II.D. Principles of Flight

References: Airplane Flying Handbook (FAA-H-8083-3), Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25)

Objectives	The student should develop knowledge of the elements related to the principles of flight. The student should understand why airplanes are designed in certain ways, as well as the forces acting on airplanes and the use of those forces in flight.
Key Elements	1. Stability vs. Maneuverability 2. Left Turning Tendency 3. Load Factors
Elements	1. Airfoil Design 2. Wing Planform 3. Stability and Controllability 4. Turning Tendency (Torque Effect – Left Turning Tendency) 5. Load Factors in Airplane Design 6. Wingtip Vortices and Precautions to be Taken
Schedule	1. Discuss Objectives 2. Review material 3. Development 4. Conclusion
Equipment	1. White board and markers 2. References 3. Model Airplane
IP's Actions	1. Discuss lesson objectives 2. Present Lecture 3. Ask and Answer Questions 4. Assign homework
SP's Actions	1. Participate in discussion 2. Take notes 3. Ask and respond to questions
Completion Standards	The student understands the principles to flight.

Instructor Notes:

Introduction:

Attention

Interesting fact or attention-grabbing story

Everything you ever wanted to know about the science of the airplane, which will result in a considerably better understanding of the airplane and make you a considerably better pilot.

Overview

Review Objectives and Elements/Key ideas

What

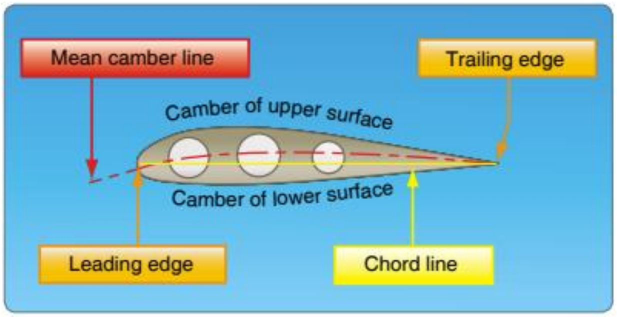
The Principles of Flight are the characteristic forces of flight as well as why and how the airplane performs certain ways.

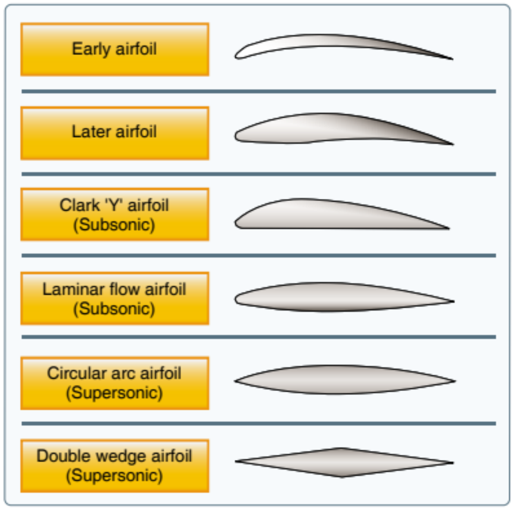
Why

To become a pilot, a detailed technical course in the science of aerodynamics is not necessary. However, with the responsibilities for the safety of passengers, the competent pilot must have a well-founded concept of the forces which act on the airplane, and the advantageous use of these forces, as well as the operating limitations of the particular airplane.

How:

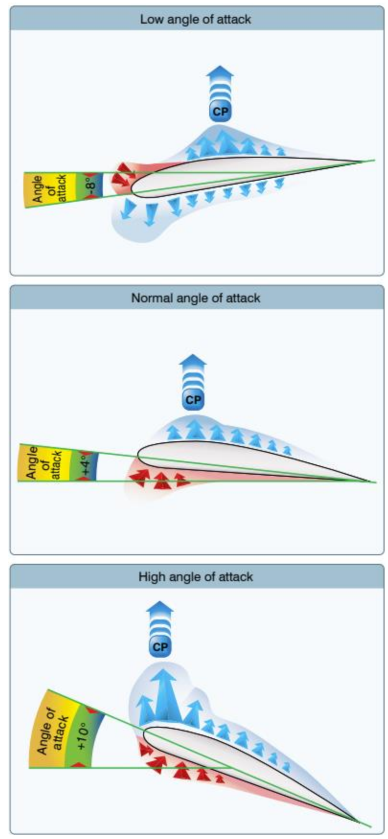
1. Airfoil Design





- A. Airfoil: Structure designed to obtain reaction upon its surface from the air through which it moves or that moves past such a structure
- B. Terminology
  - i. Camber
    - a. Curvature of the upper / lower surface
    - b. Upper surface tends to have more camber
  - ii. Leading edge / Trailing edge
    - a. Generally rounded leading edge
    - b. Generally narrow and tapered trailing edge
  - iii. Chord Line
    - a. Straight line drawn through the airfoil profile connecting the extremities of the leading and trailing edges
    - b. Distance from the chord line to the upper / lower surfaces denotes the magnitude of camber
  - iv. Mean Camber Line
    - a. Equidistant at all points from the upper and lower surfaces
- C. General Design Characteristics
  - i. Air Pressure
    - a. Airfoil is constructed to take advantage of the air's response to physical laws
    - b. This develops two actions from the air mass:

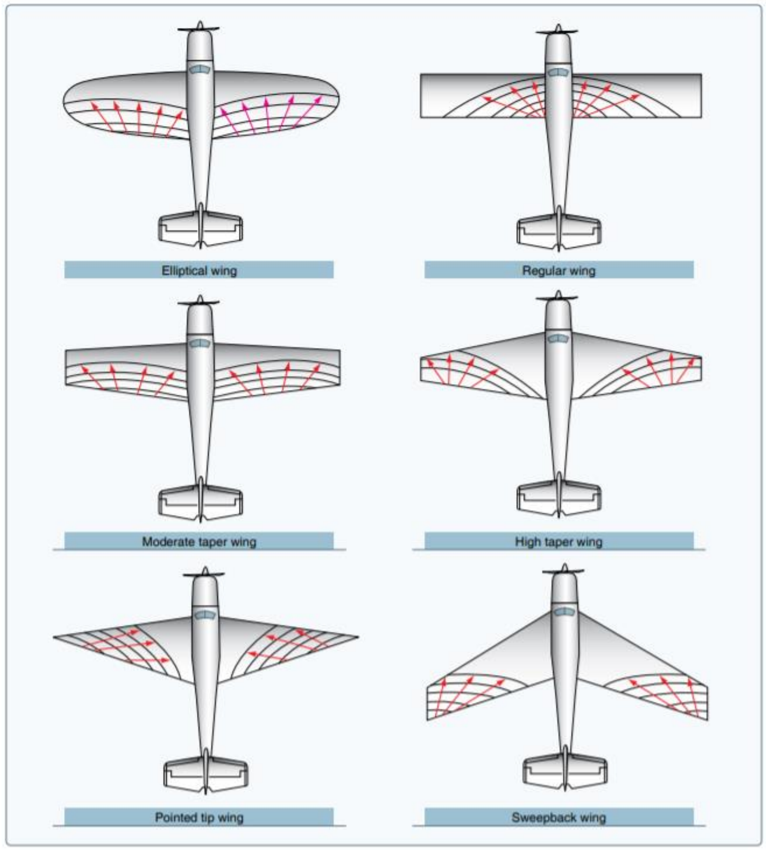
        - Negative pressure lifting action above the wing
        - Positive pressure lifting action from below the wing
    - c. Different airfoils have different flight characteristics (pictured above)
        - Aircraft weight, speed & purpose dictate the airfoil shape
- ii. Low Pressure Above
    - a. Air moving over the upper surface of the airfoil moves faster than air along the bottom
        - Upper surface has a higher camber in this case
        - Bernoulli's Principle: Increase in speed of air across the top of an airfoil decreases pressure
    - b. Downward, backward flow of air creates downwash
        - Newton's 3^{rd} Law: Downward, backward flow results in an upward force on the airfoil
- iii. High Pressure Below
    - a. Positive pressure from below the airfoil
        - Particularly at higher AOAs
        - Newton's 3^{rd} Law
    - b. Stagnation Point: Near the leading edge there is a point where the airflow is virtually stopped
        - Speed gradually increases, matching the velocity of the air on the upper surface near the trailing edge
        - Slower airflow = increased pressure (Bernoulli's principle)
- iv. Pressure Distribution (pictured, right)



    - a. At different AOAs, pressures vary between positive / negative
    - b. Negative pressure on the upper surface creates a larger force than the positive pressure from air striking the lower surface
    - c. Center of Pressure (CP): Average of the pressure variation for a given AOA
        - Aerodynamic forces act through the CP
        - At high AOAs, the CP moves forward
        - At low AOAs, the CP moves aft
    - d. CP movement is very important to wing structure design
        - Affects aerodynamic balance and controllability
- v. Note: The production of lift is much more complex than a simple differential pressure between the upper and lower airfoil surfaces, but these concepts suffice for this discussion

2. Wing Planform

- A. Planform describes the wings outline as seen from above
    - i. Many factors affect shape, including: purpose, load factors, speeds, construction and maintenance costs, maneuverability/stability, stall/spin characteristics, fuel tanks, high lift devices, gear, etc.
    - ii. There are many different shapes and advantages/disadvantages to each (many shapes are combined)
- B. Taper – The ratio of the root chord to the tip chord
    - i. Rectangular wings have a taper ratio of 1
        - a. Simpler and more economical to produce and repair (ribs are same size)
        - b. The root stalls first providing more warning and control during recovery
    - ii. Ellipse (Tapered)



        a. Provides the best span wise load distribution and lowest induced drag
        b. But, the whole wing stalls at the same time and they are very expensive/complex to build
- C. Aspect Ratio – divide the wingspan by the average chord
    - i. The greater the aspect ratio, the less induced drag (more lift)
    - ii. Increasing wingspan (with the same area) results in smaller wingtips, generating smaller vortices
        - a. Reduces induced drag and are more efficient
        - b. Planes requiring extreme maneuverability and strength have much lower aspect ratios
            - Ex: Fighter, and aerobatic aircraft
- D. Sweep – When the line connecting the 25% chord points of the ribs isn't perpendicular to the longitudinal axis
    - i. The sweep can be forward, but it is usually backward
    - ii. Helps in flying near the speed of sound, but also contributes to lateral stability in low-speed planes

