XI.C. Power-Off Stalls

References: Airplane Flying Handbook (FAA-H-8083-3), Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25), Stall and Spin Awareness Training (AC 61-67), POH/AFM

Objectives	The student should develop knowledge of power-off stalls regarding aerodynamics, factors associated with stall speeds, as well as proper recovery techniques. The student will understand situations in which power off stalls are most common and most dangerous and will have the ability to perform a power-off stall as required in the ACS/PTS.
Key Elements	1. Critical Angle of Attack 2. Reduce the AOA 3. Disconnect, Pitch, Roll, Thrust, Stabilize, Configure
Elements	1. Aerodynamics 2. Various Factors and their Effect on Stall Speed 3. Possible Situations 4. Entering the Maneuver 5. Recognizing the Stall 6. The Recovery
Schedule	1. Discuss Objectives 2. Review material 3. Development 4. Conclusion
Equipment	1. White board and markers 2. References
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 will become familiar with the conditions that produce power-off stalls and will develop the habit of taking prompt preventative and/or corrective action when in a power-off stall.

Instructor Notes:

Introduction:

Attention

Interesting fact or attention-grabbing story

Stalls can be intimidating/frightening but understanding how they work and practicing them will make you more comfortable with them, and a safer pilot. A stall can occur at any airspeed, in any attitude, or any power setting.

Overview

Review Objectives and Elements/Key ideas

What

A stall occurs when the critical angle of attack is exceeded. When this happens, the smooth airflow over the wing is disrupted resulting in a loss of lift and increased drag. Power off stalls are practiced to simulate stalls in the landing and approach conditions and configuration.

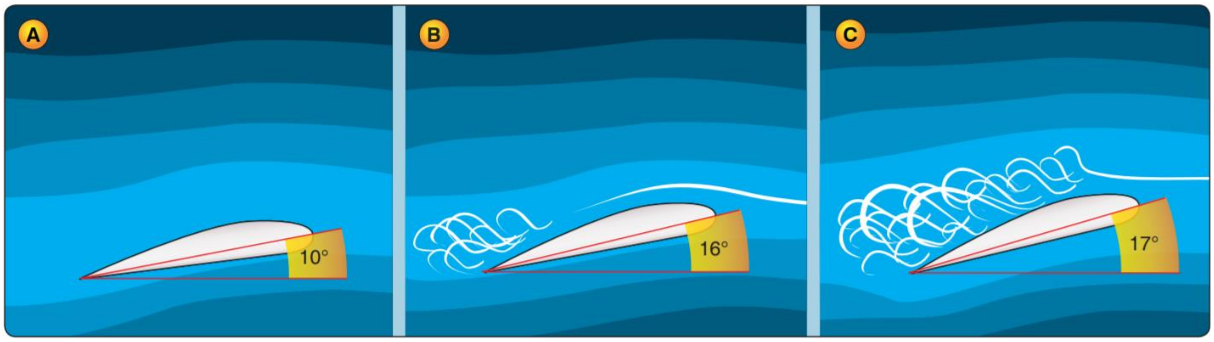
Why

Stalls in general are practiced to become familiar with an aircraft's particular stall characteristics and to avoid putting the aircraft into a potentially dangerous situation. Power-off stalls are essential to safety in the aircraft. It is important to understand how they happen, how to avoid them, and how to recover from them.

