Module – 4

AIRCRAFT STABILITY

Syllabus:

Forces on an aircraft in flight; static and dynamic stability; longitudinal, lateral and roll stability; necessary conditions for longitudinal stability; basics of aircraft control systems. Effect of flaps and stats on lift, control tabs, stalling, gliding, landing, turning, aircraft maneuvers; stalling, gliding, turning. Simple problems on these. Performance of aircraft – power curves, maximum and minimum speeds for horizontal flight at a given altitude; effect of changes in engine power and altitude on performance; correct and incorrect angles of bank; aerobatics, inverted maneuver, maneuverability. Simple problems.

1. Describe forces acting on an aircraft in flight.

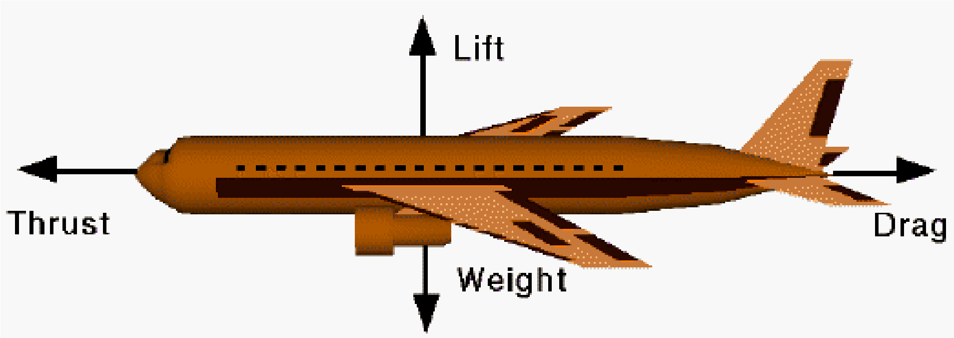
By simplified motion we mean that some of the four forces acting on the aircraft are balanced by other forces and that we are looking at only one force and one direction at a time. In reality, this simplified motion doesn't occur because all of the forces are interrelated to the aircraft's speed, altitude, orientation, etc. But looking at the forces ideally and individually does give us some insight and is much easier to understand.

In an ideal situation, an airplane could sustain a constant speed and level flight in which the weight would be balanced by the lift, and the drag would be balanced by the thrust. The closest example of this condition is a cruising airliner. While the weight decreases due to fuel burned, the change is very small relative to the total aircraft weight. In this situation, the aircraft will maintain a constant cruise velocity as described by Newton's first law of motion.

If the forces become unbalanced, the aircraft will move in the direction of the greater force. We can compute the acceleration which the aircraft will experience from Newton's second law of motion

$$F = m * a$$

Where a is the acceleration, m is the mass of the aircraft, and F is the net force acting on the aircraft. The net force is the difference between the opposing forces; lift minus weight, or thrust minus drag. With this information, we can solve for the resulting motion of the aircraft.



Flight Condition	Effect
Lift > Weight	Plane Rises
Weight > Lift	Plane Falls
Drag > Thrust	Plane Slows
Thrust > Drag	Plane Accelerates

If the weight is decreased while the lift is held constant, the airplane will rise:

Lift > Weight - Aircraft Rises

If the lift is decreased while the weight is constant, the plane will fall:

Weight > Lift - Aircraft Falls

Similarly, increasing the thrust while the drag is constant will cause the plane to accelerate:

Thrust > Drag - Aircraft Accelerates

And increasing the drag at a constant thrust will cause the plane to slow down:

Drag > Thrust - Aircraft Slows

2. Explain static and dynamic stability.

Or

With a neat sketch, explain conditions of static and dynamic stability of an aircraft.

Or

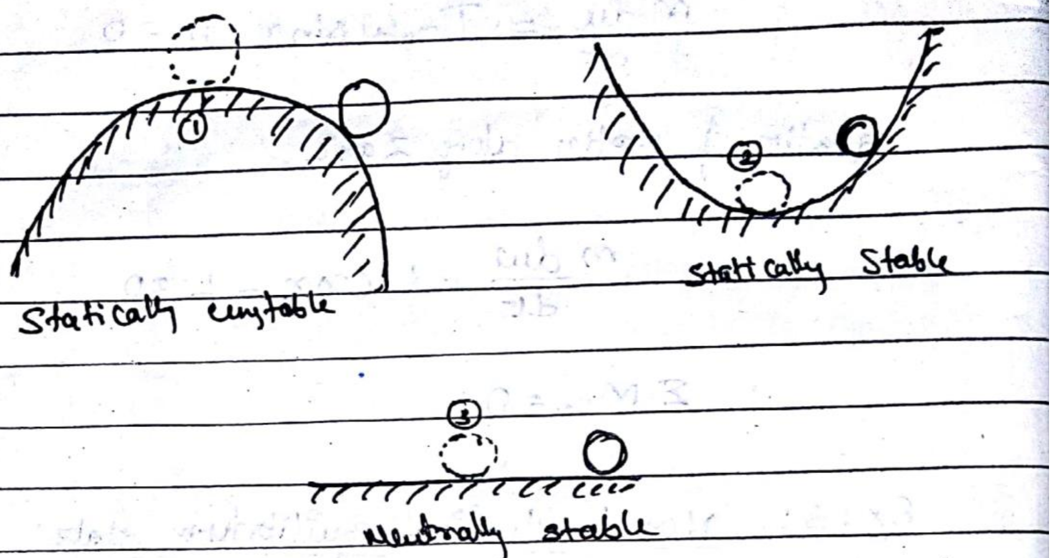
Describe in detail about the types of stability with suitable diagrams.

"Stability refers to System's property to comeback its original position when its disturbed [any physical System => Airplane]."

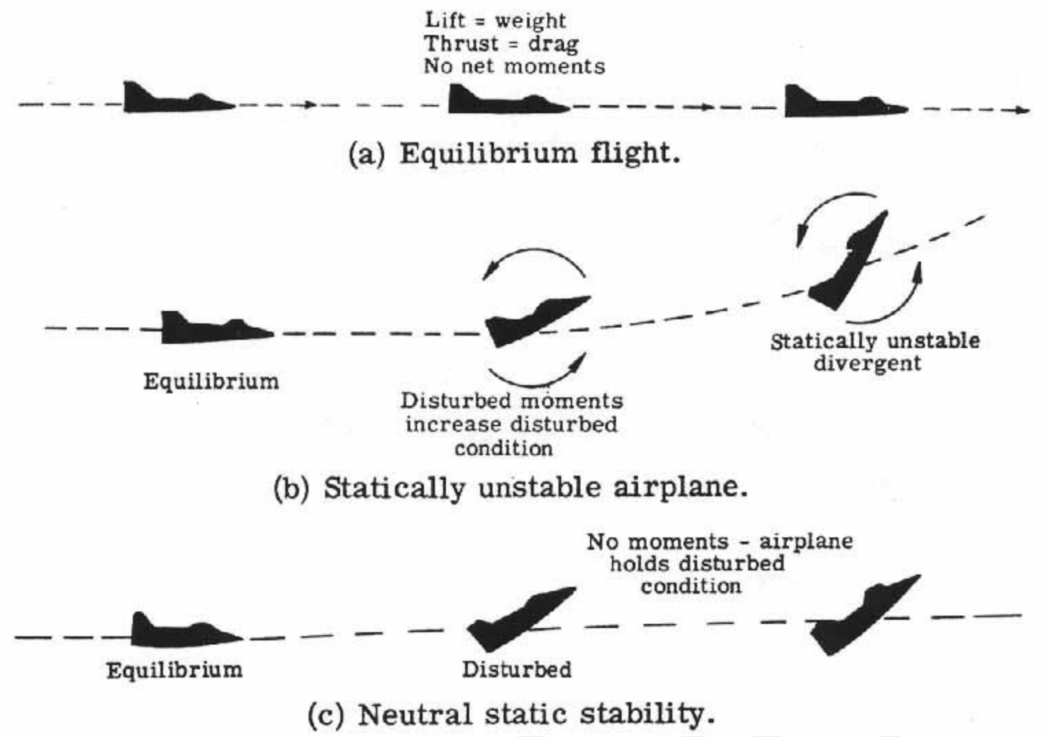
Stability →
- Static Stability
- Dynamic Stability

Static Stability:

"static stability refers to System's tendency to return to its original Equilibrium state".



Ball is in position of rest at (1) (2) & (3) how the system is responding to the disturbance comes under static stability.



(a) Equilibrium flight.

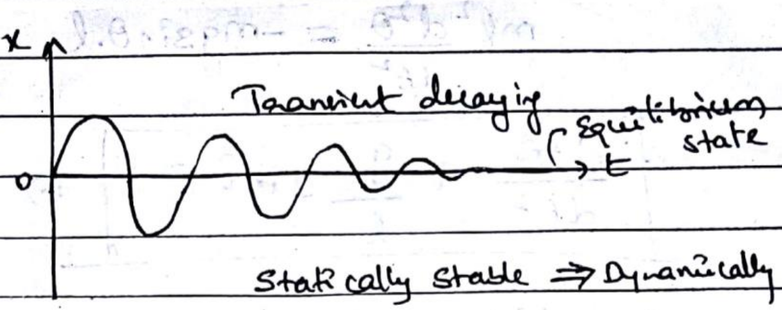
(b) Statically unstable airplane.

(c) Neutral static stability.

Dynamic Stability :

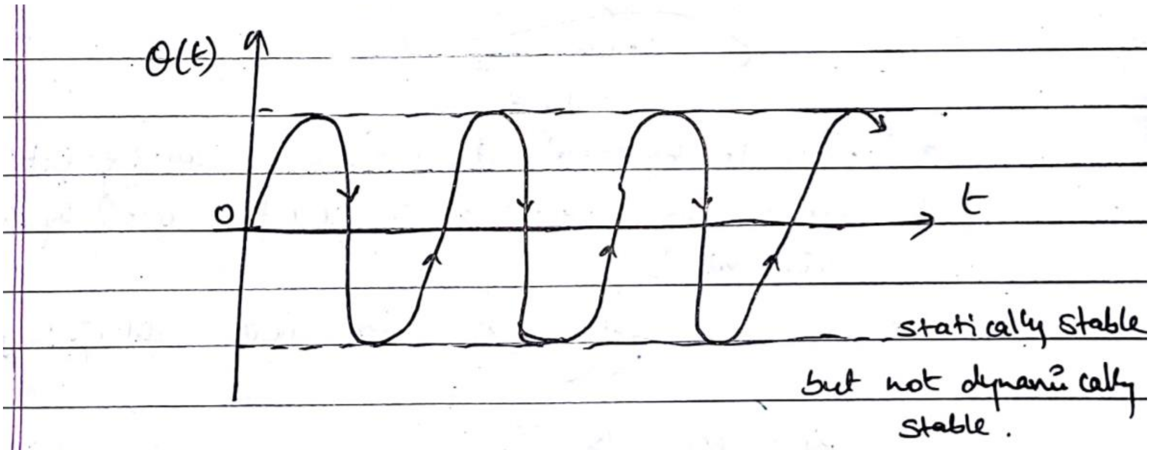
* "It is related to the actual time history of system's state."

t → ∞



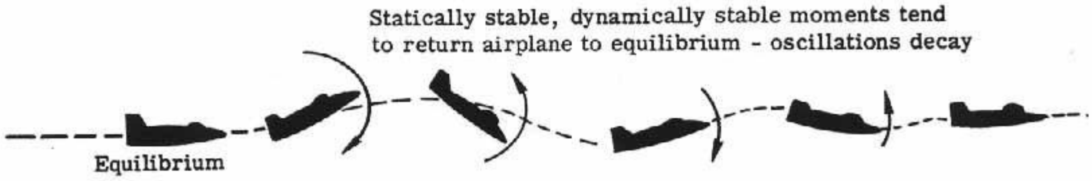
Statically stable ⇒ Dynamically stable

* " system (Airplane) is dynamically stable at an equilibrium state, when it eventually ($t \to \infty$) aquires its equilibrium state from where it was disturbed ".