3. Stability and Controllability

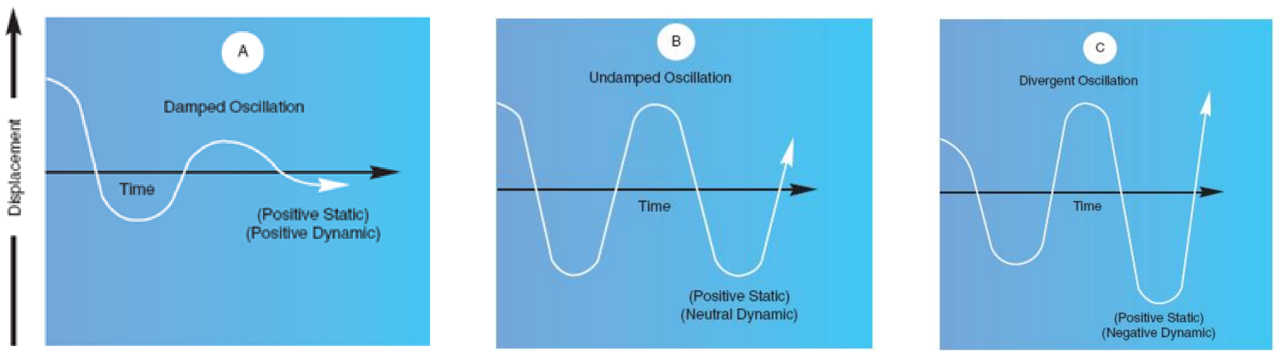
- A. Stability
    - i. The inherent quality of an airplane to correct for conditions that may disturb its equilibrium, and return to or continue on the original flight path
        - a. Stability is primarily a design characteristic
        - b. The more stability, the easier to fly, but too much results in significant effort to maneuver
            - Therefore, stability and maneuverability must be balanced
    - ii. There are two types of stability: Static and Dynamic
    - iii. Static Stability (SS)
        - a. Equilibrium: All opposing forces are balanced (Steady unaccelerated flight conditions)
        - b. SS: The *initial tendency*; The aircraft's initial response when disturbed from a given pitch, yaw, or bank
            - Positive SS: The initial tendency to return to the original state of equilibrium after being disturbed (to return to the trimmed condition)
            - Negative SS: The initial tendency to continue away from original equilibrium after being disturbed (the aircraft moves farther and farther away from the trimmed position)
            - Neutral SS: The initial tendency to remain in a new condition after equilibrium has been disturbed (the aircraft remains in a new position and does not return or trend away from the original trimmed position)

c. Positive SS is the most desirable - The plane attempts to return to the original trimmed attitude

iv. Dynamic Stability (DS)

a. SS refers to the initial tendency, DS refers to the aircraft response over time when disturbed from a given pitch, bank, or yaw
- Refers to whether the disturbed system returns to equilibrium over time or not
- The degree of stability can be gauged in terms of how quickly it returns to equilibrium
- Referred to as Positive, Negative, and Neutral – Same as SS, but over time (overall tendency)

b. Most desirable is Positive Dynamic Stability



v. Stability in an aircraft significantly affects two areas:

a. Controllability – The capability of the aircraft to respond to the pilot's control, especially in regard to flight path and attitude
- It is the quality of the aircraft's response to control application when maneuvering the aircraft, regardless of stability characteristics

b. Maneuverability - Quality of the aircraft that permits it to be maneuvered easily and to withstand stresses imposed by maneuvers
- Governed by the aircraft's weight, inertia, size and location of flight controls, structural strength and power plant
- It is a design characteristic

B. Longitudinal Stability (LS) – About the lateral axis

i. LS makes an airplane stable about its lateral axis and involves the pitching motion

a. A Longitudinally unstable plane has a tendency to dive and climb progressively steeper making it difficult/dangerous to fly

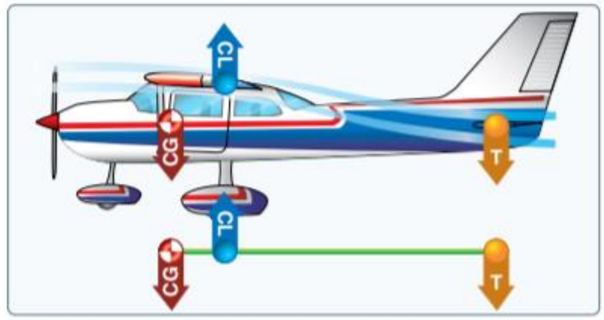
ii. To obtain LS, the relation of the wing and tail moments must be such that, if the moments are balanced and the airplane is suddenly nosed up, the wing moments and tail moments will change so that their forces will provide a restoring moment bringing the nose down again

a. And, if the plane is nosed down, the change in moments will bring the nose back up

iii. Static LS, or instability, is dependent on 3 factors:

a. Location of the wing in relation to the Center of Gravity (CG)
- The CG is usually ahead of the wing's Center of Lift (CL) resulting in nose down pitch
- This nose heaviness is balanced by a downward force generated by the horizontal tail
  - a The horizontal stabilizer is often designed with a negative AOA to create a natural tail-down force
  - b Remember, the tail down force lifts the nose of the aircraft up (pitch up motion)

