II.D. Principles of Flight

References: FAA-H-8083-3; 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 correction or use of those forces in flight.

Key Elements
1. Stability vs. Maneuverability
2. Left Turning Tendency
3. Load Factors

Elements
1. Airfoil Design Characteristics
2. Controllability and Maneuverability
3. Stability
4. Turning Tendency
5. Load Factors and Airplane Design
6. Wingtip Vortices and Precautions to Take

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.
II.D. Principles of Flight

Instructors Notes:

Introduction:
Attention
Everything you ever wanted to know about the science of the airplane which will result in a considerably better understanding of the airplane and therefore 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 Characteristics
   A. Planform is the term that 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 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 roots stall first providing more warning and more control during recovery
      ii. Ellipse (Tapered)
         a. Provides the best spanwise 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 AR, 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
   D. Sweep - A line connecting the 25% chord points of all the ribs isn’t perpendicular to the longitudinal axis
      i. The sweep can be forward, but it is usually backward
      ii. Help in flying near the speed of sound but also contribute to lateral stability in low-speed planes

2. Controllability and Maneuverability
   A. Controllability - Capability to respond to the pilot's control especially in regard to flight path and attitude
      i. Quality of response to control application when maneuvering regardless of stability characteristics
   B. Maneuverability - Quality that permits a plane to be maneuvered easily and withstand stresses imposed
      i. Governed by the weight, inertia, size/location of flight controls, structural strength and powerplant
      ii. It is a design characteristic
3. Stability
   A. The inherent quality of an airplane to correct for conditions that may disturb its equilibrium, and return to or continue on the original flightpath (This tendency is primarily a design characteristic)
      i. In other words, a stable plane will tend to return to its original condition if disturbed
         a. Therefore, stability and maneuverability must be balanced
   B. There are two types of stability: Static and Dynamic
   C. Static Stability (SS)
      i. Equilibrium: All opposing forces are balanced (Steady unaccelerated flight conditions)
      ii. SS: The initial tendency that airplane displays after its equilibrium is disturbed
         a. Pos SS: The initial tendency to return to the original state of equilibrium after being disturbed
         b. Neg SS: The initial tendency to continue away from original equilibrium after being disturbed
         c. Neu SS: The initial tendency to remain in a new condition after equilibrium has been disturbed
      iii. Pos SS is the most desirable - The plane attempts to return to the original trimmed attitude
   D. Dynamic Stability (DS)
      i. SS refers to the initial response, DS describes how the system responds over time
         a. Refers to whether the disturbed system actually returns to equilibrium or not
         b. The degree of stability can be gauged in terms of how quickly it returns to equilibrium
         c. Referred to as Positive, Negative, and Neutral – Same as SS but over time (overall tendency)
      ii. DS can be further divided into oscillatory and non-oscillatory modes
         a. Oscillatory: Smooth bowl with a marble on the bottom – the system is in equilibrium
            • If moved up the side and let go (disturb equilibrium) it comes to rest after some oscillations
               a. Positive static and oscillatory positive dynamic stability
               • The longer the oscillations (time wise) the easier the plane is to control (long period > 10s)
               • The shorter oscillations, the more difficult, if not impossible, to control (short period <1-2s)
               • Neutral/Divergent short oscillation is dangerous as structural failure can result
         b. Non-Oscillatory: Do the same thing with a cotton ball, the ball simply returns with no oscillations
      iii. Most desirable is Positive Dynamic Stability
   E. Longitudinal Stability (LS)
      i. LS is the quality that makes an airplane stable about its lateral axis and involves the pitching motion
      a. LuS plane has a tendency to dive/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 initially balanced and the airplane is suddenly nosed up, the wing moments and tail moments will change so that the sum of their forces will provide an unbalanced but restoring moment which will bring the nose down again
         a. And, if the plane is nosed down, the resulting 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 CG
            • The CG is usually located ahead of the wing’s Center of lift resulting in nose down pitch
               a. This nose heaviness is balanced by a downward force generated by the horizontal tail
               1. The stronger down force is at CG and the other, a much lesser force, at T
               • Horiz stabilizer/elevator are cambered on the bottom to create tail down force (more curve)
               • If pitched up, the negative AOA of the stabilizer is reduced and increased drag reduces AS
                  a. Both of which reduce the tail-down force, allowing the plane to pitch down
               • As the plane pitches down, and accelerates, the increasing AOA and airflow at the horizontal tail increase the tail down force, raising the nose and reducing AS again
II. D. Principles of Flight

