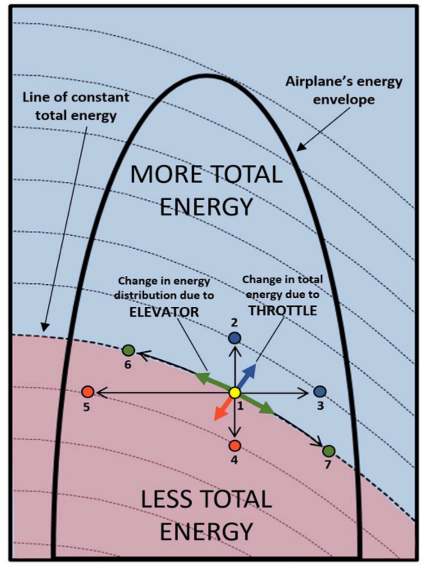
Demonstration of Flight Characteristics at Various Configurations and Airspeeds

Objective

To ensure the flight instructor applicant learns the purpose of and can exhibit a clear understanding of Aircraft Energy Management and how to demonstrate aircraft behavior in a variety of configurations and energy states.



Purpose

During flight training, students are indirectly exposed to the concept of energy management. This lesson will shine a spotlight on Aircraft Energy Management, introduce the Power Required curve, and demonstrate aircraft energy states which are "irreversible". This lesson also introduces pilots to the concept of the two kinds of "faulty approaches".

Schedule

- **Ground Lesson**: 25 minutes
- Initial
  - **Flight 1**: 40 minutes - *Demonstrate Maneuver*
- CFI Applicants Only
  - **Flight 2**: 30 minutes - *Improve Proficiency (Dual)*
  - **Flight 3**: 20 minutes - *Demonstrate Proficiency*
- **Debrief**: 10 minutes (*per flight*)

Equipment

- Airplane Checklist
- Whiteboard / Markers (optional)
- Model Airplane (optional)

Student Actions

- Ask any questions, receive study material for the next lesson.
- Watch linked video.
- Review listed references.

Instructor Actions

- Deliver the ground lesson (below).
- Demonstrate the maneuver in flight.
- Debrief after each flight.

Completion Standards

- **Ground**: Student can explain the purpose of the demonstration and how to execute it properly.
  - Can explain the concept of energy management, the power required curve, and 'region of reverse command'.
- **Flight**: Student can perform the demonstration maneuver to the applicable ACS standards.
  - **Clean:** Begins at V_A, slows to V_G, then to min. controllable airspeed. Acknowledges impending stall, recovers to level flight by reducing pitch only, then to cruise speed.
  - **Landing Config:** Begins at V_A, slows, configures for landing, and holds V_G, then to min. controllable airspeed. Acknowledges impending stall, recovers to level flight by reducing pitch only, then to cruise speed.
  - Holds altitude ±100 feet (at or above 1500ft AGL), airspeed +5/-0 knots, bank ±5°, headings ±10°.
  - See expanded Completion Standards below.

References

- Friendly Skies Film - "Energy Management: Speed vs. Altitude and everywhere in between"
    - YouTube - https://www.youtube.com/watch?v=5WwGjR7AKf0
- FAA-H-8083-3C (Airplane Flying Handbook) - Chapter 4 [Energy Management], Chapter 5, Page 8-9 [Coordinated Flight/Angle of Attack], Chapter 5, Page 9-12 [Slow Flight], Chapter 5, Page 12-16 [Stalls/Stall Recognition/Stall Recovery]
- FAA-H-8083-25C (Pilot's Handbook of Aeronautical Knowledge) - Chapter 5, Page 2-5 [Thrust, Lift, and Angle of Attack], Chapter 5, Page 5 [Lift/Drag Ratio], Chapter 5, Page 7 [Induced Drag], Chapter 5, Page 22-23 [Forces in Turns], Chapter 5, Page 25-26 [Stalls], Chapter 5, Page 30-33 [Left Turning Tendencies], Chapter 5, Page 34-35 [Load Factors and Stalling Speeds], Chapter 5, Page 37-38 [Vg Diagram]
- FAA-S-ACS-25 (CFI ACS) - Area XI Task B

Ground Lesson Outline

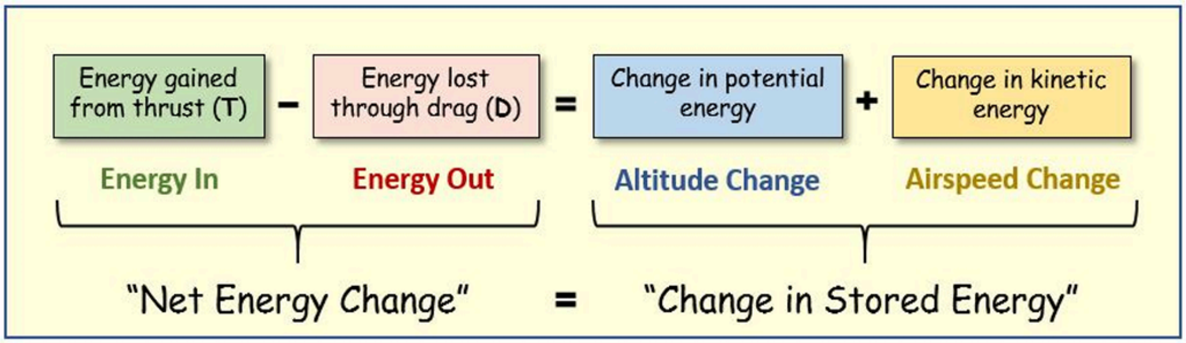
- Introduction to Aircraft Energy Management
    - Moving Between Energy States
    - Dangers of maneuvering at critically low energy states
- Behind the Power Curve
    - The Power Required Curve vs Power Available Curve
    - Minimum Power Required is a bit slower than Minimum Drag Speed (Best Glide)
    - Speed Instability / Irreversible Energy Depletion
    - Faulty Approaches, Recovering from Unstable Energy States
- Flying at Minimum Controllable Airspeed
    - Left Turning Tendencies
        - Torque Reaction, Spiraling Slipstream, P-Factor
    - Bank Angle and Load Factor
    - Factors that affect stall speed
        - Load factor, CG, Weight, Coordination
    - Airspeed Control, Trim, and Coordination
    - Airplane Configurations
        - Clean, Dirty (Landing), Airspeed Limitations
- Safety considerations
    - Flying with a Stall Warning, Use of checklists, Visual traffic scanning, Environmental factors
- Maneuver Description - step-by-step
    - Entry configuration, airspeed, etc.
- Expanded Completion Standards