- The CG-CL-Tail-down force line is like a lever with an upward force at CL and 2 downward forces (CG and Tail-down) on either side balancing each other
  - a The stronger down force is at the CG; the tail down force is weaker but has a longer arm



- In the case of a dynamically stable aircraft: If the nose is pitched up (with no other change in controls/power), airspeed will begin to decrease. As airspeed decreases, the tail-down force of the elevator will decrease. As the tail-down force decreases, the nose of the aircraft will begin to pitch down, resulting in increased airspeed. As airspeed increases, the tail-down force of the stabilizer will increase, lifting the nose back up. If left untouched, this process will continue and each pitch up/down will progressively weaken until the aircraft returns to stabilized flight.

b. Location of the horizontal tail surfaces with respect the CG
- If the plane is loaded with the CG farther forward, more tail down force is necessary
  - a This adds to longitudinal stability since the nose heaviness makes it more difficult to raise the nose and the additional tail down forces makes it difficult to pitch down
    1. Any small disturbances are opposed by larger forces, dampening them quickly
- If the plane is loaded farther aft, the plane becomes less stable in pitch
  - a If the CG is behind the CL, the tail must exert upward force so the nose doesn't pitch up
  - b If a gust pitches the nose up, less airflow over the tail will cause the nose to pitch further
  - c This is an extremely dangerous situation

c. The area or size of the tail surfaces
- The larger the area/size of the tail surface, the more force exerted

C. Lateral Stability - About the Longitudinal Axis

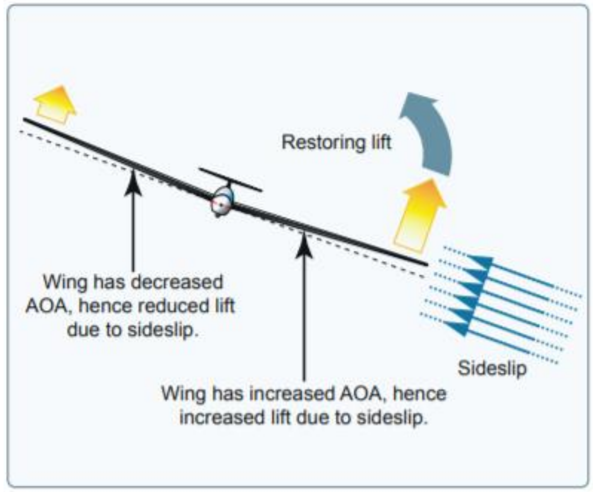
i. Lateral stability about the longitudinal axis is affected by:

a. Dihedral; Sweepback Angles; Keel Effect; Weight Distribution

ii. Dihedral is the angle at which the wings are slanted upward from the root to the tip

a. Some aircraft are designed so that the outer tips of the wings are higher than the wing roots
- Dihedral is the upward angle formed by the wings

b. Dihedral stabilizes the airplane by balancing the lift in a sideslip



- When a gust causes a roll, a sideslip will result
- The sideslip causes the relative wind affecting the airplane to be from the direction of slip
- When the relative wind comes from the side, the wing slipping into the wind (low wing) gets an increase in AOA and develops an increase in lift
- The wing away from the slip (high wing), is subject to a decrease in AOA and lift
- The changes in lift result in a rolling moment that raises the lowered wing (more stable)

c. In a shallow turn: the increased AOA increases lift on the low wing with a tendency to return the aircraft to straight and level flight

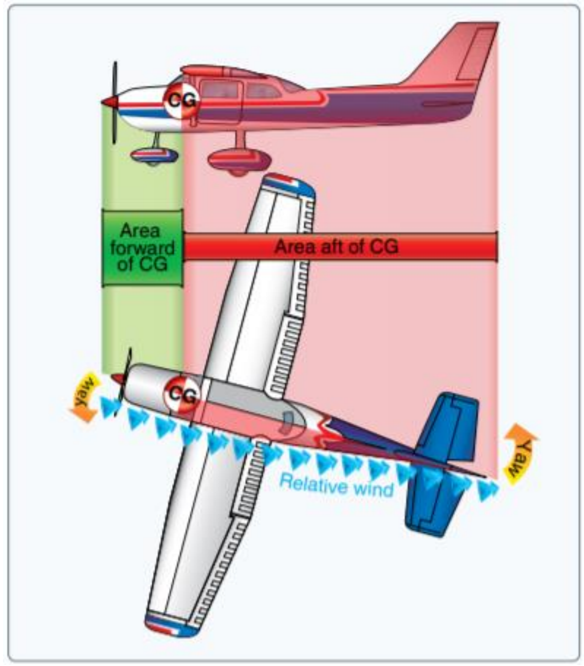
iii. Sweepback is the angle at which the wings are slanted rearward from the root tip
  a. Sweepback effectively increases dihedral to achieve stability, but the effect is not as pronounced
    - A rough estimation is that 10^{o} of sweepback is equal to about 1^{o} of effective dihedral
  b. When a disturbance causes an aircraft with a sweepback to drop a wing, the low wing presents its leading edge at an angle that is more perpendicular to the airflow. This results in more lift on the lowered wing