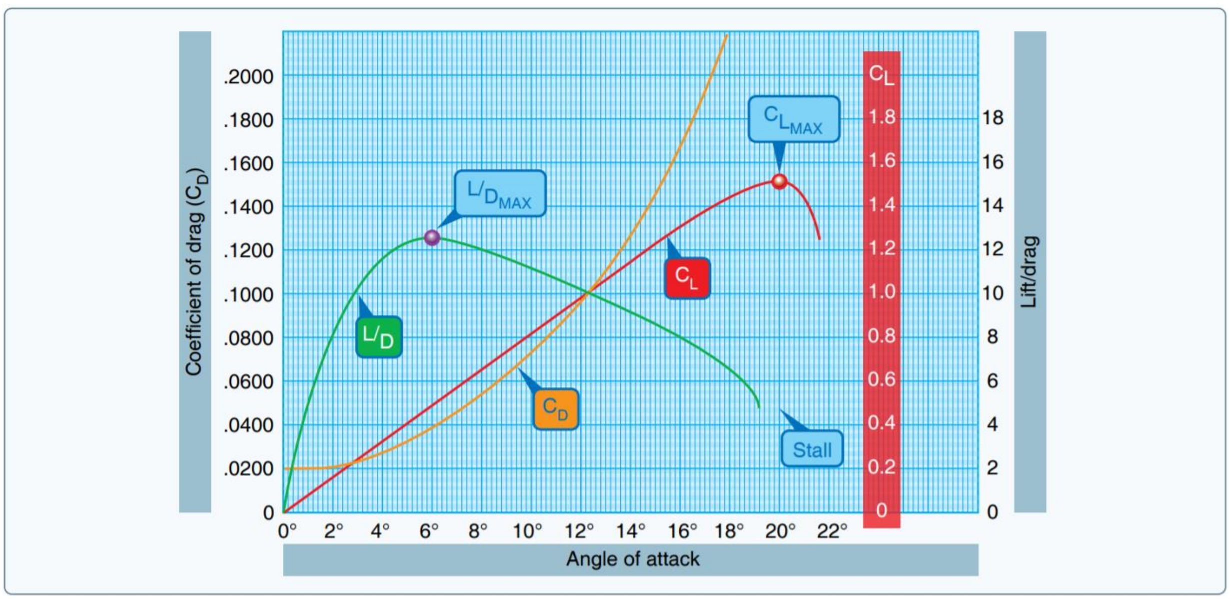
How:

1. **Aerodynamics**
   - A. Why an Aircraft Stalls
     - i. Basically…
       - a. A stall occurs when the smooth airflow over the top of the wing is disrupted and lift decreases rapidly
         - This happens when the wing exceeds its critical angle of attack (AOA)
           - a The critical AOA varies between aircraft, but is usually around 15-20^{o} in a general aviation aircraft
           - b Remember, AOA is the angle between the chord line of the wing and the relative wind
         - A stall can occur at any airspeed, in any attitude, with any power setting
     - ii. More Specifically…
       - a. Airflow Over the Wing
         - A certain amount of lift is generated by the difference in pressure between the top and bottom of the wing. This lift is dependent on the smooth airflow over the top of the wing (A in the graphic below)
         - As AOA increases, the airflow over the top of the wing cannot maintain the smooth flow and starts to burble and separate from the trailing edge (B in the graphic below)
         - As the AOA continues to increase, the separation point moves farther forward along the top of the wing hindering its ability to create lift and leading to airflow separation and a stall (C in the graphic below)

a Thus, a stall occurs due to a rapid decrease in lift caused by the separation of the airflow from the wing's surface



b. The Critical Angle of Attack/C_{LMAX}
- The point at which the airflow separates and there is a rapid reduction in lift is the stalling angle of attack, or the critical angle of attack, or C_{LMAX} (the Maximum Coefficient of Lift) – see the diagram below
  a C_L = Coefficient of Lift – A way to measure lift as it relates to the angle of attack
    1. Determined by wind tunnel tests and based on airfoil design and angle of attack
  b Any angle of attack beyond C_{LMAX} results in a stall and lift drops off rapidly



B. Stall Characteristics
  i. Most general aviation aircraft are designed to stall at the wing root first and then progress outward to the wing tips
    a. By having the root stall first, aileron effectiveness is maintained at the wingtips, maintaining controllability of the aircraft
  ii. Various design can be used to accomplish this:
    a. Twisting the wing to create a lower angle of attack at the wing tip compared to the wing root
      - Angle of Incidence – The angle of the chord line of the wing relative to the fuselage
      - These aircraft are designed with a higher angle of incidence near the wing root, leading to a lower angle of incidence at the wing tip

