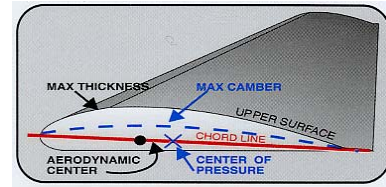


FW AERODYNAMICS

AIRFOILS An object that produces a useful aerodynamic reaction when moved through the atmosphere. The airfoil is the shape of a cross-section of a wing or rotor blade. It can be symmetrical by having the top and bottom surfaces identical, or unsymmetrical by having more curvature on one surface.



AIRFOIL TERMINOLOGY

- **Aerodynamic Center.** The point on the chord line about which the moment coefficient is constant with changes in angle of attack. It is also the point where all changes to lift effectively occur.
- **Angle of Attack.** The angle between the chord line of an airfoil and the relative wind.
- **Angle of Incidence.** The acute angle between the chord line and the longitudinal axis of the aircraft.
- **Center of Pressure.** The point along the chord line through which all aerodynamic forces act.
- **Chord Line.** A straight line that connects the leading edge and the trailing edge of an airfoil.
- **Drag Coefficient, C_D .** A non-dimensional way of expressing drag which is independent of size and velocity.
- **Dihedral.** The spanwise inclination of a wing or other surface such as a stabilizer.
- **Flight Path Velocity.** The speed and direction of the airfoil as it passes through the atmosphere.
- **Lift Coefficient, C_L .** A non-dimensional way of expressing lift which is independent of size and velocity. It is primarily a function of angle of attack.
- **Mach Number.** The ratio of the velocity of a body to that of sound in the surrounding medium.
- **Relative Wind.** Air in motion with respect to an airfoil. It is equal to and in the opposite direction of the flight path velocity of an airfoil.

NEWTON'S 3 LAWS OF MOTION

FIRST LAW A body at rest will remain at rest, a body in motion will remain in motion at the same speed and in the same direction until acted on by an unbalanced external force. An object's resistance to change is called inertia.

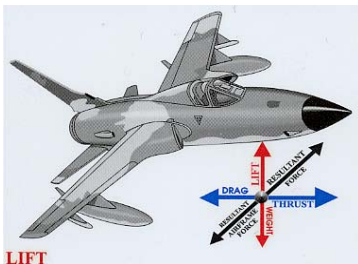
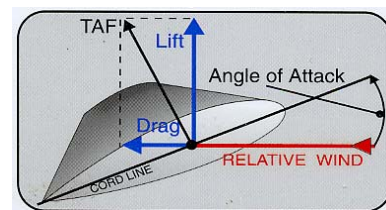
SECOND LAW The force required to produce a change in the linear motion of a body is directly proportional to the product of its mass and acceleration. Acceleration is a change in the magnitude or direction of the velocity vector with respect to time. In this case, velocity refers to the direction and rate of linear motion.

THIRD LAW Every action has an equal and opposite reaction.

FORCES ACTING ON AN AIRFOIL

TOTAL AERODYNAMIC FORCE

As air flows around an airfoil, the molecules traveling the greatest distance must go faster than those traveling the least distance. Due to this, a pressure differential is produced IAW Bernoulli's Law. The combination of the pressure differential and profile drag is known as the total aerodynamic force (TAF). This force acts at the center of pressure, and can be resolved into lift which is perpendicular to relative wind and drag which is parallel to the relative wind.



LIFT

The force that acts perpendicular to relative wind. The principle behind lift was discovered by a Swiss physicist named Bernoulli when he observed what happened to a fluid as it passed through a tube. The principle states that in a flow of incompressible fluid, subsonic flow, the sum of the static and dynamic pressure remain constant if gravity and friction are disregarded. He also found that with a constant velocity, the pressure of the air remains the same at both ends of the tube. If a constriction is placed in the tube, the same amount of air has to go through a smaller area. This increases the velocity and decreases the pressure. If you were to replace the constriction with an airfoil, the same

principle would still apply. As oncoming air meets at the leading edge of the airfoil, it separates, with part of the air going over the top, and part of it going under the bottom. Since the air going over the top has farther to go, it must travel faster. The result is a decrease in air pressure above the airfoil. Since higher pressure tends to flow toward areas of lower pressure, the airfoil is lifted. This accounts for about 75% of the lift generated. The remaining lift is from the downward deflection of air as it strikes the bottom of the airfoil, forcing the wing or airfoil upwards.

