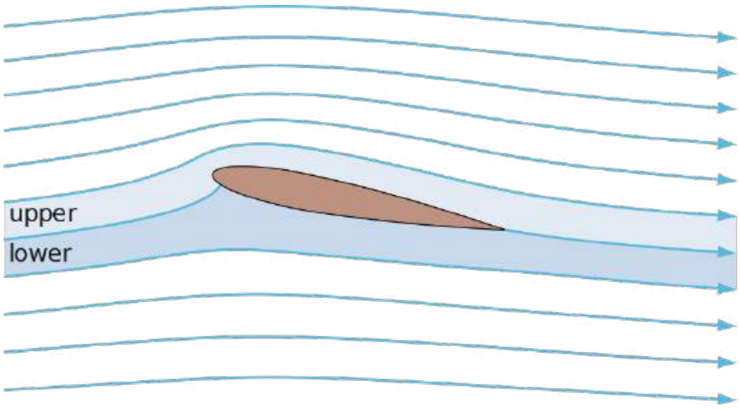

Figure 2-1. Streamlines around airfoil

Although the top surface of the conventional wing profile has greater curvature than the lower surface, the principal thing is the larger density of streamlines above the wing. The larger density of streamlines means the greater velocity of air.

According to Bernoulli's principle (previously studied in Module 2 Physics) an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. This is equivalent to the principle of conservation of energy. This states that in a steady flow the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline.

According Bernoulli's principle the product $P \times v = const$

$$\frac{P_{Above}}{P_{Below}} = \frac{v_{Below}}{v_{Above}}$$

that if the wing area is doubled, all other variables remaining the same, the lift and drag created by the wing is doubled. If the area is tripled, lift and drag are tripled.

Shape of the Airfoil

The shape of a wing (**Fig. 2-10**) consequently affects the efficiency of the wing.

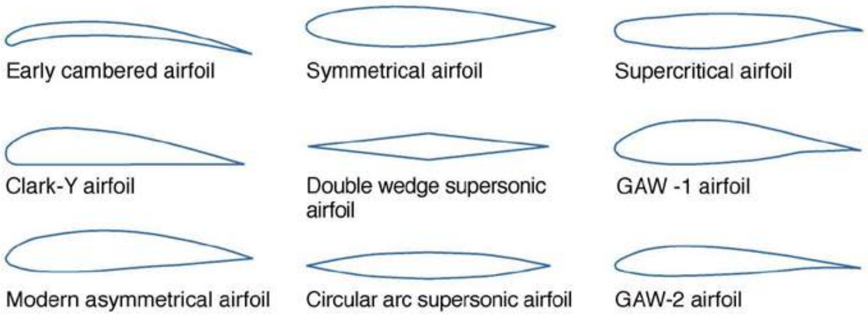

Figure 2-10. Airfoil types

Airfoil section properties differ from wing or aircraft properties because of the effect of the wing planform. A wing may have various airfoil sections from root to tip, with taper, twist, and sweepback. The resulting aerodynamic properties of the wing are determined by the action of each section along the span.

Efficiency of a wing is measured in terms of the lift over drag (L/D) ratio. This ratio varies with the angle of attack but reaches a definite maximum value for a particular angle of attack. At this angle, the wing has reached its maximum efficiency. The shape of the airfoil is the factor which determines the angle of attack at which the wing is most efficient; it also determines the degree of efficiency. Research has shown that the most efficient airfoils for general use have the maximum thickness occurring about one-third of the way back from the leading edge of the wing.

High-lift wings and high-lift devices for wings have been developed by shaping the airfoils to produce the desired effect. The amount of lift produced by an airfoil will increase with an increase in wing chamber. Camber refers to the curvature of an airfoil above and below the chord line surface. Upper chamber refers to the upper surface, lower camber to the lower surface, and mean camber to the mean line of the section. Camber is positive when departure from the chord line is outward, and negatives when it is inward. Thus, high-lift wings have a large positive camber on the upper surface and a slight negative camber on the lower surface. Wing flaps cause an ordinary wing to approximate this same condition by increasing the upper chamber and by creating a negative lower chamber.

It is also known that the larger the wingspan as compared to the chord, the greater the lift obtained. This comparison is called aspect ratio. The higher the aspect ratio, the greater the lift In spite of the benefits from an increase in aspect ratio, it was found that definite limitations were of structural and drag considerations.