        b. Adding strips to the first 20-25% of the wing's leading edge to induce a stall earlier than it would otherwise stall
    C. There's More than One Way to Exceed the Critical AOA
        i. An aircraft can stall at any speed, attitude, or power setting
        ii. Low Speed
            a. As airspeed decreases, the AOA must be increased to maintain altitude
            b. Eventually, an AOA is reached that results in the wing not producing enough lift to support the aircraft. If the airspeed is reduced further, the aircraft stalls because the AOA has exceeded the critical angle and the airflow over the wing is disrupted
        iii. High Speed
            a. Low speed is not necessary to produce a stall, the wing can exceed the critical AOA at any speed. For example:
            b. If an aircraft is in a high-speed dive, and the pilot pulls back sharply on the elevator, gravity and centrifugal force prevent an immediate alteration of the flight path
                - In this situation, the aircraft's AOA changes abruptly from quite low to very high, but even though the nose has been raised, the aircraft continues on its trajectory downward for some amount of time
            c. Since the AOA is suddenly increased while the flight path remains the same, the aircraft reaches the critical AOA at a speed much higher than the published stall speed
        iv. Turns
            a. The stall speed of an aircraft is higher in a level turn than in straight-and-level flight
            b. In a turn, the wings must produce additional lift to maintain altitude
                - Remember, in a turn the vertical component of lift is divided into a horizontal and a vertical component
            c. The additional lift comes from added back pressure which increases the AOA
                - In this situation, the flight path/relative wind remain the same, while the pitch is increased, leading to a higher AOA
            d. If at any time during the turn the AOA becomes excessive, the aircraft will stall
    D. As mentioned before, if at *ANY* time (low speed/high speed, high power/low power, straight/turning, etc.) the aircraft's AOA becomes excessive, the aircraft will stall

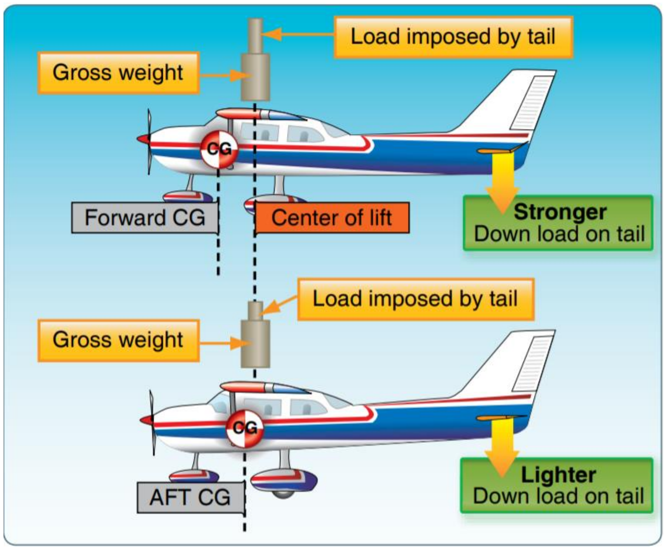
2. Various Factors and their Effect on Stall Speed
    A. A stall can occur at any airspeed, attitude, or power setting, depending on the total factors affecting the aircraft
    B. Airspeed & Power Settings (Not part of the CFI PTS – Private and Commercial ACS Requirement)
        i. As mentioned above, a stall can occur at any airspeed
            a. Low Speed and/or Low Power Setting
                - As airspeed decreases, AOA must be increased to maintain altitude
                - Eventually, an AOA is reached that results in the wing stalling because the AOA has exceeded the critical angle and the airflow over the wing is disrupted
            b. High Speed and/or High-Power Setting
                - If an aircraft is in a high-speed dive, and the pilot pulls back sharply on the elevator, gravity and centrifugal force prevent an immediate alteration of the flight path
                    a Since the AOA is suddenly increased while the flight path remains the same, the aircraft reaches the critical AOA at a speed much higher than the published stall speed
                    b More on load factors/accelerated stalls below

- Depending on the aircraft, a higher power setting may help to reduce the stall speed and increase the lift on the wings
  - a Although the wing may be stalled, a higher power setting can provide increased lift due to the propeller airflow/prop wash moving over the wing roots
  - b This is more prominent in low wing aircraft where the propeller airflow moves directly over the wing
  - c This airflow also likely has a relatively low angle of attack

C. Configuration (Gear and Flaps)
   i. Flaps
      a. Reduce the stall speed of an aircraft
         - Most flaps increase the camber of the wing and change the chord line, producing more lift
           - a The nose of the aircraft is lowered to prevent ballooning
           - b Generally, the lowered nose and additional lift assist in decreasing the stall speed (factors will vary based on aircraft/flap design)
         - Note the differing speeds on the airspeed indicator (green arc vs white arc)
   ii. Gear
      a. Flaps have the most prominent effect on stall speed
      b. The effects of gear can vary based on the aircraft design and characteristics
         - Gear (as well as flap) extension increases drag and if not properly compensated for could lead to a stall
           - a For example, gear down and a low power setting, combined with increasing pitch to maintain altitude
         - The actual effect of landing gear on the stall speed will vary between aircraft and they're design characteristics