Controlling Lift: Used individually or in combination, the following can control lift:

- **Airspeed:** If all other factors remain constant, doubling airspeed develops four times more lift.
- **Angle of Attack:** If all other factors remain constant, an increase in angle of attack increases lift.
- **Wing Configuration:** Lowering the flaps can increase the lifting efficiency of the wing and decrease the airspeed at which the aircraft stalls. As flaps extend they change both the camber and the chordline of the wing. This not only produces a lower pressure above the wing, but it also changes the wing's angle of attack. For lift to remain constant, airspeed and angle of attack must be used in conjunction with each other. If airspeed increases you must decrease the angle of attack. Conversely, if you want to maintain the same amount of lift at a slower airspeed, you must increase the angle of attack.

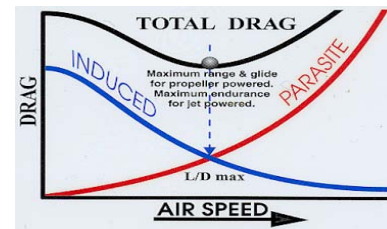


Stalls: For every wing there is a specific angle of attack and airspeed where maximum lift is obtained. This point is called C Max, or the maximum coefficient of lift. Beyond this point, airflow over the wing will not remain smooth. If it becomes too turbulent, the airfoil can no longer create lift and the wing will stall. In order for the wing to fly again, the angle of attack must be reduced. When the wing is below the critical angle of attack, the airflow smoothes out and the wing produces lift again. An airplane stalls when the critical angle is exceeded. This can occur at any flight attitude or airspeed.

DRAG

The force that acts parallel to the relative wind. At a given angle of attack the larger the aspect ratio, the less drag produced for the same amount of lift.

Parasite Drag: Includes all the drag not directly related to the production of lift. It is generated by those areas of the airplane which disrupt the otherwise streamlined flow of air. This includes parts protruding into the airflow such as the landing gear, rough surfaces, and the mixing of the air such as where the wing and the fuselage meet. As the airspeed of an aircraft increases, parasite drag also increase. **Induced Drag:** A direct byproduct of lift. It is greatest at slow speeds with a high angle of attack. Conversely, at higher speeds and at a lower angle of attack, induced drag decreases.



If the two drag curves are combined and the values added together, there is a point at which drag is at the minimum. This point is known as L / D max which is where lift when compared to drag is at its greatest.

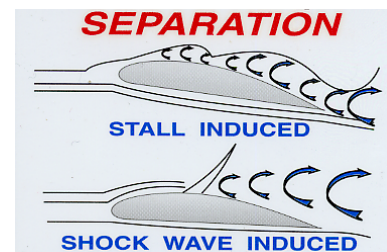
Boundary layer: The slow moving or stagnant air next to the wetted surface of an airfoil. It is usually about as thick as a playing card but can be a quarter of an inch or thicker near the trailing edge of an airfoil. The Boundary Layer can be divided into three distinct layers or phases.

- **Laminar Flow.** Area of smooth flowing, multi-layered air near the leading edge of an airfoil.
- **Transition Region.** An unstable, oscillatory disturbance some distance from the leading edge.
- **Turbulent Layer.** Past the transition region where the flow of air decays into random turbulence.

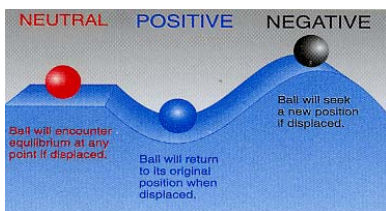
Separation: The basic characteristic of airflow separation is stagnation of the lower levels of the boundary layer. Airflow separation results when the lower levels of the boundary layer do not have sufficient kinetic energy in the presence of an adverse pressure gradient. This may be achieved through a high angle of attack or through a shock wave.

• **Angle of Attack.** An airfoil at some high angle of attack, creates a pressure gradient on the upper surface too severe to allow the boundary layer to adhere to the surface. When the airflow does not adhere to the surface near the leading edge, high suction pressures are lost and stall occurs.

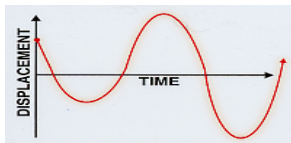
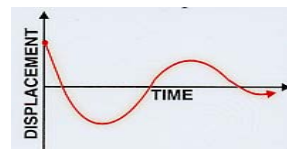
• **Shock Wave.** When a shock wave forms on the upper surface of a wing at high subsonic speeds, the increase in static pressure through the shock wave creates a very strong obstacle for the boundary layer. If the shock wave is sufficiently strong, separation will follow and "compressibility buffet" will result from the turbulent wake or separated flow.



