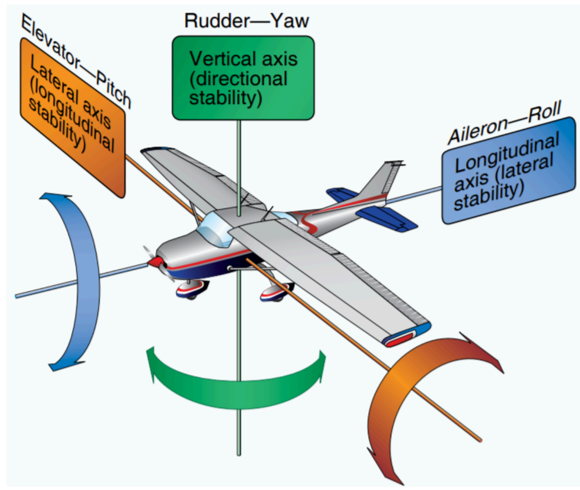
Airplane Flight Controls and Operation of Systems

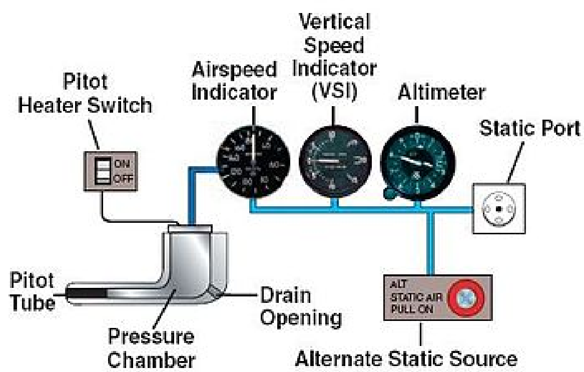
Objective

To ensure the applicant learns the purpose and use of the primary and secondary flight controls as well as the principles of operation for the systems and instruments installed in their airplane.

Purpose

The flight controls are what makes pilots. They are the mechanism by which airplanes move in controlled flight. This lesson will introduce new pilots to the various types of flight controls, and their purpose. Also, in order to operate safely and efficiently, all pilots must be familiar with the systems that are installed on the airplanes they are flying. This lesson further introduces pilots to the basic principles of operation of many common airplane systems.





Schedule	Equipment
● **Ground Lesson (Flight Controls)**: 20 minutes ● **Ground Lesson (Systems):** 40 minutes ● **Student Q&A**: 20 minutes *(each lesson)*	● Airplane POH ● Whiteboard / Markers (optional) ● Model Airplane (optional)

Student Actions	Instructor Actions
● Ask any questions, receive study material for the next lesson. ● Watch linked video. ● Review listed references.	● Deliver the ground lesson (below). ● Answer student questions.

Completion Standards

- Student can explain the purpose and use of the primary and secondary flight controls, as well as the role of the ailerons and rudder in turns.
- Student can describe and explain the basic operational principles of the following systems:
  - The Primary and Secondary Flight Controls, The Engine and Propeller System, The Fuel, Ignition, and Oil Systems, The Electrical System, Avionics, The Pitot-Static and Gyroscopic Instruments, The Landing Gear, Anti-Ice or De-Ice Systems (if installed), Oxygen Systems (if installed)

Prepared by: Ryan Binns (ryancbinns.com/flying), February 2020 (Updated April 2024)
Editable versions available at binnsflightservices.com/cfibinder