D. Weight
   i. As the weight of the aircraft is increased, the stall speed increases
      a. Remember, to maintain altitude lift must equal weight
      b. So, the greater the weight, the greater the lift required
      c. A higher AOA is required to generate the lift (all other factors remaining the same)
      d. The higher AOA puts the aircraft closer to the critical angle of attack, and therefore the aircraft will stall at a higher speed
   ii. A lighter aircraft will stall at a slower airspeed
      a. The same as above, but the opposite. Less lift is required, and the AOA can be reduced (all other factors remaining the same), lowering the stall speed

E. Center of Gravity
   i. Forward Center of Gravity (CG)
      a. Increases the stall speed
      b. A forward center of gravity has the same effect on stall speed as a heavier aircraft
         - The farther forward the center of gravity moves, the higher the angle of attack has to be to compensate for the extra load imposed by the tail (see picture)



- Due to the higher angle of attack, the aircraft is closer to the critical angle of attack and therefore will stall at a higher speed

c. The aircraft is also more controllable due to the longer arm from the CG to the elevator, improving the stall recovery capabilities
   - Additionally, the farther forward the CG, the greater the tendency for the nose to pitch down (imagine it as more “nose heavy”)

d. It’s worth noting:
   - The higher angle of attack and increased deflection of the stabilizer increases drag, and thus the aircraft is slower for a given power setting

ii. Aft CG

a. Decreases the stall speed

b. An aft center of gravity has the same effect on stall speed as a lighter aircraft
   - The farther aft the center of gravity moves, the lower the angle of attack has to be to compensate for the load imposed by the tail
   - Due to the lower angle of attack, the aircraft is farther from the critical angle of attack and will stall at a lower speed

c. Although the stall speed is lower, the aircraft is less controllable due to the shorter arm from the CG to the elevator
   - The elevator has a shorter arm to the CG, and thus produces less force making recovery more difficult
   - Recovery from a stall becomes progressively more difficult as the CG moves aft
   - Additionally, the farther aft the CG, the less tendency the nose has to pitch down on its own (imagine it as more “tail heavy”)

d. It’s worth noting:
   - a The lower angle of attack and less downward deflection of the stabilizer reduces drag, and thus the aircraft is faster for a given power setting

F. Load Factor

i. Increased load factor increases the stall speed

ii. Load factor is the ratio of the total load acting on the aircraft to the gross weight of the aircraft