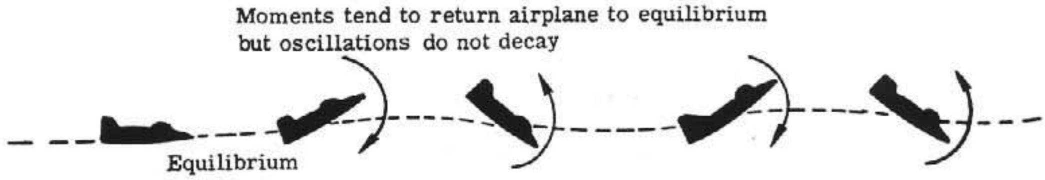


∴ Statically stable ⇏ (Does not always imply) Dynamically stable.

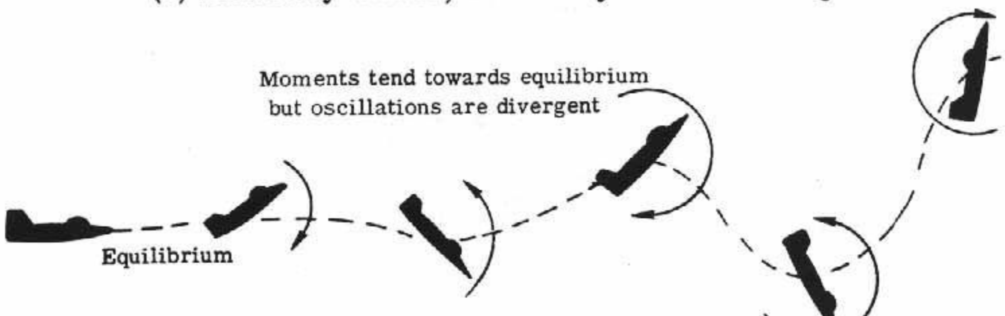
but Dynamically stable ⟹ Statically stable



(a) Statically and dynamically stable.



(b) Statically stable; neutral dynamic stability.



(c) Statically stable; dynamically unstable.

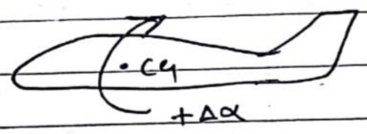
3. Describe longitudinal, lateral and roll stability.
Or
Describe stability analysis
Or
With a neat sketch, explain contribution of control surfaces in maintaining aircraft stability and control.

(i) Longitudinal Stability (Pitch Stability):

- The longitudinal axis is an imaginary line running from the nose to the tail of the aircraft, motion about this axis is called "roll," controlled by the ailerons.
- Longitudinal stability is the tendency of an aircraft to return to the trimmed angle of attack
- Accomplished through elevators and rudders
- Contributors:
    - Straight wings (negative)
    - Wing Sweep (positive)
    - Fuselage (negative)
    - Horizontal stabilizer (largest positive)
- An aerodynamic center aft of Center of Gravity (C.G.) is a stabilizing moment
- An aerodynamic center forward of C.G. is a de-stabilizing moment

* $\frac{\partial M}{\partial \alpha}$ pitching moment.

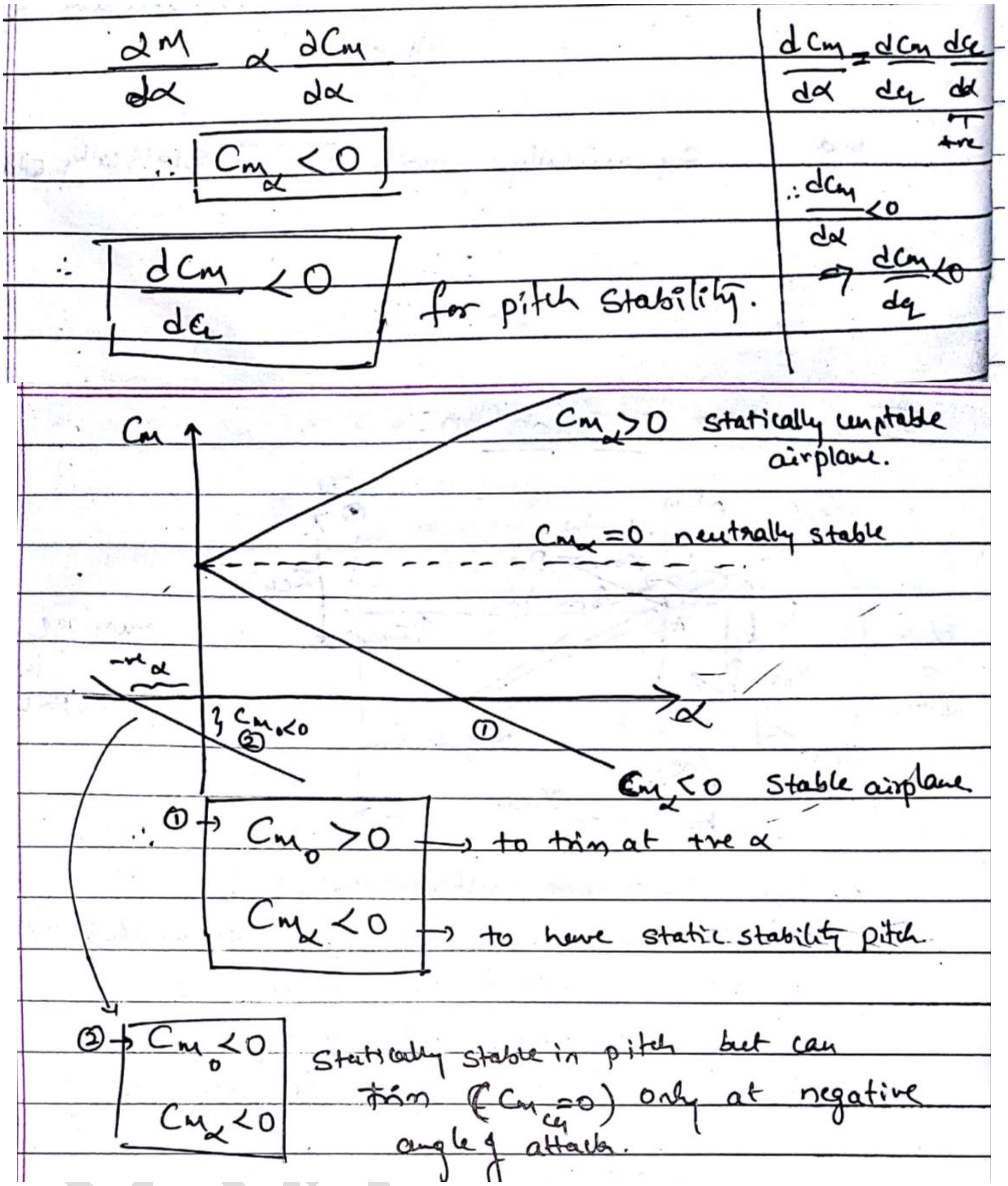
* This refers to rotational motion about cg of aircraft in their plane of axis.



* "Due to external disturbances causing pitching up motion will have to be counter acted by the aircraft".

$$\frac{\partial M}{\partial \alpha} < 0 \text{ for static stability in pitch.}$$

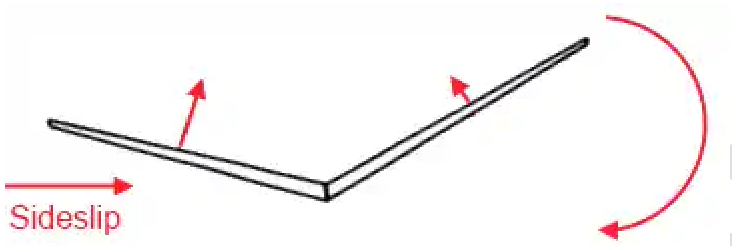
here, $M = Q S \bar{c} C_m$



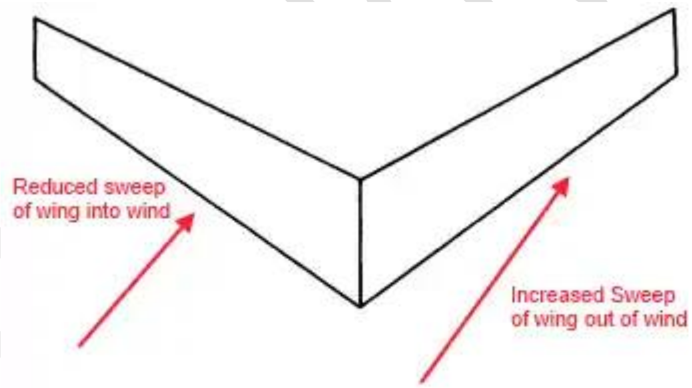
(ii) Lateral Stability (Roll Stability):

- The lateral axis is an imaginary line running from wing tip to wing tip; movement about this axis causes the nose of the aircraft to raise or lower and is caused by moving the elevators
- Lateral stability is the tendency of an aircraft to resist roll
- ***Dihedral Effect:***
    - Dihedral is evident when an aircraft rolls, creating a side-slip (assume no rudder)
    - One of the wings is lower than the other, creating an angle of attack difference for each wing

- The lower wing has an increase in the angle of attack, which causes it to create more lift and therefore rise, while the opposite is true for the higher wing
- The net result is the aircraft rolling away from the side-slip, thus resisting roll and attempting to bring the wings back to level
- Use of the rudder will smoothen the turn and overcome these forces as well as others, such as adverse yaw



- ***Swept Wing Effect:***
    - Side-slips create more direct relative wind to the upwind swept wing, which creates a roll toward wings level



$\frac{dC_l}{d\beta} < 0$ dihedral effect $C_{l_\beta} < 0$

"change in rolling moment coefficient respect to change in sideslip angle must be negative."