Common Errors

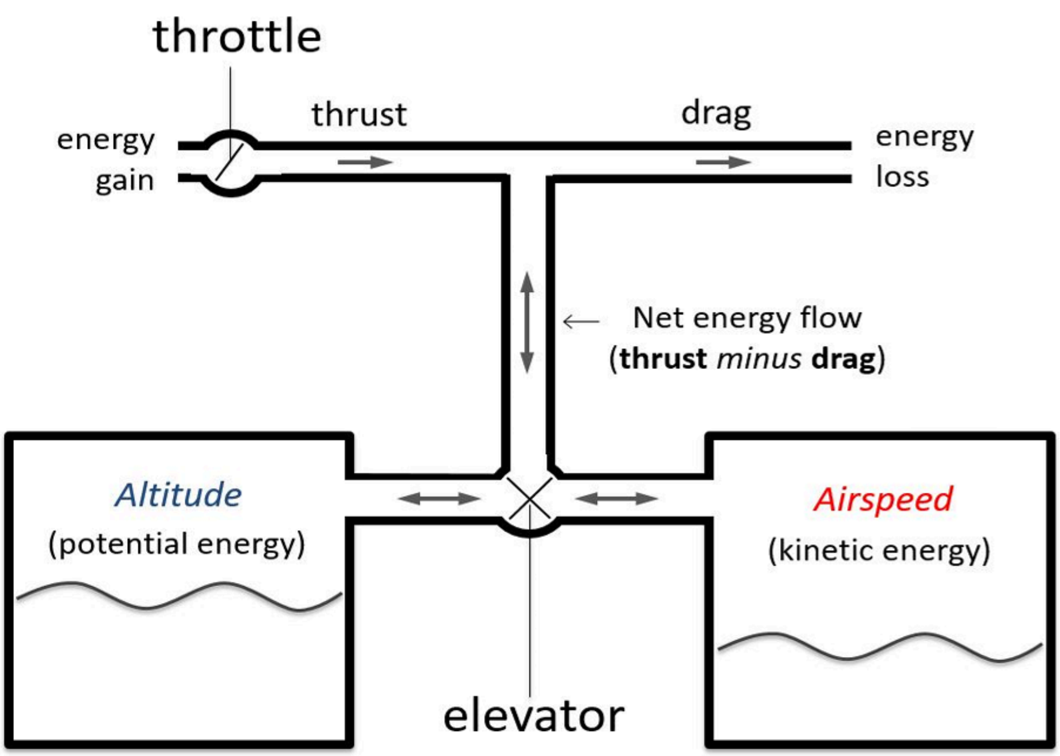
- Failure to establish specified configuration.
- **Improper entry technique (i.e. not beginning at Va).**
- **Failure to establish and maintain best glide speed before continuing to minimum controllable airspeed.**
- **Excessive variations of altitude and heading when a constant altitude and heading are specified.**
- **Improper recovery technique (i.e. recovering with power instead of pitch)**
- Uncoordinated use of flight controls.
- **Improper correction for torque effect.**
- Improper trim technique.
- Unintentional stalls and unacknowledged stall indications.
- Lack of familiarity with or exceeding airplane airspeed limitations for various configurations.

Ground Lesson Content

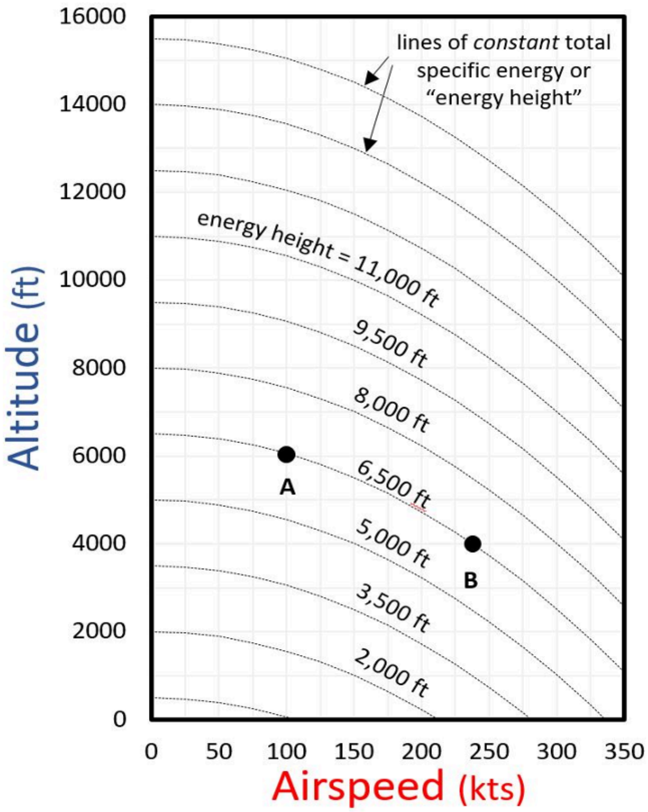
- **Introduction to Aircraft Energy Management** - Although students are indirectly exposed to energy management during their flight training, it is often not explicitly acknowledged. However, a proper explanation of the concept of 'energy', specifically the combination of kinetic (airspeed) and potential (altitude) energy, can help the student understand the sometimes unintuitive behavior of the aircraft in some situations. It is important for flight instructors to explain these fundamentals to their students to demystify this behavior.
    - Aircraft are continuously in a state of delicate balance, where the engine is providing energy in the form of thrust, and the atmosphere is stealing away that energy in the form of drag.
    - *When thrust and drag are out of balance, energy is either stored (in the form or an increase in altitude or airspeed) or released (by a decrease of altitude or airspeed).*