References

- ERAUSpecialVFR - “Aircraft Systems - 02 - Flight Controls”
  - YouTube - https://www.youtube.com/watch?v=WhQ8Ai4fa_Q
- Wren Aviation, LLC - “Constant Speed Prop Basics”
  - YouTube - https://www.youtube.com/watch?v=QKfQ6f6R82Y
- FAA-H-8083-3C (Airplane Flying Handbook) - Chapter 12 [Transition to Complex Airplanes]
- FAA-H-8083-25C (Pilot’s Handbook of Aeronautical Knowledge) - Chapter 6, Page 2-3 [Primary Flight Controls/Axes of Rotation], Chapter 6, Page 3-5 [Ailerons], Chapter 6, Page 5-7 [Elevator], Chapter 6, Page 8 [Rudder], Chapter 6, Page 8-10 [Secondary Flight Controls], Chapter 6, Page 10-12 [Trim Systems], Chapter 7 [Aircraft Systems]
- FAA-S-ACS-6C (Private Pilot ACS) - Area I Task G
- FAA-S-ACS-7B (Commercial Pilot ACS) - Area I Task G
- FAA-S-ACS-25 (CFI ACS) - Area II Task E

Ground Lesson Outline

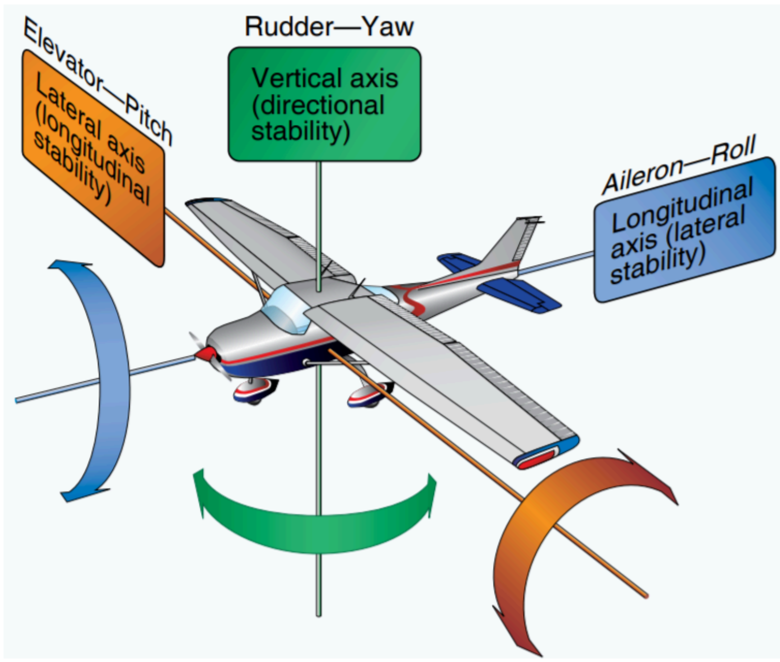
- Flying in Three Dimensions - Yaw, Pitch, Roll / Airplanes turn with roll (bank)
- The Primary Flight Controls - Yoke/Stick, Control Cables, Ailerons, Elevator, Rudder
- The Secondary Flight Controls - Flaps, Spoilers, Leading Edge Devices
- Elevator Trim - Trim Wheel
- Rudder Trim Devices - Rudder Trim, Ground Adjustable Tabs
- Proper Yoke Grip and Overcontrolling
- Role of the Rudder in Turning Flight
  - Weathervaning, Coordinated Flight
  - Two Phases of Turning Flight - Banking (Adverse Yaw) and Turning (Tail Position Rear of CG)
- Cessna 172 - Description of Systems - Refer to POH Section 7 (Systems)
- Powerplant and Propeller
  - Horizontally Opposed, Air-Cooled Engine
  - Dual Magneto Ignition
  - Carburetor vs Fuel Injection, Mixture Control / EGT
  - Fixed vs Constant Speed Propellers - How A Constant Speed Propeller Works
- Landing Gear - Fixed vs Retractable Gear Systems
- Fuel, Oil, and Hydraulic
  - Fuel - Two tanks, gravity fed
  - Oil - 8 qts total
- Electrical - 28V System, Alternator and Battery
- Avionics including Autopilot - Dual G5s, Garmin 530W, King NAV/COM Radios
- Pitot/Static System
  - Airspeed Indicator, Altimeter, Vertical Speed Indicator
- Gyro and Vacuum Instruments
  - Attitude Indicator, Directional Gyro - Vacuum-powered Gyro or AHRS
    - Gyroscopic Rigidity in Space, Precession
  - Turn Coordinator - Electrically Powered Gyro
    - Measures rate of turn by sensing precession
- Environmental
- Deicing and Anti-icing - Pitot Heat, Windscreen Defrost

