AVIATOR'S HANDBOOK OF KNOWLEDGE

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UNIT 1

Airplane Structure & Its Theory of Flight

(THIS CHAPTER PROVIDES ELEMENTARY KNOWLEDGE OF THE MAJOR COMPONENTS OF AIRPLANE AND THE DYNAMICS OF THESE PARTS WHICH CONTRIBUTE TO FLYING AN AEROPLANE)

AIRPLANE

An engine driven, fixed wing aircraft*, heavier than air that is supported in flight by the reaction of air against it wings.

(* The term '*aircraft'* is used here and described as any device which is intended for the purpose of flight in air which includes airplanes, helicopters, balloons or Gliders)

MAJOR COMPONENTS

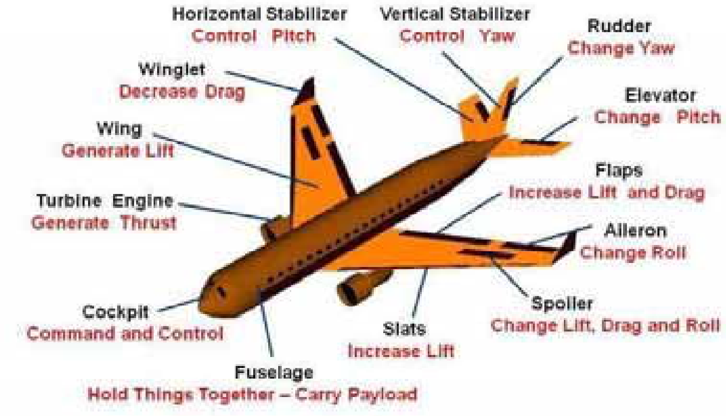

Figure 1

FUSELAGE: It is a structure which provides room for cockpit, cabin and carrying cargo.

Different types of Fuselage:

- TRUSS TYPE: It is constructed by steel or aluminium tubing, and strength and rigidity is achieved by welding these tubing together in triangular shapes called *trusses*.

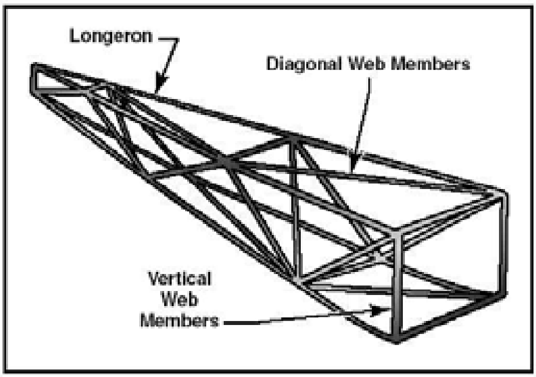

Figure 2- Truss fuselage design

- MONOCOQUE: It consists of skin, formers and bulkhead. Formers and bulkhead provide shape to the fuselage. This design uses stressed skin to support all imposed loads but cannot tolerate dents and deformation which can be easily demonstrated by a beverage can.

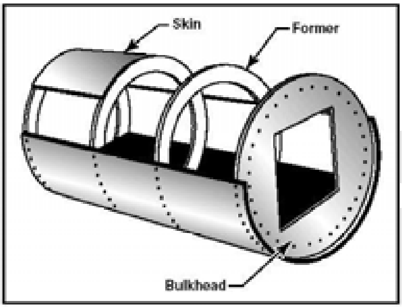

Figure 3- Monocoque Fuselage

- SEMI-MONOCOQUE: Due to limitations of monocoque design, a semi-monocoque was introduced which uses a substructure of bulkheads and/or formers of various sizes and stringers. This reinforces the stressed skin by taking some of the bending stress from the fuselage. This structure is being used on many of today's aircraft.

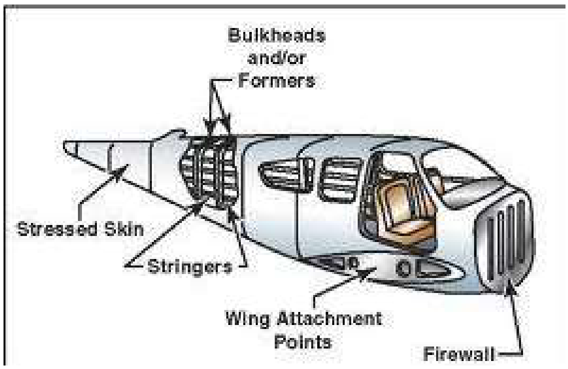

Figure 4- semi monocoque fuselage

WINGS: It is an airfoil* which is attached on each side of the fuselage to provide lifting force to support the airplane during flight.