- After a series of progressively smaller oscillations, the plane returns to Straight and Level
- Location of the horizontal tail surfaces with respect to the CG
  - If the plane is loaded with the CG farther forward, more tail down force is necessary
    - 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
  - Small disturbances are opposed by larger forces, making them damp out quickly
- If the plane is loaded further aft, the plane becomes less stable in pitch
  - If CG is behind the CL, the tail must exert an upward force so the nose doesn’t pitch up
  - If a gust pitches the nose up, less airflow over the tail will cause the nose to pitch further
- This is an extremely dangerous situation
- The area or size of the tail surfaces

F. Lateral Stability (About the Longitudinal Axis)
  i. Lateral stability about the longitudinal axis is affected by:
    - 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
    - Dihedral involves a balance of lift created by the wings’ AOA on each side of the longitudinal axis
      - The airplane tends to sideslip or slide downward toward the lowered wing
      - Dihedral causes the air to strike the low wing at a greater AOA than the high wing
      - This increases the low wing lift/decreases high wing lift restoring the original attitude
    - Shallow turn: the increased AOA increases lift on the low wing with a tendency to return to S&L
  iii. Sweepback is the angle at which the wings are slanted rearward from the root tip
    - Sweepback increases dihedral to achieve stability, but the effect is not as pronounced
  iv. Keel effect depends on the action of the relative wind on the side area of the fuselage
    - Laterally stable airplanes are made the greater portion of the keel area is above/behind the CG
      - When the plane slips to one side, the combo of the plane’s weight and the pressure of the airflow against the upper portion of the keel area tends to roll the plane back to wings level
    - To Summarize: The fuselage is forced by keel effect to parallel the wind
  v. Weight Distribution
    - If more weight is located on one side, it will have a tendency to bank that direction

G. 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
    - Which make the airplane act like a weathervane, pointing its nose into the relative wind
  ii. SIDE - In order for a weathervane to work, a greater surface must be aft of the pivot point
    - Therefore the side surface must be greater aft than ahead of the CG
  iii. VERT FIN – the fin acts similar to the feather on an arrow in maintaining straight flight
    - The farther aft the fin is placed and larger its size, the greater the directional stability
    - Motion is retarded and stopped by the vert fin because as the plane rotates one way, the air is striking the other side at an angle
      - This causes pressure on the left side resisting the turn and slowing the yaw
      - It acts like the weathervane and turns the airplane into the relative wind

4. Turning Tendency (Torque Effect – Left Turning Tendency)
   A. Torque is made up of 4 elements which produce a twisting axis around at least 1 of the planes 3 axes
      i. Torque Reaction; Corkscrew Effect of the Slipstream; Gyroscopic Action of the Prop; P-Factor
   B. Torque Reaction
      i. Newton’s 3rd Law – For every action there is an equal and opposite reaction
        - Engine parts/prop revolve one way, an equal force attempts to rotate the plane the other way
      ii. When airborne, this force acts around the longitudinal axis, tending to make the airplane roll left
II. D. Principles of Flight

a. It is corrected by offsetting the engine, aileron trim tabs

iii. On the ground during T/O, 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
      • Magnitude is dependent on engine size/hp, prop size/rpm, plane size and ground surface

C. Corkscrew/Slipstream Effect
i. The high speed rotation of the prop gives a corkscrew/spiraling rotation to the slipstream
   ii. At high prop speeds/low forward speeds, 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