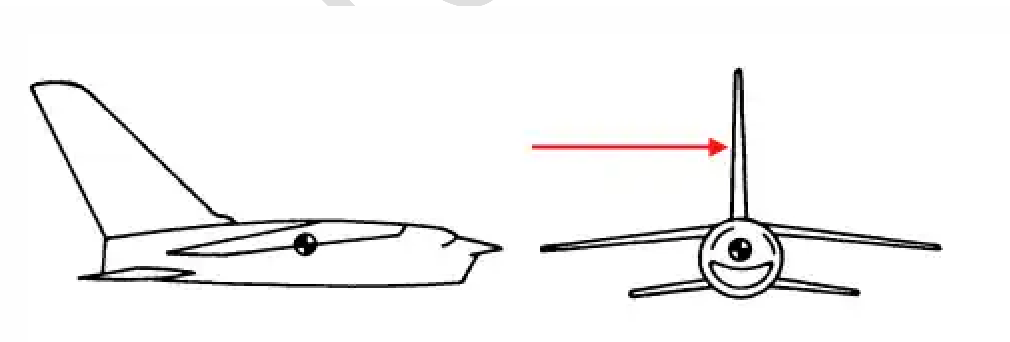
here, C_l = rolling coefficient.

β = side slip angle.

(iii) Vertical Stability (Yaw Stability):

- The vertical axis is an imaginary line running from the top of the plane to the bottom of the plane

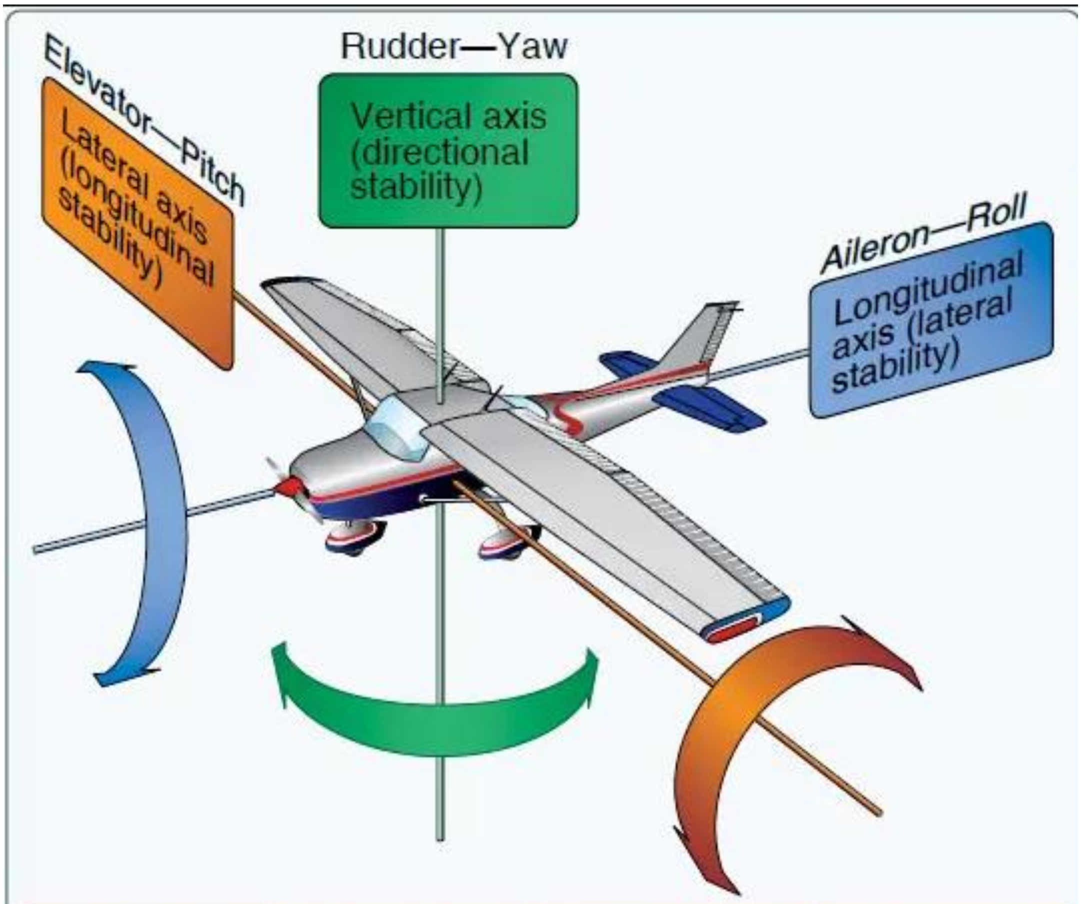
- The rudder controls rotation about this axis and is called "yaw"
- Tendency to resist yawing
- The more surface area behind the CG, the more directional stability
- ***Dutch Roll:***
    - Coupling of the lateral and directional axes causes Dutch roll
    - Dutch roll is a combined yawing-rolling motion of the aircraft but may only be a nuisance unless allowed to progress to large bank angles
    - Large rolling and yawing motions can become dangerous unless properly damped
    - The side-slip disturbance will cause the aircraft to roll
    - The bank angle, in turn, causes a side-slip in the opposite direction
    - While not unstable, this continual trade-off of side-slip and angle of bank is uncomfortable
    - Dutch roll may be excited by rough air or by lateral-directional over-controlling
    - Once induced, normal aircraft stability dampens the effect
    - Poor Dutch roll characteristics may make the aircraft susceptible to pilot induced oscillations (PIO)
    - Lateral-directional PIO is most common when the pilot attempts to line up in the landing configuration



$$\frac{\partial C_n}{\partial \beta} > 0 \Rightarrow C_{n_\beta} > 0$$

C_n = Yawing moment coefficient.

4. Draw a neat diagram showing primary control surface, Airplane movement, Axes of Rotation and type of stability with respect to Aircraft.



Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Roll	Longitudinal	Lateral
Elevator/ Stabilator	Pitch	Lateral	Longitudinal
Rudder	Yaw	Vertical	Directional

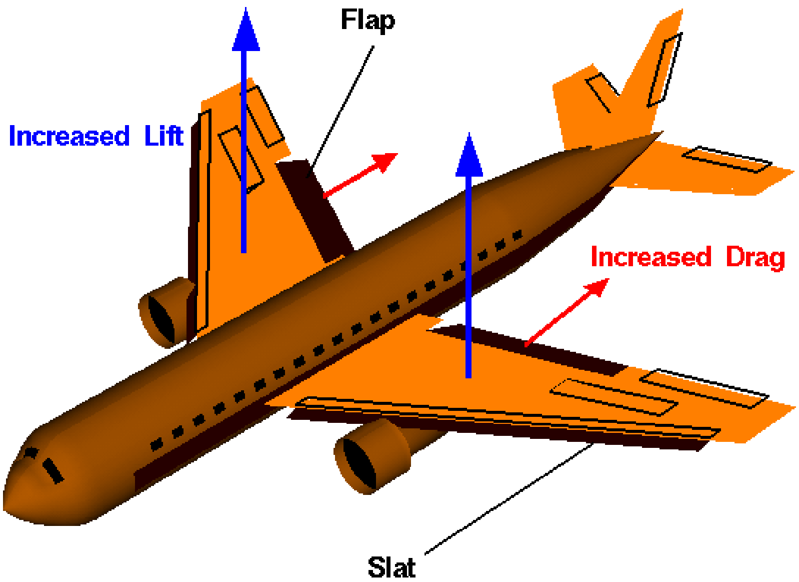
Aircraft control systems are carefully designed to provide adequate responsiveness to control inputs while allowing a natural feel. At low airspeeds, the controls usually feel soft and sluggish, and the aircraft responds slowly to control applications. At higher airspeeds, the controls become increasingly firm and aircraft response is more rapid.

Movement of any of the three primary flight control surfaces (ailerons, elevator or stabilizer, or rudder), changes the airflow and pressure distribution over and around the airfoil. These changes affect the lift and drag produced by the airfoil/ control surface combination, and allow a pilot to control the aircraft about its three axes of rotation.

Design features limit the amount of deflection of flight control surfaces. For example, control-stop mechanisms may be incorporated into the flight control linkages, or movement of the control column and/or rudder pedals may be limited. The purpose of these design limits is to prevent the pilot from inadvertently over controlling and overstressing the aircraft during normal maneuvers.

A properly designed aircraft is stable and easily controlled during normal maneuvering. Control surface inputs cause movement about the three axes of rotation. The types of stability an aircraft exhibits also relate to the three axes of rotation.

5. Describe the effects of flaps and stats on lift.
Or
Explain with neat diagram: i) Flap and Slats ii) Control Tabs.

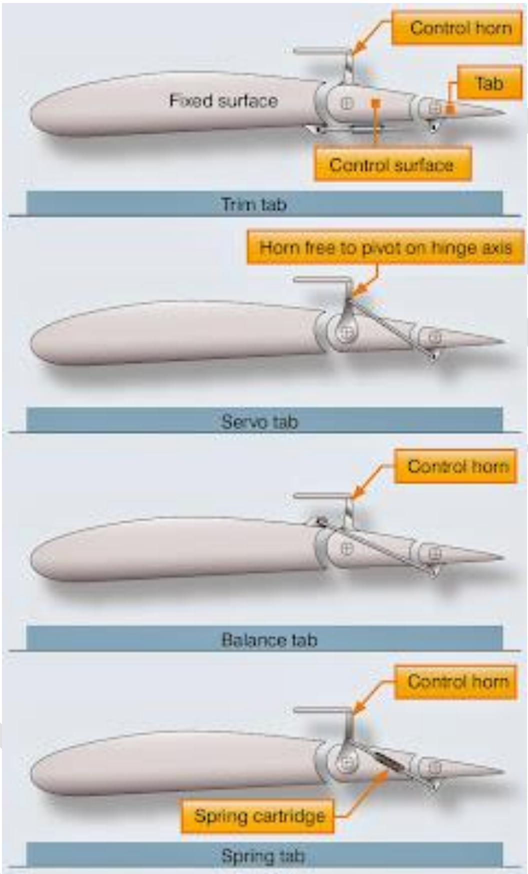


- The amount of lift generated by a wing depends on the shape of the airfoil, the wing area, and the aircraft velocity.
- During takeoff and landing the airplane's velocity is relatively low. To keep the lift high (to avoid objects on the ground!), airplane designers try to increase the wing area and change the airfoil shape by putting some moving parts on the wings' leading and trailing edges.
- The part on the leading edge is called a slat, while the part on the trailing edge is called a flap.
- The flaps and slats move along metal tracks built into the wings. Moving the flaps aft (toward the tail) and the slats forward increases the wing area.
- Pivoting the leading edge of the slat and the trailing edge of the flap downward increases the effective camber of the airfoil, which increases the lift.
- In addition, the large aft-projected area of the flap increases the drag of the aircraft. This helps the airplane slow down for landing.

