I.F. Performance and Limitations

References: Weight and Balance Handbook (FAA-H-8083-1), Airplane Flying Handbook (FAA-H-8083-3), Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25), Risk Management Handbook (FAA-H-8083-2), POH/AFM

KNOWLEDGE

The applicant demonstrates understanding of:

1. **Preflight Action Requirements** (this is not part of the ACS, but it is applicable and important to this section)
   - A. FAR 91.103: Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. This information must include:
     - i. For a flight under IFR or a flight not in the vicinity of an airport, weather reports and forecasts, fuel requirements, alternatives available if the planned flight cannot be completed, and any known traffic delays of which the pilot in command has been advised by ATC;
     - ii. For any flight, runway lengths at airports of intended use, and the following takeoff and landing distance information:
       - a. For civil aircraft for which an approved Airplane or Rotorcraft Flight Manual containing takeoff and landing distance data is required, the takeoff and landing distance data contained therein; and
2. **Performance and Limitations Charts**
   - A. Airplane performance is found in Section 5 of the POH (Performance and Limitations)
     - i. Supplement 4, for the DA20 (any charts not shown in the supplement are found in Chapter 5)
   - B. Using the performance charts, and the accompanying instructions, we can calculate
     - i. Cruise Performance
     - ii. Stall Speeds based on airplane configuration
     - iii. Wind Components (Crosswind and Headwind)
     - iv. Takeoff Distance and Landing Distance
     - v. Climb Performance (In cruise and takeoff configurations as well as Balked Landing)
     - vi. True Airspeed
     - vii. Maximum Flight Duration (Chart in which the Pressure Altitude is combined with RPM to find % bhp, KTAS, GPH)
   - C. In order to make use of these charts we need to know the Pressure Altitude (PA)
     - i. Pressure Altitude – The altitude indicated when the altimeter setting window is set to 29.92
       - a. PA = 1,000(29.92-Current Altimeter Setting) + Elevation
         - EX: Altimeter = 30.42 and Elevation = 808, so PA = 308'
         - EX: Altimeter = 29.84 and Elevation = 808, so PA = 888'
     - ii. From Pressure Altitude we can compute Density Altitude (DA)
       - a. DA: Pressure Altitude corrected for non-standard temperature (Directly related to airplane performance)
       - b. DA = 120(Current Temperature-15°C) + PA
         - EX: Temp = 23°C and PA = 308', so DA = 1,268'
         - EX: Temp = 03°C and PA = 308', so DA = -1,132
         - This is a good estimate of DA, the equation is not perfect
   - D. Using the Charts (This is tailored to the Diamond 20 Performance Charts)

i. Using the Pressure Altitude, start at the temperature at the bottom of the chart and move up to the PA
    a. From there, move straight across until reaching the next stage of the chart
        - Once you reach the next step, mirror the trend line and then move straight across to the next stage of the chart

ii. This is done until we reach the performance number

E. How the Charts Work
    i. The charts take into account the various factors that affect the performance criteria you're trying to obtain
        a. EX: On takeoff, the chart requires, the temperature, pressure altitude, weight, wind (head or tailwind), etc.
    ii. The charts also represent how each factor affects the performance criteria
        a. EX: For takeoff, a headwind will decrease the amount of runway required, and a tailwind will increase the amount of runway required for takeoff

3. Factors Affecting Performance

A. Atmospheric Conditions
    i. General
        a. Though air is light, it has mass and is affected by gravity and therefore, it has a force
        b. Under standard conditions at sea level, the average pressure exerted is approximately 14.7 pounds per square inch
        c. Since air is a gas, it can be compressed or expanded
        d. The density of the air has significant effects on the airplane's performance
            - As the density of the air increases (high air pressure), airplane performance increases and vice versa
    ii. What Changes Air Density?
        a. Barometric Pressure, Temperature, Altitude, and Humidity all affect air density
            - Density varies directly with pressure - As pressure increases, density increases and vice versa
            - Density varies inversely with temperature – As temp increases, density decreases and vice versa
            - Density varies inversely with altitude - As altitude increases, density decreases and vice versa
            - Density varies inversely with humidity – As humidity increases, density decreases and vice versa
                a In simple terms, the reason for this is that Oxygen molecules (O_2) are being replaced with water molecules (H_2O). Hydrogen is considerably lighter than oxygen. By replacing oxygen with hydrogen, the density of the air decreases
    iii. How it affects Performance
        a. As the air becomes less dense, it reduces:
            - Power since the engine takes in less air
                a Power is produced in proportion to air density (As density increases, power does too)
            - Thrust since the propeller is less effective in thin air
                a Thrust is produced in proportion to the mass of air being accelerated, less dense air means less air being accelerated
            - Lift because the thin air exerts less force on the airfoils
                a As air density decreases, the lift efficiency of the wing is decreased