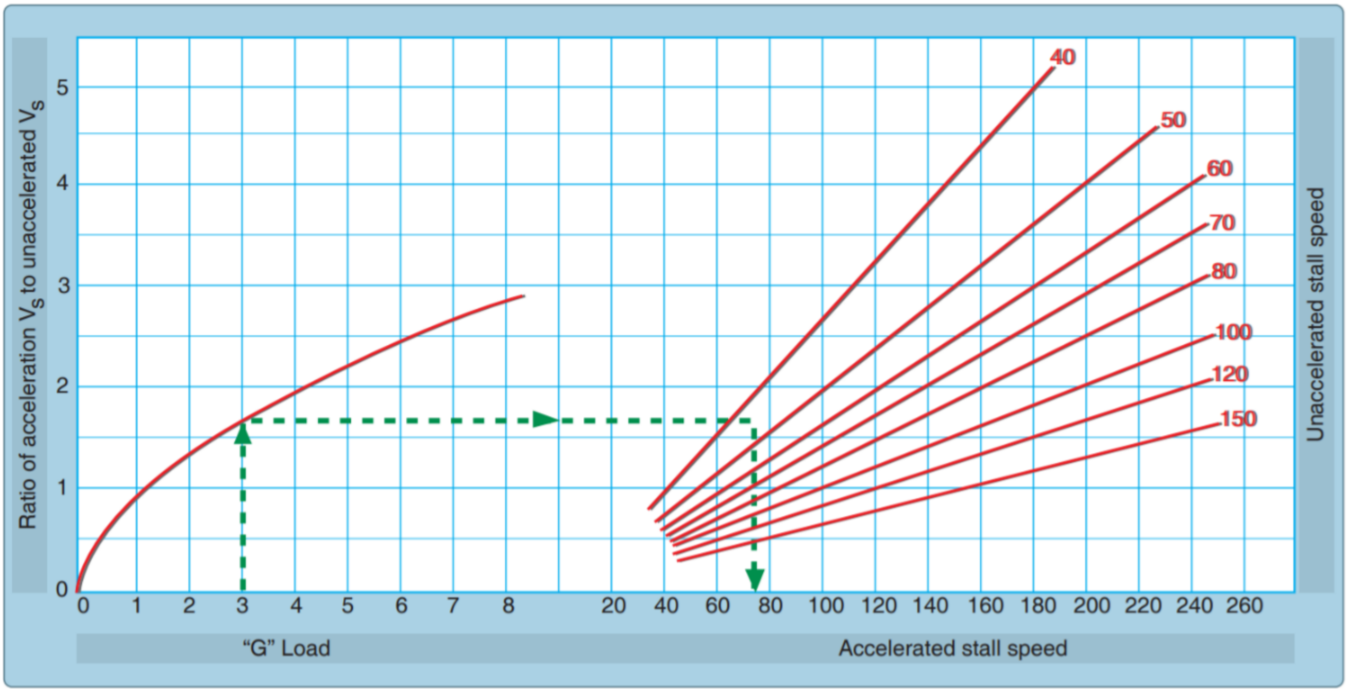
a. Expressed in terms of G’s

iii. Any increase in the load factor increases the stall speed

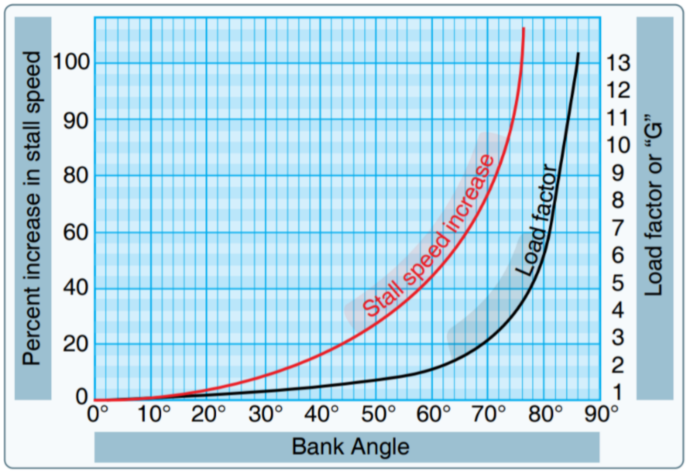
a. The stall speed increases in proportion to the square root of the load factor

b. When an aircraft is stalled at a higher than indicated air speed due to excessive maneuvering loads, it is called an accelerated maneuver stall

iv. Pulling out of a steep descent, steep turns, aggressive control inputs, etc. Anything that puts G's on the aircraft can increase the load factor and therefore the stall speed



G. Bank Angle
   i. Increased bank angle increases the stall speed
   ii. Increased load factors are a characteristic of all banked turns
   iii. Tremendous loads are imposed as bank is increased beyond 45°
      a. At a 60° bank, a load factor of 2 G's is imposed on the airplane structure
      b. At a 70° bank, a load factor of approximately 3 G's is placed on the airplane
      c. At approx. 63° of bank the stall speed is increased by approximately ½



H. Snow, Ice, and Frost
   i. Increase the stall speed
   ii. Snow, ice and frost disrupt the smooth flow of air over the wing causing the boundary layer to separate at an angle of attack lower than the critical angle of attack
      a. To make matters worse, lift is greatly reduced due to the disrupted air, and if ice accumulates, the weight of the aircraft is increased
         - More lift is required due to the added weight, but less lift is available due to the ice
      b. As little as .8 millimeters of ice on the upper wing increases drag and reduces lift by 25%
I. Turbulence
   i. Can increase the stall speed

        a. Sudden changes in the relative wind, and/or aggressive control inputs to maintain altitude can lead to exceeding the critical angle of attack and a stall
        b. When flying in moderate to severe turbulence or strong crosswinds, a higher than normal approach speed should be used

3. Possible Situations

- A. Approach to landing conditions and configurations
    - i. Crossed-control turns from base to final
    - ii. Attempting to recover from a high sink rate on final approach using only an increased pitch attitude
        - a. Just pitching, can quickly slow and stall the aircraft resulting in a further increased sink rate
    - iii. Improper airspeed control on final approach and other segments of the traffic pattern