Control Tabs (Trim Tabs):

A tab is like an additional, miniature control surface, with its own change in lift. Since it sits near the trailing edge of a larger control surface, this lift change affects the hinge moment of the larger surface.

Included in the trim controls are the trim tabs, servo tabs, balance tabs, and spring tabs. Trim tabs are small airfoils recessed into the trailing edges of the primary control surfaces. Trim tabs can be used to correct any tendency of the aircraft to move toward an undesirable flight attitude. Their purpose is to enable the pilot to trim out any unbalanced condition which may exist during flight, without exerting any pressure on the primary controls.

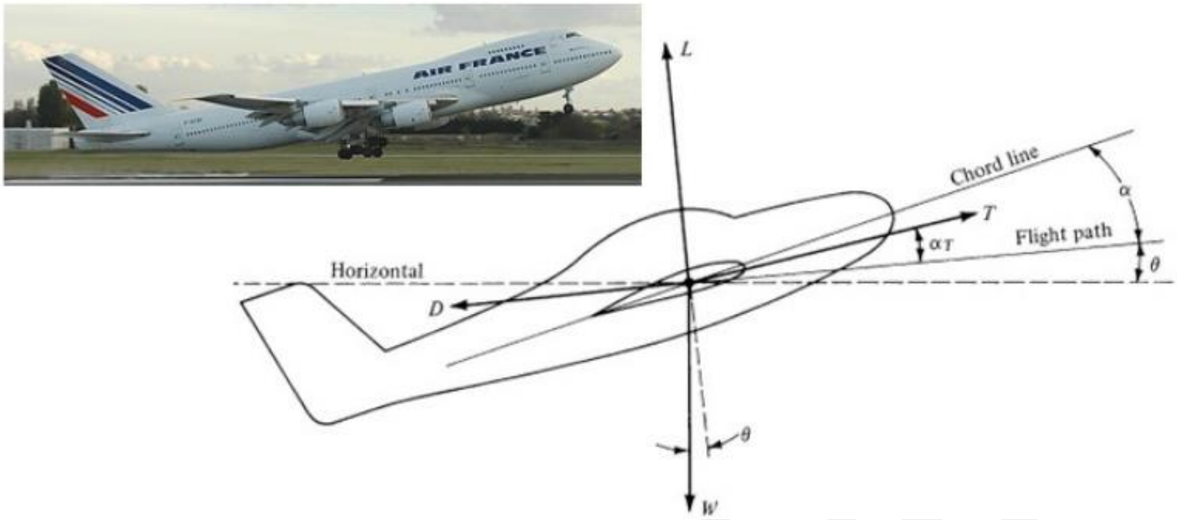


Servo tabs, sometimes referred to as flight tabs, are used primarily on the large main control surfaces. They aid in moving the main control surface and holding it in the desired position. Only the servo tab moves in response to movement by the pilot of the primary flight controls.

Balance tabs are designed to move in the opposite direction of the primary flight control. Thus, aerodynamic forces acting on the tab assist in moving the primary control surface.

Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators—to aid the pilot in moving the primary control surface.

6. Derive the basic equations of motion for a leveled and unaccelerated flight with a neat sketch.



Apply Newton's Second Law (**F**=m**a**) to curvilinear flight path

- Force balance in direction parallel to flight path
- Force balance in direction perpendicular to flight path

$$\sum F_{parallel} = T\cos\alpha_T - D - W\sin\theta = ma = m\frac{dV}{dt}$$

$$\sum F_{perpendicular} = T\cos\alpha_T - D - W\sin\theta = m\frac{V^2}{r_c}$$

Static Performance: Zero Accelerations ($dV/dt = 0$, $V^2/r_c = 0$)

- Maximum velocity
- Maximum rate of climb
- Maximum range
- Maximum endurance

Equations of motion reduce to very simple expressions

- Aerodynamic drag is balanced by thrust of engine
- Aerodynamic lift is balanced by weight of airplane

For most conventional airplanes α_T is small enough such that $\cos(\alpha_T) \sim 1$

$$T = D$$

$$L = W$$

7. How high lift devices are classified? Also explain its effects on lift.

The passive high-lift devices, commonly referred to as flaps, are based on the following three principles:

- Increase of camber.
- Increase of wet surface (typically by increasing the chord).
- Control of the boundary layer.

There are many different types of flaps depending on the size, speed, and complexity of the aircraft they are to be used on, as well as the era in which the aircraft was designed. Plain flaps, slotted flaps, and Fowler flaps are the most common trailing edge flaps. Flaps used on the leading edge of the wings of many jet airliners are Krueger flaps, slats, and slots (Notice that slots are not explicitly flaps, but more precisely boundary layer control devices).

The plain flap is the simplest flap and it is used in light . The basic idea is to design the airfoil so that the trailing edge can rotate around an axis. The angle of that deflexion is the flap deflexion δf . The effect is an increase in the camber of the airfoil, resulting in an increase in the coefficient of lift.

Another kind of trailing edge high-lift device is the slotted flap. The only difference with the plain flap is that it includes a slot which allows the extrados and intrados to be communicated. By this mean, the flap deflexion is higher without the boundary layer dropping off.

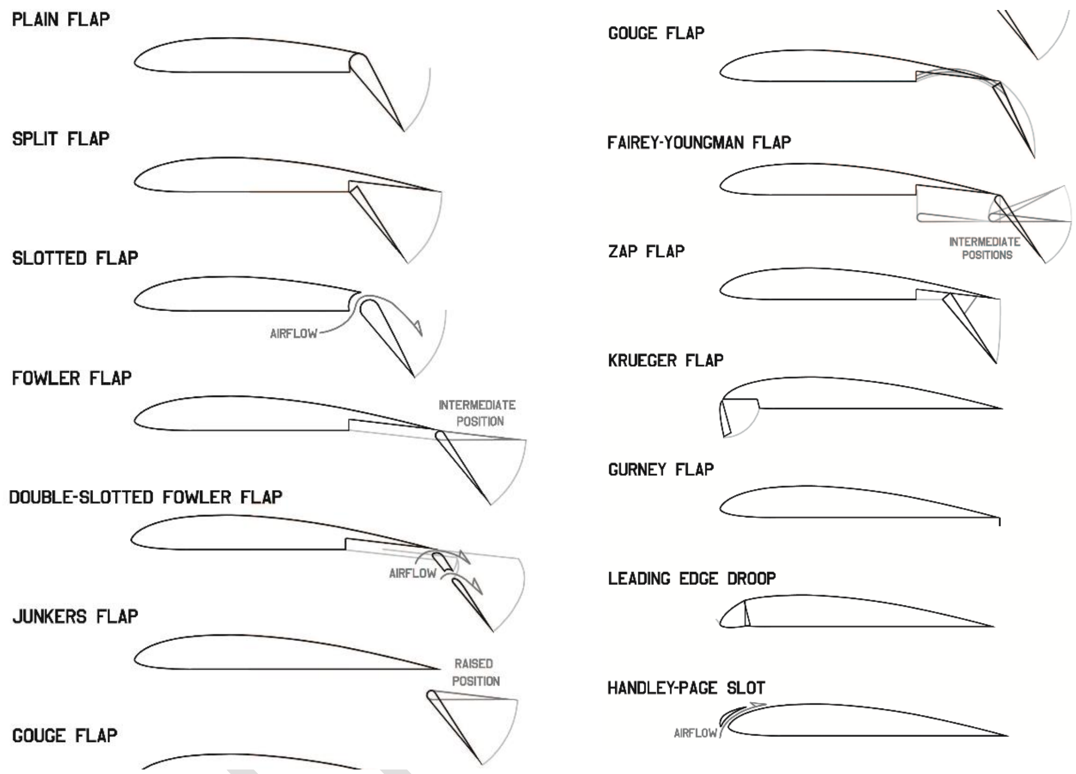
The last basic trailing edge high-lift device is the flap Fowler. This kind of flap combines the increase of camber with the increase in the chord of the airfoil (and therefore the wet surface). This fact increases also the slope of the lift curve. Combining the different types, there exist double and triple slotted Fowler flaps, combining also the control of the boundary layer. The Fairey-Youngman, Gouge, and Junkers flaps combine some of the exposed properties.

The last trailing edge high-lift device is the split flap (also refereed to as intrados flap). This flap provides, for the same increase of lift coefficient, more drag but with less torque.

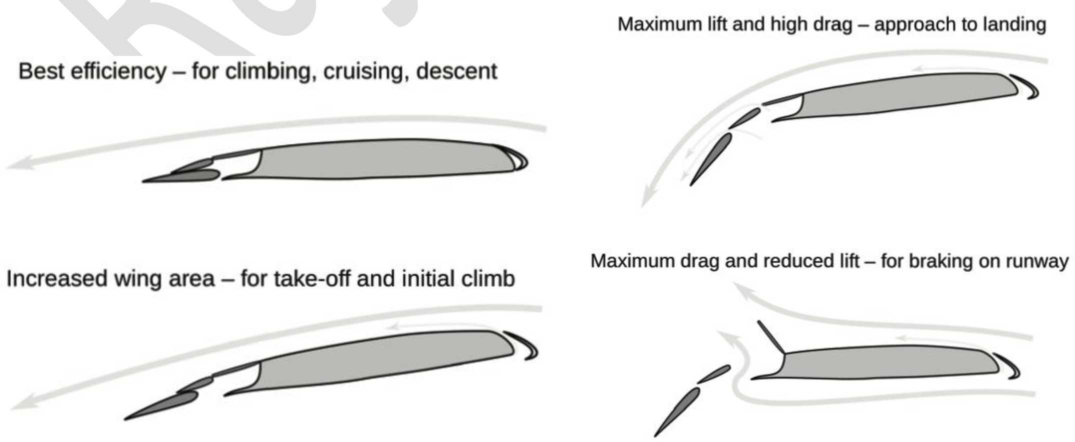
The most important leading edge high devices are: slot, the leading edge drop flap, and the flap Krueger.

The slot is a slot in the leading edge. It avoid the dropping off of the boundary layer by communicating extrados and intrados. The leading edge drop has the same philosophy as the plain flap, but applied in the leading edge instead of the trailing edge. The Kruger flaps works modifying the camber of the airfoil but also acting in the control of the boundary layer.

Types of high-lift devices:



Effects of high lift devices in airfoil flow, showing configurations for normal, take-off, landing, and braking:



8. Describe altitude effects on power available and power required. Or
Explain with a characteristics chart effect of power and altitude on performance of the aircraft.