iv. Leaning the Engine
    a. At power settings less than 75% or at Density Altitudes > 5,000' the engine must be leaned for max power on takeoff
        - An excessively rich mixture deters engine performance
        - Less dense air needs less fuel
    b. At higher elevations, high temperatures may have such an effect on density altitude that safe operations may not be possible
        - Even at lower temperatures with excessive humidity, performance can be marginal, and weight may need to be reduced

B. Pilot Technique
    i. Different techniques can change aircraft performance
        a. EX: Climbing at speeds other than what is recommended in the POH
            - This negates any climb performance data you may have calculated from the charts
    ii. A simple way to fix this is to fly by the book – the charts are designed based on specific aircraft configurations and speeds; fly those!

C. Aircraft Configuration
    i. The configuration of the aircraft can have a large effect on performance
        a. Gear, whether retracted or extended, can significantly influence drag
        b. Flaps increase lift but also increase drag. Different flap settings may have larger effects on lift and/or drag influencing the aircraft's performance
        c. Use the charts and information in the POH to determine the aircraft's performance capabilities in various configurations

D. Airport Environment
    i. Different airport environments can affect the performance of the aircraft in various ways
        a. Inclined or declined runways can adjust takeoff and landing distance
        b. Hills, mountains, trees, buildings, etc. can affect wind patterns creating changing winds and at times up or down drafts
        c. High altitude airports greatly decrease performance
            - Also, at high altitudes, true airspeed is increased. Even though you're flying an approach at a normal indicated airspeed, you are moving much faster than you would be at sea level. This greatly affects landing distances

E. Effects of Loading on Performance
    i. Weight and Flight Performance
        a. A heavier gross weight will result in:
            - Higher takeoff speed, longer takeoff run, reduced rate and angle of climb, lower maximum altitude, shorter range, reduced cruise speed, reduced maneuverability, higher stall speed, higher approach and landing, longer landing roll, excessive weight on the nose or tail wheel
            - Climb and cruise performance is reduced which can lead to:
                a Overheating in climbs, added wear on engine, and increased fuel use
    ii. Weight and Structure
        a. Structural failures which result from overloading may be catastrophic but they often affect structure progressively making it difficult to detect or repair
        b. An airplane is certified to withstand certain loads on its structure based on the category
            - As long as gross weight and load factors limits are observed, the total load will remain in limits

- If the max gross weight is exceeded, load factors within the load factor limits can cause damage

c. The results of routine overloading are cumulative and may result in failure later during normal ops

F. Effects of Weight and Balance
   i. A stable and controllable plane may have very different characteristics when overloaded
      a. Weight distribution has the most effect, but gross weight also adversely affects stability
   ii. An airplane with forward loading
      a. The aircraft acts heavier than it actually is, and consequently slower than the same airplane with a further aft center of gravity
         - Nose up trim is needed which requires the tail surfaces to produce a greater down force. This adds to the wing loading, increasing the total lift required from the wings
      b. Requires a higher angle of attack, which results in more drag and, in turn, produces a higher stalling speed
      c. The airplane is more controllable (the longer arm from the CG makes the elevator more effective) – More below in Part E
   iii. An airplane with aft loading
      a. With aft loading, the aircraft acts lighter than it actually is
      b. The aircraft requires less nose down force allowing for a faster cruise speed
         - Faster cruise because of the reduced drag (smaller angle of attack and less down deflection of stabilizer)
         - The tail surface is producing less down force, relieving the wing of loading and lift which results in a lower stall speed
            a Although the stall speed is lower, recovery from a stall becomes progressively more difficult as the center of gravity moves aft
   iv. The CG and the Lateral Axis
      a. Unbalanced lateral loading (more weight on the right or left side of the aircraft centerline) may result in adverse effects
         - This can be caused by: fuel imbalance, people, baggage, etc.
      b. Compensate for any imbalance with trim (if available), or constant control pressure
         - This places the aircraft in an out-of-streamline condition, increasing drag, and decreasing efficiency
   v. Weight and Controllability
      a. Generally, an airplane becomes less controllable as the center of gravity moves aft
         - The elevator has a shorter arm and requires greater deflection for the same result
         - Stall recovery is more difficult because the plane's tendency to pitch down is reduced
            a If the center of gravity moves beyond the aft limit, stall and spin recovery may become impossible
      b. As the center of gravity moves forward, the airplane becomes more nose-heavy
         - Although the aircraft is more controllable, since the arm between the center of gravity and elevator is larger, the aircraft may become so nose heavy that the elevator may not be able to hold up the nose, particularly at low airspeeds (takeoff, landing, glides)
            a On landing the elevator may not be able to produce sufficient force to lift the nose wheel during the flare, in extreme cases a safe landing could be impossible