D. Gyroscopic Action
i. Gyroscopes are based on two fundamental principles:
   a. Rigidity in space
   b. Precession - The resultant action of a spinning rotor when a deflecting force is applied to its rim
      • If a force is applied, the resulting force takes effect 90° ahead of and in the direction of turn
         a. Causes a pitching/yawing moment or combo of the two depending on where applied
   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 necessary elevator and rudder pressures

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 prop disc area (causing a yaw to the left)
      b. To prove this it would be necessary to work wind vector problems which is crazy
   ii. Caused by the resultant velocity, which is generated by the combination of the prop blade velocity in its rotation and the velocity of the air passing horizontally through the prop disc
      a. At positive AOA, the R blade is passing through an area of resultant velocity greater than the L
      b. 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
   iii. EXAMPLE: Visualize the prop shaft mounted perpendicular to the ground (like a helicopter)
      a. If there were no air movement at all, except that generated by the prop, identical sections of the blade would have the same AS
      b. But, with air moving horizontally across the vert mounted prop, the blade proceeding forward into the flow of air will have a higher AS than the blade retreating
         • The blade proceeding is creating more lift or thrust, moving the center of lift toward it
      c. Visualize rotating the prop to shallower angles relative to the moving air (as on an airplane)
         • The unbalanced thrust gets smaller until it reaches zero when horizontal to the airflow

5. Load Factors (LF) and Airplane Design
A. LF - Force applied to an airplane to deflect its flight from a straight line produces a stress on its structure
   i. Load factor is the ratio of the total airload acting on the airplane to the gross weight of the airplane
      a. EX: a LF of 3 means that total load on the structure is 3x its gross weight, expressed as 3 G’s
         • Subjecting a plane to 3 G’s will result in being pressed into the seat by 3x the your weight

B. LF are important to the pilot for 2 distinct reasons
   i. Because of the obviously dangerous overload that is possible for a pilot to impose on the structure
   ii. Because an increased LF increases the stall speed and makes stalls possible at seemingly safe speeds

C. Airplane Design
II. D. Principles of Flight

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 to efficient, extremely abnormal loads must be dismissed
      • So, the problem becomes determining 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 these LF with no structural damage

ii. Airplane’s are now designed in accordance with the Category System
   a. Normal Category limit load factors are 3.8 G’s to -1.52 G’s
   b. Utility Category limit load factors are 4.4 G’s to -1.76 G’s (Mild acrobatics, including spins)
   c. Acrobatic Category limit load factors are 6.0 G’s to -3.0 G’s

iii. The more severe the maneuvers, the higher the load factors

D. The Vg diagram shows the flight operating strength of a plane that is valid for a certain weight/altitude
   i. It presents the allowable combination of AS and LF for safe operation

6. Wingtip Vortices and Precautions to Take

A. Whenever the wing is producing lift, pressure on the lower surface of the wing is greater than the upper
   i. The air tends to flow from the high pressure area below, upward to the low pressure area above
   ii. This causes a rollup of the airflow aft of the wing and swirling air masses trailing behind the wingtips
      a. After completed, the wake consists of 2 counter-rotating cylindrical vortices

B. The strength of the vortex is governed by the weight, speed, and shape of the wing
   i. The AOA directly affects the strength
      a. As weight increases, AOA increases
      b. A wing in the clean configuration has a greater AOA than with flaps
      c. As AS decreases, AOA increases
   ii. The greatest strength occurs when heavy, clean, and slow (during landing and T/O)

C. Behavior
   i. Remain spaced less than a wingspan apart, drifting with wind, greater than a wingspan AGL
   ii. Sink at a rate of several hundred fpm, slowing and diminishing the further behind the aircraft
   iii. When larger aircraft vortices sink to the ground (100/200’), they tend to move laterally (2-3 knots)
      a. A X-wind will decrease lateral movement of the upwind and increase movement of downwind
      b. A tailwind can move the vortices of the preceding AC forward into the touchdown zone

