

The Airplane and Basic Aerodynamics

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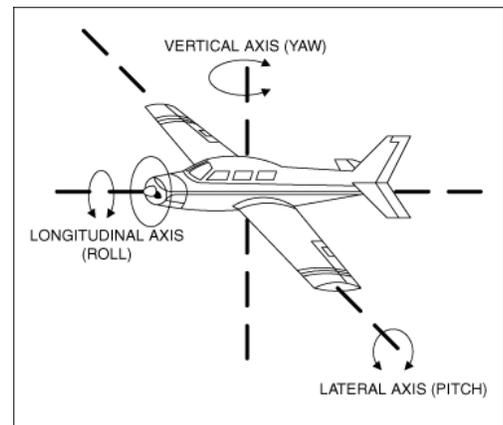
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Aircraft Parts



Figure 1: A Piper Saratoga II TC low-wing airplane

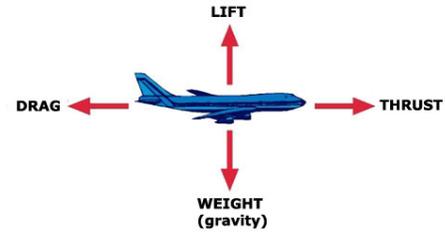
- The *fuselage* is the central body of the airplane that contains the crew, passengers, and cargo
- The *empennage* is the tail of the airplane that contains the *vertical stabilizer*, *rudder*, and *elevator* or *stabilator*
 - The vertical stabilizer acts as a weathervane to keep the airplane flying straight
 - The rudder is used to *yaw* the airplane around the vertical axis
 - The elevator or stabilator is used to change the pitch around the lateral axis
- The *engine* is at the front of the airplane inside the *cowling*
- The *propeller* is at the very front of the airplane and is usually directly connected to the engine
 - A *fixed-pitch* propeller is rigidly attached to the *crankshaft* and covered by the *spinner*. It maintains a constant angle. It is most efficient at a particular airspeed.
 - A *constant-speed* propeller is allowed to change pitch (blade angle) under pilot control. This allows it to be efficient at a variety of airspeeds.
- The *wings* stick out from the side of the aircraft and include *ailerons* and *flaps*
 - Ailerons are used to increase or decrease the lift on a wing, and thus roll the airplane about the longitudinal axis
 - **Flaps are used to increase lift and drag, and allow approaches to landing with a steeper angle without increasing airspeed**
- The *landing gear* is under the aircraft and is attached either to the wings or the fuselage. The gear is either *fixed* or *retractable*.



- An *elevator trim tab* is controllable from the cockpit and is used to set the elevator to a particular pitch angle in flight. This allows the pilot to not use constant (and tiring) pressure on the control yoke to keep the elevator at the desired angle.

The Four Forces

- There are four forces that act on an aircraft: **thrust, drag, lift, and weight (gravity)**. In unaccelerated flight (straight and level, or straight constant-rate climb or descent), weight equals lift and thrust equals drag. The forces are in equilibrium.



Power and Thrust

- An engine produces *power* (for example, a 160 horsepower engine). Generally a piston engine can convert about 30% of the energy in the fuel into power. The rest is lost as heat.
- The propeller converts engine power into *thrust*. A propeller can generally convert 80-90% of engine power into thrust.
- **Thrust acts in the direction the airplane is pointing**

Weight

- Weight is the force on an aircraft due to gravity
- **Weight always acts towards the center of the earth, regardless of what direction the airplane is pointing**

Lift

- Lift is caused by the *Bernoulli effect*
 - Airflow over the top of the wing travels faster than air under the wing because of the camber
 - As a result, the air over the wing is at a lower pressure, and the air under the wing is at a higher pressure, causing a net upward force, which is lift
 - Anyone who tells you that two particles of air starting at the leading edge, one going over the top and one going under the bottom, must *meet at the trailing edge* doesn't know what they're talking about
 - In reality, the air flowing over the top of the wing arrives at the trailing edge *much earlier* than air going under the wing
 - Air at the trailing edge is deflected downward