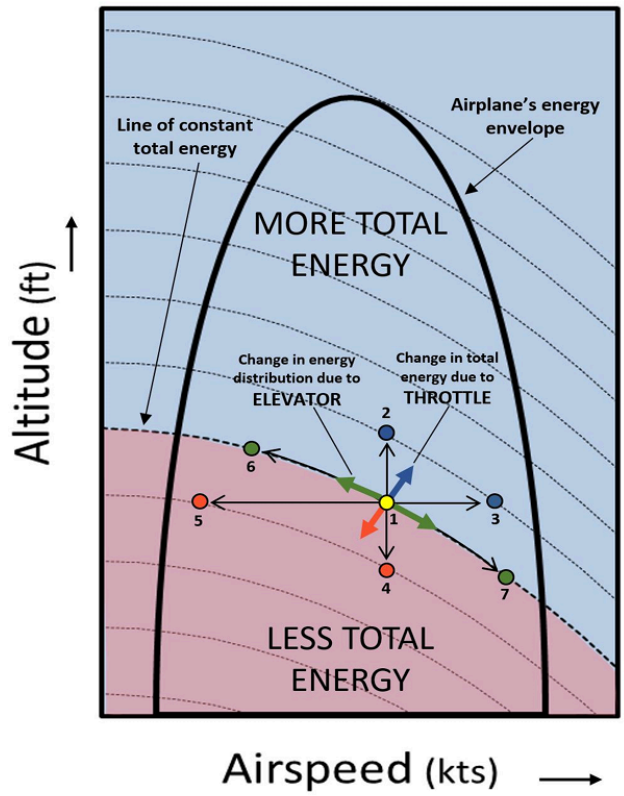


- Additionally, stored energy (altitude or airspeed) can be exchanged for each other by use of the elevator, e.g. by pulling back on the elevator, airspeed can be exchanged for altitude, etc.
- We can think of this as a system where energy is continuously coming in and going out, and the thrust (via the throttle), drag, and elevator position determine whether this energy is stored, released, or exchanged.

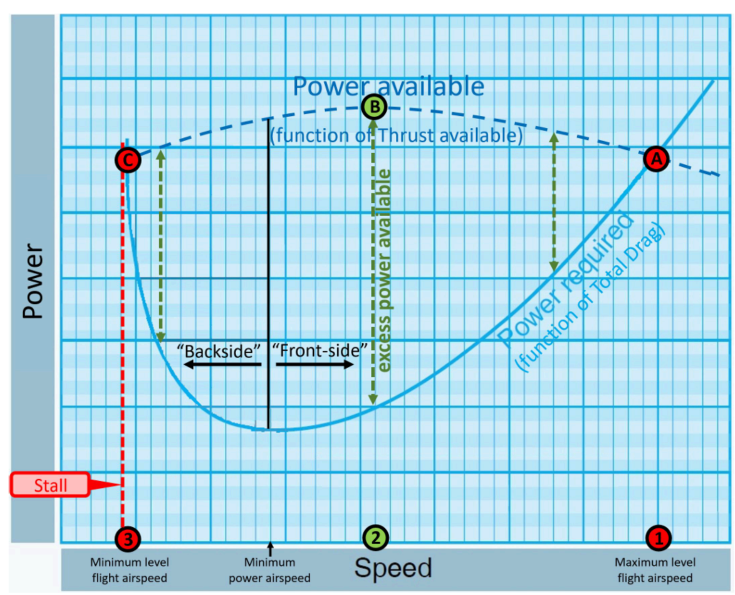


- **Moving Between Energy States -** We can plot all of the energy states that are equivalent by placing contours on an altitude vs. airspeed graph. That is to say: any two energy states connected by a contour line are equivalent, and can be exchanged for one another with no net energy added or removed.
  - E.g. in the below example, A represents 100kts at 6000 ft. A change in aircraft pitch can exchange some of this altitude for airspeed, placing it at B, 2000 feet lower but at more than twice the airspeed. This would represent the aircraft 'diving'.



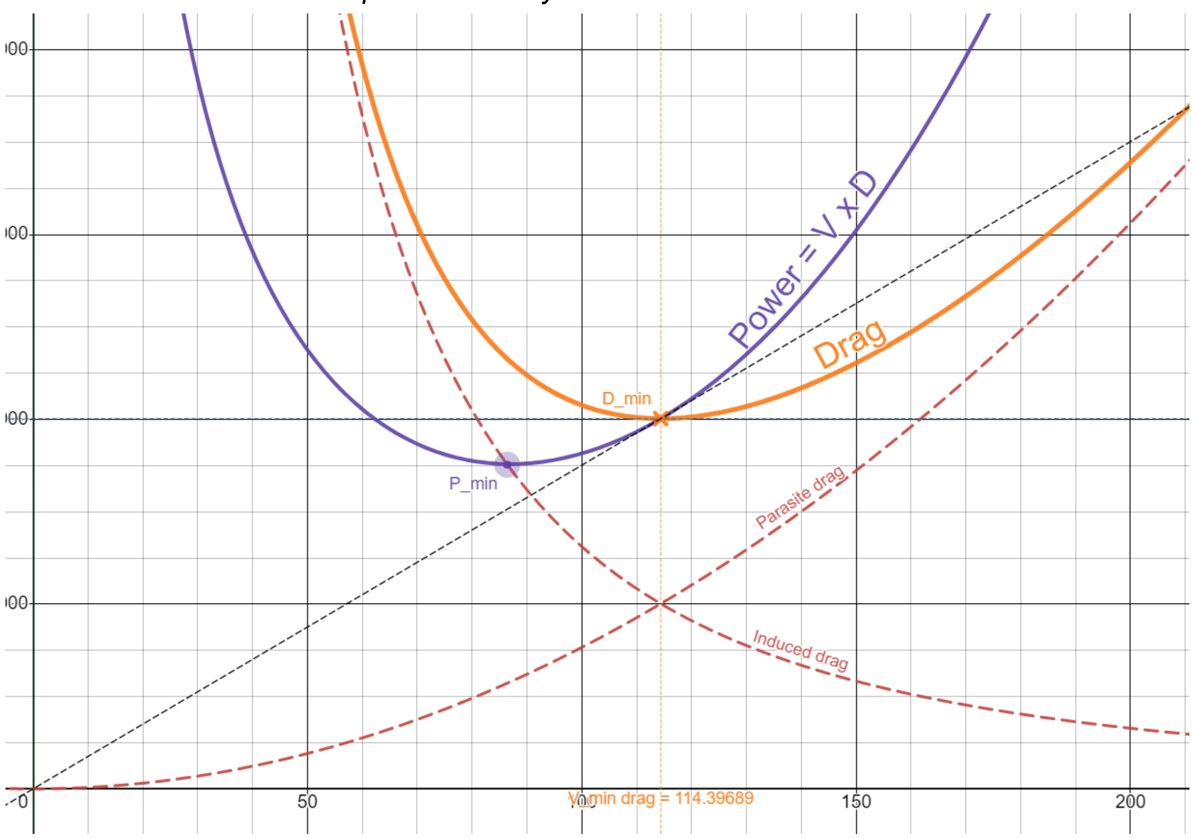


- **Behind the Power Curve -** When flying at low airspeeds, the airplane is said to be *behind the power curve*. The power curve represents the amount of power required to maintain a given airspeed without accelerating. This is at a minimum when flying slightly slower than when the amount of total drag is at a minimum.



  - **Minimum Power Required Speed** - Airspeeds below the minimum power required speed are sometimes called the *region of reverse command*. This is because any increase in pitch, and therefore angle of attack, will result in a higher power requirement, which will *increase* the rate of descent.