iv. Keel effect depends on the action of the relative wind on the side area of the fuselage
  a. Laterally stable airplanes: The greater portion of the keel area is above and behind the CG
    - When the plane slips to one side, the combination of the airplane's weight and the pressure of the airflow against the upper portion of the keel area rolls the plane back to wings level
      a The fuselage behaves like a keel, exerting a steadying influence on the aircraft
  b. To Summarize: The fuselage is forced by keel effect to parallel the wind

v. Weight Distribution
  a. If more weight is located on one side, it will have a tendency to bank that direction

D. Directional Stability (DS) - Stability about the vertical axis
  i. DS is affected by the area of the vertical fin and the sides of the fuselage aft of the CG
    a. Makes the airplane act like a weathervane, pointing the nose into the relative wind
  ii. SIDE - For a weathervane to work, a greater surface area must be aft of the pivot point (the CG)

a. If the same amount of surface area were exposed to the wind in front of and behind the pivot point, the forces would balance and there would be little or no directional movement
b. Therefore, it is necessary to have a greater surface area aft of the CG than forward of it
c. Ex: If the nose yaws left, it will pivot around the CG. As the aircraft yaws, the relative wind will push on the right side of the fuselage. Since there is more surface area behind the pivot point (CG), there is more force applied behind the CG and the nose will be pushed back to the right

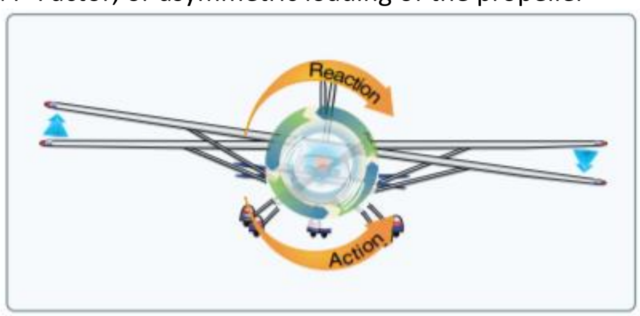


iii. VERTICAL FIN – the vertical fin acts like a feather on an arrow in maintaining straight flight
   a. The farther aft the fin is placed and the larger its size, the greater the DS
   b. As the plane yaws in one direction, the air strikes the opposite side of the vertical fin
      - This puts pressure on vertical fin, stopping the motion and then turning the nose into the relative wind (like a weathervane)
      - Ex: If the nose yaws right, the relative wind puts pressure on the left side of the vertical stabilizer stopping the yaw and moving the nose back to the left

4. Turning Tendency (Torque Effect – Left Turning Tendency of the airplane)

A. Torque is made up of 4 elements which produce a twisting or rotating motion around at least 1 of the planes 3 axes
   i. Torque Reaction from the engine and propeller, Corkscrew Effect of the Slipstream, Gyroscopic Action of the Propeller, and P-Factor, or asymmetric loading of the propeller

B. Torque Reaction
   i. Newton's 3rd Law – For every action there is an equal and opposite reaction
      a. The engine parts/propeller rotate one way; an equal force attempts to rotate the plane the opposite direction



   ii. When airborne, this force acts around the longitudinal axis, resulting in a left rolling tendency
   iii. On the ground, during takeoff, the left side is being forced down resulting in more ground friction
      a. This causes a turning moment to the left that is corrected with rudder
   iv. The strength of the torque reaction is dependent on engine size and horsepower, propeller size and rpm, airplane size, and the condition of the ground surface
      - The higher the power setting, the greater the left turning tendency
   v. Torque is corrected by offsetting the engine, aileron trim tabs, and/or aileron/rudder use

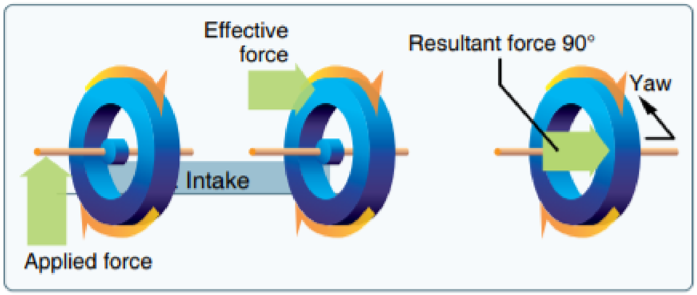
a. Most aircraft engines are not installed on the centerline of the aircraft (on the longitudinal axis), they are offset in order to counteract a portion of the rolling motion caused by torque
b. Trim tabs can be adjusted to counter the turning tendency in level flight
c. Some airplanes are designed to create more lift on the wing that is forced downward as well
d. Torque not countered by the engine and trim tab position must be corrected with coordinated rudder and aileron inputs