D. Avoidance
   i. Wake turbulence can be a hazard to any aircraft significantly lighter than the generating aircraft
      a. Could incur major structural damage, induced rolling is possible making the plane uncontrollable
   ii. Landing – Stay above/Land beyond the jet’s TD point and Land prior to another jet’s T/O point
      a. Parallel runways – stay at/above jets path for the possibility of drift
      b. Crossing runways – cross above the larger jet’s flightpath
   iii. T/O – T/O after another jet’s LDG point and T/O before and stay above another jet’s T/O path

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.
II.D. Principles of Flight

2. Airplane stability and controllability.
3. Turning tendency (torque effect).
4. Load factors in airplane design.
5. Wingtip vortices and precautions to be taken.
II.D. Principles of Flight

- **Damped Oscillation**
  - Time vs. Displacement
  - Positive Static (Positive Dynamic)

- **Unclamped Oscillation**
  - Time vs. Displacement
  - Positive Static (Neutral Dynamic)

- **Divergent Oscillation**
  - Time vs. Displacement
  - Positive Static (Negative Dynamic)

### Vertical Axis (Directional Stability)
- **Lateral Axis** (Longitudinal Stability)
- **Longitudinal Axis** (Lateral Stability)

### Table: Airplane Movement vs. Axes of Rotation and Type of Stability

<table>
<thead>
<tr>
<th>Airplane Movement</th>
<th>Axes of Rotation</th>
<th>Type of Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>Longitudinal</td>
<td>Lateral</td>
</tr>
<tr>
<td>Pitch</td>
<td>Lateral</td>
<td>Longitudinal</td>
</tr>
<tr>
<td>Yaw</td>
<td>Vertical</td>
<td>Directional</td>
</tr>
</tbody>
</table>

### Diagrams:
- Vertical and lateral axis illustrations
- Lateral and directional stability
- Airplane movement and axis interaction
- Diagrams of airplane orientation and forces

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7
II.D. Forces of Flight


Objectives  The student should become familiar with the four forces of flight.

Key Elements  1. Pilot Control of Lift
2. Parasite vs. Induced Drag
3. Ground Effect

Elements  1. Intro
2. Lift
3. Airfoils
4. Pilot Control of Lift
5. Weight
6. Thrust
7. Drag
8. Ground Effect
9. Climbs, Descents, and Turns

Schedule  1. Discuss Objectives
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Equipment  1. White board and markers
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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 displays the ability to explain the forces of flight and their interaction and affect on flight.
II. Forces of Flight

**Instructors Notes:**

**Introduction:**

**Attention**

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

**Overview**

Review Objectives and Elements/Key ideas

**What:**
The four forces of flight are in essence the fundamental principles that govern flight; they are what make an airplane fly.

**Why:**
How well a pilot performs in flight depends on the ability to plan and coordinate the use of power and flight controls for changing the forces of thrust, drag, lift, and weight. It is the balance between these forces that the pilot must always better control. The better the understanding of the forces, and means of controlling of them, the greater pilot’s skill will become.

**How:**

1. **Intro - Forces of Flight**
   A. Lift – The upward force created by the effect of airflow as it passes over and under the wing
   B. Weight – Opposes lift, and is caused by the downward pull of gravity
   C. Thrust – The forward force which propels the airplane through the air
   D. Drag – Opposes thrust, and is the backward, or retarding force, which limits the speed of the airplane

2. **Lift**
   A. The force that opposes weight
   B. Principles of Lift
      i. Newton’s three laws of motion:
         a. Newton’s 1st Law: A body at rest tends to remain at rest, and a body in motion tends to remain moving at the same speed and in the same direction
         b. Newton’s 2nd Law: When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force
            • The law may be expressed by the following formula: Force = Mass x Acceleration (F=ma)
         c. Newton’s 3rd Law: For every action, there is an equal and opposite reaction
      ii. Bernoulli’s Principle
         a. As the velocity of a fluid (air) increases, its internal pressure decreases