G. Effects of Weight and Balance over the course of the Flight

i. During the flight the weight and balance of the aircraft will change based on any weight that is moved or lost
    a. The most common example is the en route fuel burn
        - As fuel is burned, weight is lost in the fuel tanks and the center of gravity will change
            a Whether it moves forward or backward depends on the aircraft you're flying and the location of the fuel tanks
        - In order to compensate for the changing fuel, calculate the center of gravity at the fuel level for departure, and calculate the center of gravity with empty tanks
            a If the center of gravity stays within limits throughout the transition from full (or departure level) tanks to empty tanks, there will be no center of gravity problem en route
    b. If for any reason the weight or balance will change en route (EX: passengers, baggage, fuel etc.) ensure the center of gravity remains within limits in order to preclude a potential loading emergency in flight

4. Aerodynamics

A. Airfoil Design Characteristics
- i. Planform is the term that describes the wings outline as seen from above
    - a. 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.
    - b. There are many different shapes and advantages/disadvantages to each (many shapes are combined)
- ii. Taper – The ratio of the root chord to the tip chord
    - a. Rectangular wings have a taper ratio of 1
        - Simpler and more economical to produce and repair (ribs are same size)
        - The root stalls first providing more warning and control during recovery
    - b. Ellipse (Tapered)
        - Provides the best span wise load distribution and lowest induced drag
        - But, the whole wing stalls at the same time and they are very expensive/complex to build
- iii. Aspect Ratio – divide the wingspan by the average chord
    - a. The greater the aspect ratio, the less induced drag (more lift)
    - b. Increasing wingspan (with the same area) results in smaller wingtips, generating smaller vortices
        - Reduces induced drag and are more efficient
        - Planes requiring extreme maneuverability and strength have much lower aspect ratios
            - a Ex: Fighter, and aerobatic aircraft
- iv. Sweep – When the line connecting the 25% chord points of the ribs isn't perpendicular to the longitudinal axis
    - a. The sweep can be forward, but it is usually backward
    - b. Help in flying near the speed of sound but also contributes to lateral stability in low-speed planes

B. Airplane Stability and Controllability
- i. Controllability - Capability to respond to the pilot's control especially in regard to flight path and attitude

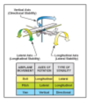
    a. Quality of response to control application when maneuvering regardless of stability characteristics

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

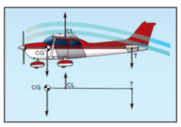
iii. Stability
    a. The inherent quality of an airplane to correct for conditions that may disturb its equilibrium, and return to or continue on the original flight path (This tendency is primarily a design characteristic)
        - In other words, a stable plane will tend to return to its original condition if disturbed
            a The more stability, the easier to fly, but too much results in significant effort to maneuver
                1. Therefore, stability and maneuverability must be balanced
    b. There are two types of stability: Static and Dynamic
    c. Static Stability (SS)
        - Equilibrium: All opposing forces are balanced (Steady un-accelerated flight conditions)
        - SS: The *initial tendency* that airplane displays after its equilibrium is disturbed
            a Positive SS: The initial tendency to return to the original state of equilibrium after being disturbed (to return to the trimmed condition)
            b 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)
            c 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)
        - Positive SS is the most desirable - The plane attempts to return to the original trimmed attitude
    d. Dynamic Stability (DS)
        - SS refers to the initial response, DS describes how the system responds over time
            a Refers to whether the disturbed system returns to equilibrium over time 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)
        - 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
                1. 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
                2. The longer oscillations (time), the easier the plane is to control (long period > 10 sec)
                3. The shorter oscillations, the more difficult, to control (short period < 1-2 sec)