Dihedral Angle

The upward inclination of the wing to the plane through the lateral axis (**Fig. 2-15**).

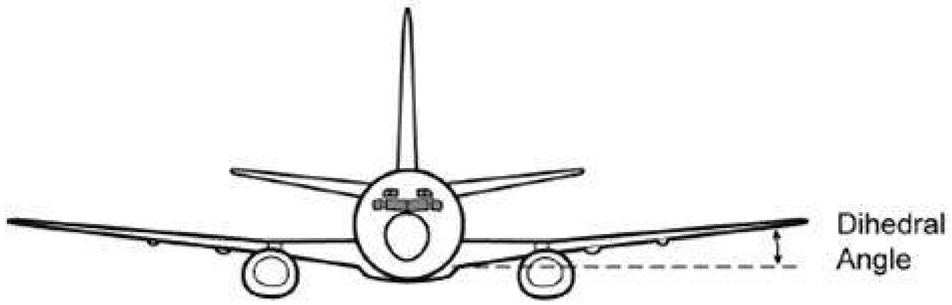

Figure 2-15. Dihedral angle

Anhedral Angle

The downward inclination of the wing to the plane through the lateral axis (**Fig. 2-16**).

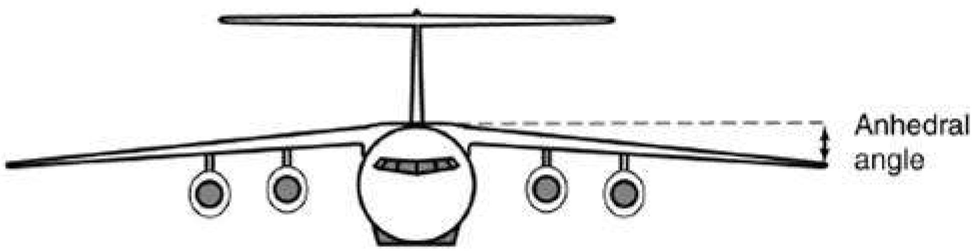

Figure 2-17. Anhedral angle

The total amount of drag on an aircraft is made up of many drag forces with three main:

- Parasite drag;
- Profile drag and
- Induced drag.

Parasite drag is made up of a combination of many different drag forces. Any exposed object on an aircraft offers some resistance to the air, and the more objects in the airstream, the more parasite drag. While parasite drag can be reduced by reducing the number of exposed parts to as few as practical and streamlining their shape, skin friction is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces when inspected under magnification have a ragged uneven appearance. These ragged surfaces deflect the air near the surface causing resistance to smooth airflow. Skin friction can be reduced by using glossy flat finishes and eliminating protruding rivet heads, roughness, and other irregularities.

Profile drag may be considered the parasite drag of the airfoil. The various components of parasite drag are all of the same nature as profile drag. The combination of induced and profile or form drag is shown on **Fig. 2-27**.

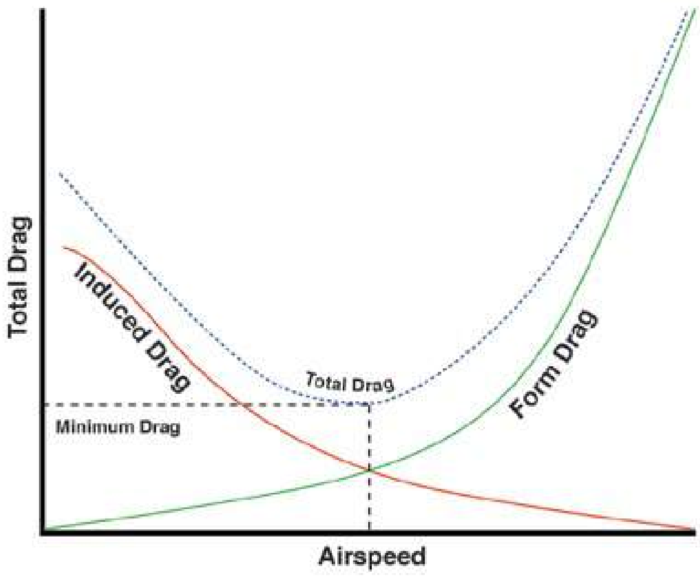

Figure 2-27. Drag

The action of the airfoil that gives us lift also causes induced drag. Remember that the pressure above the wing is less than atmospheric, and the pressure below the wing is equal to or greater than atmospheric pressure. Since fluids always move from high pressure toward low pressure, there is a spanwise movement of air from the bottom of the wing outward from the fuselage and upward around the wing tip. This flow of air results in “spillage” over the wing tip, thereby setting up a whirlpool of air called a vortex (**Fig. 2-28**).