3. **Airfoils**
   A. Definition
      i. An airfoil is any surface, such as a wing, which provides aerodynamic force when it interacts with a moving stream of air
   B. Airfoils and Lift
      i. Circulation of the airstream about the airfoil is an important factor in the generation of lift
      ii. The wing’s shape is designed to take advantage of both Newton’s Laws and Bernoulli’s Principle
         a. The greater curvature on the upper portion causes air to accelerate as it passes over the wing
II.D. Forces of Flight

- According to Bernoulli, the increase in the speed of the air on the top of an airfoil produces a drop in pressure and this lowered pressure is a component of total lift
  a. Molecules moving over the upper surface are forced to move faster
  b. A downward-backward flow of air also is generated from the top surface of the wing
     - The reaction to this downwash results in an upward force on the wing (Newton’s 3rd Law)
  c. The action/reaction principle is also apparent as the airstream strikes the lower surface of the wing when inclined at a small angle (the angle of attack) to its direction of motion
     - The air is forced downward and therefore causes an upward reaction resulting in positive lift

4. Pilot Control of Lift
   A. Lift = \( \frac{1}{2} \rho v^2 C_L S \)
      i. \( \rho \) = Rho or a pressure constant
      ii. \( v \) = Velocity
      iii. \( C_L \) = Coefficient of Lift – A way to measure lift as it relates to the angle of attack
          a. Determined by wind tunnel tests and based on airfoil design and angle of attack
      iv. \( S \) = Surface Area (Constant)
   B. The amount of lift generated is controlled by the pilot as well as determined by aircraft design factors
      i. EX: You can change the AOA, the AS or you can change the shape of the wing by lowering the flaps
   C. Changing the Angle of Attack
      i. AOA - The angle between the chord line of the airfoil and the direction of the relative wind
      ii. Increasing the AOA increases the lift
          a. By changing pitch, you change the AOA of the wings, and at the same time the \( C_L \) is changing
   D. Changing Airspeed
      i. The faster the wing moves through the air, the greater the lift
          a. Lift is proportional to the square of the AS
             - EX: At 200 knots, an airplane has 4 times the lift of the same airplane traveling at 100 knot
               (if the angle of attack and other factors are constant)
             a. But, if the speed is reduced by ½, lift is decreased to ¼ of the previous value
   E. Angle of Attack and Airspeed
      i. The AOA establishes the \( C_L \) for the airfoil and lift is proportional to the square of the AS
          a. Since you can control both the AOA and the AS, you can control lift

5. Weight
   A. Definition
      i. The force of gravity which acts vertically through the center of the plane toward the center of earth
      ii. The combined load of the airplane itself, the crew, the fuel, and the cargo or baggage
   B. Weight pulls the airplane downward because of the force of gravity
   C. In stabilized level flight, when the lift = weight, the plane is in equilibrium and doesn’t gain/lose altitude
      i. If lift becomes less than weight, the airplane loses altitude and the other way around

6. Thrust
   A. Thrust is the forward-acting force which opposes drag and propels the airplane
      i. This force is provided when the engine turns the prop
      ii. Acts parallel to the longitudinal axis
      iii. \( F = MA \)
          a. Force is provided by the expansion of burning gases in the engine which turns the propeller
          b. A mass of air is accelerated opposite to the direction of the flight path (Newton’s 3rd Law)
             - The equal/opposite reaction is thrust, a force on the plane in the direction of flight
II.D. Forces of Flight

B. Thrust begins the airplane moving, it continues to move and gain speed until thrust and drag are equal
   i. In order to maintain a constant AS, thrust and drag must be equal
   ii. If thrust (power) is reduce the plane will decelerate as long as thrust is less than drag
       a. Likewise, if AS is increased, thrust becomes greater than drag and the AS increases until equal