(* The term 'Airfoil' is defined as a structure which is designed to obtain useful reaction upon itself during motion through air. It produces a force which is perpendicular to its motion, called LIFT)

- Wing needs strength; therefore it should be thick enough to contain structural members such as ribs, spars and stringers.
- Wings also should have enough room to contain items such as fuel and control mechanisms.

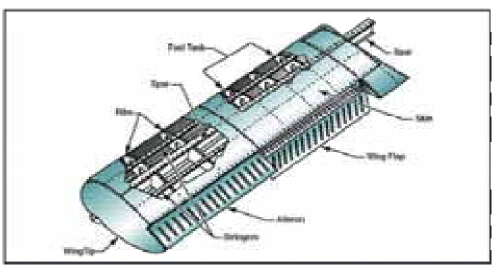

Figure 5- Wing and its components

- Airplanes with single set of wings are called as MONOPLANES, and planes with two set of Wings are called as BI-PLANES.
- Many high wing airplanes may have been fitted with external braces to sustain the load of landings, which are called SEMI-CANTILEVER.
  - Other Components of a Wing consist of Ailerons, Flaps, spoilers, winglets, Vortex Generators. To understand the importance of all these parts, we first need to understand Different forces acting on an airplane and then how all these parts help to maintain a smoother flight.

FORCES ACTING ON THE AIRPLANE:

1. LIFT: It is the force which acts underneath the wing and pushes it in the upward direction.
2. WEIGHT: It is the combines load (fuel passengers, baggage etc) of the airplane which pulls the airplane downward due to gravity and opposes Lift.
3. THRUST: It is forward force produced by the power plant/ propeller.
4. DRAG: It is a retarding force which opposes Thrust and is produced by disruption of airflow by the wing, fuselage and other objects.

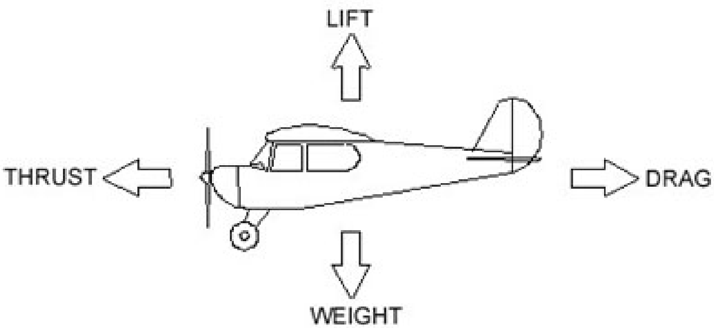

Figure 6- forces on airplane

- In a steady flight sum of the opposing forces is equal to zero, i.e. they are in equilibrium.

- For an airplane to initiate climb, Lift must exceed the weight of the aircraft.
- For an Aircraft to Accelerate Thrust must exceed the force of Drag.

SOME IMPORTANT DEFINITIONS:

- AIRFOIL CHORD LINE: It is a straight line from leading edge of the wing to the trailing edge.
- ANGLE OF INCIDENCE: It is the fixed angle between the airfoil chord line and the longitudinal axis of the airplane.
- ANGLE OF ATTACK: It is the angle between the chord line of the airfoil and the relative wind.

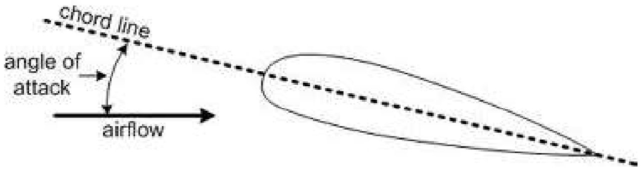

Figure 7- Angle of attack

LIFT GENERATION:

As discussed earlier that LIFT is a force which is underneath the wing and pushes it in the upward direction. There are two ways in which Lift generation can be explained.