From the relations obtained in the previous discussions, i.e,

$$P_{req} = T_{req}V = DV = \frac{WV}{\frac{C_L}{C_D}} = \sqrt{\frac{2W^3C_D^2}{S\rho C_L^3}}$$

and

$$P_{req} = \frac{1}{2}\rho V^3 SC_{D_o} + \frac{\frac{W^2}{\frac{1}{2}\rho VS}}{\pi ARe}$$

for sea level conditions, we have:

$$V_o = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho_o C_L}} \quad (1)$$

$$P_{R,o} = \sqrt{\frac{2W^3C_D^2}{S\rho_o C_L^3}} \quad (2)$$

At an altitude where density is ρ, these relations are:

$$V_{alt} = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho C_L}} \quad (3)$$

$$P_{R,alt} = \sqrt{\frac{2W^3C_D^2}{S\rho C_L^3}} \quad (4)$$

For a fixed value of C_L and C_D between sea level and altitude, dividing Equation 3 by Equation 1 and Equation 4 by Equation 2, we obtain

$$V_{alt} = V_o\sqrt{\frac{\rho_o}{\rho}} \quad (5)$$

$$P_{R,alt} = P_{R,o}\sqrt{\frac{\rho_o}{\rho}} \quad (6)$$

So, from the known values of power required, $P_{R,o}$ and velocity, V_o of an aircraft at sea level we can obtain power required, $P_{R,alt}$ and velocity, V_{alt} at an altitude.

A typical variation of P_R v/s V for various altitudes has been presented in Figure 5. It could be seen that power required curves experience an upward and rightward translation and as well as slight clockwise rotation as altitude increases.

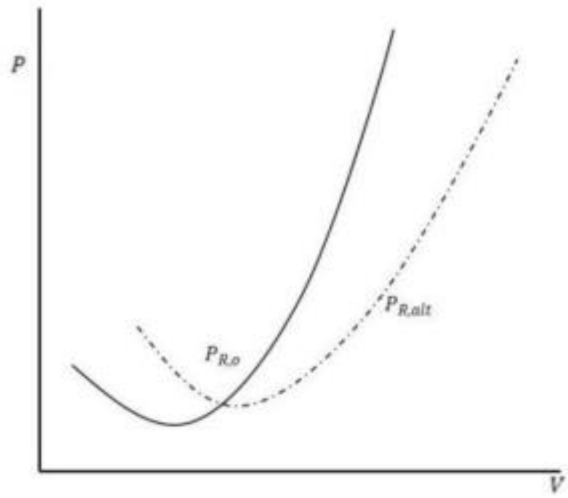


Figure 5: Change in the power required curve with altitude

In this discussion we will assume that P_A and T_A are directly proportional to the altitude density. The variation of maximum power available and power required both at sea level and at an altitude is shown in Figure 6. It can be understood that by plotting power available and power required as function of velocity for various altitudes, one can quickly estimate the maximum speed at a given altitude.

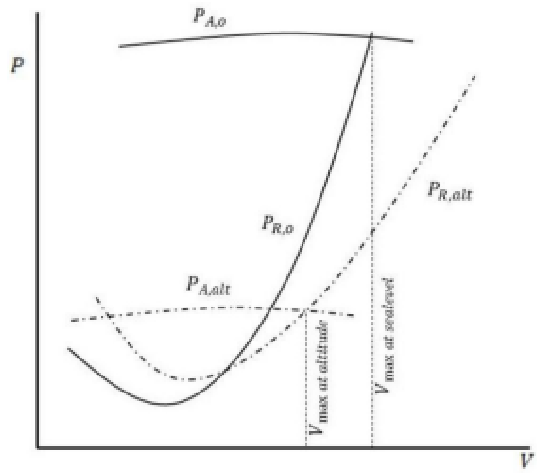


Figure 6: Change in the power required and power available curve with altitude

9. Explain power required curve for the CP – 1 at sea level.
Or
Explain with neat graph i) Power curve ii) Maximum and Minimum speed for horizontal flight at a given attitude.

Now we can look at the propulsion system requirements to maintain steady level flight since

$$T_{\text{req}} = D$$

and

$$P_{\text{req}} = T_{\text{req}} V = DV.$$

$$P_{\text{req}} = \frac{1}{2}\rho V^3 S C_{D_0} + \frac{W^2}{\frac{1}{2}\rho V S}\left(\frac{1}{\pi e AR}\right).$$

Thus the power required (for steady level flight) takes the form of Figure 13.3.

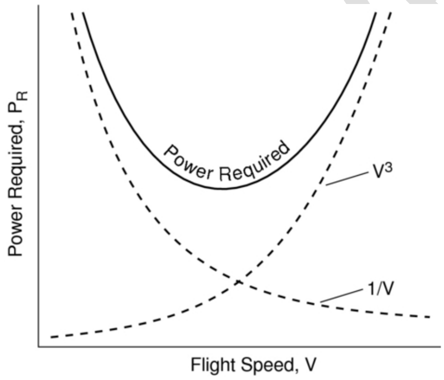


Figure 13.3: Typical power required curve for an aircraft.

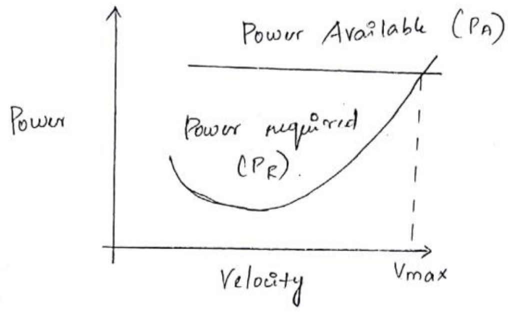
The velocity for minimum power is obtained by taking the derivative of the equation for P_{req} with respect to V and setting it equal to zero.

$$V_{\text{minimum power}} = \left[\frac{4}{3}\left(\frac{W}{S}\right)^2 \frac{1}{\rho^2}\frac{1}{C_{D_0}}\left(\frac{1}{\pi e AR}\right)\right]^{\frac{1}{4}}.$$

As we will see shortly, maximum **endurance** (time aloft) occurs when the minimum power is used to maintain steady level flight. Maximum **range** (distance traveled) is obtained when the aircraft is flown at the most aerodynamically efficient condition (maximum C_L/C_D).

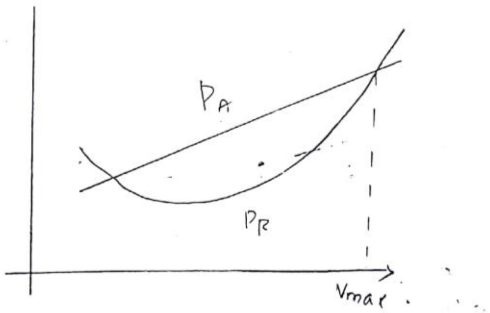
Maximum velocity

→ For a propeller driven engine the maximum velocity is obtained by the intersection of power available curve and power required curve varying with velocity. For a straight and levelled flight condition.



→ For a jet driven A/c Assuming T_A is constant with velocity, the power available @ subsonic speed varies linearly with V_∞.

→ Max Velocity is obtained by intersection P_A & P_R curve

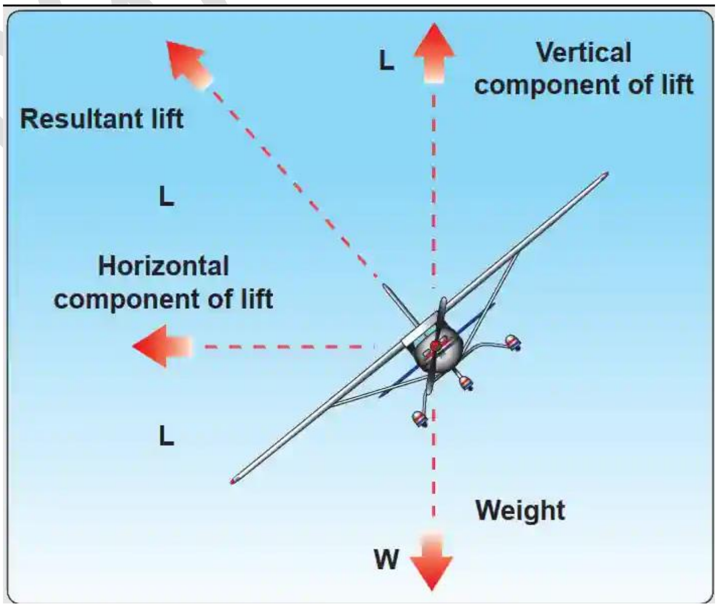


10. Explain with neat sketch Turning flight performance.

Or

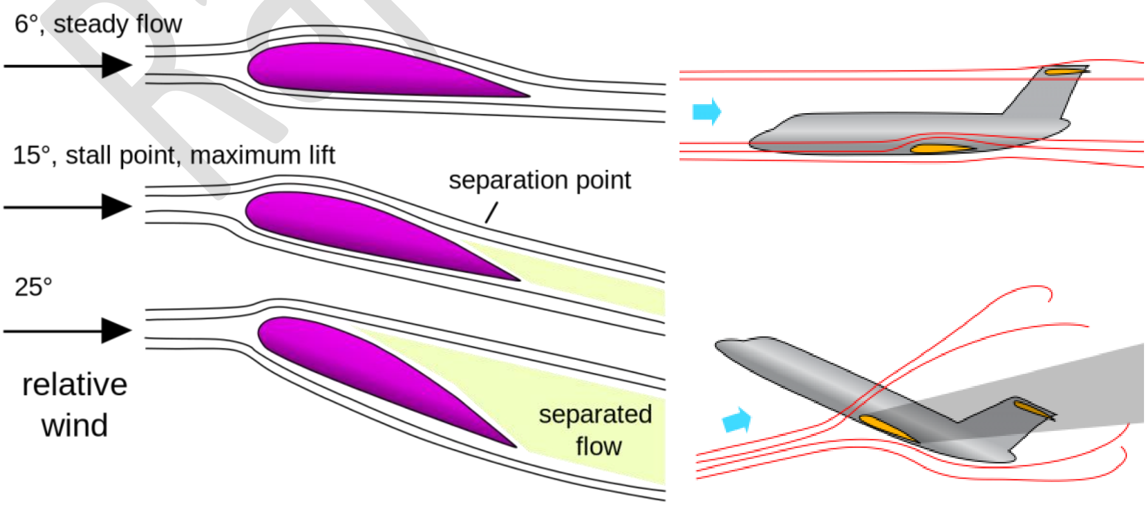
Banking

- When an aircraft banks, the resultant lift splits between a vertical and horizontal component, providing the horizontal forces necessary to turn.
- Lift is a key principle of flight, essential to flight and therefore turn performance.
- When an aircraft is placed in a bank, the lift vector of an aircraft rotates with it, producing a vertical and horizontal component.
- The relationship between the aircraft's speed and bank angle determines the rate and radius of turns.
- The bank angle, in conjunction with aircraft speed, form a relationship between the rate of turn and radius of turn.
- The equal and opposite reaction to this side-ward force is centrifugal force, which is merely an apparent force as a result of inertia.
- Pilots endeavor to maintain coordination throughout turns to avoid slipping/skidding.
- Understanding the rate, radius, and performance in a turn, aircraft performance while turning is easier to understand.
- Pilots must be careful to not over-anticipate or over-compensate, leading to overbanking in a turn.
- These principles are typically in reference to turns, but they are foundational to several maneuvers, including aerobatics.