7. Drag
   A. Definition
      i. Rearward, retarding force, caused by the disruption of airflow by the wing, fuselage, other objects
      ii. Drag opposes thrust, and acts rearward parallel to the relative wind
          a. Acts in opposition to the direction of flight, opposing the forward-acting force of thrust, and
             limits the forward speed of the airplane
   B. Two types of drag
      i. Parasite Drag
         a. Caused by an aircraft surface which deflects/interferes with the smooth airflow of the airplane
         b. Factors Influencing Parasite Drag
            • The shape of an object is a big factor
            • Indicated airspeed, however, is an equally important factor
      c. Three Types
         • Form Drag: Results from the turbulent wake caused by the separation of airflow from the
           surface of a structure (The amount is related to both the size and shape of the structure)
         • Interference Drag: Occurs when varied currents or air over an airplane meet and interact
           a. EX: Mixing of air over structures like wing and tail surface brace struts and gear struts
         • Skin Friction Drag: Caused by the roughness of the airplane’s surfaces
           a. A thin layer of air clings to these surfaces and creates small eddies which add to drag
      d. Parasite Drag and Airplane Speed
         • The combined effect of all parasite drag varies proportionately to the square of the airspeed
           a. EX: Plane, at a constant altitude has 4x as the parasite drag at 160 knots than at 80 knots
      ii. Induced Drag
         a. Systems in General
            • Physical fact that no system, doing work in the mechanical sense, can be 100% efficient
               a. Whatever the nature of the system, the required work is obtained at the expense of
                  certain additional work that is dissipated or lost in the system
               b. The more efficient the system, the smaller the loss
         b. The Wing as a System
            • In level flight, the aerodynamic properties of the wing produce a desired lift, but this is
              obtained at the expense of a penalty
            • The penalty in this case is Induced Drag
              a. Induced drag is inherent whenever lift is produced
            How it Works
               • When lift is produced, the pressure on the lower surface is greater than the upper surface
               a. The air flows from the high pressure area below the wingtip upward to the low pressure
               • The high pressure air beneath the wing joins the low pressure air above the wing at the
                 trailing edge and wingtips causing a spiral or vortex which trails behind each wingtip
               a. The spiral is a lateral flow outward from the underside to the upper surface of the wing
               b. Basically, induced drag is made by the air circulation around the wing as it creates lift
               • There is an upward flow of air beyond the wingtip and a downwash behind the trailing edge
               a. The downwash has nothing to do with the downwash necessary to produce lift
II. D. Forces of Flight

1. It is the source of induced drag
   a. Vortices increase drag because of the energy spent in producing the turbulence

   - Downwash – The Source
     a. The vortices deflect the airstream downward, creating an increase in downwash
     1. The wing operates in an average relative wind which is inclined downward and rearward near the wing
     b. Because the lift produced by the wing is perpendicular to the relative wind, the lift is inclined aft by the same amount, reducing it
     c. The greater the size and strength of the vortices, and therefore the downwash component, the greater the induced drag becomes

   - The lower the AS, the greater the AOA required to produce lift equal to the airplane’s weight and, the greater the induced drag
     a. Induced drag varies inversely as the square of the airspeed

iii. Total Drag
   a. Total drag is the sum of induced and parasite drag

8. Ground Effect
   A. Associated with the reduction of induced drag
   B. Explanation
     i. During takeoff/landing when you are flying very close to the ground, the earth’s surface actually alters the three-dimensional airflow pattern around the airplane because the vertical component of the airflow around the wing is restricted by the ground surface
     a. This causes a reduction in wingtip vortices and a decrease in upwash and downwash
     b. Since ground effect restricts downward deflection of the airstream, induced drag decreases

   C. Effects on Flight
     i. Takeoff
        a. With the reduction of induced drag, the amount of thrust required to produce lift is reduced
        • Therefore, the airplane is capable of lifting off at lower than normal takeoff speed
        b. As you climb out of ground effect, the power (thrust) required to sustain flight increases significantly as the normal airflow around the wing returns and induced drag is increased
        • If you climb out before reaching the normal takeoff speed you might sink back to the surface

     ii. Landing
        a. The decrease in induced drag makes the airplane seem to float
        • Power reduction is usually required during the flare to help the airplane land