- *Why? Horsepower = Force x Distance / Time*. This is slightly counterintuitive, but the important thing to realize is that it measures *the rate of work performed over time*, and has a *time and distance* component. In short, flying at the minimum drag speed requires the lowest amount of *thrust*, but requires slightly more horsepower.
    - If we want to stay airborne as long as possible, we must minimize the energy consumption per unit of time. In this case, the speed to fly at is the speed which has the minimum power required.
    - If the object is to fly as far as possible, we must minimize the energy consumption per unit of distance traveled. Since energy consumed equals force (thrust) times distance, the minimum energy per unit of distance is found when the thrust and thus drag is lowest.
- Refer to the below graph which plots the Power Required curve versus the Total Drag Curve. As the speed is reduced below the minimum drag speed, the power required continues to decrease slightly, before rising rapidly. At these lower speeds, in order to maintain altitude, the airplane's engine must produce more horsepower. This means that **for any airspeed below minimum power required speed, flying at slower airspeeds actually requires *more* power.** This creates an unstable situation and is referred to as *speed instability.*

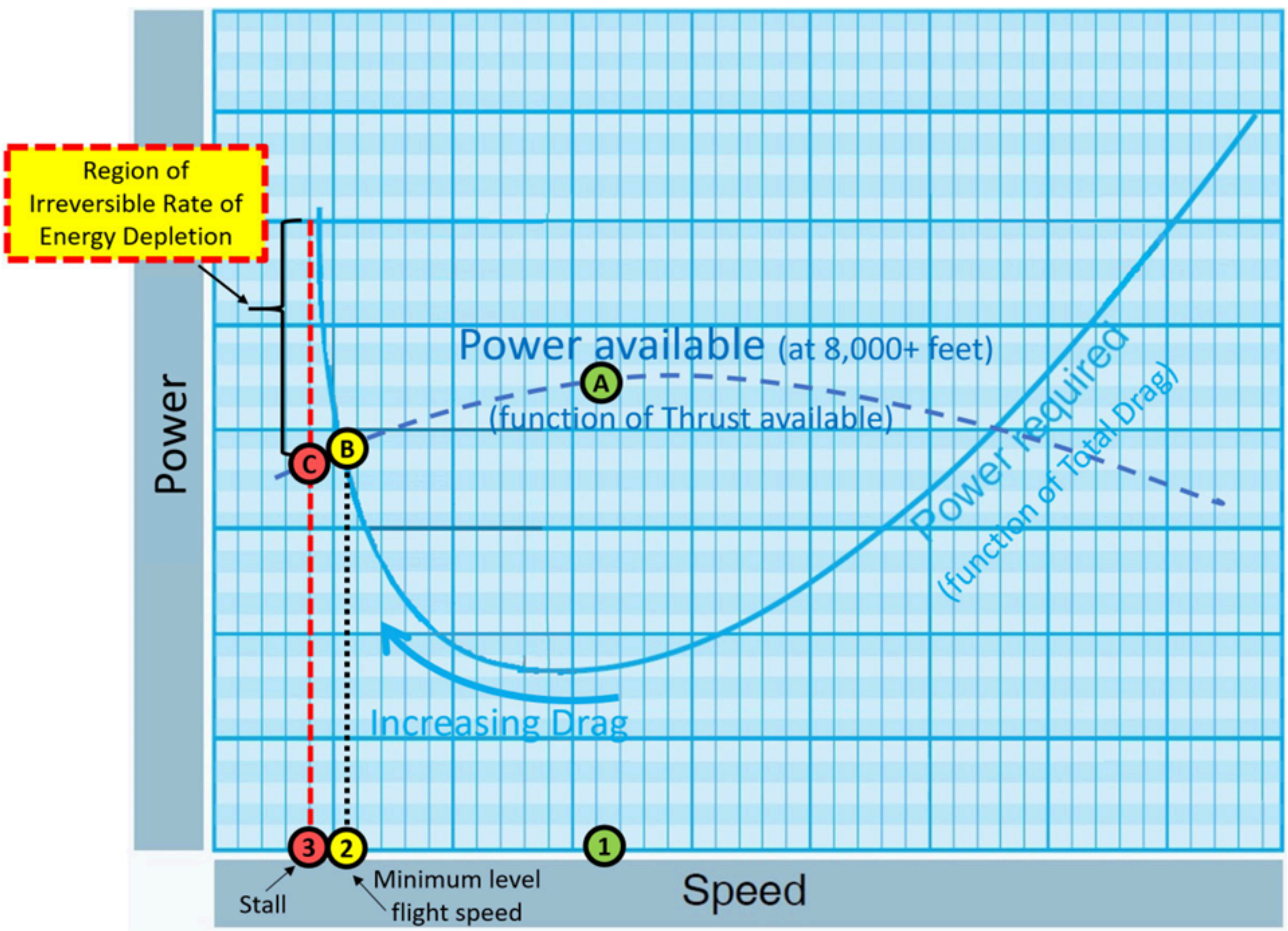


https://aviation.stackexchange.com/questions/98084/why-does-an-aircraft-require-less-power-when-it-is-flying-slower-than-the-most-e

- **Minimum Power Required is a bit slower than Minimum Drag Speed (Best Glide)** - It is important to realize that the Minimum Power Required speed is slightly less than when Total Drag is at a minimum. This minimum drag point is easy to determine, as it is the same as the Best Glide speed, however manufacturers typically do not publish Minimum Power Required, also called *Minimum Sink*. (Although Best Glide is typically published for Max Gross weight, and must be adjusted downward slightly for lighter weights)

- *Therefore, for the purposes of this maneuver, we will use Best Glide speed as a close approximation of Minimum Power Required*