Common Errors

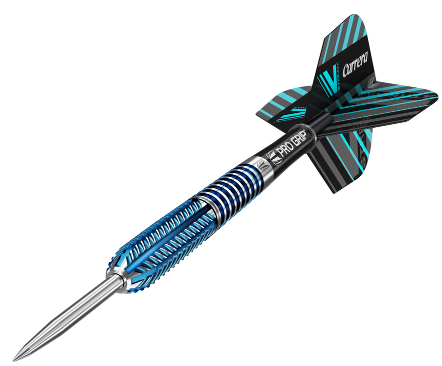
- **Lack of understanding of the purpose and usage of the rudder.**
- Lack of understanding of the purpose and usage of trim devices.

Ground Lesson Content

- **Flying in Three Dimensions -** Unlike cars, which turn only left or right in two dimensions, airplanes can move in three dimensions, and rotate around 3 separate axes. The orientation of the airplane is called the *attitude*. The 3 axes of flight are:
  - **Yaw** - *Yaw* is the familiar 'turning' left and right. Rotating around the *vertical axis*.
  - **Pitch** - *Pitch* is the up and down axis. The airplane is rotating around the *lateral axis*, and the nose will be pointing 'uphill' or 'downhill'.
  - **Roll** - *Roll* is somewhat unique to airplanes. **Roll is also often called *bank*.** The airplane is rotating around the *longitudinal* axis. There is no real similarity to cars in this dimension, but it can be thought of as the airplane *leaning* left or right.



  - Airplanes climb and descend in part by increasing or decreasing pitch, however, somewhat unexpectedly, **airplanes do not turn by simply changing yaw. Airplanes turn by banking towards the direction of the turn**, which directs the wings lift force to the side. The vertical tail surface keeps the airplane aligned with the direction of travel, causing the airplane to yaw. This is similar to how the fins or feathers on a dart or arrow keep it flying in the direction it is thrown.



- **The Primary Flight Controls**
  - Airplanes are commonly designed with 3 *primary* flight controls, which are connected to a *control yoke*, or *stick* by a series of *control cables* or mechanical linkages like *pushrods*:
    - **Ailerons** - Ailerons move the airplane around its *Roll* axis. **The angle of roll is called the *bank angle* and pilots use the airplane to *bank* in the direction they wish to**

turn. Most airplanes control the ailerons with a *yoke*, which is similar to a steering wheel. Turning the wheel left or right causes the airplane to bank left or right.