C. Corkscrew/Slipstream Effect
i. The high-speed rotation of the propeller sends the air in a corkscrew/spiraling rotation to the rear of the aircraft where the air strikes the left side of the vertical stabilizer, pushing the nose to the left
ii. At high prop speeds/low forward speeds the rotation is very compact

a. This exerts a strong sideward force on the vertical tail causing a left turn around the vertical axis
b. The corkscrew flow also creates a rolling moment around the longitudinal axis
   - The rolling moment is to the right and may counteract torque to an extent

iii. As the forward speed increases, the spiral elongates and becomes less effective
iv. The slipstream effect is countered with coordinate rudder and aileron and is most pronounced in takeoffs and climbs (high prop speed and low forward speed)

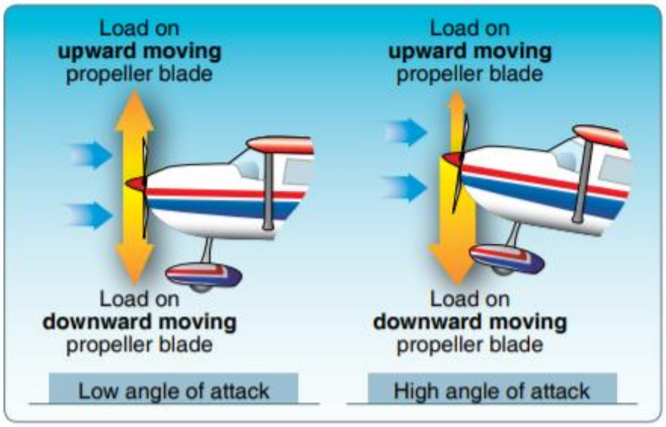
D. Gyroscopic Action
i. Gyroscopes are based on two fundamental principles:
a. Rigidity in space (not applicable to this discussion)
b. Precession - The resultant action of a spinning rotor when a force is applied to its rim
   - If a force is applied, it takes effect 90° ahead of, and in the direction of turn
     a This causes a pitch moment, yaw moment, or combination of the two depending on where the force is applied
   - Ex: This most often occurs with tail wheel aircraft when the tail is raised on the takeoff roll
     a The change in pitch (lifting the tail wheel) has the same effect as applying a forward force to the top of the propeller
       1. This force is felt 90° in the direction of rotation (clockwise viewed from the cockpit)



     b The forward force will take effect on the right side of the propeller, yawing the nose left

ii. Any yawing around the vertical axis results in a pitching moment
iii. Any pitching around the lateral axis results in a yawing moment

    iv. Correction is made with proper elevator and rudder pressures to prevent undesired pitch and yaw
- E. Asymmetric Loading (P Factor)
    - i. When flying with a high AOA, the bite of the down moving blade is greater than the up moving blade
        - a. This moves the center of thrust to the right of the propeller disc area (causing a yaw to the left)
    - ii. P-factor is caused by the propeller's resultant velocity, which is generated by the combination of two parts:
        - a. The velocity of the propeller blade in its plane of rotation
        - b. The velocity of the air passing horizontally through the propeller disc



    - iii. At positive AOAs, the right (down swinging) blade is passing through an area of resultant velocity greater than the left (up swinging) blade
        - a. Since the prop is an airfoil, increased velocity means increased lift
            - Therefore, the down blade has more lift and tends to yaw the plane to the left
    - iv. Ex: Visualize the propeller shaft mounted perpendicular to the ground (like a helicopter)
        - a. If there were no air movement at all, except that generated by the propeller, identical sections of the blade would have the same airspeed
        - b. But, with air moving horizontally across the vertically mounted prop, the blade proceeding forward into the flow of air will have a higher airspeed than the blade retreating with the airflow
            - The blade proceeding into the airflow creates more lift, moving the center of lift toward it
        - c. Visualize rotating the vertically mounted propeller to shallower angles relative to the moving air (as on an airplane)
            - This unbalanced thrust gets proportionately smaller until it reaches zero when the propeller shaft is exactly horizontal in relation to the moving air
    - v. Summary: The descending blade of the propeller has a higher AOA, resulting in a bigger bite of air, therefore the center of thrust is moved to the right side of the aircraft's centerline and the aircraft will have a tendency to yaw to the left