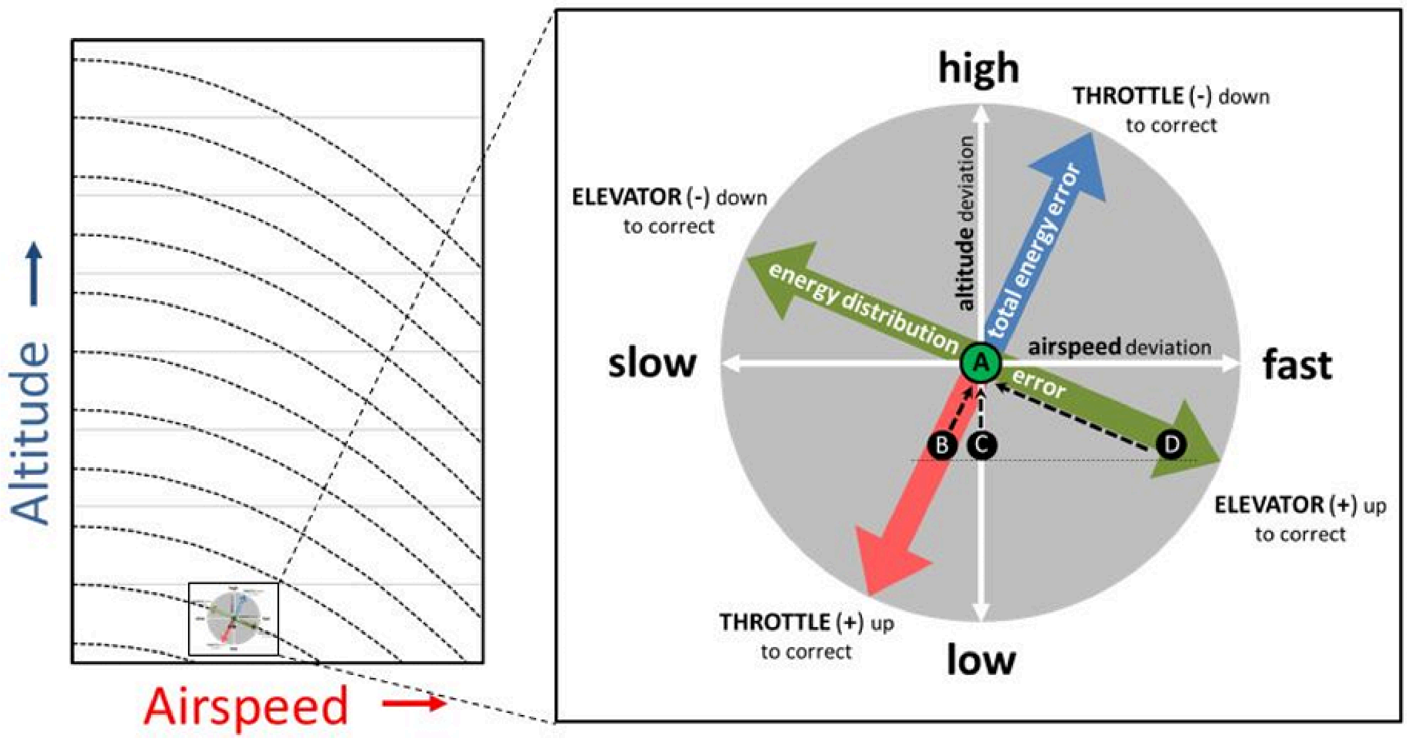
○ **Speed Instability / Irreversible Energy Depletion -** Recall that far behind the power curve, an aircraft will suffer from speed instability. This is most noticeable when the aircraft is flying at airspeeds very close to the stall. Notice that the left (slow) side of the total drag curve increases rapidly as airspeed decreases. **This means that the power required can quickly exceed the power available!** When this situation occurs, the aircraft will continuously lose energy, and if the pilot attempts to maintain altitude (potential) energy, the energy loss will be primary from kinetic energy: airspeed. In short, *the airspeed will decay irreversibly* and the aircraft will eventually stall if action is not taken to correct the low energy situation! **When the power required is more than the power available, the only remaining solution is to trade altitude for airspeed.**



○ **Faulty Approaches -** These concepts are most relevant to student pilots as they pertain to approaches to land. Specifically, in these situations, aircraft are flying at slow airspeeds, usually behind the power curve, in the region of reverse command. Small errors in glidepath and airspeed management can result in faulty approaches, and improper recognition and correction of these situations can have serious consequences!

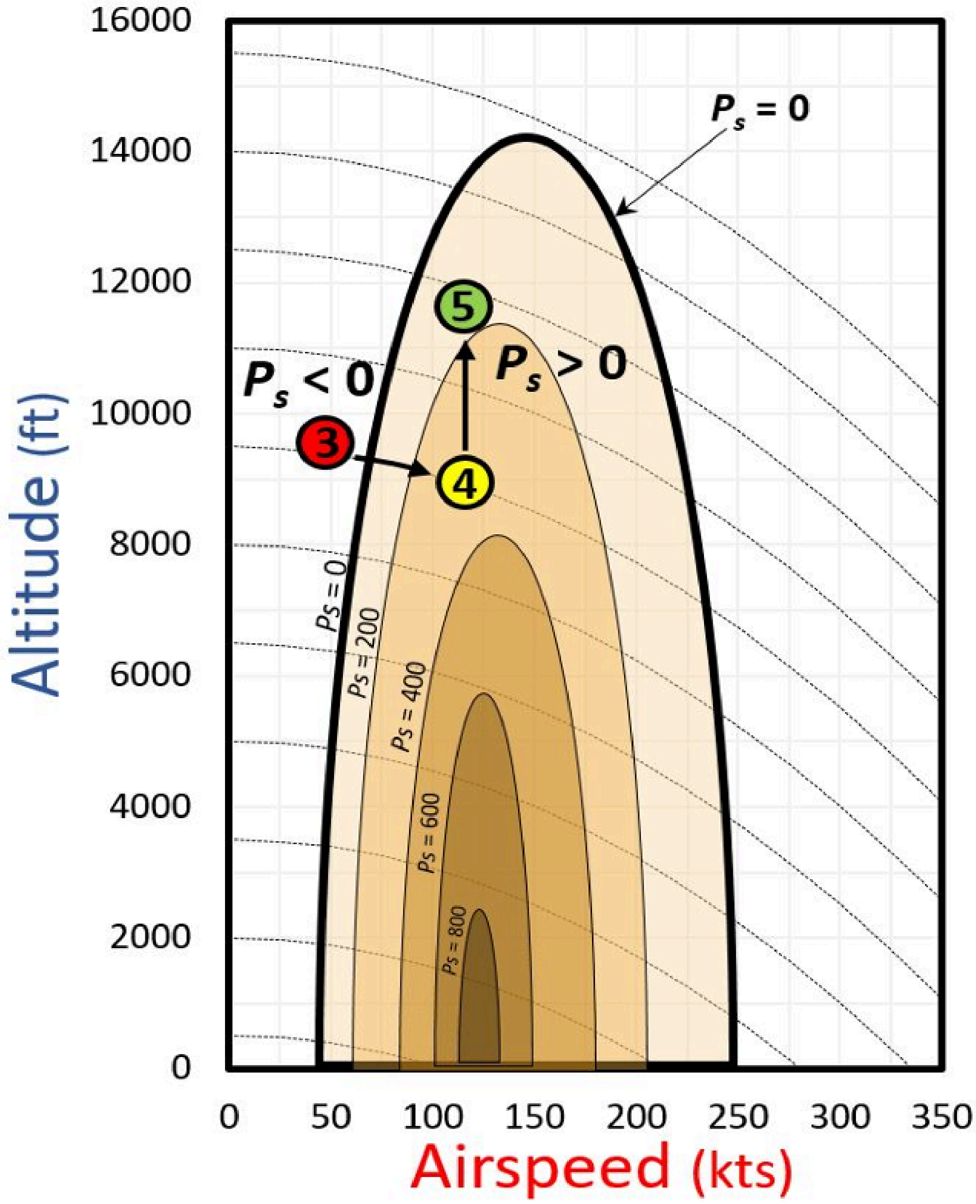
- **Energy State -** Faulty Approaches fall into either *Low Energy*, or *High Energy* categories. It is crucial that pilots understand energy management, because these errors require pilots to take steps to move the aircraft up or down the energy contours, not just along them!