1. When the air passes over the wing towards the trailing edge, it not only moves rearward, but also moves in downward direction called downwash. Also the air which passes below the wing, it is deflected downward. Therefore, as per Newton Third law of motion, the downward deflected air gives an equal and opposite reaction by pushing the wing in the upward direction.
2. Other phenomenon is based over BERNOULLI'S PRINCIPLE. Due to the curvature (Camber) of the wing on the top, the airflow will have to travel more distance in order to reach the trailing edge at the same time as the air travelling through its flat bottom side. This faster air over the wing creates a low pressure over the wing as compared to the pressure below the wing. This pressure difference results in the upward lift force.

- A common misconception prevails that wing should be shaped thick in order to create lift. But even a Flat plate/ Symmetrical aerofoil (Same camber above and below the wing) is capable of producing lift, provided, it is subjected to a positive angle of attack. The common shape of the wing is due to the requirement of strength and enough room for fuel/control mechanism, which has been discussed earlier in this chapter.

• FACTORS EFFECTING LIFT:

The factors effecting lift can easily be understood by the formula of lift, which is as follows

$$\boxed{\text{LIFT} = \tfrac{1}{2}\, R + V^2 + S + C_L}$$

Where,

R - Air Density

V - Velocity (Lift increases in proportion to square of its Speed i.e. a wing travelling at 500 knots has four times the lift to the wing travelling at 250 knots)

S - Span/ Area (Lift increases as the area of the blade increases i.e. a wing with an area of 100 sq.ft has double the lift capability as to a blade of 50 sq.ft

C_L - Coefficient of Lift (Lifting capability of the wing, which depends upon the shape of the wing as well as the Angle of Attack).

- At a given weight, lower the airspeed, higher is angle of attack required to maintain level flight.
- Angle of attack can be increased to a point, where the airflow no longer follows the curvature of the wing and Lift is lost. This is called CRITICAL ANGLE OF ATTACK. Critical angle is called the STALLING ANGLE which is the angle of Maximum Lift. Beyond this angle, Lift decreases rapidly. It is approximately 15^o to 16^o.
- Normally, stalling speed is 1/3 to 2/5 of the max speed of the airplane.

STALL: A stall is a condition wherein the airflow over the surface of the wing breaks away from the surface, due to exceeded critical angle of attack (irrespective of airspeed) causing an overall loss of lift. Stall occurs at a Constant Angle of attack (15° - 16°), but as there is no indication for angle of attack, pilot has to rely Airspeed Indicator.

STALL SPEED varies according to:

- Weight – (heavier the airplane, higher is the stalling speed)
- Altitude – (higher the altitude, higher is the stall speed)
- Configuration (Flaps reduces stall speed)*discussed later*
- Engine Power
- Centre of Gravity / CG (It is a point where all the weight of the airplane is considered to act.)
- Wing Contamination (Snow/Ice/Frost) – Increases the stall speed due to reduced lifting capabilities of the wing.
- Turn – (More bank angle, higher is the stall speed; because during a turn, lift is lost due to effective reduction in wing span. Therefore Lift needs to be restored by either adding Power or increasing angle to attack)
- Stall Warner's and stick pushers are used to protect against a stall.

• STALL RECOVERY:

1. Lower the nose of the airplane to decrease angle of attack.
2. Increase the power in case airplane is not in full power.

TERMS/DEFINITIONS:

- Boundary Layer: It is a thin wall between the surface of the wing and full laminar airflow where full stream value of air reduces to zero.(It is not more than fraction of a millimetre)
- Stagnation Point: A point on the leading edge of the wing where the airflow is splitting up, the flow velocity reduces to zero. Hence, Pressure is maximum.
- Burble Point: It is the angle of attack (AOA) where streamline flow begins to break down.
- Transition Point: It is the point at which boundary layer changes from laminar to turbulent flow.

