Four Forces of Flight

A Primer into Aerodynamics

Washington Pilots Association

If you want to go up, pull back on the stick
If you want to go down, pull back a little more.
If you want to go down real fast and spin around and around, just keep pulling back.
- Aviation proverb

Aerodynamics is the study of forces acting on an object because air or another gas is moving around it.

Definitions

- Camber - The amount of curve of an airfoil.
- Chord - a line drawn through an airfoil from its leading edge to its trailing edge. (determines curve)
- Angle of Attack - Is the angle at which the air hits the wing.
- Relative Wind - The direction which the wind strikes an airfoil
- Angle of Incidence - The angle at which the wings are attached to the fuselage.
- Four Components
  - Lift - The force that pushes an object up against the weight is lift. On an airplane the lift is created by the movement of the air around the wings.
    - ◊ Induced - The air over the top increases in velocity, causing a decrease in pressure.
    - ◊ Dynamic - Lift that is caused by air striking the lower surface of an airfoil
  - Drag
    - ◊ Friction (Parasite) - Skin friction, caused by the movement of air over the airplane
    - ◊ Form - related to the shape of the body. Brick or cone?
    - ◊ Induced - Drag due to lift. As the lift force is generated, a small amount of excess force can be generated in the direction opposing the motion, or in the direction of drag.
    - ◊ Wave - shock waves as the airplane travels faster than the speed of sound.
  - Weight - The weight of the aircraft is equal to its mass times the acceleration of gravity. It is a measure of the force that pulls the airplane down towards the earth.
  - Thrust - A forward direction force called thrust is generated by the engines of the airplane. The engines push high velocity air out behind the plane. The difference between the gases and the original velocity creates the forward directed thrust

1 Controlling Lift and Drag

a Lift, Angle of Attack, and Airspeed

1 The amount of lift that a given wing generates at a given altitude is directly related to its angel of attack and airspeed.

(a) As angle of attack or airspeed is increased, lift is increased

(b) We can express this relationship in the following equation:

$$L = a \times V$$

If: L is lift
A is angle of attack
V is airspeed

1 When the airplane is in steady-state, unaccelerated flight, lift is equal to weight.

(a) Since this makes lift a constant in steady-state flight, it can be seen that there is one and only one angle of attack for any given airspeed that will maintain the airplane in steady state flight.

(b) As airspeed increases, angle of attack must decrease, and vice versa.

(c) A heavily loaded airplane must fly at a higher angle of attack for any given airspeed that the same airplane does when lightly loaded.

b Drag, Angle of Attack, and Airspeed

1 As airspeed decreases in level flight, angel of attack increases, causing an increase in induced drag.

(a) However, parasite drag decreases as airspeed decreases. (L/Dmax chart)

2 The amount of drag present at a given airspeed is equal to the amount of thrust required to maintain level flight at that airspeed and angle of attack.

(a) If thrust is increased beyond that required for level flight, the airplane will climb unless it is re-trimmed for a lower angle of attack and a higher airspeed.

(b) If thrust is reduced, the airplane will descend.

3. Minimum drag occurs at the same airspeed at which the maximum lift/drag ratio takes place.

a At this point the least amount of thrust is required for level flight.

b Many important items happen at L/Dmax

(i) Maximum range

(ii) Maximum power-off glide range. (best glide)

c Flight at airspeeds above and below L/Dmax produces more total drag and requires more thrust to maintain level flight.

c *Pitch, Power, and Performance*

1 Adjusting the angle of attack varies the amount of lift and drag being produced by the wing

2 Adjust the airplanes power varies the relationship of thrust to drag, allowing the airplane to change airspeed, altitude, or both

3 Thus, the pilot can achieve a desired performance from the airplane in terms of airspeed and altitude through a variety of pitch and power combination.

(a) A climb may be initiated by raising the nose to increase the angle of attack, or by increase power, or by both.

(b) A descent may be initiated by lowering the nose to reduce the angle of attack, or by decreasing power, or by both

(c) To increase airspeed in level flight, power must be increased and angle of attack reduced to maintain level flight.