    4. Neutral/Divergent short oscillation is dangerous as structural failure can result
  b Non-Oscillatory: Do the same thing with a cotton ball, it simply returns with no oscillations
- Most desirable is Positive Dynamic Stability

e. Longitudinal Stability (LS)



- 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
- 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 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
- Static LS or instability is dependent on 3 factors:



  a Location of the wing in relation to the Center of Gravity (CG)
    1. The CG is usually ahead of the wing's Center of Lift (CL) resulting in nose down pitch
    2. 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)
    3. 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)
    4. 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 diminish until the aircraft returns to stabilized flight.
  b Location of the horizontal tail surfaces with respect the CG
    1. 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
          i. Any small disturbances are opposed by larger forces, dampening them quickly
    2. 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 an 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

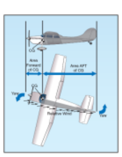
c The area or size of the tail surfaces
1. The larger the area/size of the tail surface, the more force exerted

f. Lateral Stability (About the Longitudinal Axis)

- Lateral stability about the longitudinal axis is affected by:
  - a Dihedral; Sweepback Angles; Keel Effect; Weight Distribution
- Dihedral is the angle at which the wings are slanted upward from the root to the tip
  - a Dihedral balances lift created by the wings' AOA on each side of the longitudinal axis
    1. The airplane tends to sideslip or slide downward toward the lowered wing
    2. Dihedral causes the air to strike the low wing at a greater AOA than the high wing
    3. This increases the low wing lift/decreases high wing lift restoring the original attitude
  - b Shallow turn: the increased AOA increases lift on the low wing with a tendency to return the aircraft to Straight and Level flight
- Sweepback is the angle at which the wings are slanted rearward from the root tip
  - a Sweepback increases dihedral to achieve stability, but the effect is not as pronounced
- 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
    1. 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 rolls the plane back to wings level
  - b To Summarize: The fuselage is forced by keel effect to parallel the wind
- Weight Distribution
  - a 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)

- 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
- SIDE - For a weathervane to work, a greater surface area must be aft of the pivot point
  - a Therefore, the side surface must be greater aft of the CG than ahead of the CG
  - b 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



- 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

1. This puts pressure on vertical fin stopping the motion and then returning the nose into the relative wind (like a weathervane)
2. Ex: If the nose yaws right, the relative wind puts pressure on the left side of the vertical stabilizer stopping the movement and moving the nose of the aircraft back to the left

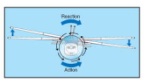
C. Turning Tendency (Torque Effect – Left Turning Tendency)

i. Torque is made up of 4 elements which produce a twisting axis around at least 1 of the planes 3 axes

a. Torque Reaction, Corkscrew Effect of the Slipstream, Gyroscopic Action of the Prop, and P-Factor

ii. Torque Reaction

a. Newton's 3rd Law – For every action there is an equal and opposite reaction



- The engine parts/propeller rotate one way; an equal force attempts to rotate the plane the opposite direction

b. When airborne, this force acts around the longitudinal axis, resulting in a left rolling tendency

c. On the ground, during takeoff, the left side is being forced down resulting in more ground friction

- This causes a turning moment to the left that is corrected with rudder

a Strength is dependent on engine size/hp, propeller size/rpm, plane size and ground surface

1. The higher the power setting, the greater the left turning tendency

d. Torque is corrected by offsetting the engine, and using aileron trim tabs, and aileron/rudder use

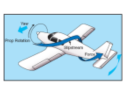
- Most aircraft engines are not installed on the centerline of the aircraft (on the longitudinal axis), they are offset in order to counteract a portion of the rolling motion caused by torque
- Trim tabs can be adjusted to counter the turning tendency in level flight
- Torque not countered by the engine and trim tab position must be corrected with coordinate rudder and aileron inputs

iii. Corkscrew/Slipstream Effect

a. The high-speed rotation of the propeller sends the air in a corkscrew/spiraling rotation to the rear of the aircraft

- The air strikes the left side of the vertical stabilizer, pushing the nose of aircraft left

b. At high prop speeds/low forward speeds the rotation is very compact



- This exerts a strong sideward force on the vertical tail causing a left turn around the vertical axis
- The corkscrew flow also creates a rolling moment around the longitudinal axis

a The rolling moment is to the right and may counteract torque to an extent

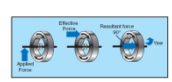
c. As the forward speed increases, the spiral elongates and becomes less effective

d. The slipstream effect is countered with coordinate rudder and aileron and is most pronounced in climbs (high prop speed and low forward speed)

iv. Gyroscopic Action

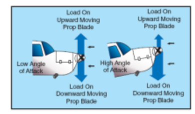
a. Gyroscopes are based on two fundamental principles:

- Rigidity in space (not applicable to this discussion)



- Precession - The resultant action of a spinning rotor when a force is applied to its rim
    - a If a force is applied, it takes effect 90º ahead of, and in the direction of turn
        1. This causes a pitch/yaw moment or combo of the two depending on where applied
        2. Ex: This most often occurs with tail wheel aircraft when the tail is being 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
                i. This force is felt 90º in the direction of rotation (clockwise as viewed from the cockpit)
            b. The forward force will take effect on the Right side of the propeller, yawing the aircraft Left

b. Any yawing around the vertical axis results in a pitching moment
c. Any pitching around the lateral axis results in a yawing moment
d. Correction is made with necessary elevator and rudder pressures



v. Asymmetric Loading (P Factor)
    a. When flying with a high AOA, the bite of the down moving blade is greater than the up moving blade
        - This moves the center of thrust to the right of the propeller disc area (causing a yaw to the left)
    b. This is 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
        - At positive AOA, the R blade is passing through an area of resultant velocity greater than the L
        - Since the prop is an airfoil, increased velocity means increased lift
            - a Therefore, the down blade has more lift and tends to yaw the plane to the left
    c. EXAMPLE: Visualize the prop shaft mounted perpendicular to the ground (like a helicopter)
        - If there were no air movement at all, except that generated by the prop, identical sections of the blade would have the same airspeed
        - 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
            - a The blade proceeding is creating more lift or thrust, moving the center of lift toward it
        - Visualize rotating the prop to shallower angles relative to the moving air (as on an airplane)
            - a The unbalanced thrust gets smaller until it reaches zero when horizontal to the airflow
    d. 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

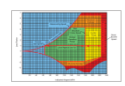
D. Load Factors (LF) in Airplane Design
    i. LF – The force applied to an aircraft to deflect its flight from a straight line that produces a stress on its structure

a. Load factor is the ratio of the total air load acting on the airplane to the gross weight of the airplane
   - EX: a LF of 3 means that total load on the structure is 3x its gross weight; expressed as 3 G's
     a Subjecting a plane to 3 G's will result in being pressed into the seat by 3x your weight

ii. LF is important to the pilot for two distinct reasons
   a. The obviously dangerous overload that is possible for a pilot to impose on the structure
      - An excessive load can result in the structural failure of an aircraft
   b. An increased LF increases the stall speed and makes stalls possible at seemingly safe speeds

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

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



E. Wingtip Vortices and Precautions to be Taken

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

ii. The strength of the vortex is governed by the weight, speed, and shape of the wing
   a. The AOA directly affects the strength
      - 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
   b. The greatest vortex strength occurs when heavy, clean, and slow (during takeoff and landing)
      - The wake of these vortices can be very dangerous and impose rolling moments exceeding the roll authority of the encountering aircraft

iii. Vortices 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 X-wind will decrease lateral movement of the upwind and increase movement of downwind
            a Be cautious, this could move another aircraft's vortices into your path
        - A tailwind can move the vortices of the preceding aircraft forward into the touchdown zone

iv. Avoidance
    a. Wake turbulence can be a hazard to any aircraft significantly lighter than the generating aircraft
        - Could result in major structural damage, or induced rolling making the aircraft uncontrollable
    b. Landing – Stay above and land beyond a landing jet's touchdown point; land prior to a departing jet's takeoff point
        - Parallel runways – stay at and above the other jet's flight path for the possibility of drift
        - Crossing runways – cross above the larger jet's flight path
    c. Takeoff – Takeoff after a landing jet's touchdown point, and takeoff before and stay above another departing jet's path

F. Forces of Flight
    i. Lift – The upward force created by the effect of airflow as it passes over and under the wing
    ii. Weight – Opposes lift, and is caused by the downward pull of gravity
    iii. Thrust – The forward force which propels the airplane through the air
    iv. Drag – Opposes thrust, and is the backward, or retarding force, which limits the speed of the airplane
    v. Terminology:
        a. Chord Line: The imaginary straight line joining the leading and trailing edges of an airfoil
        b. Relative Wind: The direction of movement of the wind relative to the aircraft's flight path. It is opposite the aircraft's flight path, and irrespective of the angle of attack
            - EX: Straight and level slow flight and high-speed flight have the same relative wind
        c. Angle of Attack: The angle between the chord line and the relative wind