8.3 THEORY OF FLIGHT

Aviation mechanic must understand the relationships between the atmosphere, the aircraft, and the forces acting on it in flight, in order to make intelligent decisions affecting the flight safety of both airplanes and helicopters.

Understanding why the aircraft is designed with a particular type of primary and secondary control system, and why the surfaces must be aerodynamically smooth, becomes essential when maintaining today's complex aircraft

The Forces Acting in Flight

As the air flows over the upper surface of an airfoil, its speed or velocity increases and its pressure decreases. An area of low pressure is thus formed. There is an area of greater pressure on the lower surface of the airfoil, and this greater pressure tends to move the wing upward. This difference in pressure between the upper and lower surfaces of the wing is called lift. Three-fourths of the total lift of an airfoil is the result of the decrease in pressure over the upper surface. The impact of air on the under surface of an airfoil produces the other one-fourth of the total lift.

An aircraft in flight is acted upon by four forces (**Fig. 3-1**):

1. Gravity, or weight, the force that pulls the aircraft toward the earth;
2. Lift, the force that pushes the aircraft upward;
3. Thrust, the force that moves the aircraft forward;
4. Drag, the force that exerts a braking action.

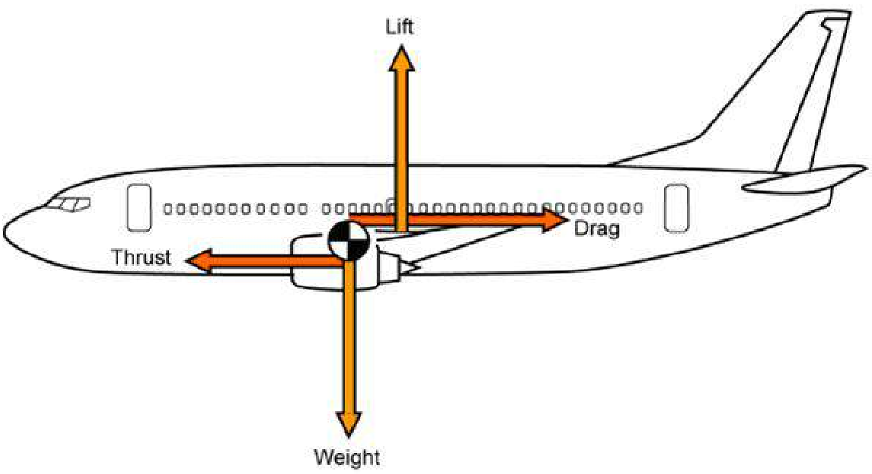

Figure 3-1. Lift/Weight and Thrust/Drag pitching moments

Common Considerations

Lift acts through the centre of pressure and weight through the centre of gravity. For simplicity, thrust and drag forces are considered as acting parallel to the longitudinal axis, and their displacement from carried out by actually transferring fuel from the main tanks in the wings to fuel tanks in the tail of the aircraft as in the A380. The CoG changes slightly as passengers move about the aircraft.

Arrangement of the Four Forces

The aircraft is designed so the four forces are arranged to make it reasonably stable. In straight and level flight at constant speed with no turning moments the aircraft is said to be in equilibrium. This means

THRUST = DRAG and WEIGHT = LIFT.

Each pair is equal and opposite in direction. Nevertheless they are not usually opposite in position. For straight and level flight the AA is adjusted by the pilot to make the lift equal to the weight, if it is greater the aircraft will climb. If lift is less than weight the aircraft will descend. The engine thrust is adjusted by the throttles to make it equal to the drag, if it is greater the aircraft will increase airspeed - if it is less the aircraft's airspeed will decrease.

The Perfect Interaction of Four Forces

Fig. 3-1 and **Fig. 3-4** shows the perfect interaction of the four forces. For various reasons some aircraft have their forces in a not a perfect arrangement with thrust line higher than the drag line (as seaplanes).