9. Climbs, Descents, and Turns
   A. Climbs
     i. In a steady state, normal climb the wings lift is the same as it is in steady level flight at the same AS
        a. Though the flight path has changed when the climb has been established, the AOA of the wing with respect to the inclined flight path reverts to practically the same values, as does lift
     ii. There is an initial, momentary change, however, when back pressure is first applied

   B. Descents
   C. Turns

Conclusion:
Brief review of each main point

PTS Requirements:
II.D. Forces of Flight

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.
II.D. Forces of Flight

[Diagram showing forces of flight: Lift, Drag, Weight, and Thrust]

[Graph showing drag forces: Total Drag, Parasite Drag, Induced Drag]

[Three images showing flight path with different angles: Level (High Speed), Level (Cruise Speed), Level (Low Speed)]

[Vortices fully formed at altitude, vortices "compressed" near the ground, vortices "blocked" by the ground]

[Diagram showing airflow above and below the wing and air spoilage]
II.D. Forces in Flight Maneuvers

References: FAA-H-8083-25

Objectives The student should become familiar with the forces of flight maneuvers and stalls.

Key Elements 1. Result of a Force
2. Weight Vector
3. Centrifugal Force

Elements 1. Climbs
2. Descents
3. Turns
4. Stalls

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 displays the ability to explain the forces of flight maneuvers and their affects.
II.D. Forces in Flight Maneuvers

Instructors Notes:

1. Climbs
   A. In a steady state, normal climb the wings lift is the same as it is in steady level flight at the same AS
      i. Though the flight path has changed when the climb has been established, the AOA of the wing with
         respect to the inclined flight path reverts to practically the same values, as does lift
   B. During the change from S&L to a climb a change in lift occurs when back elevator is 1st applied
      i. Raising the airplane’s nose increases the AOA and momentarily increases lift
      ii. Lift at this moment is now greater than weight and starts the airplane climbing
   C. Once the flight path is stabilized, the AOA and lift revert to approx level flight values
   D. If the climb is entered with no change in power settings, the AS gradually diminishes
      i. This is because thrust required to maintain an AS in level flight cannot maintain the AS in a climb
      ii. When inclined upward, a component of weight acts in the same direction as, and parallel to drag
         a. This increases drag (Drag is greater than thrust and therefore AS will decrease until equal)
   E. Since, in a climb, weight is not only acting downward but rearward along with drag, additional power is
      needed to maintain the same AS as in level flight
      i. The amount of reserve power determines the climb performance

2. Descents
   A. When forward pressure is applied, the AOA is decreased and, as a result, the lift of the airfoil is reduced
      i. Reduction in lift/AOA is momentary and occurs during the time the flight path changes downward
      ii. The change to a downward flight path is due to the lift momentarily becoming less than the weight
         of the airplane as the AOA is reduced
   B. When the flight path is in a steady descent, the airfoil’s AOA again approaches the original value and lift
      and weight become stabilized
   C. From the time the descent is started until it is stabilized, the AS will gradually increase
      i. This is due to a component of weight acting forward along the flightpath (like rearward in a climb)
         a. Thrust is greater than drag
   D. To descend at the same AS, power must be reduced when the descent is entered
      i. The amount of power is dependent on the steepness of the descent
         a. The component of weight acting forward will increase with an increase in angle of descent

3. Turns
   A. Like any moving object, an airplane requires, a sideward force to make it turn
      i. In a normal turn, this force is supplied by banking so that lift is exerted inward as well as upward
   B. When the airplane banks, lift acts inward toward the center of the turn, as well as upward
      i. Lift is divided into two components, the horizontal component and the vertical component
         a. Vertical Component – Acts vertically and opposite to weight
         b. Horizontal Component – Acts horizontally toward the center of the turn (Centripetal Force)
            i. This is what makes the airplane turn, it is the force that pulls the airplane, making it turn
      ii. The division of lift reduces the amount of lift which opposes gravity and supports weight
         a. Consequently, the airplane will lose altitude unless additional lift is created
            i. This is done by increasing the AOA until the vertical component of lift again is equals weight
         b. Since the vertical component of lift decreases as bank increases, the AOA must be progressively
            increased as the bank angle is steepened
II.D. Forces in Flight Maneuvers