- **Dangers of Low Energy Approaches -** The most dangerous category of Faulty Approaches, *Low Energy*, is dangerous precisely because of the speed instability described previously, and can rapidly cause the airspeed to decay to stalling speed, or the glidepath to sink unacceptably lo

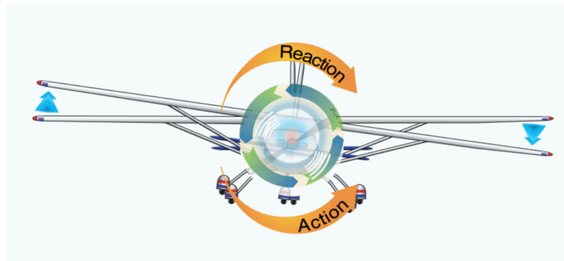
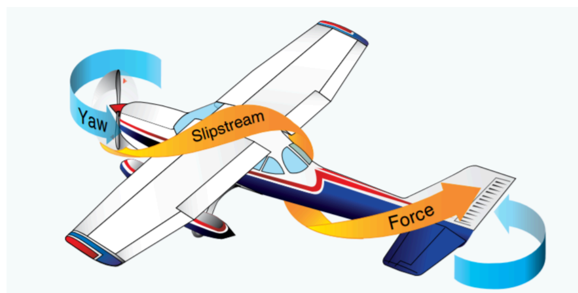
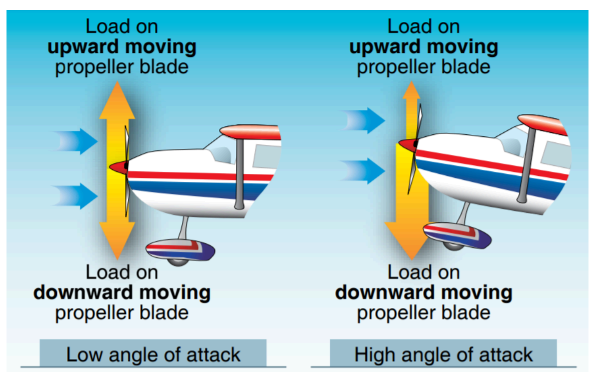


- **Recovering from Unstable Energy States** - Consider a scenario (in red) where the airspeed has been allowed to decay such that the Power Required is greater than the Power Available. (All energy states outside the bold line represent Power Required > Power Available) In order to recover from this state, engine power cannot be increased any further, however, if altitude is available, pitch can be reduced to trade altitude for airspeed (in yellow). This increase in airspeed does not require any additional energy (it moves *along* an energy contour), however it moves the aircraft into a state where less power is required and/or more power is available. *This more favorable energy situation means that the aircraft can climb again!* (in green)

- **In short, when dealing with very low airspeed situations, it will often be necessary to trade altitude for airspeed**, however by moving to a more favorable energy situation, the aircraft may still be able to climb, or climb more rapidly! (Until the Absolute Ceiling, when Vx and Vy converge and the Power Required is equal to Power Available)

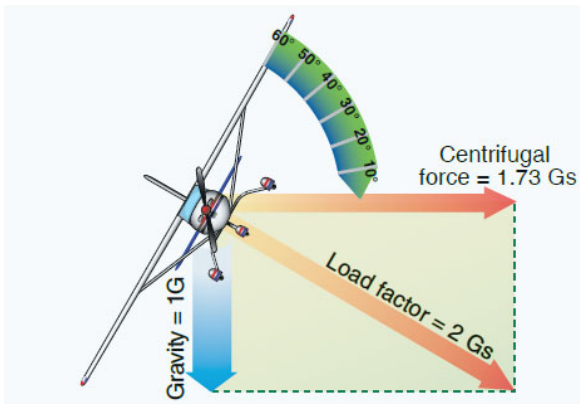


- **Flying at Minimum Controllable Airspeed**
  - **Left-Turning Tendencies** - Because slow flight requires a relatively high power setting, and is flown at a high angle of attack, airplanes during slow flight are subject to more pronounced left-turning tendencies.

○ **Torque Reaction** - As the engine turns the propeller to move the air, Newton's laws of motion require an equal and opposite reaction. In particular, as the propeller turns clockwise (from the pilot's point of view), **the airplane wants to rotate (bank) opposite the propeller rotation, to the left**. In order to counteract this, airplanes are generally designed so that the left wing makes slightly more lift than the right wing (which also produces slightly more drag), but these design features are tuned for cruising flight. At higher power settings, this will produce a noticeable left-turning tendency.	
○ **Spiraling Slipstream** - As the airflow moves through the propeller and around the fuselage, wings, and control surfaces, it is spinning. The spinning propeller imparts a considerable spiraling motion to the slipstream, and **because the vertical tail surface extends only above, and not below, the spiraling slipstream pushes the tail slightly right, leading to left yaw.**	
○ **P-Factor** - As the airplane bites into the oncoming air, it is important to realize that it is just a rotating wing, and it has an angle of attack just as any other wing. However, because the engine is mounted in a fixed orientation relative to the airplane, when the airplane itself is flying at a high angle of attack, the angle of attack of the descending blade is considerably different (higher) than the ascending blade. **This produces more thrust on the right side of the propeller disc, and pushes the nose to the left.**	