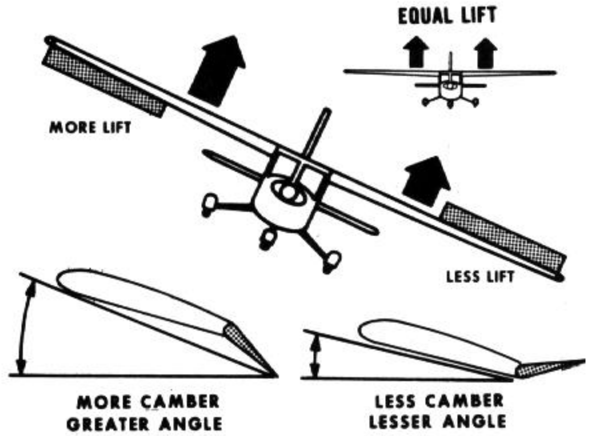
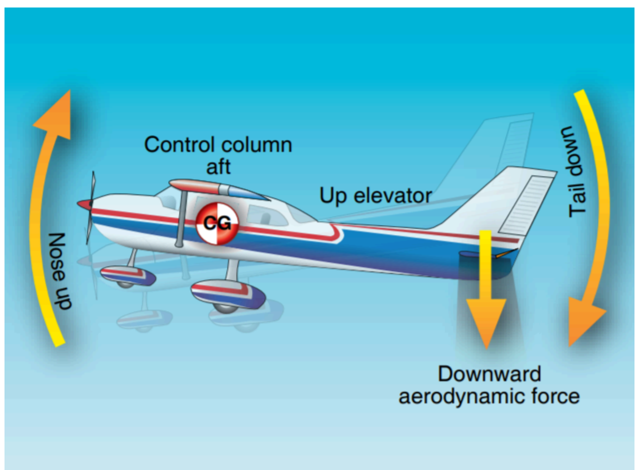
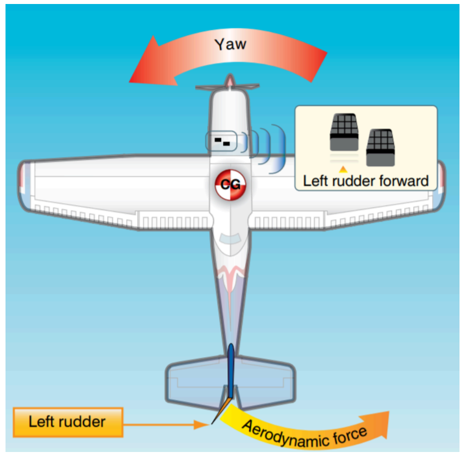


Figure 4–3 Forces Exerted by Ailerons

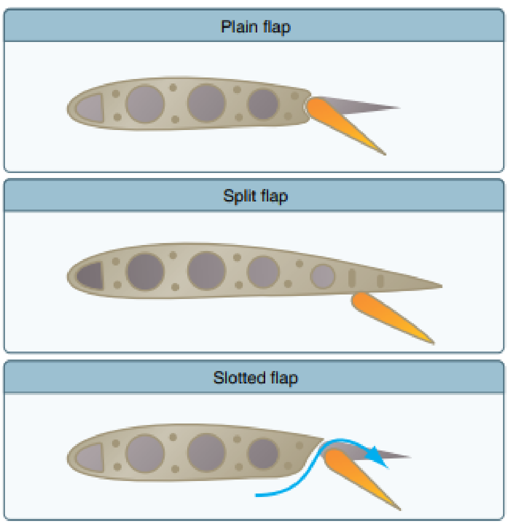
- **Elevator -** The Elevator moves the airplane around its *Pitch* axis. Pilots can initiate a climb or descent by pulling back or pushing forward on the yoke, respectively. Most new pilots are already familiar with this concept from TV and movies, e.g. “pull up” to pitch up.



- **Rudder -** The Rudder moves the airplane around its *Yaw* axis. The rudder is a very mysterious control for most new pilots, because **it is not used to turn the airplane**, as one might expect. The sole purpose of the rudder is to aid the airplane in maintaining a proper (called *coordinated*) flight path during turns made with the ailerons (bank).



- **Secondary Flight Controls -** Airplanes are also equipped with a variety of *secondary flight controls*, which to some degree affect the aerodynamics of the airplane, but some are typically used only in certain situations.
    - **Trim -** Trim devices are a form of secondary flight controls which will be discussed separately, but their primary function is to alleviate control pressures felt in flight.
    - **Flaps -** The most common secondary flight control is the *flaps*, which simply increase the *camber* of the wing, and sometimes lengthen the *chord line* (See the lesson on *Basic Aerodynamics*), in order to provide more lift and lower the stall speed, while creating more drag to enable a steeper descent for landing. Flaps are usually controlled with a level or switch in the cockpit, and usually have multiple positions, corresponding to varying degrees of deflection.