4. Entering the Maneuver

- A. Entry
    - i. *Pre-Maneuver Checklist: Fuel Pump ON, Mixture RICH, Lights ON, Gauges GREEN
    - ii. Clear the Area
    - iii. Select an altitude – Recover prior to 1,500' AGL
    - iv. *Landing Configuration: Landing Flaps
        - a. *Use the same procedure as entering slow flight but maintain (descend at) 65 knots
    - v. Note the Heading
    - vi. Common Error - Failure to establish the specified configuration prior to entry
- B. Getting into the Straight Stall
    - i. *Slow to normal approach speed (65 knots) while maintaining the originally established altitude
        - a. Extend the flaps (landing flaps)
        - b. Visually - Find a reference off the nose to maintain direction and to assist with pitch attitude
    - ii. *Then, smoothly lower the nose to the normal approach attitude and maintain approach speed (65 knots)
    - iii. Once stabilized, power should be reduced to idle and the nose should be smoothly raised to and held at an attitude that will induce a stall
        - a. Simulate a flare to landing
        - b. Maintain directional control with rudder, wings level with ailerons, pitch with elevator until a stall occurs
    - iv. Common Error - Improper pitch, heading, yaw, and bank control during straight-ahead stalls
        - a. Visual references and instruments are used
    - v. Common Error - Rough and/or uncoordinated use of the flight controls
        - a. Just like in slow flight, use smooth movements in controlling the airplane, nothing jerky
- C. Getting into the Turning Stall
    - i. In a descending turn, the same procedures apply as a straight-ahead stall, except a specified bank angle is maintained
        - a. When the power is set and the descent established, establish the desired bank angle
        - b. Aileron pressure must be continually adjusted to keep the bank constant
            - Opposite aileron may be necessary when slow due to the overbanking tendency
        - c. Take care to ensure the aircraft remains coordinated and the turn continues at a constant bank angle until the stall occurs
            - If the aircraft is allowed to develop a slip, the outer wing may stall first and move downward abruptly

ii. Common Error - Improper pitch, yaw, and bank control during turning stalls
   a. Increase control pressure as the aircraft slows and controls become less effective

5. Recognizing the Stall

A. Announce the onset of the stall
   i. Stall Warning Horn
   ii. Reduced Control Effectiveness
   iii. Buffet
   iv. Stall
B. Sight
   i. Attitude of the airplane
C. Sound
   i. Stall warning horn
   ii. Noise will tend to decrease with airspeed and the lessening flow of air around the aircraft
D. Kinesthesia (the sensing of movements by feel, "seat of the pants" sensations, your "spidey sense")
   i. The physical sensation of changes in direction is an important indicator to the trained and experienced pilot in visual flight
   ii. If properly developed, it can warn the pilot of an impending stall
      a. The pilot can recognize when something doesn't feel right
E. Feel
   i. Control pressures become progressively less effective (mushy)
      a. The lag between control movements and response of the aircraft become greater
   ii. Buffeting, uncontrollable pitching or vibrations just before the stall
      a. The buffet is caused by the turbulent air flowing over the fuselage/horizontal stabilizer
   iii. Leaning back
F. Common Errors
   i. Failure to recognize the first indications of a stall/poor stall recognition and delayed recovery
   ii. Failure to achieve a stall