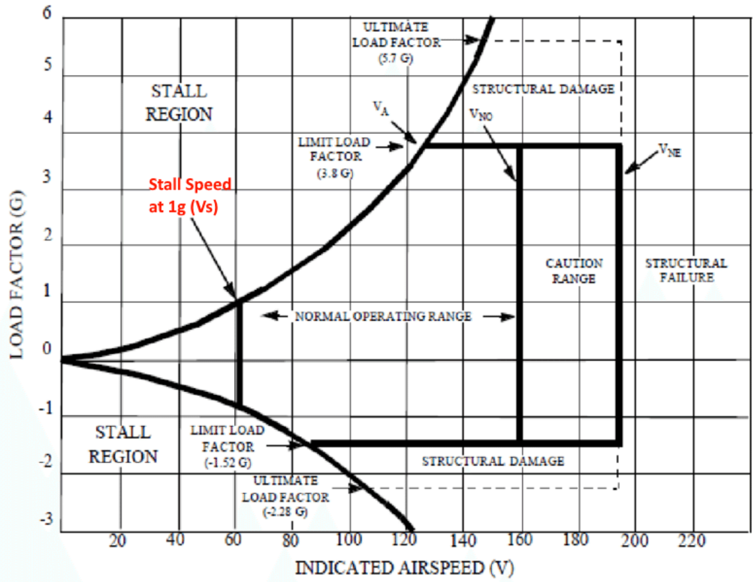
- Specifically, a high power setting produces a high torque reaction and a larger spiraling slipstream effect, and the high angle of attack makes P-factor very pronounced, **especially in a turn to the right**. Rudder pressure to maintain coordinated flight may be significant.

- **Bank Angle and Load Factor -** As an airplane turns, its weight remains the same, and therefore the upward component of lift must remain equal to its weight. During a turn, some of the lift must be directed towards the center of the turn, reducing the upward component of lift. If no pilot corrections were applied, the airplane would not produce any more than the normal 1g of lift, and the airplane would begin to descend. In order to correct for the loss of vertical lift, and maintain a level altitude, the wing must produce more lift, which requires increased *back elevator pressure*. This increased back elevator pressure will cause the wing to fly at a ***higher angle of attack***, producing the increased lift that is required. This can be felt by the pilot as a higher than normal G-force.
  - In order to maintain 1g of vertical lift, while also turning, the wing must produce more than 1g of total lift. The amount of total lift is called the ***load factor***.



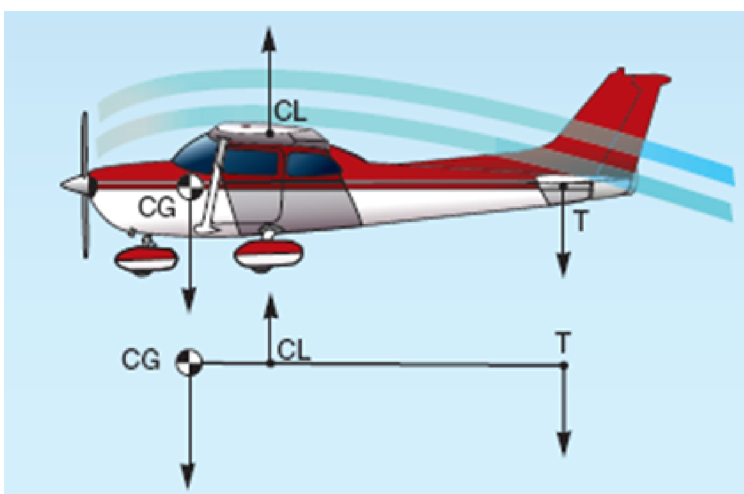
  - As the bank angle increases, the load factor required to maintain level flight increases slowly at first, but increases rapidly, especially at bank angles beyond 45 degrees. The load factor created by a *level, coordinated* turn **depends only on the bank angle**. Note that **airspeed does not affect the load factor of a turn.**
- While flying at a higher angle of attack necessary to meet the demands of a higher load factor, the wing will produce more *induced drag*. This will result in the airspeed decreasing unless power is added to compensate for the increased drag.

- **Factors that affect Stall Speed**
  - **Load Factor -** As the load factor increases in a turn, it is important to recognize that **the stall speed also increases**. We can see this relationship depicted in a so-called *Vg diagram*, shown below. The Stall Speed we normally see for our aircraft, Vs or Vs_0, applies only to 'unaccelerated' flight--that is, flight at 1g load factor. Observe from the Vg diagram that as the load factor increases, the stall speed also increases.
  - Slow flight, which is usually flown just above 1g stall speed, requires that **bank angles be kept very low** to minimize the increase in load factor.



■ **Center of Gravity** - When conventionally designed airplanes fly, the center of gravity is always *in front of* the center of lift. You can think of the center of lift as a sort of pivot point in a seesaw. Because the horizontal stabilizer is far behind the center of lift, it produces *downward* force (essentially lift, but downward) to keep the nose of the airplane level. This downward force opposes the upward force of the main wing, requiring it to produce slightly more lift to compensate. Also, because any airfoil that produces lift also produces drag, the amount of drag caused by the horizontal stabilizer depends on the force it must produce.

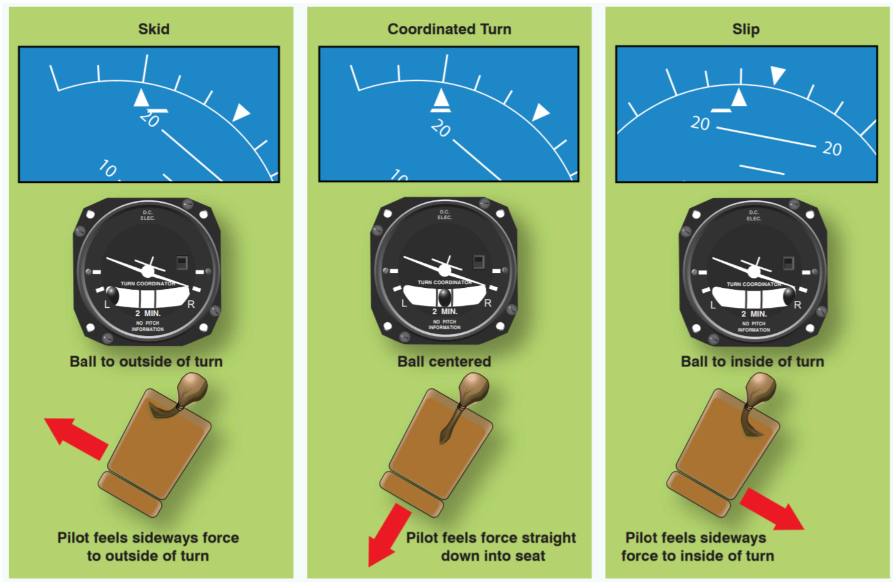
- When the center of gravity is further forward, the horizontal stabilizer must produce more downward force, and therefore it creates more drag and causes the main wing to fly at a higher angle of attack for the same airspeed. We know that a wing will always stall at the same angle of attack, so we also know that **as the center of gravity moves further forward, the airplane will stall at a higher airspeed.**