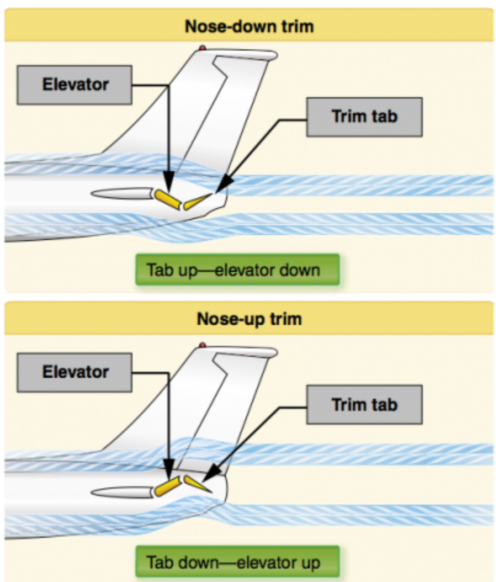


    - **Spoilers -** Large, fast, and efficient airplanes often include *spoilers* which are devices used to deliberately create drag and 'spoil' lift. These are not normally found on small airplanes.
    - **Leading Edge Devices -** Large airplanes also often include leading edge devices, often *slots, leading edge flaps* or *slats*, which also increase lift and lower stall speed by delaying airflow detachment and stall at low airspeeds. Some small airplanes, typically used for very short takeoff and landing roles, are equipped with slots or slats, but these are not common on training airplanes.

- **The Elevator Trim -** In order to hold the nose the proper distance from the horizon and maintain altitude, **new pilots often discover that it may require continuous forwards or backwards elevator**

pressure on the control yoke. This is not only uncomfortable, it also requires pilots to devote more attention to maintaining straight and level flight and prevents them from multitasking effectively. There is another, *secondary* flight control, called *pitch trim* or *elevator trim*. These terms are interchangeable, and refer to a control wheel **(the *trim wheel*) which can be used to relieve these control pressures**.

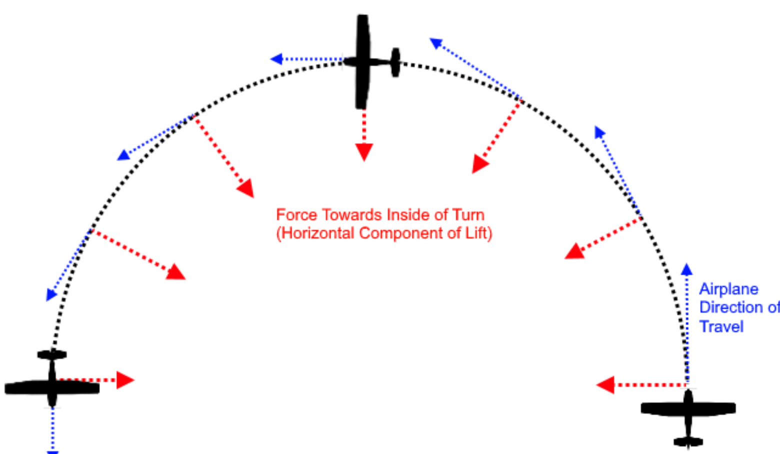
- The trim mechanism is different on different airplanes, but it usually consists of a small tab, called the *trim tab* on the elevator control surface itself. The trim tab services to 'rebalance' the neutral position of the elevator control and help maintain low control pressures.
- The trim tab is moved with the *trim wheel*, which when rolled forward moves the trim *nose down*, and when rolled rearwards, moves the trim *nose up*.