G. Lift
    i. The force that opposes weight
    ii. Principles of Lift
        a. Newton's three laws of motion:
            - 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
            - 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
                a The law may be expressed by the following formula: Force = Mass x Acceleration (F=ma)
            - Newton's 3rd Law: For every action, there is an equal and opposite reaction
        b. Bernoulli's Principle
            - As the velocity of a fluid (air) increases, its internal pressure decreases

H. Airfoils
    i. Definition
        a. An airfoil is any surface, such as a wing, which provides aerodynamic force when it interacts with a moving stream of air
    ii. Airfoils and Lift
        a. Circulation of the airstream about the airfoil is an important factor in the generation of lift
        b. The wing's shape is designed to take advantage of both Newton's Laws and Bernoulli's Principle
            - The greater curvature on the upper portion causes air to accelerate as it passes over the wing
                a 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 results in lift
                    1. Molecules moving over the upper surface are forced to move faster
                        a. Since the upper molecules travel a greater distance, pressure is reduced above
            - A downward-backward flow of air also is generated from the top surface of the wing
                a The reaction to this downwash results in an upward force on the wing (Newton's 3rd Law)
            - 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
                a The air is forced downward and therefore causes an upward force resulting in positive lift

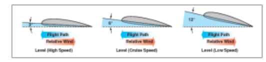
I. Pilot Control of Lift
    i. Lift = ½ pC_Lv^2S (Memory Aid: **½ P**int, **C**hug a $_L$iter, **V**omit **twice**, **S**leep it off)
        a. P = Rho or a pressure constant
        b. C_L = Coefficient of Lift – A way to measure lift as it relates to the angle of attack
            - Determined by wind tunnel tests and based on airfoil design and angle of attack
        c. V = Velocity
        d. S = Surface Area
            - We'll assume the surface area is a constant for our conversation, although surface area can be changed by the pilot in aircraft with flaps/slats that extend and retract
    ii. The amount of lift generated is controlled by the pilot as well as determined by aircraft design factors
        a. The pilot can change the Angle of Attack (AOA), the airspeed (AS) or you can change the shape of the wing by lowering the flaps
    iii. Changing the Angle of Attack
        a. AOA - The angle between the chord line of the airfoil and the direction of the relative wind
        b. Increasing the AOA increases lift
            - By changing pitch, you change the AOA of the wings, and at the same time the coefficient of lift (C_L) is changing
    iv. Changing Airspeed
        a. The faster the wing moves through the air, the more lift is produced
            - Lift is proportional to the square of the airspeed

- a EX: At 200 knots, an airplane has 4 times the lift as if it was traveling at 100 knots (if other factors remain constant)
  1. But, if the speed is reduced by ½, lift is decreased to ¼ of the previous value

v. Angle of Attack and Airspeed

a. The AOA establishes the C_L for the airfoil and lift is proportional to the square of the AS

- Since you can control both the AOA and the AS, you can control lift



J. Weight

i. Definition

a. The force of gravity which acts vertically through the center of the plane toward the center of earth

b. The combined load of the airplane itself, the crew, the fuel, and the cargo or baggage (everything)

ii. Weight pulls the airplane downward because of the force of gravity

iii. In stabilized level flight, when the lift = weight, the plane is in equilibrium and doesn't gain/lose altitude

a. If lift becomes less than weight, the airplane loses altitude and the other way around

K. Thrust

i. Thrust is the forward-acting force which opposes drag and propels the airplane

a. This force is provided when the engine turns the prop and acts parallel to the longitudinal axis

b. F=MA

- Force is provided by the expansion of burning gases in the engine which turns the propeller
- A mass of air is accelerated opposite to the direction of the flight path (Newton's 3rd Law)
  - a The equal/opposite reaction is thrust, a force on the plane in the direction of flight

ii. Thrust begins the airplane moving, it continues to move and gain speed until thrust and drag are equal

a. In order to maintain a constant AS, thrust and drag must be equal

b. If thrust (power) is reduced the plane will decelerate as long as thrust is less than drag