11. Write a note on stalling

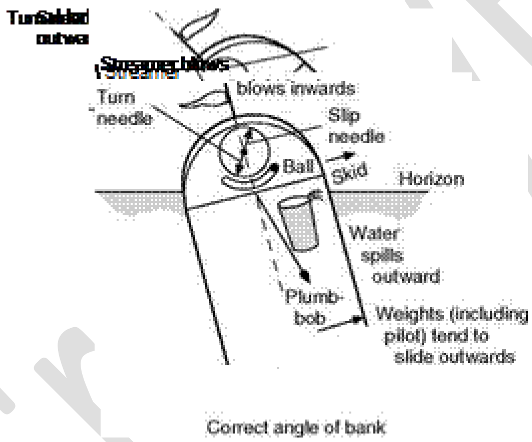
- A stall is a condition in aerodynamics and aviation such that if the angle of attack increases beyond a certain point, then lift begins to decrease.
- The angle at which this occurs is called the critical angle of attack. This angle is dependent upon the airfoil section or profile of the wing, its planform, its aspect ratio, and other factors, but is typically in the range of 8 to 20 degrees relative to the incoming wind ("relative wind") for most subsonic airfoils.
- The critical angle of attack is the angle of attack on the lift coefficient versus angle-of-attack (Cl~alpha) curve at which the maximum lift coefficient occurs.
- Stalling is caused by flow separation which, in turn, is caused by the air flowing against a rising pressure.
- For the trailing-edge stall, separation begins at small angles of attack near the trailing edge of the wing while the rest of the flow over the wing remains attached. As angle of attack increases, the separated regions on the top of the wing increase in size as the flow separation moves forward, and this hinders the ability of the wing to create lift. This is shown by the reduction in lift-slope on a Cl~alpha curve as the lift nears its maximum value.
- The separated flow usually causes buffeting.
- Beyond the critical angle of attack, separated flow is so dominant that additional increases in angle of attack cause the lift to fall from its peak value.
- Piston-engined and early jet transports had very good stall behaviour with pre-stall buffet warning and, if ignored, a straight nose-drop for a natural recovery.



12. Explain the effects of correct and in correct angles of bank with neat diagram.

We have so far assumed that the airplane is banked at the correct angle for the given turn. Fortunately the pilot has several means of telling whether the bank is correct or not (Fig. 8.6, overleaf), and since the methods help us to understand the mechanics of the turn, it may be as well to mention them here.

A good indicator is the wind itself, or a vane, like a weather cock, mounted in some exposed position. In normal flight and in a correct bank the wind will come from straight ahead (neglecting any local effects from the slipstream); if the bank is too much, the airplane will sideslip inwards and the airplane, and pilot if he is in an open cockpit, will feel the wind coming from the inside of the turn, whereas if the bank is too small, the wind will come from the outside of the turn, due to an outward skid on the part of the airplane.



Angle of bank too small

Fig 8.6 Effects of correct and incorrect angles of bank

Another indication would be a plumb-bob hung in the cockpit out of contact with the wind. In normal flight this would, of course, hang vertically; during a correct bank it would not hang vertically, but in exactly the same pos-ition relative to the airplane as it would in normal flight, i. e. it would bank with the airplane. If over-banked the plumb-line would be inclined inwards; if under-banked, outwards from the above position. This plumb-bob idea, in the form of a pendulum, forms the basis of the sideslip indicator which is pro-vided by the top pointer of the so-called turn and bank indicator. The pointer is geared so as to move in such a way that the pilot must move the control column away from the direction of the pointer, this being the instinctive reac-tion. Sometimes a curved transparent tube containing a metal ball is used, and again the control column must be moved away from the indication given on the instrument. It is interesting to note that in early airplanes the slip indicator was, in effect, a spirit level, the tube being curved the opposite way and with a bubble (in liquid) instead of the ball; the pilot was then told to ‘follow the bubble’ – not the instinctive reaction. Nowadays such simple mechanical devices are being replaced by electronic or digital displays which nevertheless often mimic the appearance of the older instruments. Figure 8.6 shows how a tumbler full of water would not spill even when tilted at 80° in a correct bank; if the bank were too small it would spill outwards over the top lip of the tumbler!

Lastly, during a correct bank the pilot will sit on his seat without any feeling of sliding either inwards or outwards; in fact, he will be sitting tighter on his seat than ever, his effective weight being magnified in the same proportions as the lift so that if he weighs 800 N in normal flight he will feel that he weighs 8000 N when banking at 84°! If he over-banks he will tend to slide inwards, but outwards if the bank is insufficient.

13. Explain aerobatics and inverted manoeuvre.

Or

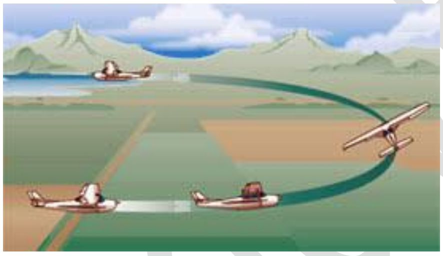
Explain with neat sketch inverted maneuvers of aircraft.

Or

Write notes on Aircraft maneuvers

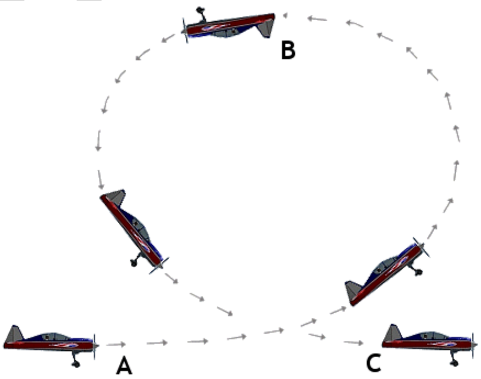
Aerobatic maneuvers are flight paths putting aircraft in unusual attitudes, in air shows, dogfights or competition aerobatics. Aerobatics can be performed by a single aircraft or in formation with several others.

Chandelle: This is a combination of a vertical climb and a turn. It's actually a basic flying fundamental, rather than a true aerobatic move.



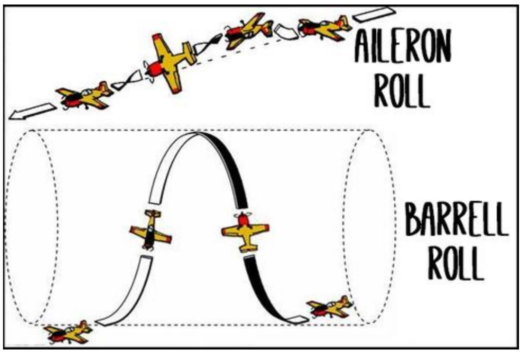
Dive: This one's just like it sounds. The plane's nose is turned downward, though the plane is not necessarily completely perpendicular to the ground. Diving causes an increase in air speed, which the pilot can use to pull up at the right moment.

Loop: A loop is when an aircraft flies upward and then, at the top of its arc, begins to slow down, so that it turns down and completes the circle. You can do an inward or outward loop.



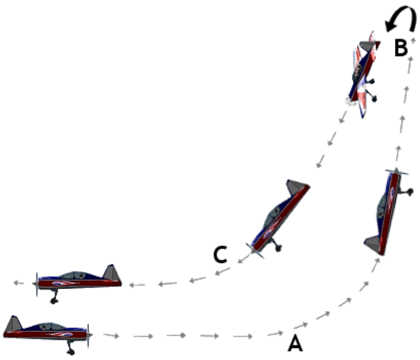
Roll: A roll is a 360-degree revolution along the plane's longitudinal axis.

Barrel roll: A barrel roll is a combination of a loop and a roll. The flight path is the shape of a corkscrew.

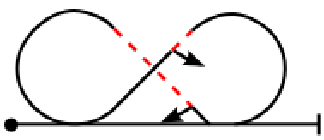
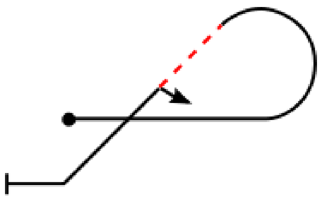
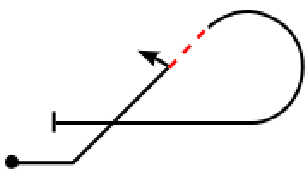


Wingover: A wingover is a left or right 180-degree tight turn at the top of an upward quarter loop. (Point B in below stall turn fig.)

Hammerhead or stall turn: Contrary to its name, this maneuver doesn't actually involve stalling. The plane soars upward and then abruptly turns 180 degrees and descends.



Cuban eight: The plane does five-eighths of a loop to the 45 degree line, a half-roll, another five-eighths of a loop back to the 45 degree line again, another half roll, and then three-eighths of a loop to level out. If that's too complicated to picture, imagine a Hot Wheels car doing a figure eight on one of those loop-de-loop tracks. The variations include the Half Cuban Eight and the Reverse Half Cuban Eight.

Cuban Eight		
Cuban Eight	5/8s of a loop to the 45 degree line, 1/2 roll,3/4s of a loop to the 45 degree line, 1/2 roll, 1/8s of a loop to level flight (half of the Cuban Eight is called a "half Cuban Eight", and the figure can be flown backwards, known as a "Reverse Cuban Eight").	
Half Cuban Eight	From level flight, 5/8s loop to the inverted 45° line, 1/2 roll to erect down 45° line, pull to level flight.	
Reverse Half Cuban Eight	From level flight pull to the 45° up line, 1/2 roll to inverted 45° up line, then 5/8s of a loop to level flight.	

14. Explain Gliding

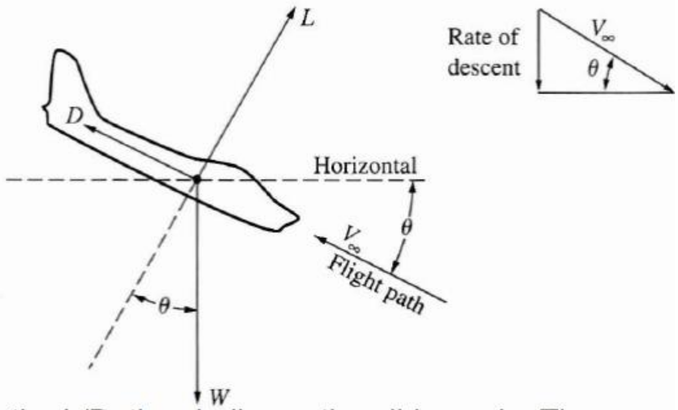
Whenever an airplane is flying such that the power required is ***larger*** than the power available, it will descend rather than climb. In the ultimate situation, there is no power at all; in this case, the airplane will be in gliding. This will occur for a conventional airplane when the engine quits during flight (e.g., engine failure). Also, this is the case for gliders and sailplanes.