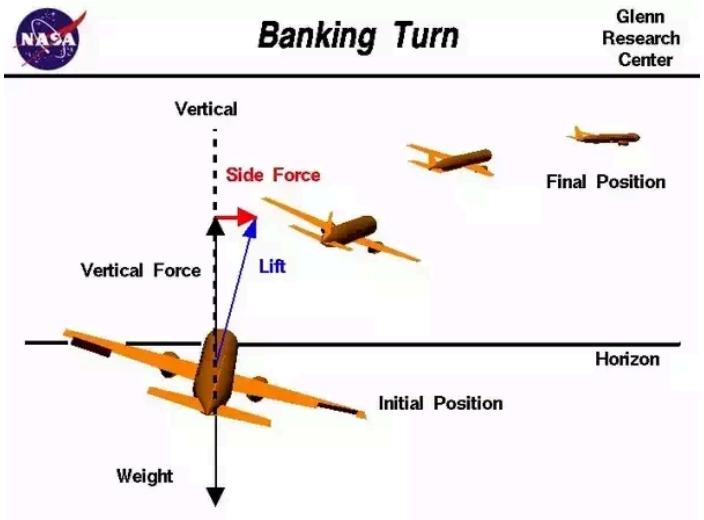


- **Rudder Trim Devices -** Even during cruise flight, airplanes are subject to left-turning tendencies because the airplane is almost never flying at 0 angle of attack, and the spiraling slipstream is continuously pushing the nose slightly to the left. This results in **the airplane naturally flying somewhat uncoordinated, and would necessitate the pilot flying with slight right rudder pressure at all times**, a very uncomfortable situation. To alleviate this, there are a couple types of rudder trim that some airplanes provide:
  - **Rudder Trim -** Rudder trim is just like elevator trim, in that there is usually a wheel which is turned to alleviate the rudder control forces. Some airplanes have a rudder trim tab on the rudder, but it is also commonly just an adjustment on a spring or cable which applies some force to the rudder pedals directly.
  - **Ground Adjustable Rudder Tabs -** Most small airplanes are also equipped with a *ground adjustable tab* on the rudder, which can be literally bent to provide a slight amount of rudder deflection. **This is a trial and error process and should not be done except by the airplane owner or maintenance personnel!**

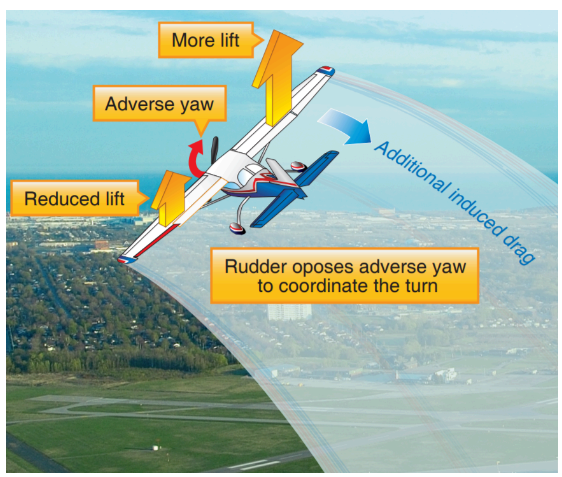
- **Proper Yoke Grip and Overcontrolling -** Proper control of the airplane requires that pilots avoid *overcontrolling*. Unlike driving a car, which requires large movements of the wheel, flying an airplane rarely requires large movements, or a lot of force on the controls.
  - Pilots who grip the yoke tightly with both hands often struggle with maintaining straight and level flight or making smooth turns or other maneuvers. Pilots coping with turbulent or bumpy conditions often make the bumpiness *worse* by holding the yoke too firmly.
  - In most situations, pilots should attempt to relax, as **the airplane can be flown mostly with *control pressures*, rather than *control movements***. A one-handed, light grip on the yoke also frees the pilots other hand for manipulating the throttle, or adjusting the radios, etc.

- **Role of the Rudder in Turning Flight -** New pilots discover quickly and intuitively that turning an airplane requires banking, however the rudder also plays a very important role. In order to understand why, it is necessary to briefly describe the aerodynamics involved.
  - **Weathervaning -** As the airplane flies around the turn, there is a horizontal component of lift, which is a force directed towards the center of the turn, and a vertical component of lift, which acts upward and opposes gravity. **As the airplane begins to move sideways, the relative wind strikes the vertical tail surfaces, and causes it to rotate towards the wind, just as in a weather vane.** This keeps the nose of the airplane pointed towards the relative wind, producing a *yaw* in the direction of the bank.