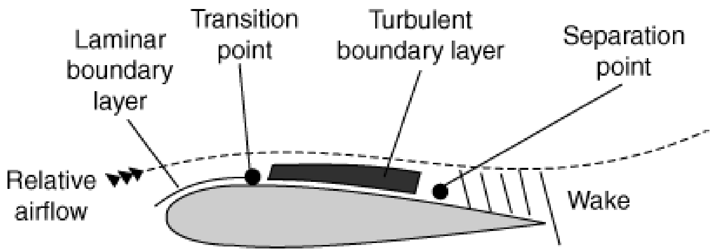

Figure 8

• CENTRE OF PRESSURE: It is the point on the chord, where aerodynamic forces may be considered.

OR

It is the point on the chord where maximum lift is achieved.

- As angle of attack increases, CP moves forward and vice versa.
- If AOA increases beyond Burble point, then CP remains at same position or moves slightly backwards.
- On a Flat plate, CP moves backward as AOA increases and vice versa.
- For Symmetrical airfoil, CP remains constant.

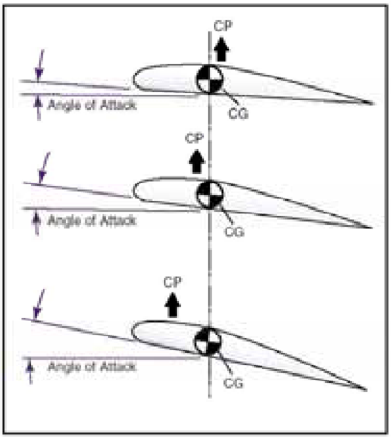

Figure 9 - CP movement

- DRAG: As discussed earlier, that Drag is a force which opposes Thrust (Forward Motion).
  1. Types of Drag:
     1. Profile Drag: It is the resistance of skin friction due to stickiness/viscosity of the air as it passes over the wing surface. This also works in combination to FORM DRAG which is due to the shape of the Airplane.

        Profile drag = Skin Friction + Form drag

        Also, Profile Drag is directly proportional to $(\text{speed})^2$
     2. Parasite drag: It is a Drag which is created by the parts which do not contribute to lift. E.g. Fuselage, landing gear etc
     3. Induced Drag: This is a direct result of the downward velocity (downwash) imparted to air, It increases as AOA increases i.e. Increases with increasing lift.

$$\text{Induced drag} = (C_L)^2/\pi A$$

A= Aspect Ratio

- ✓ Induced Drag is greatest at lower speeds due to high AOA required to maintain necessary lift.
- ✓ Induced Drag is maximum during Take-Off

STREAMLINING: It is a design in which body is so shaped, that the drag is minimised.

OPTIMUM ANGLE OF ATTACK: It is the angle of attack at which the L/D ratio is the maximum i.e. 3^o-4^o during cruise.

- ✓ At this angle Lift is nearly 24 times the Drag, but after this the ratio falls gradually. Lift still increases but Drag increases much more rapidly.
- ✓ MAXIMUM GLIDE* RANGE is produced by flying the airplane at OPTIMUM AOA.

* GLIDE: A manoeuvre in which the airplane makes a gentle descent without Engine power. And, the angle between the Horizontal and the Glide path is called GLIDING ANGLE

Vx- BEST ANGLE OF CLIMB SPEED: Greatest gain in altitude for a given distance over ground.

Vy- BEST RATE OF CLIMB SPEED: Greatest gain in altitude per unit time.

- <u>WEIGHT:</u> As discussed earlier, Weight is a force which opposes LIFT.
  - ✓ The Limiting factor on "Airplane's structural weight" is the Lifting capabilities of the airplane.
- Effect of WEIGHT on Performance:
  1. Increase in airplane's Take-off and Landing Roll.
  2. Increase in stalling speed.
  3. Slight reduction in max speed.
  4. Reduction in Rate of Climb.
  5. Manoeuvrability is reduced
  6. Wear and Tear of brakes and Tyres is increased.
- Effect of weight on Gliding: Glide Range depends upon Maximum L/D ratio, which is independent of weight. Therefore, Glide range does not vary with airplane weight.

  Though heavier the airplane, Higher is the Rate of descent and therefore will glide the same distance as lighter airplane but will take less time to do so.
- Effect of weight on Descent point: Heavier the airplane, earlier is the descent point, because heavy airplane has high ROD (rate of descent), so it will have to maintain shallower ROD to check on its speed.
- <u>CENTRE OF GRAVITY (CG):</u> It is a point on airplane's longitudinal axis where all the weight of the airplane is considered to act.