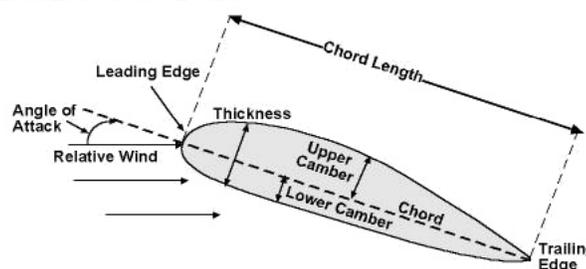


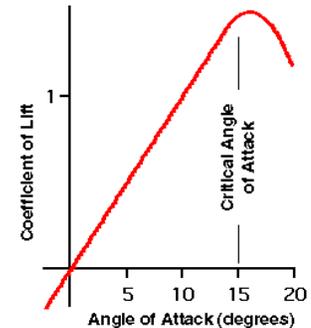
Figure 2: Airfoil cross section

- The *relative wind* is the direction of the airflow from the perspective of the wing *chord* (the line from the leading edge to the trailing edge)

- The relative wind is not necessarily coming from where the airplane is pointed because the airplane may not be moving in the direction it's pointed
- **The angle of attack is the angle between the relative wind and the chord**
- Lift is always generated perpendicular to the relative wind
- Lift is affected by air density, airspeed, and angle of attack

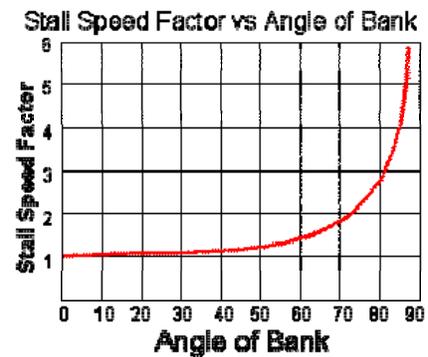
$$\text{Lift} = \text{Density} * \text{Airspeed}^2 * \text{Angle of attack} * \text{constant}$$

- Generally speaking, at a given airspeed, the amount of lift increases linearly with the angle of attack, until a critical angle of attack is reached
- At the *critical angle of attack* (usually 15-18 degrees), the airflow on the surface of the wing begins to separate causing a rapid reduction in lift
- **The critical angle of attack for a wing is affected *only* by the design of wing and is constant for that wing. It is not affected by weight, center of gravity, or anything else!**
- Beyond the critical angle of attack the wing is said to be *stalled*
- The *stall speed* is the airspeed at which the wing is at the critical angle of attack in level, unaccelerated flight



IMPORTANT: A stall is only caused by an airfoil exceeding the critical angle of attack. A stall can happen at any airspeed, any bank, and any pitch attitude!

- In level, unaccelerated flight *lift must equal weight*. If the weight of airplane goes up, the amount of lift required must go up to maintain level flight. For a constant speed, this is done by increasing the angle of attack.
- In order to maintain level flight near the critical angle of attack at a higher weight, the airspeed must be higher to generate the necessary additional lift. **Thus the stall speed increases with weight.**
- In order to maintain level flight in a bank (see below), the wing must generate additional lift. **Thus, the stall speed increases with bank.**
- **A stall is generally preceded by a buffet or vibration because turbulence from the air over the wing is hitting the elevator**
- Lift decreases with increased density altitude. Thus, *true* stall speed increases as altitude increases. However, because the airspeed indicator is affected by air density in exactly the same way, *the indicated stall speed does not change with altitude*
- Wings must have a relatively smooth surface in order to produce lift. **Frost can produce a very rough wing surface that significantly reduces the production of lift resulting in higher takeoff speeds and higher stalling speeds.** Wings must be cleared of frost before flight.