WEIGHT Results from the pull of gravity acting on a body with mass. Moving objects tend to travel in a straight line unless something acts on them to create a turn. This turning force is called centripetal force. The resultant of weight and centripetal force is the load that the wings must support. It can be expressed as load factor or Gs, and is the ratio of the load supported by the wings to the actual gross weight of the aircraft. In straight and level flight, the wings must only produce the lift necessary to offset gravity. In this case the load factor is one times the force of gravity or one G. When the aircraft performs maneuvers such as turns or climbs, the G-Force on the aircraft may increase or decrease. An increase will result if the aircraft accelerates away from the center of the earth. A decrease will occur if the aircraft accelerates towards the earth less than $32.2 \text{ FT}^2/\text{SEC}^2$. When you enter a turn, the wings must support the weight of the aircraft and produce the lift necessary to turn the airplane. By the time you reach a 60° angle of bank, the additional lift has increased to twice the weight of the aircraft or 2 Gs. As the bank angle gets steeper or increases, the load factor increases dramatically. **THRUST** The force that propels an aircraft in the direction of die resultant thrust and Drag vector. At a constant velocity, this force is equal to but opposed by Drag. **BASIC STABILITY** Stability is a design characteristic that causes an airplane to return to equilibrium after being disturbed. • **Static Stability**. The initial tendency displayed by an object after it is disturbed from equilibrium. • **Positive Static Stability**. When an object is disturbed from equilibrium and its initial tendency is to return to equilibrium. • **Negative Static Stability**. When displaced, the object continues in the direction of the disturbance. • **Neutral Static Stability**. When a displaced object has neither the tendency to return nor the tendency to continue in the displacement direction. • **Dynamic Stability**. How an object responds over time as opposed to its initial reaction to displacement.

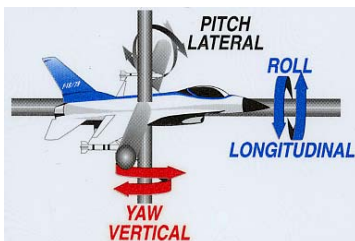
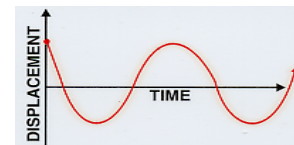


• An airplane with both positive static and dynamic stability does not immediately return to its original attitude after displacement. It goes through a series of oscillations, with each one getting smaller.



• The initial reaction of an airplane with positive static but negative dynamic stability is to return to equilibrium. However, instead of the oscillations getting smaller, they increase in size, making the aircraft difficult to control.

• An aircraft with both positive static and neutral dynamic-stability is also characterized by oscillations, but this time the oscillation remain the same size, and the airplane will not return to its original position.



REFERENCE AXIS

An airplane's movement can be reduced to rotation about three perpendicular axes. The three axis all intersect at the balance point of the airplane called the center of gravity, or **CG**. Your airplane pitches, rolls, and yaws about this point.

Longitudinal: When an aircraft is banked it rolls about an imaginary line that passes through the nose and tail. This line is called the longitudinal axis.

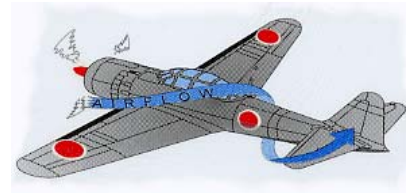
Lateral: Moving the control wheel fore and aft moves the elevator or stabilator and creates a pitching movement around the lateral axis.

Vertical: The movement of the nose to the left and right is called yaw and occurs about the vertical axis.

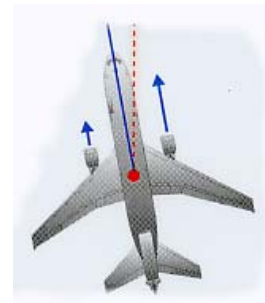
STABILITY IN FLIGHT General aviation airplanes are designed to have both positive static and positive dynamic stability. **Longitudinal Axis.** Stability about the longitudinal axis is called lateral stability. Positive lateral stability is the tendency of an airplane to roll back toward a wings level attitude following displacement by a gust of wind or inadvertent control movement. The most common design feature used to obtain positive lateral stability is wing dihedral. The vertical tail and wing sweepback also contribute to lateral stability. **Yaw Axis.** Stability about the vertical axis is referred to as directional stability or "weathercock". When an airplane is subject to a positive sideslip angle, static directional stability will be evident if a positive yawing moment results. Thus, when the relative wind comes from the right, a yawing moment to the right should be created which tends to weathercock the airplane and return the nose into the wind.