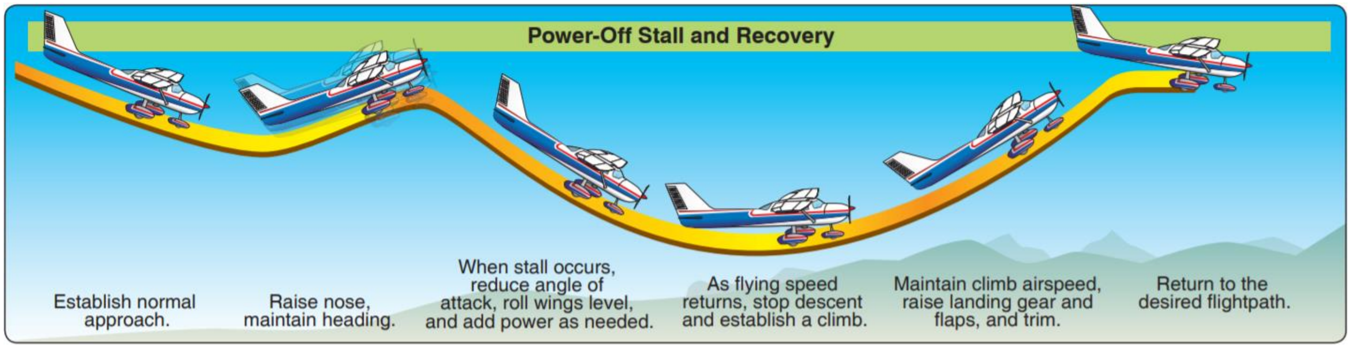
6. The Recovery

A. Basics: Disconnect, Pitch, Roll, Thrust, Stabilize, Configure (perform each step as appropriate)
   i. Disconnect the autopilot (if applicable)
   ii. Pitch nose down
      a. Pitch attitude/angle of attack must be decreased positively and immediately
      b. The cause of any stall is an excessive angle of attack, decreasing the angle of attack is crucial
      c. Be familiar with the control pressures required for your aircraft
         - Excessive pitch down can result in excessive altitude loss
         - Insufficient pitch down will not break the stall
         - If the nose is trimmed up, additional pressure will be required to break the stall
            a If able/necessary, trim the nose down during the recovery
   iii. Roll wings level
      a. Regain/maintain directional control with coordinated aileron and rudder
      b. Reorients the lift vector vertical for a more effective recovery and climb
      c. Do not attempt to level the wings prior to reducing angle of attack
         - A stalled wing can roll the opposite direction of aileron input (more info below)
   iv. Thrust/power as necessary
      a. Stalls can occur at high/low power settings and airspeeds so adjust power as required

b. In general, maximum allowable power should be applied to increase airspeed and help increase airflow over the wings, assisting in stall recovery
c. Power is not essential to stall recovery, reducing the AOA is the only way of recovering
d. Right rudder will be required to maintain coordination/heading
    - Use outside references - add rudder to keep the nose from yawing across the horizon

v. Stabilize/establish the desired flight path
    a. In this case, perform a go around and climb at the desired airspeed V_Y (V_X if necessary)

vi. Configure
    a. Once in a climb, configure the aircraft as necessary
    b. Same flap and gear retraction procedure as a go around



B. Ailerons and Recovery
   i. Most general aviation aircraft are designed to stall progressively outward from the wing root
      a. The wings are designed in this manner so that aileron control will be available at high AOA and give the airplane more stable stalling characteristics
      b. During the recovery, the return of lift begins at the tips and progresses towards the roots
         - Thus, ailerons can be used to level the wings
   ii. If the wing is fully stalled (ailerons included), using the ailerons can aggravate the stall
      a. EX: If the right wing dropped, and excessive aileron was applied to raise the wing, the right wing (aileron down) would produce a greater AOA and more (induced) drag
         - Increasing the AOA on an already stalled wing will aggravate the stall on that wing
         - The increase in drag and aggravated stall on the low wing will yaw the aircraft in the direction of that wing and could result in a spin

C. Rudder and Recovery
   i. The primary cause of an inadvertent spin is exceeding the critical AOA while applying excessive or insufficient rudder and, to a lesser extent, aileron
      a. Therefore, it is important that the rudder be used properly during the entry and recovery
   ii. The primary use of rudder is to counteract any tendency of the airplane to yaw or slip

D. Common Errors During Recovery:
   i. Excessive altitude loss or excessive airspeed during recovery
      a. Only lower the nose enough to break the stall, after the stall is broken establish a climb
      b. Excessive speeds and nose low attitudes close to the ground are extremely hazardous
   ii. Poor stall recognition and delayed recovery

   a. Do not delay recovery, recover at the first indication of stall (unless required otherwise by the ACS/PTS) - At slow airspeeds, in a descent, close to the ground any delay could be hazardous

iii. Secondary stall during recovery
   a. Once the stall is broken, do not aggressively lift the nose to reestablish a climb as this can quickly result in a secondary stall
   b. Use smooth, controlled inputs; monitor performance to ensure the airplane is ready to climb

iv. Rough and/or uncoordinated use of the flight controls
   a. Just like in slow flight, use smooth movements in controlling the airplane, nothing jerky
   b. A smooth controlled recovery is the goal, this will also help to avoid a secondary stall