- Likewise, if AS is increased, thrust becomes greater than drag and AS increases until equal

L. Drag

i. Definition

a. Rearward, retarding force, caused by disruption of airflow by the wing, fuselage, or other objects

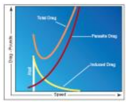
b. Drag opposes thrust, and acts rearward and parallel to the relative wind

- Acts in opposition to the direction of flight, opposing the forward-acting force of thrust, and limits the forward speed of the airplane

ii. Two types of drag – Parasite and Induced Drag

a. Parasite Drag

- Caused by an aircraft surface which deflects/interferes with the smooth airflow of the airplane
- Three Types of Parasite Drag

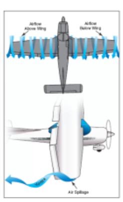


- a Form Drag: Results from the turbulent wake caused by the separation of airflow from the surface of a structure (The amount is related to the size and shape of the structure)
  1. Basically, how aerodynamic is the aircraft?
- b Interference Drag: Occurs when varied currents or air over an airplane meet and interact
  1. EX: Mixing of air over structures like wing and tail surface brace struts and gear struts
- c Skin Friction Drag: Caused by the roughness of the airplane's surfaces
  1. A thin layer of air clings to these surfaces and creates small eddies which add to drag

- Parasite Drag and Airplane Speed
  - a The combined effect of all parasite drag varies proportionately to the square of the airspeed
    1. EX: Plane, at a constant altitude has 4x as the parasite drag at 160 knots than at 80 knots
- Main Point: As airspeed increases, Parasite drag increases

b. Induced Drag

- Systems in General
  - a Physical fact that no system, doing work in the mechanical sense, can be 100% efficient
    1. 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
    2. The more efficient the system, the smaller the loss

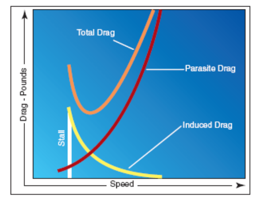


- The Wing as a System
  - a In level flight, the aerodynamic properties of the wing produce lift, but this is obtained at the expense of a penalty, Drag
    1. Induced drag is inherent *whenever* lift is produced
- How it Works
  - a When lift is produced, the pressure on the lower surface is greater than the upper surface
    1. The air flows from the high-pressure area below the wingtip upward to the low pressure
  - b 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
    1. The spiral is a lateral flow outward from the underside to the upper surface of the wing
    2. Basically, induced drag is made by the air circulation around the wing as it creates lift
  - c There is an upward flow of air beyond the wingtip and a downwash behind the trailing edge
    1. The downwash has nothing to do with the downwash necessary to produce lift
       a. It is the source of induced drag
          i. Vortices increase drag because of the energy spent in producing the turbulence
  - d Downwash – The Source

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

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

- Main Point: As lift increases, induced drag increases



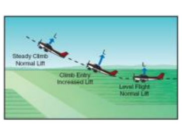
c. Total Drag
- Total drag is the sum of induced and parasite drag

M. Ground Effect
i. Associated with the reduction of induced drag
ii. Explanation
a. 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
- This causes a reduction in wingtip vortices and a decrease in upwash and downwash
- Since the ground effect restricts downward deflection of the airstream, induced drag decreases

iii. Effects on Flight
a. Takeoff
- With the reduction of induced drag, the amount of thrust required to produce lift is reduced
    a Therefore, the airplane is capable of lifting off at lower-than-normal takeoff speed
- 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
    a If you climb out before reaching the normal takeoff speed you might sink back to the surface

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

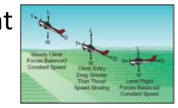
N. Climbs



i. In a steady state, normal climb the wing's lift is the same as it is in steady level flight at the same airspeed (AS)
a. Though the flight path has changed when the climb has been established, the Angle of Attack (AOA) of the wing with respect to the inclined flight path reverts to practically the same values, as does lift

ii. During the change from straight and level to a climb, a change in lift occurs when elevator is 1st applied
a. Raising the airplane's nose increases the AOA and momentarily increases lift
b. Lift at this moment is now greater than weight and starts the airplane climbing

iii. Once the flight path is stabilized, the AOA and lift revert to approximately level flight values
iv. If the climb is entered with no change in power settings, the AS gradually diminishes
    a. This is because thrust required to maintain an AS in level flight cannot maintain the AS in a climb
    b. When inclined upward, a component of weight acts in the same direction as, and parallel to drag
        - This increases drag (drag is greater than thrust and therefore AS will decrease until equal)
v. Since, in a climb, weight is not only acting downward but rearward along with drag, additional power is needed to maintain the same airspeed as in level flight