<u>CG= Total moment/total weight</u>

- ✓ Effect of CG too far aft:
  - Stalling speed will be less.

- Airplane will have spinning tendencies
- Pilot will have difficulty recovering from a stall.

✓ Effect of CG too far forward:

- Stalling speed will be higher.
- Will have difficulty during landing.

✓ Airplane will be more stable at forward CG limit.

✓ Airplane will cruise faster with AFT CG location because of reduced drag (because it will have a natural nose up tendency and elevator will streamline with horizontal stabilizer.

✓ CG movement in flight is caused due to passenger movement and fuel burn.

➢ LIFT-WEIGHT PITCHING MOMENT: If the forces of Lift and weight are not acting the same point, it will set up either a nose up tendency or nose down tendency, depending on whether Lift is acting in front or rear of CG point.

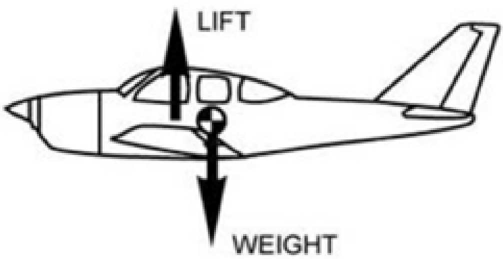

Figure 10- This situation will cause a nose up tendency

➢ Wing Loading: Gross weight/wing area

➢ Span Loading: Gross weight/span

➢ Power Loading: Gross weight/Total horsepower

❖ PRIMARY CONTROL SURFACES:

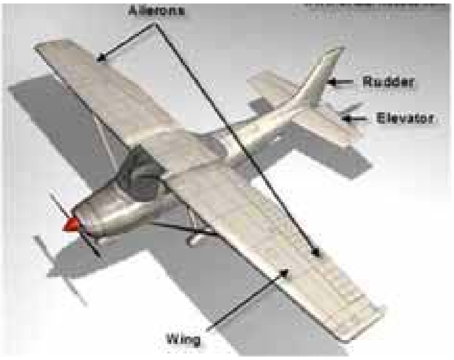

Figure 11- control surface of airplane

- AILERONS - It is a type of airfoil which extends from the middle towards the tip of the wing. It helps in controlling ROLL motion of the airplane. Ailerons deflect in opposite direction to cause Roll motion.

✓ Types of Ailerons:

1. Differential Aileron: It is a simple mechanical arrangement in which upward moving aileron deflects through a larger angle than the aileron which moves downward. This is done to reduce drag on down going aileron.
2. Frise Type Aileron: This type of aileron creates a slot to make air move smoothly to downward going aileron and reduces drag on the same. (These both type of ailerons are constructed to reduce ADVERSE YAW (Yawing in opposite direction of turning) created by drag on down going aileron.

- ELEVATOR: This is an airfoil which is attached to the EMPENNAGE (tail section), and controls the Pitching motion of the airplane.
- RUDDER: This control surface is also attached to the empennage in a vertical position and controls the YAW

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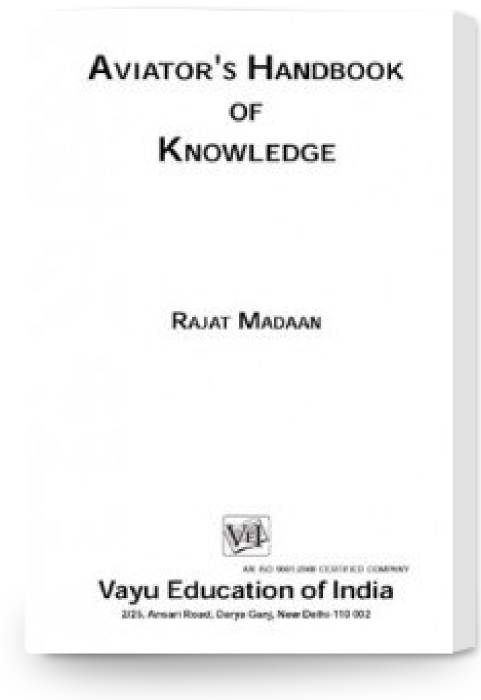

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