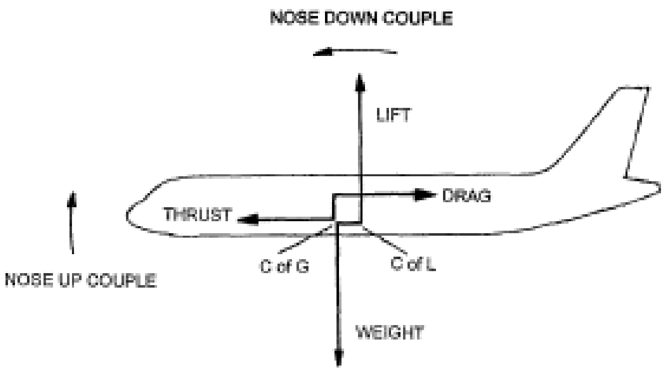

Figure 3-4. The perfect interaction of the four forces

The ideal arrangement is where the CoG is forward of the CoL (CoP)**,** which produces a nose down couple - and the thrust line is lower than the CoD (Centre of Drag), which produces a nose up couple. In level flight each couple opposes the other and cancell each other out.

8.4 FLIGHT STABILITY AND DYNAMICS

Axes of an Aircraft

Whenever an aircraft changes its attitude in flight, it must turn about one or more of three axes. **Fig. 4-1** shows the three axes, which are imaginary lines passing through the center of the aircraft. The axes of an aircraft can be considered as imaginary axles around which the aircraft turns like a wheel. At the center, where all three axes intersect, each is perpendicular to the other two. The axis which extends lengthwise through the fuselage from the nose to the tail is called the longitudinal axis. The axis which extends crosswise, from wing tip to wing tip, is the lateral axis. The axis which passes through the center, from top to bottom is called the vertical axis.

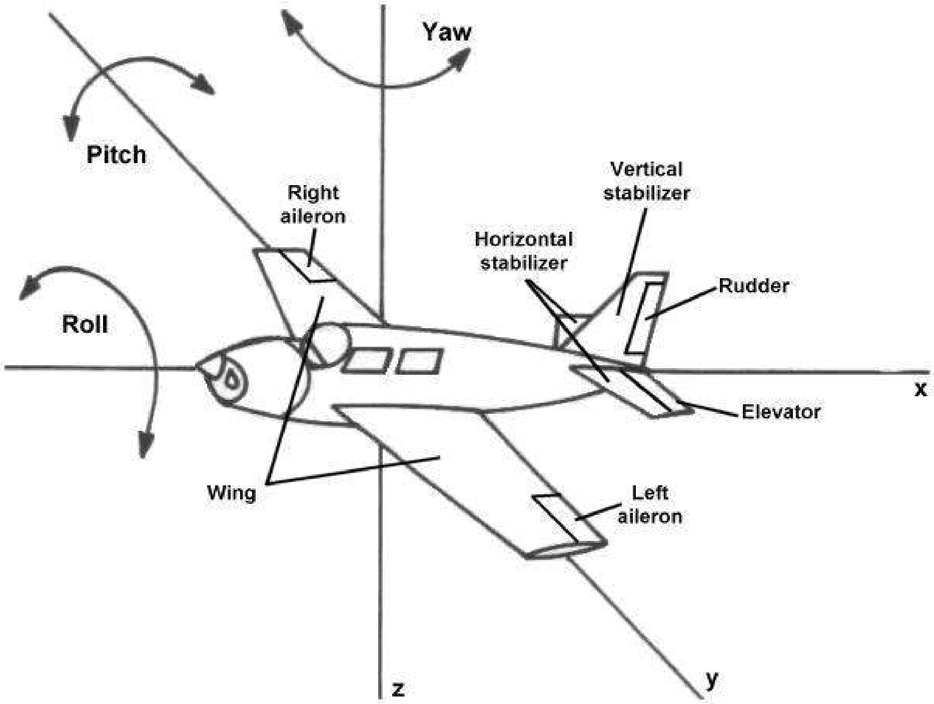

Figure 4-1. Motion of an aircraft about its axes

Motion about the longitudinal axis resembles the roll of a ship from side to side. In fact, the names used in describing the motion about an aircraft’s three axes were originally nautical terms. They have been adapted to aeronautical terminology because of the similarity of motion between an aircraft and a ship.

Thus, the motion about the longitudinal axis is called roll; motion along the lateral (cross-wing) axis is called pitch. Finally, an aircraft moves about its vertical axis in a motion which is termed yaw. This is a horizontal movement of the nose of the aircraft.