- **Adverse Yaw:** When you deflect the ailerons to bank the airplane, roll is produced by an unbalanced production of lift. The wing with the down aileron produces more lift than the wing with the up aileron. The wing producing the increased lift is also producing increased drag. Since one wing is producing more drag than the other, a yawing force is created causing the airplane's nose to move towards the outside of the turn.

- **Spiraling Slip Stream:** The airflow behind a propeller takes on a spiraling characteristic in the direction of rotation. From the cockpit position, if the propeller is rotating clockwise, the slipstream the vertical stabilizer to the right causing the airplane to yaw left and roll right. It is most noticeable at high power settings and high angles of attack, such as those used during takeoff and climb-out.

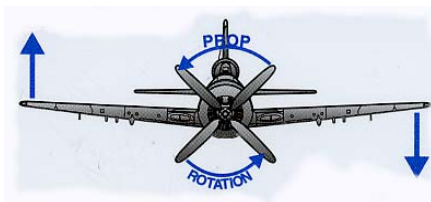


- **Asymmetrical Thrust.** An unbalance of thrust due to a condition of unsymmetrical power, such as engine failure, produces a yawing moment dependent upon the degree of thrust unbalance and the lever arm of the force. A rudder deflection will help counter this yawing moment. Every aircraft has a minimum airspeed for which directional control can be maintained. If operated below that airspeed, the aircraft will tend to yaw uncontrollably into the inoperative engine.



Lateral Axis: Stability about the lateral axis is known as longitudinal stability. It is normally obtained by locating the center of gravity ahead of the center of lift. This creates a slight nose-heavy condition. To balance this condition, a tail down, or a nose up force is created by installing a horizontal stabilizer that has a slight negative angle of attack.

P-Factor: When the propeller's plane of rotation is perpendicular to the relative wind, the ascending and descending propeller blades have equal angles of attack. If you rotate the airplane to a nose high attitude without changing the relative wind, the descending blade of the propeller has a higher angle of attack. The net result is that more thrust is produced on the right side of the airplane than on the left, causing a turning tendency towards the left.



Torque: The force required to spin a propeller clockwise, as viewed from the cockpit, acts on the rest of the airframe as a force in the opposite direction. The airframe tries to rotate counterclockwise about its longitudinal axis.

STABILITY PROBLEMS

Spins: The fundamental requirement of the spin is that the aircraft be placed at an excessive angle of attack to produce an aggravated stall which results in an autorotational descent. The most effective procedure for recovery is to use opposite rudder to stop the sideslip, then lower the angle of attack with the elevators. With sufficient rudder power this procedure will produce a positive recovery with a minimum loss of altitude. Care should be taken during pullout from the ensuing dive to prevent excessive angle of attack and entry into another spin. **Caution:** Do not attempt a spin recovery by applying opposite aileron. Follow the procedures outlined in your aircraft Operator's Handbook.

Pitch-up: The term "pitch-up" generally applies to the static longitudinal instability encountered by certain configurations at high angle of attack. There are several items which may contribute to a pitch up tendency.

1. Sweepback of the wing platform can contribute unstable moments when separation or stall occurs at the tips first.
2. The downwash at the horizontal tail. This is dependent on the change in tail lift when the aircraft has an angle of attack change.

Pilot Induced Oscillations: The pilot may purposely induce various motions to the aircraft by the action of the controls. In addition, certain undesirable motions may occur due to inadvertent control inputs. When the pilot induced oscillation is encountered, the most effective solution is an immediate release of the controls. Any attempt to forcibly damp the oscillation simply continues the excitation and amplifies the oscillation. Freeing the controls removes the unstable (but inadvertent) excitation and allows the aircraft to recover by virtue of its inherent dynamic stability.

Roll Coupling: When a disturbance about one axis causes a disturbance about another axis. Depending on the flight condition where the roll coupling problem exists, four types of behavior are possible:

- Coupled motion stable but unacceptable.** The motion is stable but unacceptable.
- Coupled motion stable and acceptable.** The behavior of the aircraft is stable and adequately damped. The amplitudes of motion are too slight to result in structural failure or loss of control.
- Coupled motion divergent and unacceptable.** The rate of divergence is too rapid for the pilot to recognize the condition and recover prior to structural failure or complete loss of control.
- Coupled motion divergent but acceptable.** For such a condition the rate of divergence is quite slow and considerable roll displacement is necessary to produce a critical amplitude. The condition can be recognized easily in time to take corrective action.