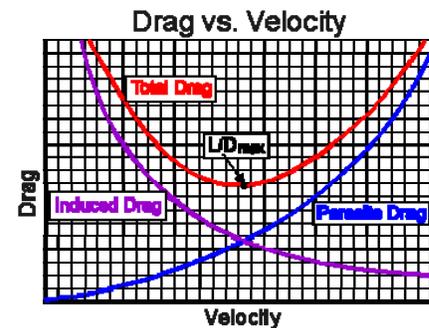


Spins

- **A spin is caused when *both* wings are stalled and a yawing force is introduced**
- The up wing is less stalled than the low wing, which causes a rotation
- A spin is an aerodynamically stable maneuver that causes a rapid rate of rotation and a rapid loss of altitude
- Spins are very dangerous when done at an altitude too low to allow for recovery (1000-2000 feet minimum)

Drag

- Drag is always produced parallel to the relative wind
- There are two main components of drag
- *Induced drag* is an unavoidable byproduct of the production of lift and is affected by the angle of attack
 - Because lift is perpendicular to the chord line of the airfoil, at increased angles of attack a component of the lift vector is pointed backwards, causing drag
 - The angle of attack seen by the wing is affected by airflow around the wing which flows from the high pressure under the wing to the low pressure over the wing
 - Induced drag varies inversely with the square of the airspeed
 - Induced drag is highest at low airspeeds because the angle of attack is the highest
- *Parasite drag* is caused by the viscous flow of the air over the structure of the airplane and surface friction
 - Parasite drag varies with the square of the airspeed
 - Parasite drag is highest at high airspeed
- The *total drag* is the sum of the induced drag and the parasite drag
- For a particular weight, there exists a particular airspeed at which the total drag is the least
- At this same point, the ratio of lift to drag (L/D) is the highest
- The max L/D speed provides the best glide range in the event of a power failure
- Max L/D always occurs at the same angle of attack



Turns

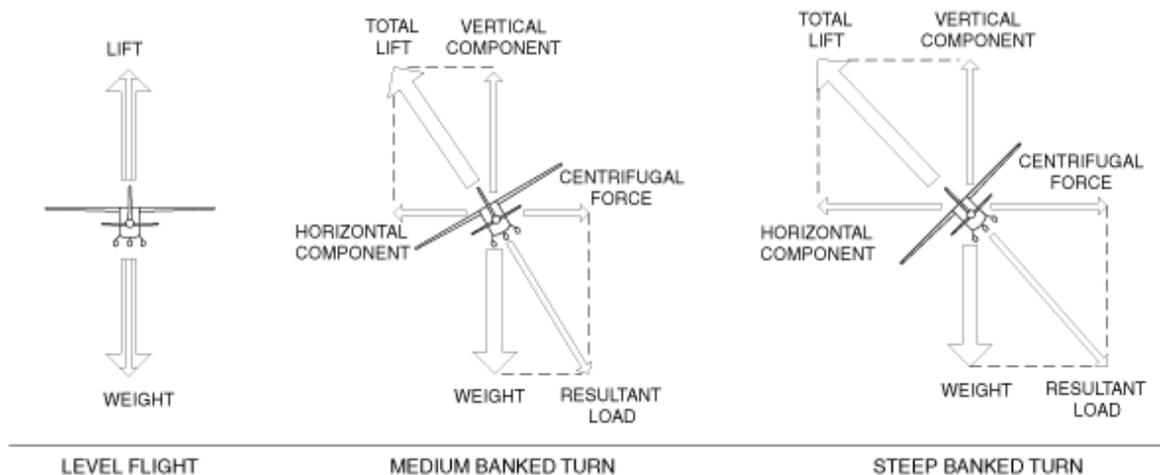
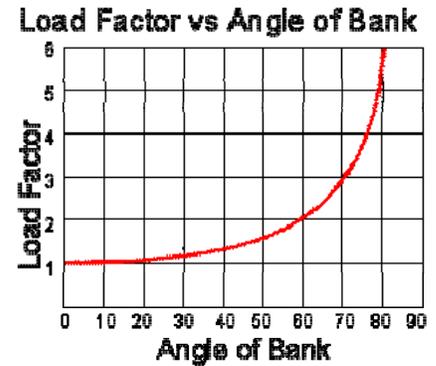