Roll, pitch, and yaw - the motions an aircraft makes about its longitudinal, lateral, and vertical axes - are controlled by three control surfaces. Roll is produced by the ailerons, which are located at the

Fig. 4-5 shows a simplified aileron control system using push/pull rods, pulleys and cables and **Fig. 4-6** shows a simplified elevator control system using the same basic control system components.

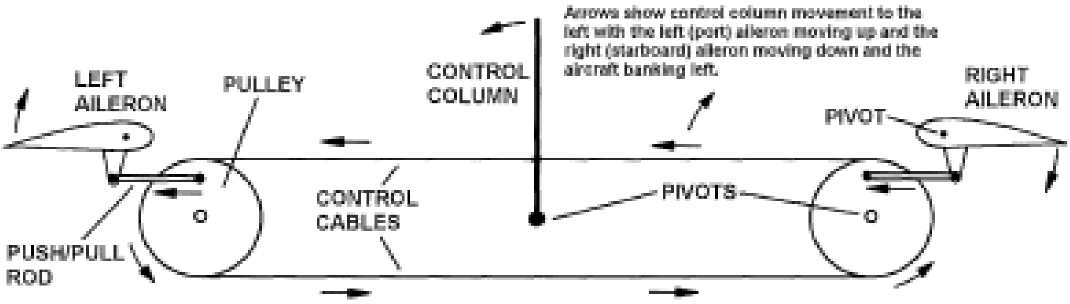

Figure 4-5. A simplified aileron control system

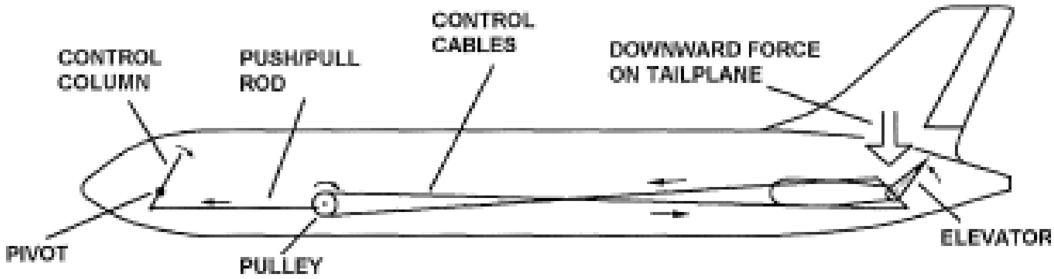

Figure 4-6. A simplified elevator control system

The control systems of smaller aircraft are very similar to those shown but for larger /faster aircraft the controls are powered (usually with hydraulically powered units at the control surface end being signalled by a mechanical control system from the flight-deck end).

Some systems are fully computer controlled with signals to the computer coming from the pilot's flight-deck controls. The powered units (usually hydraulic) get their signals from the computers.

Fig. 4-4 to Fig. 4-6 help memorize the pilot's control movement, the control system movement and the subsequent control surface/surfaces movement.

Fig. 4-7 shows the control surfaces as fitted to an airliner. The slats are fitted to the complete length of the outer wing leading edge and the leading edge flaps are fitted to the inboard leading edge. The trailing edge flaps are fitted in-board of the ailerons.

The ailerons are used for roll control (to bank the aircraft) - also to assist in improving the L/D ratio of the wing during take-off and landing by being drooped (automatically).

When selected to the drooped position they are moved symmetrically (both sides move down together). Any movement as ailerons (asymmetric movement) is achieved about the new drooped neutral position.

Directional Stability

This is assisted by the fin and rudder and the side area of the fuselage aft of the Centre of Gravity - taken all together called the Effective Keel Surface (**Fig. 4-16**).

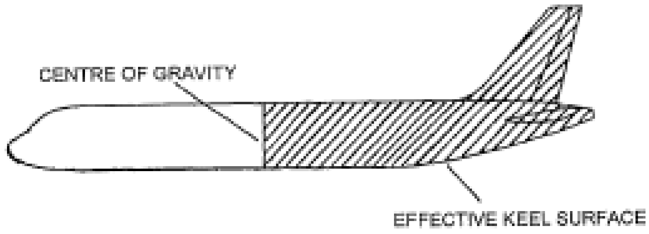

Figure 4-16. Effective keel surface

If the aircraft is caused to yaw then, like a weather-cock or weather vane on a church spire, the airflow will „blow“ it back to it's original position.
When aircraft yaws it will tend to fly in it's original direction for a short time due to it's momentum (Newton's 1st law – Law of inertia, as described in Module 2 Physics) - thus for a short time the airflow will be acting on the side of the fuselage. This correcting moment is also assisted by the small sideways „lift“ produced by the fin.
This correcting action may set up an oscillating motion which is corrected by fitting powered automatic yaw dampers to the rudder control system.
For most aircraft the fin is vertical and its chord line is parallel to the aircraft's longitudinal datum line. For some single engined propeller driven aircraft, however, the fin chord line is set at a small angle to the longitudinal datum line to counter the effect of the swirling propeller slipstream.