5. Load Factors (LF) in Airplane Design

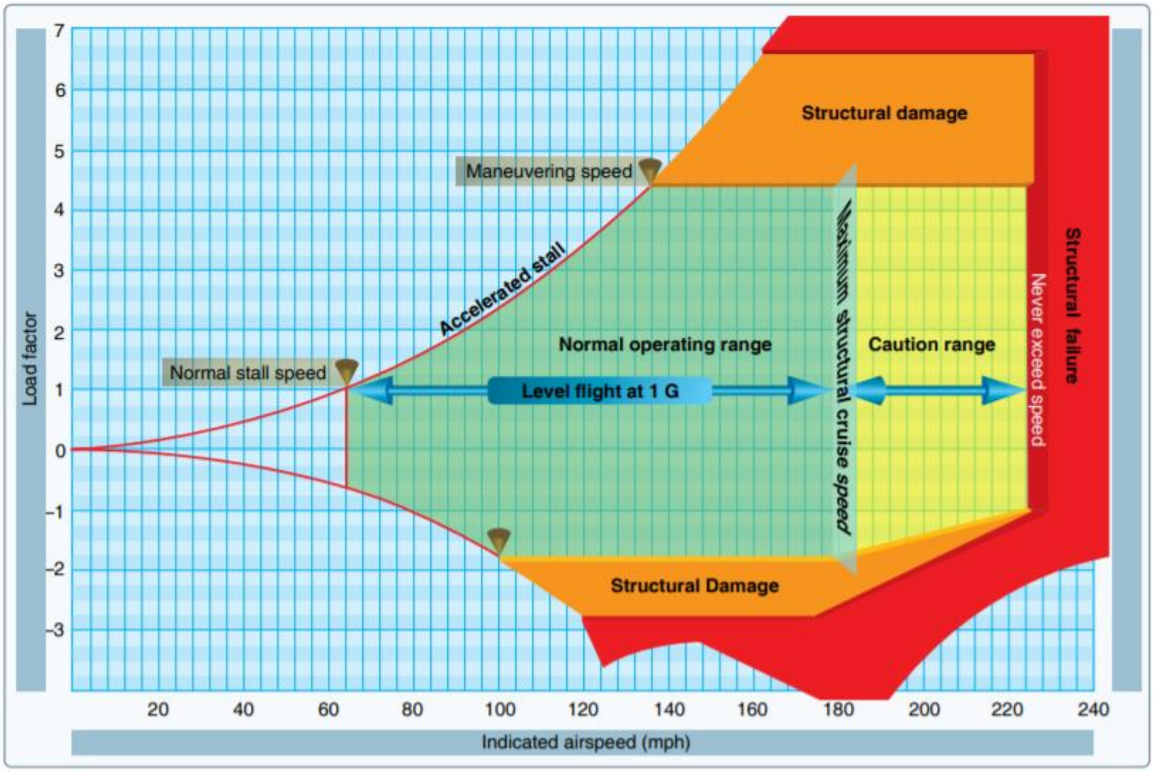
- A. General
    - i. Load factor is the ratio of the total air load acting on the airplane to the gross weight of the airplane
    - ii. Measured in Gs (acceleration of gravity)
        - a. Gs can be positive or negative
            - Ex of positive Gs: A sharp pull up and the resulting force pushing the pilot into the seat
            - Ex of negative Gs: A sharp push down and the resulting force lifting the pilot off the seat
        - b. 1 G is equivalent to normal gravitational forces (at 1 G, a 200 lb. person weighs 200 lbs.)
        - c. 2 Gs is double – (at 200 Gs, a 200 lb. person weighs 400 lbs.), 3 is triple, etc.
        - d. 0.5 Gs is equivalent to half of the weight of the aircraft or person

iii. Ex: A load factor of 3 means that the total load supported by the airplane is three times its weight
    - Expressed as 3 Gs
    - If an aircraft is pulled up from a dive, subjecting the pilot to 3 Gs, the pilot would be pressed down into the seat with a force equal to three times their weight
        - a The wings of the airplane would also be supporting 3x the weight of the airplane

iv. Load factor is important to the pilot for two distinct reasons:
    a. It is possible for the pilot to impose a dangerous overload on the aircraft structures
        - Aircraft are designed to withstand a certain range of load factors
        - For example, normal category aircraft are designed to operate between -1.52 and 3.8 Gs
            - a Exceeding these ranges can damage the structure and lead to failure
    b. An increased LF increases the stall speed and makes stalls possible at seemingly safe speeds

B. Airplane Design
  i. How strong an airplane should be is determined largely by the use it will be subjected to
    a. This is difficult as maximum possible loads are much too high to incorporate in efficient design
        - If planes are to be built efficiently, extremely excessive loads must be dismissed
        - The idea is to determine the highest LF that can be expected in normal operation under various operational situations – These are 'limit load factors'
            - a Planes must be designed to withstand limit load factors with no structural damage
  ii. Airplanes are designed in accordance with the category system:
    a. Normal Category limit load factors are -1.52 G's to 3.8 G's
    b. Utility Category limit load factors are -1.76 G's to 4.4 G's (Mild acrobatics, including spins)
    c. Acrobatic Category limit load factors are -3.0 G's to 6.0 G's

C. The Vg diagram shows the flight operating strength of a plane based on load factor (vertical scale) and indicated airspeed (horizontal scale) – describes the allowable airspeed/LF



combinations for safe flight

i. Each aircraft has its own Vg diagram that is valid at a certain weight and altitude

ii. Areas to note on the Vg diagram:

a. Lines of Maximum Lift Capability (curved lines)