(d) To decrease airspeed in level flight, power must be reduced and angle of attack increased to maintain level flight

(e) It is evident, then, that level flight can be performed with any angle of attack between the angle for maximum lift or critical angle of attack and the relatively small negative angles found sometimes at high speeds.

2 Flights at Slow Airspeeds

a Slow flight is any airspeed from below normal cruise airspeed to the stall airspeed

b While straight and level flight is maintained a constant airspeed during slow flight, thrust is equal in magnitude to drag, and lift is equate in magnitude to weight, but some of these forces are separated into components.

1 In slow flight, thrust no longer acts parallel and opposite to the flight path and drag. Thrust has two components:

(a) One acting perpendicular to the flight path in the direction of lift.

(b) One acting along the flight path

2 Because the actual thrust is inclined, its magnitude must be greater than drag if its component acting along the flight path is equal to drag.

(a) Note that the forces acting upward (wing lift and the component of thrust) equal the forces acting downward (weight and tail down force)

3 Win loading is actually less during slow flight because the vertical component of thrust helps support the airplane.

c As the airspeed decreases from cruise to L/Dmax, total drag and the amount of thrust required decrease to maintain a constant altitude.

d As the airspeed decreases below L/Dmax, additional power is required to maintain a constant altitude.

1 Here, total drag increase because induced drag increases faster due to higher angle of attack than parasite drag decreases

2 This is known as the backside of the power curve or region of reverse command

(a) The region of reverse command means that more power is required to fly at slower airspeeds while maintaining a constant altitude.

3 Stall and Spin Considerations

a Stalls

1 A stall is the loss of lift and the increase in drag that occur when an aircraft is flown at an angle of attack greater than the angle for maximum lift. The angle of attack for maximum lift is also called the critical angle of attack

(a) Thus, a stall occurs whenever the critical angle of attack is exceeded.

(i) When the angle of attack is increased to approximately 18 - 20 degrees on most airfoils, the airstream can no longer follow the upper curvature of the wing because of the excessive change in direction. This is the critical angle of attack.

(i) As the critical angle attack is approached, the airstream begins separating from the rear of the upper wing surface. As the angle of attack is further increased, the airstream is forced to flow straight back, away form the surface of the wing and from the area of highest camber.

(ii) This causes a swirling or burbling of the air as it attempts to flow over the upper surface of the wing. When the critical angle of attack is reached, the turbulent airflow, which appeared near the trailing edge of the wing at lower angles of attack, quickly spreads forward over the entire upper wing surface.

(iii) This results in a sudden increase in pressure on the upper wing surface and a considerable loss of lift.

(iv) To recover from a stall, the angle of attack must be decreased so that the airstream can once again flow smoothly over the wing surface.

1. An airplane can be stalled in any attitude of flight with respect to the horizon, at any airspeed, and at any power setting, if the critical angle of attack is exceeded.

(ii) Most airplanes are designed so the wings stall progressively outward from the wing roots to the wingtips.

Review

1 The amount of lift that a given wing generates at a given altitude is directly related to its angle of attack and airspeed
   a True
   b False

2 As airspeed decreases in level flight, angle of attack increases, causing an increase in parasite drag.
   a True
   b False

3 The amount of drag present at a given airspeed is equal to the amount of thrust required to maintain level flight at that airspeed and altitude.
   a True
   b False

4 Flight at airspeeds above and below L/Dmax produces more drag and requires more thrust to maintain level flight
   a True
   b False

5 The airspeed at L/Dmax is that airplanes best rate of climb airspeed
   a True
   b False

6 The region of reverse command means that, as the airspeed decreases below L/Dmax, less power is required to fly at slower airspeeds while maintaining a constant altitude.
   a True
   b False

7 A stall is the loss of lift and the increase in drag that occur when an aircraft is flown at an angle of attack greater than the angle for maximum lift
   a True
   b False

8 To recover from a stall, the angle of attack must be increased so that the airstream can once again flow smoothly over the wing surface.
   a True
   b False

9 An airplane can be stalled only in a nose high attitude of flight with respect to the horizon, at any airspeed, at any power setting.
   a True
   b False

10 Most airplanes are designed so that the wings will stall progressively inward from the wingtips to the wing roots
   a True
   b False