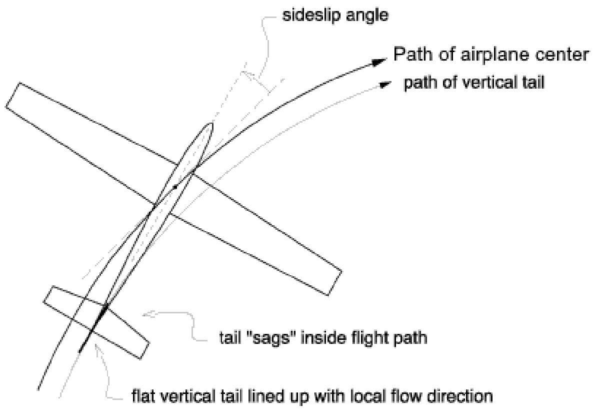




- **Two 'Phases' of Turning Flight** - The above explanation, however, is oversimplified. There are two distinct phases that an airplane goes through in turning flight:
  - **Banking** - Although banks *cause* airplanes to turn, banking by itself is not a turn. When banking, the airplane uses its ailerons to roll the airplane around the longitudinal axis. The *outside* (away from the turn) wing aileron lowers, producing a higher angle of attack and more lift, and the *inside* wing aileron raises, producing a lower angle of attack and less lift. **This increase in lift on the outside wing causes that wing to produce more drag on that side, which actually initially causes the airplane to turn away from the intended direction of turn!** This tendency is called *adverse yaw*. **Pilots should correct for adverse yaw by using the rudder pedals to counteract it whenever they use the ailerons.**



  - **Turning** - Once the airplane is established in a bank, the effects of adverse yaw are mostly no longer present since the ailerons are neutral or nearly neutral. **However, an airplane banked towards a turn will still not by itself fly perfectly in line with the relative wind!** This is because, due to the curve flight path, the relative wind is angled slightly differently at the front and rear of the airplane. The larger, vertical tail surface will tend to assume an orientation that is aligned with the wind, but this causes the nose of the airplane to actually point slightly outside of the turn! This is called a *slipping turn*. A turn where the nose points to the inside of the turn is called a *skidding turn*, and is fairly similar to a car skidding turing a turn. (The turn is ‘too flat’, with not enough bank angle for the rate of turn) **Both slipping and skidding turns are undesirable!**