The force diagram is

$$L = W\cos\theta$$
$$D = W\sin\theta$$

$$\frac{\sin\theta}{\cos\theta} = \frac{D}{L}$$

$$\text{Tan}\,\theta = \frac{1}{L/D}$$



$$\text{Tan}\,\theta_{\min} = \frac{1}{(L/D)_{\max}}$$

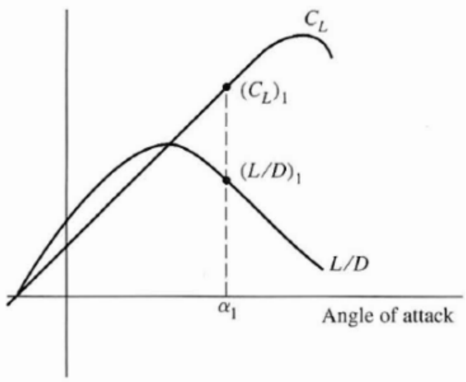
the higher the L/D, the shallower the glide angle. The smallest equilibrium glide angle occurs at (L/D)max.

The equilibrium glide angle does not depend on altitude or wing loading, it simply depends on the lift-to-drag ratio. However, to achieve a given L/D at a given altitude, the aircraft must fly at a specified velocity V, called the *equilibrium glide velocity,* and this value of V, *does* depend on the altitude and wing loading, as follows:

$$\tfrac{1}{2}\rho_\infty V_\infty^2 S C_L = W\cos\theta$$

$$V_\infty = \sqrt{\frac{2\cos\theta}{\rho_\infty C_L}\frac{W}{S}}$$

it depends on altitude (through rho) and wing loading. The value of CL and L/D are aerodynamic characteristics of the aircraft that vary with angle of attack. A specific value of L/D, corresponds to ***a*** specific angle of attack which in turn dictates the lift coefficient (CL). If L/ D is held constant throughout the glide path, then CL is constant along the glide path. However, the equilibrium velocity along this glide path will change with altitude, decreasing with decreasing altitude (because rho increases).



15. Write a note on Landing.

The essential problem of landing is that of being able to fly slowly—and that, as we have said, is one of the main problems of flight.

The art of landing is to transfer the aeroplane from the medium in which it has been flying—namely the air—as gently as possible on to the ground. In order to approach the ground the aeroplane must have both a forward and a downward velocity. The forward velocity—*relative to the ground*—is reduced by landing head to wind (Fig. 81), though, with the

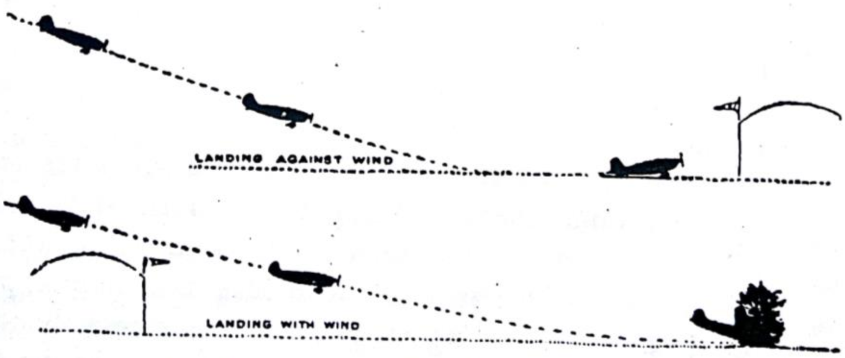


Fig. 81. **Landing with and against the wind**

modern prevalence of runways, it may often be necessary to land with the wind on one side, and this involves a special technique. When very close to the ground the forward velocity —*relative to the air*—is reduced to the minimum at which flight is possible. This is effected by increasing the angle of attack (by raising the elevators), so that, as the speed falls, the lift is still kept equal to the weight by the increase of angle. This process cannot go on for ever (as explained in Section 63), because eventually we shall reach a stage when an increase in angle will, *in itself*, cause a decrease in lift, quite apart from the falling-off in lift due to the decreasing speed. Ordinary flight at any lower speed is impossible for that particular aeroplane.

The slowest and most effective landing will be made if the aeroplane touches the ground just exactly when this condition of flight has been reached. It can no longer fly, its wheels are just about to touch the ground, and thus it subsides gently on to the ground. In order to achieve this state of affairs it must be possible to incline the aeroplane so that its wings are striking the air at an angle of at least 15° before the tail wheel touches the ground. For this reason it will be found that when an aeroplane (not one with a tricycle or nose-wheel undercarriage) is resting on the ground its wings are inclined at about 15° to the horizontal, and if this is so, it means that a three-point landing can be made at the lowest possible speed, i.e. the two main wheels and the tail wheel will touch the ground just as the aeroplane stalls.

It is interesting to note that when the wings are very close to the ground there is a slight, but noticeable, cushioning effect, sometimes called *ground effect*—in other words there is just a little of the air-cushion vehicle, or hovercraft principle, involved in the landing of an aeroplane, especially one like a glider in which the wings approach very close to the ground.

Slots raise a problem in this connection. When slots are used, the aeroplane can fly at a larger angle of attack, and therefore more slowly, without stalling. Thus the landing speed may be reduced, *provided such an angle of attack can be reached before the tail wheel touches the ground*. This means a very high undercarriage, which, of course, will add to the drag of the aeroplane when it is lowered, and which will be difficult to make retractable. An alternative method would be to have the wings adjustable so that their angle relative to the fuselage can be altered during flight just as some tail planes are. Unless such a device is used, slots cannot be employed to their full advantage in so far as reducing landing speed is concerned.

It is not *always* necessary to land as slowly as possible, and good landings may be made on smooth ground at speeds much higher than the stalling speed. The aeroplane will, however, land with its tail up, and the length of run after landing will be much increased. There will also be some danger of striking bumps on the ground which will cause the aircraft—which still has flying speed—to leave the ground again. If the pilot is careful, this may not matter very much; but on the other hand, it may lead to dangerous bouncing. This is where the *nose-wheel or tricycle undercarriage* is interesting. With this device the centre of gravity of the aeroplane is in front of the main wheels, and the aeroplane is prevented from going on to its nose by an extra wheel farther forward. In this way, two great advantages are achieved. In the first place, the aircraft becomes directionally stable when taxying (see Section 72). Secondly, the danger of bouncing is lessened because even if the aeroplane lands at high speed it will pitch on to its front wheel, the angle of attack will be reduced, the lift reduced, and it is less likely to bounce into the air again.

If aeroplanes are to be in ordinary use among ordinary people (a state of affairs that has not been achieved after more than sixty years of power-driven flight), *they must be capable of landing in a small space*. In order to obtain this ideal they must, first of all, be able to land slowly, which is the same thing as saying to fly slowly, *but that is not all.* They must be able to *approach the ground at a steep angle* so that they can avoid obstacles, such as buildings, trees, telegraph wires and suchlike on the boundaries of the landing-ground and also touch the ground as close as possible to the near boundary (more will be said about this under the heading of gliding). Finally, *they must be able to pull up quickly after landing.*

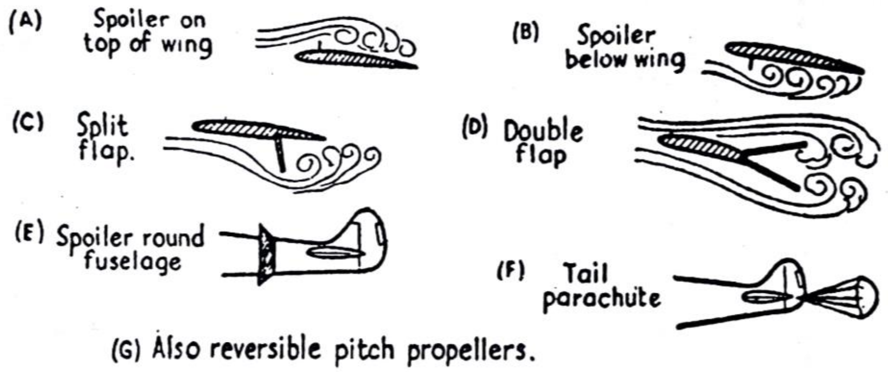


Fig. 82. **Air brakes**

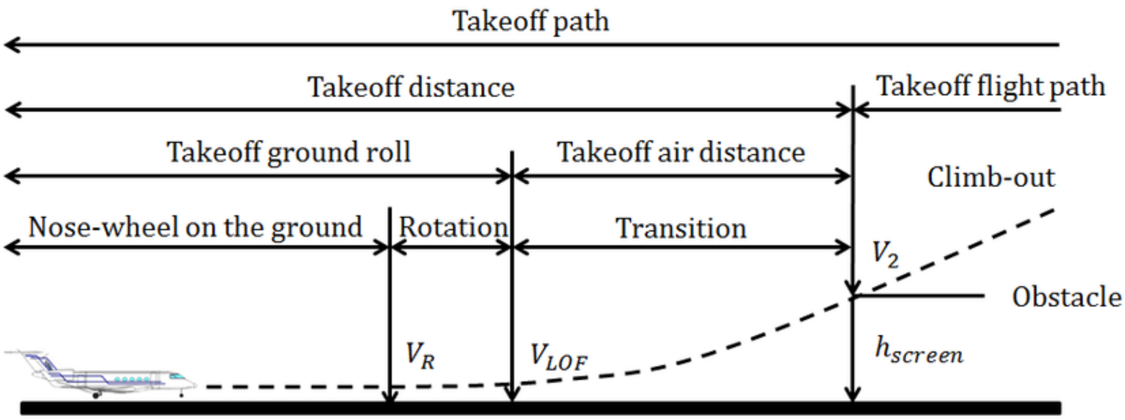
These important points have been sadly neglected until recently, and it was at one time considered a silly idea to fit an aeroplane—the fastest means of mechanical transport—with brakes. But then, retractable undercarriages, streamlining and lots of other things which we know to be sensible today were at one time considered silly. The run after landing can be reduced by wheel brakes and air brakes. An air brake is any means of increasing the air resistance, and the wings themselves, when inclined at a large angle, form a very efficient air brake. Air brakes cannot, of course, reduce the actual landing speed, i.e. the speed of flight *just before* landing, but they can reduce the run *after* landing. Air brakes are becoming important in flight too, and Fig. 82 illustrates some of the ideas that have been tried.