C. Rate of Turn
   i. The rate at which an airplane turns depends on the magnitude of the horizontal component of lift
      a. And, the horizontal component of lift is proportional to the angle of bank
   ii. Therefore, at any given AS, the rate of turn can be controlled by adjusting the angle of bank

D. Holding Altitude
   i. To provide a vertical component of lift sufficient to hold altitude, an increase in the AOA is required
   ii. Since drag is directly proportional to its AOA, induced drag will increase as lift is increased
      a. This in turn, causes a loss of AS in proportion to the angle of bank
   iii. Additional power must be applied to prevent airspeed from reducing in level turns
      a. The required amount of additional thrust is proportional to the angle of bank

E. Turning Radius
   i. Increased AS results in an increase in turn radius and centrifugal force is directly related to radius
      a. The increase in the radius of the turn causes an increase in centrifugal force which must be
         balanced by an increase in the horizontal component of lift
      • The horizontal component of lift can only be increased by increasing bank angle
   ii. To maintain a constant rate of turn with an increased AS, the AOA must remain and the angle of
       bank must be increased

F. Slipping Turns
   i. In a slipping turn, the rate of turn is too slow for the angle of bank since the plane is yawed to the
      outside of the turning flight path
      a. The horizontal component of lift is greater than CF
   ii. \( H_{CL} \) and centrifugal force equilibrium is reestablished by decreasing bank/increasing the rate of turn

G. Skidding Turns
   i. In a skidding turn, the rate of turn is too great for the angle of bank and the plane is yawed inside
      a. There is excess centrifugal force over the \( H_{CL} \)
   ii. Correction involves reducing the rate of turn/increasing the bank

4. Stalls
   A. As long as the wing is creating sufficient lift to counteract the load imposed on it, the plane will fly
      i. When the lift is completely lost, the airplane will stall
   B. The direct cause of every stall is an excessive angle of attack
   C. The stalling speed of a particular airplane is not a fixed value for all flight situations
      i. However, a given airplane will always stall at the same AOA regardless of the speed, weight, load
         factor, or density altitude
      ii. Each plane has a particular AOA where airflow separates from the upper wing and it stalls (16°-20°)
   D. 3 situations where the critical AOA can be exceeded:
      i. Low Speed Flying
         a. As AS is being decreased, the AOA must be increased to retain the lift required to hold altitude
         b. The slower the AS, the more AOA must be increased until the airplane cannot be supported
            • If AS is reduced further, the airplane will stall, since the AOA has exceeded the critical angle
      ii. High Speed Flying
         a. Low speed is not necessary to produce a stall
         b. The wing can be brought to an excessive angle of attack at any speed
         c. EX: diving at 200 knots with a sudden increase in back elevator pressure
            • Because of gravity and centrifugal force, the plane can not immediately alter its flight path
            a. It would merely change its AOA abruptly from very low to very high
II.D. Forces in Flight Maneuvers

- Since the flight path of the airplane in relation to the oncoming air determines the direction of the relative wind, the AOA is increased, and the stalling angle would be reached

iii. Turning Flight
   a. The stalling speed of an aircraft is higher in a level turn than in straight and level flight
      - This is because the centrifugal force is added to the plane’s weight
         a. The wing must produce sufficient additional lift to counteract the load imposed
   b. In a turn, the necessary additional lift is acquired by applying back pressure
      - This increases the wing's AOA (The AOA increases with the bank angle)
   c. If at any time during a turn the AOA becomes excessive, the airplane will stall

**Conclusion:**
Brief review of each main point

**PTS Requirements:**
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II.D. Forces in Flight Maneuvers

CLIMBS

TURN S