- The aircraft in this diagram is capable of developing no more than 1 G at 64 mph, the wings level stall speed of the airplane
- Since the maximum load factor varies with the square of the airspeed, the maximum positive lift capability of this aircraft is 2 G at 92 mph, 3 G at 112, 4.4 G at 137, etc.
- Any load factor above this line is unavailable aerodynamically
  - a i.e., the aircraft cannot fly above the line of maximum lift capability because it stalls
  - b The same situation occurs for negative lift flight
- If the aircraft is flown at a positive load factor greater than the limit of 4.4 Gs, structural damage is possible

b. Maneuvering Speed

- The intersection of the positive limit load factor (4.4 Gs) and the line of maximum positive lift capability
- This is the minimum airspeed at which the limit load can be developed aerodynamically
- Any speed greater than this provides the capability to damage the aircraft
- Speeds less than this do not provide the lift capability to cause damage from excessive loads

c. Intersection of the Negative Limit Load Factor and Line of Maximum Negative Lift Capability

- Airspeeds greater than this provide a negative lift capability that can damage the aircraft
- Airspeeds less do not provide the lift capability to cause damage from excessive loads

d. Limit Airspeed (redline)
- This aircraft is limited to 225 mph
- Above this speed, structural damage or failure may result

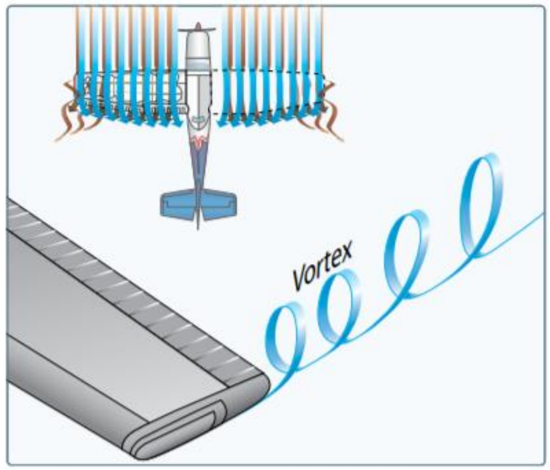
6. Wingtip Vortices and Precautions to be Taken

A. How They Work

i. When an airfoil is flown at a positive AOA, a pressure differential exists above and below the wing

ii. The pressure above the wing is less than atmospheric pressure

iii. The pressure below the wing is equal to or greater than atmospheric pressure



iv. Since air always move from higher to lower pressure, and the path of least resistance is the tips of the wings, there is a spanwise movement of air from the bottom of the wing outward from the fuselage to the tips

v. This flow of air spills over the wingtips

vi. As the air curls upward around the wingtip, it combines with downwash to form a fast-spinning trailing vortex

a. These vortices increase drag because of energy spent in producing the turbulence

vii. Thus, whenever an airfoil is producing lift, induced drag occurs and wingtip vortices are created

a. Just as lift increases with AOA, induced drag also increases

b. As AOA increases, there is a greater pressure difference between the top/bottom of the wing
- Greater pressure difference = greater lateral airflow and stronger vortices

B. Strength of the Vortices

i. As mentioned, the greater the AOA, the stronger the vortices

a. Therefore, the strongest vortices occur when the aircraft is heavy, clean, and slow

b. Strength is directly proportional to weight and inversely proportional to wingspan and airspeed
- As weight increases, AOA increases
- A wing in the clean configuration has a greater AOA than with flaps, slats, etc. in use
- As airspeed decreases, AOA increases

ii. Thus, the strongest vortices occur during takeoff, climb, and landing

C. Dangers of Vortices

i. Wake turbulence can be a hazard to any aircraft significantly lighter than the generating aircraft

ii. Flying through another aircraft's wake can result in major structural damage, or induced rolling making the aircraft uncontrollable

D. Behavior and Avoidance

i. Behavior
    a. Sink at a rate of several hundred fpm, slowing/diminishing the further they get behind an aircraft
    b. When vortices sink to the ground, they tend to move laterally with the wind
        - A crosswind will decrease lateral movement of the upwind vortex and increase movement of downwind vortex
            a Be cautious, this could move another aircraft's vortices into your path
        - A tailwind can move the vortices of a preceding aircraft forward into the touchdown zone

ii. Avoidance
    a. To minimize the chances of flying through another aircraft's wake:
        - Takeoff:
            a Takeoff prior to the point the preceding aircraft rotated, and attempt to climb above or away from their flight path
            b Takeoff after a landing jet's touchdown point
        - Enroute:
            a Avoid flying through another aircraft's flight path
            b Avoid following another aircraft on a similar flight path at an altitude within 1,000'
        - Landing:
            a Stay above a preceding aircraft's path, and land past their touch down point
            b Parallel runways – stay at and above the other jet's flight path for the possibility of drift
            c Crossing runways – cross above the larger jet's flight path
            d Land prior to a departing aircraft's takeoff point

E. For more information, see lesson VI.B. Traffic Patterns, Section 6.B.

Conclusion:
Brief review of the main points
The competent pilot must have a well-founded concept of the forces which act on the airplane, and the advantageous use of these forces, as well as the operating limitations of the particular airplane.

PTS Requirements:
To determine that the applicant exhibits instructional knowledge of the elements of principles of flight by describing:

1. Airfoil design characteristics.
2. Airplane stability and controllability.
3. Turning tendency (torque effect).
4. Load factors in airplane design.
5. Wingtip vortices and precautions to be taken.