    a. The amount of reserve power determines the climb performance

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

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

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

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

v. Turning Radius
a. Increased AS results in an increase in turn radius and centrifugal force is directly related to radius
   - 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
     - a The horizontal component of lift can only be increased by increasing bank angle
b. To maintain a constant rate of turn with an increased AS, the angle of bank must be increased

vi. Slipping Turns
a. In a slipping turn, the rate of turn is too slow for the angle of bank, and the plane is yawed to the outside of the turning flight path
   - The horizontal component (H_{CL}) of lift is greater than Centrifugal Force (CF)
b. H_{CL} and CF equilibrium is reestablished by decreasing bank/increasing the rate of turn
   - Increase or decrease rudder pressure to center the ball or adjust bank

vii. Skidding Turns
a. In a skidding turn, the rate of turn is too great for the angle of bank and the plane is yawed inside the turn
   - There is excess centrifugal force compared to the H_{CL}
b. Correction involves reducing the rate of turn/increasing the bank
   - Increase of decrease rudder pressure as necessary or adjust bank

Q. Stalls

i. As long as the wing is creating sufficient lift to counteract the load imposed on it, the plane will fly
a. When the lift is completely lost, the airplane will stall

ii. The direct cause of every stall is an excessive angle of attack

iii. The stalling speed of a particular airplane is not a fixed value for all flight situations
a. However, a given airplane will always stall at the same AOA regardless of speed, weight, load factor, or density altitude
b. Each plane has a particular AOA where airflow separates from the upper wing and it stalls (16^o-20^o)

iv. 3 situations where the critical AOA can be exceeded:
a. Low Speed Flying
   - As airspeed is decreased, the AOA must be increased to retain the lift required to hold altitude

- The slower the AS, the more AOA must increase. At the critical AOA, lift cannot increase further
    - a If AS is reduced, the airplane will stall, since the AOA has exceeded the critical AOA

b. High Speed Flying
- Low speed is not necessary to produce a stall
- The wing can be brought to an excessive angle of attack at any speed
- EX: diving at 200 knots with a sudden increase in back elevator pressure
    - a Because of gravity and centrifugal force, the plane cannot immediately alter its flight path
        1. It would merely change its AOA abruptly from very low to very high
    - b 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

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

RISK MANAGEMENT

The applicant demonstrates the ability to identify, assess, and mitigate risks, encompassing:

1. **Inaccurate use of Manufacturer's Performance Charts, Tables, and Data**
    A. Ensure you understand how to properly use the performance charts
        i. Improperly used, they're worthless and dangerous - the pilot has no real grasp on the aircraft's performance abilities based on the conditions
2. **Exceeding Aircraft Limitations**
    A. Understand the limitations of the aircraft and do not exceed them
    B. It's a great idea to consistently review the aircraft limitations
        i. Not only to ensure you don't exceed them, but also so that you're aware if they are exceeded and can take the proper action
    C. Weight and Balance
        i. Always calculate any expected changes in weight and balance en route while on the ground
            a. Always find the center of gravity at takeoff and with empty tanks to ensure the center of gravity will not ever be out of limits
            b. Understand how the aircraft performance will change as the center of gravity moves
            c. An out of balance center of gravity is never something to mess around with – don't exceed limitations
3. **Possible Differences between Calculated Performance and Actual Performance**

A. Use the performance charts and relate them to the airport information (runway lengths, climb rates vs obstacles in the area, etc.)
    i. The charts will provide performance for all phases of flight
    ii. Remember, the charts don't make an allowance for pilot proficiency or mechanical deterioration
        a. Does the airplane have problems that may limit performance?
B. There is always the possibility of changing weather resulting in useless original calculations
    i. Just because the plane will perform well now doesn't mean it will perform well later
    ii. Plan ahead and be aware that as conditions change so does the aircraft performance. Stop and reassess the aircraft capabilities if necessary.

SKILLS

The applicant demonstrates the ability to:

1. Compute the weight and balance, correct out-of-center of gravity (CG) loading errors and determine if the weight and balance remains within limits during all phases of flight.
2. Demonstrate use of the appropriate aircraft manufacturer's approved performance charts, tables and data.