Longitudinal Stability

This is associated with the tail-plane or horizontal stabiliser. For many large passenger aircraft the tailplane may be designed with its maximum camber on the underside thus producing downwards lift. On some aircraft the chordline is set at a small negative angle to the longitudinal datum line (negative angle of incidence) also to produce negative lift.

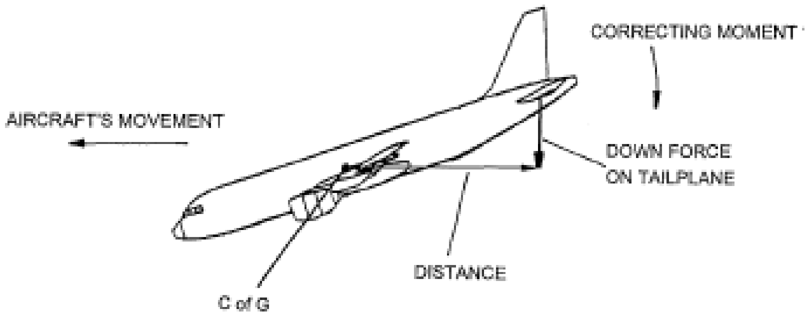

Figure 4-17. Longitudinal stability

Heavy Damping

An aircraft is said to be dynamically stable when it returns to it's original trimmed position with no overshoot (**Fig. 4-20A**). It's movement is said to be heavily damped. There are no oscillations and the aircraft returns steadily to it's original flight path. Because of the damped nature of the return it may take some time to get back to its original position.

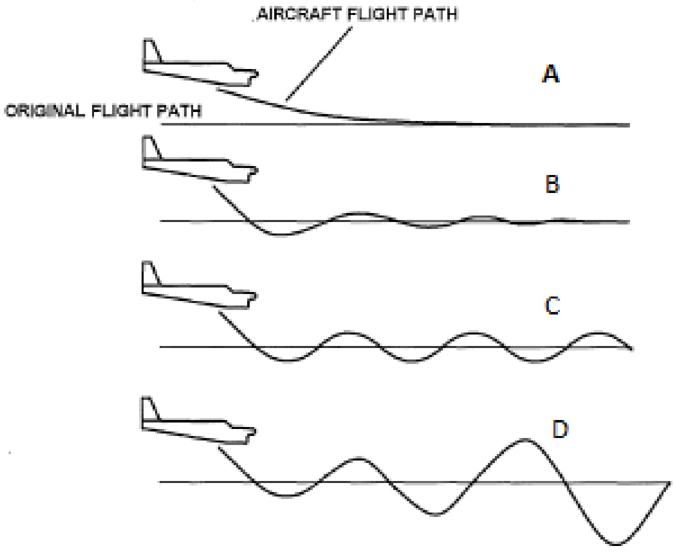

Figure 4-20. Dynamic stability

Partial Damping

This is where the aircraft returns to it's original trimmed position but overshoots (**Fig. 4-20B**). It is stable enough to correct this overshoot but moves back passed it's original position.These oscillations gradually decrease in amplitude until the aircraft regains it's original flight attitude.

Undamped

In this case (**Fig. 4-20C**) called neutral dynamic stability the aircraft returns to it's original flight path and overshoots. It corrects this overshoot to return back to the same overshoot position but on the other side.

These overshoots either side of the original flight path do not decrease or increase in amplitude but remain the same. This is not an uncommon condition with some aircraft stabilities and may require the fitment of auto-stabilising systems within the flying control system.

Negatively Damped

This is similar to the undamped dynamic stability but the amplitude of the oscillations get worse (**Fig. 4-20D**). The amplitudes get greater until there is a mechanical failure or the pilot or some automatic stability system takes a hand in correcting the situation. In the past there have been catastrophic failures caused by this type of instability.