Figure 3: Vectors in a turn

- **An airplane turns by banking and directing part of the lift vector (the horizontal component of lift) in the direction of the desired turn**
- In level, non-turning flight the vertical component of lift equals the total lift
- In level, turning flight the vertical component of lift is less than the total lift
- Because the vertical component of lift must equal weight, additional lift must be generated (by increasing the angle of attack with pitch)
- **The force opposite the lift vector (the “resultant load” or “centrifugal force”) is felt as increased weight, or increased “g load”**

- The *load factor* is the ratio of this force to the force of gravity and is expressed in “g”s
- As mentioned earlier, the angle of bank affects the stall speed. **Thus an airplane will stall at a higher airspeed when in a level turn than when in level flight.**
- **An airplane banks through the use of ailerons.** An aileron can increase or decrease the angle of attack on a wing thus causing more or less lift than the other wing. Ailerons work together – one wing increases lift while the other decreases lift. This causes the airplane to roll around its longitudinal axis.
- Because lift causes induced drag, the wing being raised will also produce more drag, causing the airplane to yaw in the direction *away* from the turn. Rudder must be used to counteract this *adverse yaw*.
- The use of rudder to always point the airplane in the direction it’s going is called *coordination*.

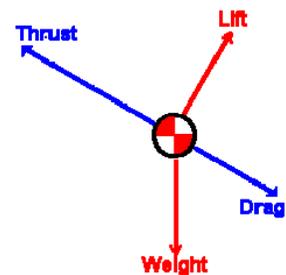


Yaw

- **An airplane can be yawed by use of the rudder. The rudder is not generally used to make the airplane turn.**
- When the yaw occurs, one wing is momentarily going faster than the other. This wing will produce more lift, and thus the airplane will roll in the direction of the yaw.
- The interaction between roll and yaw illustrates the need to always use bank and yaw *together* in a smooth, coordinated manner

Climbs

- An airplane climbs by changing the thrust vector to have a vertical component
- Excess thrust causes the airplane to climb
- The vertical component of lift is actually less than weight in a climb because there is a vertical component of thrust

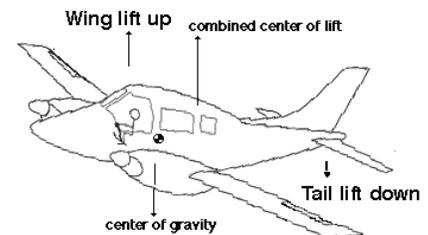


Left-turning tendency

- **There are three factors that cause an airplane to want to turn left at high power settings and slow airspeeds (high angles of attack)**
- *Torque* is the rotational force placed on the airplane by the turning propeller. Because most airplanes have propellers that turn clockwise (as seen from the cockpit), the reaction force causes the airplane to want to roll counterclockwise, or left.
- The airflow from the propeller (the *slipstream*) wraps around the fuselage and strikes the vertical tail fin from the left, causing the airplane to yaw to the left
- Asymmetric propeller disc loading, or *P factor*, is caused by the difference in relative wind between the right and left hand sides of the propeller disc. **At high pitch attitudes (high wing angles of attack), the right hand side of the propeller disc (as seen from the cockpit) has a higher angle of attack, and thus produces more thrust.** This causes the airplane to yaw to the left.
- The airplane is designed to counteract these forces at cruise airspeed, but the forces become pronounced when flying at slower airspeeds
- Right rudder, sometimes in very significant amounts, is required when at high power settings and slow airspeeds, such as during takeoff

Longitudinal Stability

- *Stability* is the tendency of a system to return to an equilibrium state after it is perturbed
 - Airplanes are generally stable
 - Helicopters are extremely unstable
- *Controllability* is the characteristic of an aircraft that means there is sufficient control authority to manipulate the aircraft's orientation
- **The FAA says a stable aircraft "requires less effort to control"**
- *Longitudinal stability* is the characteristic of an aircraft that allows it to return to its original pitch orientation after a momentary upset, such as a wind gust
- An airplane has the center of lift (also known as the center of pressure) of the wings behind the center of gravity, and the center of lift of the tail even further back
- The tail is an upside-down airfoil and produces "negative" lift (pointing downwards) to offset the rotational moment induced by the lift of the wings to keep the airplane balanced
- When a disturbance causes the angle of attack of the wings to increase, the angle of attack of the tail is reduced and causes the airplane to pitch downward, thus reducing the angle of attack on the wings
- **Moving the center of gravity further rearward reduces the length of the arm from the center of gravity to the wing and the tail, and thus reduces stability**
- **An aft center of gravity may make it difficult to recover from a stall**
- The airflow over the tail is strongly affected by the amount of engine power being used and thus the amount of airflow produced from the propeller
 - When power is increased, the tail produces more negative lift and thus pitches the airplane up
 - When power is decreased, the tail produces less negative lift and thus pitches the airplane down