Common Errors:

- Failure to establish the specified configuration prior to entry
- Improper pitch, heading, yaw, and bank control during straight-ahead stalls
- Improper pitch, yaw, and bank control during turning stalls
- Rough and/or uncoordinated use of the flight controls
- Failure to recognize the first indications of a stall
- Failure to achieve a stall
- Improper torque correction
- Poor stall recognition and delayed recovery
- Excessive altitude loss or excessive airspeed during recovery
- Secondary stall during recovery

Conclusion:

Brief review of the main points

Exceeding the critical angle of attack causes a stall. A stall can occur at any airspeed, in any attitude, or ay any power setting, depending on the total number of factors affecting the particular airplane.

PTS Requirements:

To determine that the applicant:

1. Exhibits instructional knowledge of the elements of power-off stalls, in descending flight (straight or turning), with selected landing gear and flap configurations by describing:
   a. Aerodynamics of power-off stalls.
   b. Relationship of various factors, such as landing gear and flap configuration, weight, center of gravity, load factor, and bank angle to stall speed.
   c. Flight situations where unintentional power-off stalls may occur.
   d. Entry technique and minimum entry altitude.
   e. Performance of power-off stalls in descending flight (straight or turning).
   f. Coordination of flight controls.
   g. Recognition of the first indications of power-off stalls.
   h. Recovery technique and minimum recovery altitude.
2. Exhibits instructional knowledge of common errors related to power-off stalls, in descending flight (straight or turning), with selected landing gear and flap configurations by describing:
   a. Failure to establish the specified configuration prior to entry.

   b. Improper pitch, heading, yaw, and bank control during straight-ahead stalls.
   c. Improper pitch, yaw, and bank control during turning stalls.
   d. Rough and/or uncoordinated use of flight controls.
   e. Failure to recognize the first indications of a stall.
   f. Failure to achieve a stall.
   g. Improper torque correction.
   h. Poor stall recognition and delayed recovery.
   i. Excessive altitude loss or excessive airspeed during recovery.
   j. Secondary stall during recovery.
3. Demonstrates and simultaneously explains power-off stalls, in descending flight (straight or turning), with selected landing gear and flap configurations, from an instructional standpoint.
4. Analyzes and corrects simulated common errors related to power-off stalls, in descending flight (straight or turning), with selected landing gear and flap configurations.

Private Pilot ACS Skills Standards

1. Clear the area.
2. Select an entry altitude that will allow the Task to be completed no lower than 1,500 feet AGL (ASEL) or 3,000 feet AGL (AMEL).
3. Configure the airplane in the approach or landing configuration, as specified by the evaluator, and maintain coordinated flight throughout the maneuver.
4. Establish a stabilized descent.
5. Transition smoothly from the approach or landing attitude to a pitch attitude that will induce a stall.
6. Maintain a specified heading, ±10 if in straight flight; maintain a specified angle of bank not to exceed 20°, ±10°, if in turning flight, while inducing the stall.
7. Acknowledge cues of the impending stall and then recover promptly after a full stall occurs.
8. Execute a stall recovery in accordance with procedures set forth in the POH/AFM.
9. Configure the aircraft as recommended by the manufacturer and accelerate to V_X or V_Y.
10. Return to the altitude, heading, and airspeed specified by the evaluator.

Commercial Pilot ACS Skills Standards

1. Clear the area.
2. Select an entry altitude that will allow the Task to be completed no lower than 1,500 feet AGL (ASEL) or 3,000 feet AGL (AMEL).
3. Configure the airplane in the approach or landing configuration, as specified by the evaluator, and maintain coordinated flight throughout the maneuver.
4. Establish a stabilized descent.
5. Transition smoothly from the approach or landing attitude to a pitch attitude that will induce an impending stall.
6. Maintain a specified heading, ±10 if in straight flight; maintain a specified angle of bank not to exceed 20°, ±5°, if in turning flight, until an impending or full stall occurs, as specified by the examiner.
7. Acknowledge the cues at the first indication of a stall (e.g., aircraft buffet, stall horn, etc.).
8. Recover at the first indication of a stall or after a full stall has occurred, as specified by the evaluator
9. Configure the airplane as recommended by the manufacturer and accelerate to V_X or V_Y.
10. Return to the altitude, heading, and airspeed specified by the evaluator.