16. Write a short note on Takeoff.

Power settings:

- Takeoff is the phase of flight in which an aerospace vehicle goes from the ground to flying in the air.
- For aircraft that take off horizontally, this usually involves starting with a transition from moving along the ground on a runway.
- For balloons, helicopters and some specialized fixed-wing aircraft (VTOL aircraft such as the Harrier), no runway is needed. Takeoff is the opposite of landing.
- For light aircraft, usually full power is used during takeoff. Large transport category (airliner) aircraft may use a reduced power for takeoff, where less than full power is applied in order to prolong engine life, reduce maintenance costs and reduce noise emissions.
- In some emergency cases, the power used can then be increased to increase the aircraft's performance. Before takeoff, the engines, particularly piston engines, are routinely run up at high power to check for engine-related problems.
- The aircraft is permitted to accelerate to rotation speed (often referred to as Vr). The term rotation is used because the aircraft pivots around the axis of its main landing gear while still on the ground, usually because of manipulation of the flight controls to make this change in aircraft attitude.
- The nose is raised to a nominal 5°–15° nose up pitch attitude to increase lift from the wings and effect liftoff. For most aircraft, attempting a takeoff without a pitch-up would require cruise speeds while still on the runway.
- Fixed-wing aircraft designed for high-speed operation (such as commercial jet aircraft) have difficulty generating enough lift at the low speeds encountered during takeoff. These are therefore fitted with high-lift devices, often including slats and usually flaps, which increase the camber and often area of the wing, making it more effective at low speed, thus creating more lift. These are deployed from the wing before takeoff, and retracted during the climb. They can also be deployed at other times, such as before landing.
- The speeds needed for takeoff are relative to the motion of the air (indicated airspeed). A headwind will reduce the ground speed needed for takeoff, as there is a greater flow of air over the wings.

- Typical takeoff air speeds for jetliners are in the 130–155 knot range (150–180 mph, 240–285 km/h). Light aircraft, such as a Cessna 150, take off at around 55 knots (63 mph, 100 km/h). Ultralights have even lower takeoff speeds.
- For a given aircraft, the takeoff speed is usually dependent on the aircraft weight; the heavier the weight, the greater the speed needed. Some aircraft are specifically designed for short takeoff and landing (STOL), which they achieve by becoming airborne at very low speeds.



Speed required:

- The takeoff speed required varies with air density, aircraft gross weight, and aircraft configuration (flap or slat position, as applicable).
- Air density is affected by factors such as field elevation and air temperature. This relationship between temperature, altitude, and air density can be expressed as a density altitude, or the altitude in the International Standard Atmosphere at which the air density would be equal to the actual air density.
- Operations with transport category aircraft employ the concept of the takeoff V-Speeds, V1, VR and V2. These speeds are determined not only by the above factors affecting takeoff performance, but also by the length and slope of the runway and any peculiar conditions, such as obstacles off the end of the runway.
- Below V1, in case of critical failures, the takeoff should be aborted; above V1 the pilot continues the takeoff and returns for landing. After the co-pilot calls V1, he/she will call VR or "rotate," marking speed at which to rotate the aircraft. The VR for transport category aircraft is calculated such as to allow the aircraft to reach the regulatory screen height at V2 with one engine failed. Then, V2 (the safe takeoff speed) is called. This speed must be maintained after an engine failure to meet performance targets for rate of climb and angle of climb.

17. Describe stall speed.

Stall speed refers to the minimum speed at which an airplane must fly to produce lift. Going back to the basics of aerospace dynamics, airplanes produce lift in response to the air moving over their wings. At high speeds, the fast-moving air "lifts" the airplane so that it doesn't fall to the ground. At low speeds, on the other hand, the lack of air movement will result in little or no lift being produced, in which case the airplane may stall.

All airplanes have a specified stall speed. Stall speed is simply the minimum speed needed for an airplane to produce lift. If an airplane drops below its specified stall speed, it will no longer produce lift. Stall speeds vary depending on many factors, some of which include the airplane's weight, dimensions, altitude and even the weather dimensions. Regardless, airplanes must fly faster than their respective stall speed to maintain lift.

18. Problems:

① The wing has an NACA 2412 Aerofoil & a chord length of 1.3m. The flow is @ an velocity of 50m/s @ sea level condn. If the wing is @ a 4° AOA Calculate C_l, lift, drag & moment about Quater chord point. Per unit span.

For NACA 2412 Aerofoil @ 4° AOA

$$C_l = 0.63 \quad ; \quad C_{m_{c/4}} = -0.035.$$

To obtain C_d calculate Reynold's number

$$Re = \frac{\rho_\infty V_\infty c}{\mu} = \frac{(1.225)(50\ m/s)(1.3)}{1.789 \times 10^{-5}} = 4.45 \times 10^6.$$

From this Re the C_d value $= \underline{0.007}$.

Now for unit span to calculate the value of L, D.

$$L = \tfrac{1}{2} \rho_\infty V_\infty^2 S \cdot C_L$$

$$= \tfrac{1}{2}(1.225)(50)^2 \times (1.3)(0.63)$$

$$= \underline{\underline{1254\ N}}.$$

$$D = \tfrac{1}{2} \rho_\infty V_\infty^2 S \cdot C_D$$

$= \frac{1}{2}(1.225)\cdot(50)^2 \times (1.3)(0.007)$

$= \underline{13.9 N}$

Aerodynamic efficiency $L/D = \frac{C_L}{C_D} = \frac{1254}{13.9} = \underline{90.2}$

$M_{c/4} = q_\infty S c_{m\,c/4} \times c$

$= \frac{1}{2}(1.225)(50)^2 \times 1.3 \times (-0.035)(1.3)$

$= \underline{-90.6 N.m}$

(2) The Pressure @ a point on Wing is $7.58 \times 10^4 N/m^2$. The A is flying @ an Velocity of 70 m/s @ an altitude of 2000 m. Calculate Pressure Co-eff @ the pt of wing

For an altitude of 2000m

$P_\infty = 7.95 \times 10^4 N/m^2$

$\rho_\infty = 1.0066 kg/m^3$.

so; $q_\infty = \frac{1}{2}\rho_\infty V_\infty^2 = \frac{1}{2}(1.006)(70)^2$

$= 2466 N/m^2$

$C_p = \frac{P - P_\infty}{q_\infty}$

$= \frac{(7.58 - 7.95) \times 10^4}{2466}$

$\boxed{C_p = -1.5}$

3.

Highlight the basic flight gliding equation and calculate the maximum glide angle and maximum range measured along the ground if maximum $\left(\frac{l}{D}\right)$ ratio is 13.6 and guide starts at an altitude of 3048 m. **(10 Marks)**

Basic Gliding Equation:

12. Gliding Flight (Steady State)

If the engine is turned off, (T = 0), and one desires to maintain airspeed, it is necessary to put the vehicle at such an attitude that the component of the gravity force in the direction of the velcocity vector balances the drag. The equations of motion are given by:

$$0 - D - W\sin\gamma = m\dot{V} = 0 \qquad (1)$$
$$L - W\cos\gamma = mV\dot{\gamma} = 0$$

where γ is the flight path angle (the angle the velocity makes with the horizontal).

If we divide one equation by the other, we get:

$$\tan\gamma = -\frac{D}{L} = -\frac{1}{\frac{L}{D}} \qquad (2)$$

We see from Eq. (2) that the flight path angle is negative, as expected! We can then define the glide angle as the negative of the flight path angle and write:

$$\tan\gamma_1 = \frac{1}{\left(\frac{L}{D}\right)} \qquad (3)$$

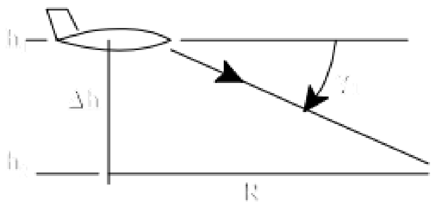
where γ_1 = glide angle (and is positive).

We can observe the following: 1) the glide angle depends only on L/D and is independent of the weight of the vehicle!, 2) the flattest glide angle occurs at the maximum L/D.

Glide Range

The glide range is how far it travels along the ground during the glide descent. It is easy to see from the figure that

$$\tan\gamma_1 = \frac{h_1 - h_2}{R} = \frac{-\Delta h}{R}$$



or

$$R = \frac{h_1 - h_2}{\tan\gamma_1} = \frac{L}{D}(h_1 - h_2) \qquad (4)$$

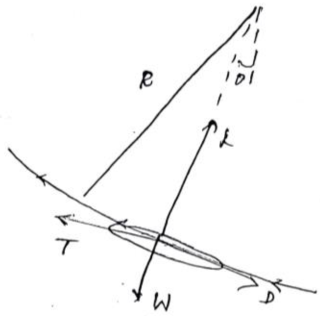
Hence the range for gliding flight depends on the L/D and Δh. It is clear that the maximum range occurs when L/D is maximum. Therefore the maximum range glide is flown at the minimum drag airspeed, V_{md}.

19. Pull up and Pull down Maneuver

→ Consider an A/c @ levelled flight cond'n ; now the Pilot pitches up the A/c because of which lift is increased

→ Because of that the flight path becomes curved with a turn radius R and turn rate $d\theta/dt$. This is Called pull up maneuver.

→ For the Pull up maneuver the equation is given by



$$\frac{m V_\infty^2}{R} = L - W\cos\theta$$

here conside θ is very small so θ = 0

$$\frac{m V_\infty^2}{R} = L - W$$

$$R = \frac{m V_\infty^2}{(L-W)} \qquad \left(m = W/g \ ; \ W = m \times g\right)$$

so

$$R = \frac{W V_\infty^2}{g(L-W)} = \frac{V_\infty^2}{g\left(L/W - 1\right)}$$

here (L/W) is load factor ie = n .

so

$$R = \frac{V_\infty^2}{g(n-1)}$$

The instantaneous rate of turn is given by $\omega = V_\infty / R$

so $\boxed{\omega = \frac{g(n-1)}{V_\infty}} \Rightarrow R = \frac{V_\infty^2}{g(n-1)}$

$$g(n-1) = \frac{V_\infty^2}{R}$$

$$g(n-1) = V_\infty \times \omega$$

so $\Rightarrow \omega = \frac{g(n-1)}{V_\infty}$.

Now for pull down maneuver the A/c which is at a levelled position suddenly rolled to inverted position. so both L and W are acting downward for that case

$$\frac{mV_\infty^2}{R} = L + W$$

$$R = \frac{mV_\infty^2}{L+W} = \frac{W}{g}\left(\frac{V_\infty^2}{L+W}\right)$$

$$R = \frac{V_\infty^2}{g\left(L/W + 1\right)} = \frac{V_\infty^2}{g(n+1)}$$

$$\omega = \frac{g(n+1)}{V_\infty}$$

For both pull up and pull down maneuver the value of ω depends only on V_∞ and n.