Ground effect

- When an airplane is close to the surface, the ground interferes with the flow of air from the high pressure under the wing to the low pressure over the wing
- Since this airflow is the cause of induced drag, induced drag is significantly reduced when close to the ground
- This effect is called *ground effect*
- Ground effect is most pronounced when less than one wing span's height above the ground, and falls off rapidly with altitude
- When taking off, the airplane may lift off the ground at an airspeed that does not permit continued climb due to ground effect
- When landing, speed control is very important because any excess speed will take longer to bleed off in ground effect due to the reduced drag, resulting in floating

Airspeed Limitations

Load Limitations and Maneuvering Speed (Va)

- An airplane is designed to support a given amount of "g force" before the wings buckle
- For "normal category" airplanes this is 3.8G
- **The amount of load that can be imposed through lift on the wings depends on airspeed – at a higher airspeed, more load can be imposed before the wings stall**

- V_a is the speed beyond which any abrupt nose up motion can impose more force than the designed load limit
- Below V_a the wing will stall before the load limit is exceeded
- V_a varies with weight: higher weight means lower V_a
- **V_a is not marked on the airspeed indicator!**
- **When turbulence is encountered, the pilot should slow the airplane below V_a and maintain a constant pitch attitude. Attempting to chase the pitch to maintain a constant altitude or airspeed can overstress the airplane.**

Stall Speeds (V_{s0} and V_{s1})

- V_{s0} is the stall speed in the landing configuration (usually flaps down, landing gear extended)
- V_{s0} is indicated on the airspeed indicator by the bottom of the white arc
- The range of the white arc (from V_{s0} to V_{fe}) is called the *normal flap operating range*
- V_{s1} is the stall speed in a “specified” configuration (usually no flaps, landing gear retracted if applicable)
- V_{s1} is indicated on the airspeed indicator by the bottom of the green arc

Flap Extension Speed (V_{fe})

- V_{fe} is the maximum speed at which the flaps may be extended without damage
- V_{fe} is indicated by the top of the white arc

Maximum Structural Cruising Speed (V_{no})

- V_{no} is the maximum “normal” cruising speed
- **V_{no} should be exceeded only in smooth air, and then only with caution**
- V_{no} is indicated by the top of the green arc/bottom of the yellow arc
- The range of the yellow arc (from V_{no} to V_{ne}) is called the *caution range*

Never Exceed Speed (V_{ne})

- V_{ne} is the airspeed beyond which the airplane should *never* be operated because structural failure may result
- **V_{ne} is indicated by the red line** at the top of the yellow arc

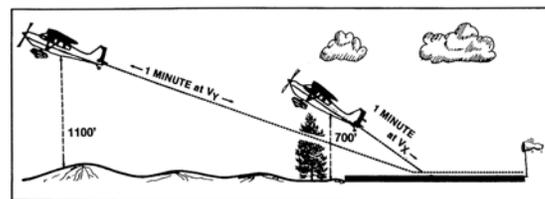
Landing Gear Extension Speed (V_{le})

- V_{le} is the maximum speed at which the landing gear can be extended without damage

Performance Airspeeds

Best Rate of Climb (V_y)

- V_y is the speed at which the most altitude will be gained *per unit time*
- Use this speed to gain altitude quickly on takeoff (the ground is not your friend and you want to get away from it quickly!)



Best Angle of Climb (V_x)

- V_x is the speed at which the most altitude will be gained *per horizontal distance traveled*
- Use this speed to gain altitude over an obstacle on takeoff