■ **Weight** - Likewise, when flying at higher weights, the total load on the wing is higher, again resulting in a higher angle of attack for the same airspeed. **Heavier aircraft stall at a higher airspeed.**

- **Coordination** - Airplanes flying in an uncoordinated fashion generate a considerable amount of increased drag, and the fuselage may blanket one wing or the other, increasing the stall speed. **This can actually cause the left and right wing to stall at a different airspeed! This is a *very* dangerous situation and must be avoided.**

- **Airspeed Control, Trim, and Coordination** - When performing slow flight, it is important to maintain a stable airspeed. Generally slow flight is performed just above stall speed, which depends on the configuration of the airplane (clean or landing configuration). **It is important to use the elevator trim to hold the desired airspeed throughout the maneuver!**
  - Because of the proximity to the stall, **it is crucial that slow flight be performed in coordinated flight.** Pay close attention to the ball and the sensations being experienced to ensure that the airplane stays in coordinated flight.



- **Airplane Configuration** - Because conditions similar to Slow Flight are often encountered during takeoffs, landings, and go-arounds, the slow flight maneuver is performed in a variety of configurations:
  - **Clean** - Simulates slow flight after takeoff, typically around Vx.
  - **Dirty (Full Flaps or Landing Flaps)** - Simulates slow flight before landing, or during go-arounds.
    - Flaps add lift as well as drag, and result in lower pitch angles. It is often more comfortable to fly slow flight with landing flaps.
    - **It is important to realize that flaps change the shape of the wing and therefore affect the airspeeds and angle of attack at which the wing stalls!** Airspeeds which work in the Clean configuration will not match
  - **Airspeed Limitations** - This demonstration requires the aircraft to be flown between Maneuvering Speed (V_a) and Minimum Controllable Airspeed (~V_s/V_{s0}), and the aircraft must be configured as specified by the evaluator. Therefore, **airspeed limits on flaps (V_{fe}) and landing gear (V_{le}, V_{lo}, if applicable) must be respected at all times throughout the maneuver!**

- **Safety Considerations**
    - **Flying with a stall warning** - Any warning that goes unheeded and unacknowledged will quickly become part of the 'background noise' and be ignored. Therefore, we want our students to always react promptly to acknowledge stall indications.
    - As with any maneuver, the **use of checklists is important**. Before beginning the maneuver, perform a pre-maneuver checklist, including performing clearing turns and identifying possible emergency landing sites.
    - It is crucial to not become so focused on performing the maneuver that an unsafe situation is created. Maintain situational awareness, make appropriate practice area radio calls, and **remember to continuously scan for traffic!**
    - **Environmental Factors** - When operating at very slow airspeeds near the stall, keep in mind that small wind gusts or turbulence can cause abrupt stalls. Avoid performing this demonstration in rough or gusty conditions.

Maneuver Description

- **Entry Altitude** - Flight near stalling speeds should always be performed at a safe altitude, in case of an inadvertent stall or other problems. The maneuver should be performed such that the aircraft is always at least 1,500 feet AGL or more. **The recovery procedure will necessitate a small loss of altitude, so choosing a starting altitude of at least 2,000 feet AGL is recommended.**
- **Entry Airspeed** - The maneuver should be started at $\mathbf{V_a}$ (maneuvering speed).
- **Checklists** - Pilots must perform a pre-maneuver checklist before beginning the maneuver.
- **Entry Power** - Initially, reduce the power to allow the aircraft to decelerate.
- **Configuration** - If the landing configuration is specified by the evaluator, as the aircraft slows below the applicable airspeed limits, extend the flaps and/or landing gear as appropriate. **Do not exceed any airspeed limitations!**
- **Continue Speed Reduction** - Airspeed should be allowed to slow from entry airspeed down to **approximate minimum power required speed (i.e. Best Glide)** in the current configuration.
- **Acknowledge Minimum Power Required** - Maintain coordinated straight-and-level flight at Best Glide speed and call the student's attention to the current power setting.
- **Continue Speed Reduction** - Slow the airplane further with pitch and power adjustments to *minimum controllable airspeed*, i.e. an airspeed at which any further increase in angle of attack causes an immediate aerodynamic stall.
- **Maintaining Minimum Controllable Airspeed** - Once minimum controllable airspeed is reached, add a generous amount of power back to maintain airspeed and altitude. Do not allow the airspeed to decay any further, and do not allow the airspeed to increase.
- **Acknowledge Minimum Controllable Airspeed and Power Required** - Acknowledge the stall warnings verbally, and call the student's attention to the new power setting, which is higher than the previous (best glide) power setting.
- **Begin Recovery** - Recover to normal cruise flight by **reducing pitch only, without adjusting the power setting,** allowing the airspeed to increase and temporarily descending below the entry altitude.
- **Acknowledge Altitude Loss and Airspeed Gain** - Call the student's attention to the fact that the airspeed has now increased, note the altitude loss, and that the aircraft is now maintaining straight-and-level flight at the same power setting at a higher airspeed.

- **Continue Recovery -** Climb back to the entry altitude and resume normal cruise flight. If performed in the dirty or landing configuration, progressively retract flaps, landing gear, etc.
- **This is a visual maneuver!** Eyes should remain outside the cockpit as much as possible to scan for traffic and to hold heading.

Expanded Completion Standards

- The flight instructor applicant can explain the purpose of the demonstration maneuver and can explain the concept of energy management, the power required curve, and ‘region of reverse command’.
- The pilot can perform the maneuver to the following standards:
    - Pilot clears the area, performs a pre-maneuver checklist, and selects an altitude not less than 2,000ft AGL.
    - Pilot establishes cruise flight at maneuvering speed (V_a).
    - Pilot reduces power to establish level flight at Best Glide (V_g) speed, and configures the airplane as specified by the evaluator, without exceeding any airspeed limits.
    - Pilot calls attention to the power setting.
    - Pilot further reduces airspeed to minimum controllable airspeed.
    - Pilot calls attention to the stall indications and the new higher power setting.
    - Pilot reduces pitch to increase airspeed and allows the aircraft to stabilize at a lower altitude and higher airspeed.
    - Pilot calls attention to the new higher airspeed for the same power setting.
    - Pilot completes the recovery to normal cruise flight at the entry altitude.
    - Pilot can hold altitude ±100 feet (always at or above 1500ft AGL), airspeed +5/-0 knots, bank ±5°, headings ±10° throughout the maneuver.