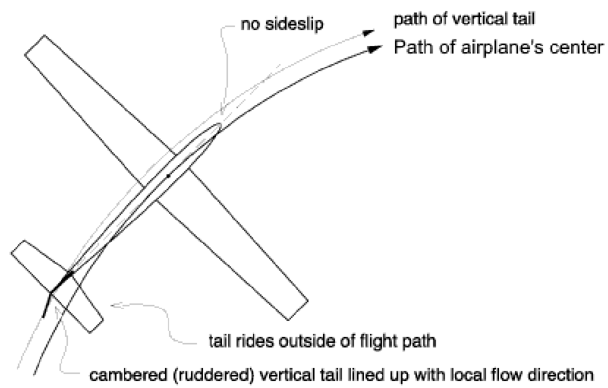
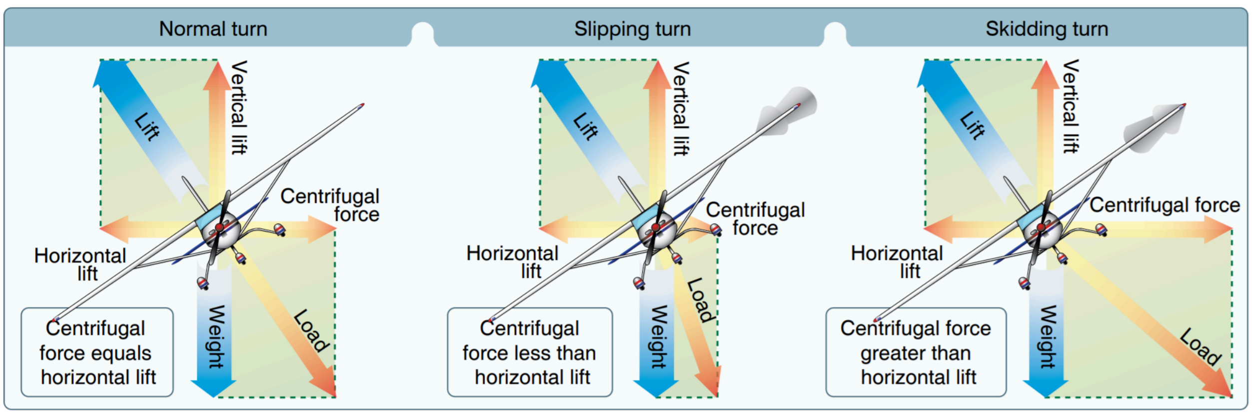
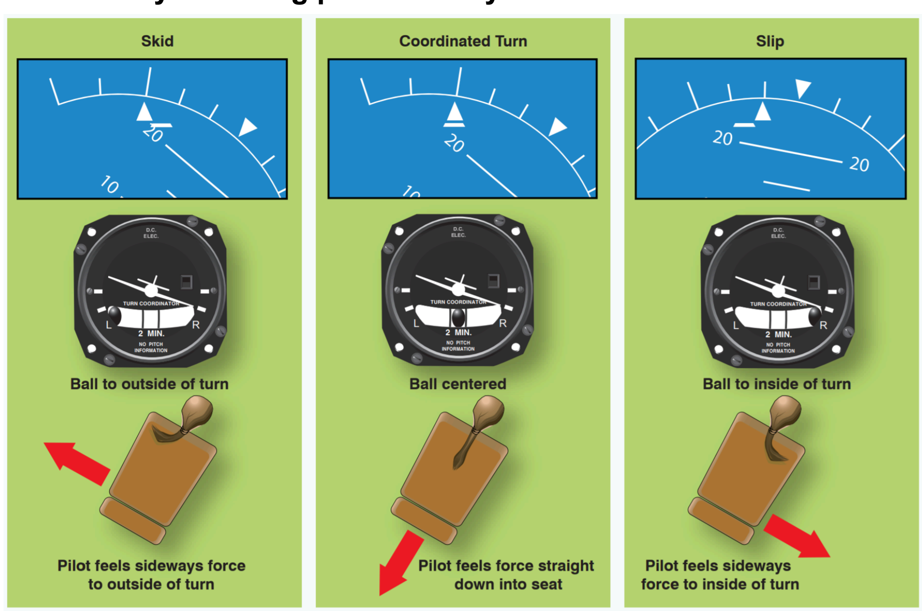


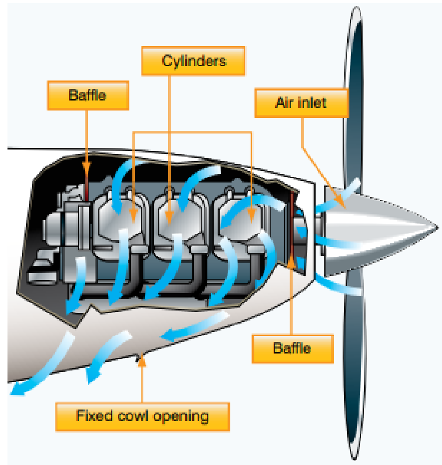
Figure 1a. Zero rudder deflection in sustained tight turn produces sideslip. **Figure 1b. Rudder deflection for zero sideslip.**

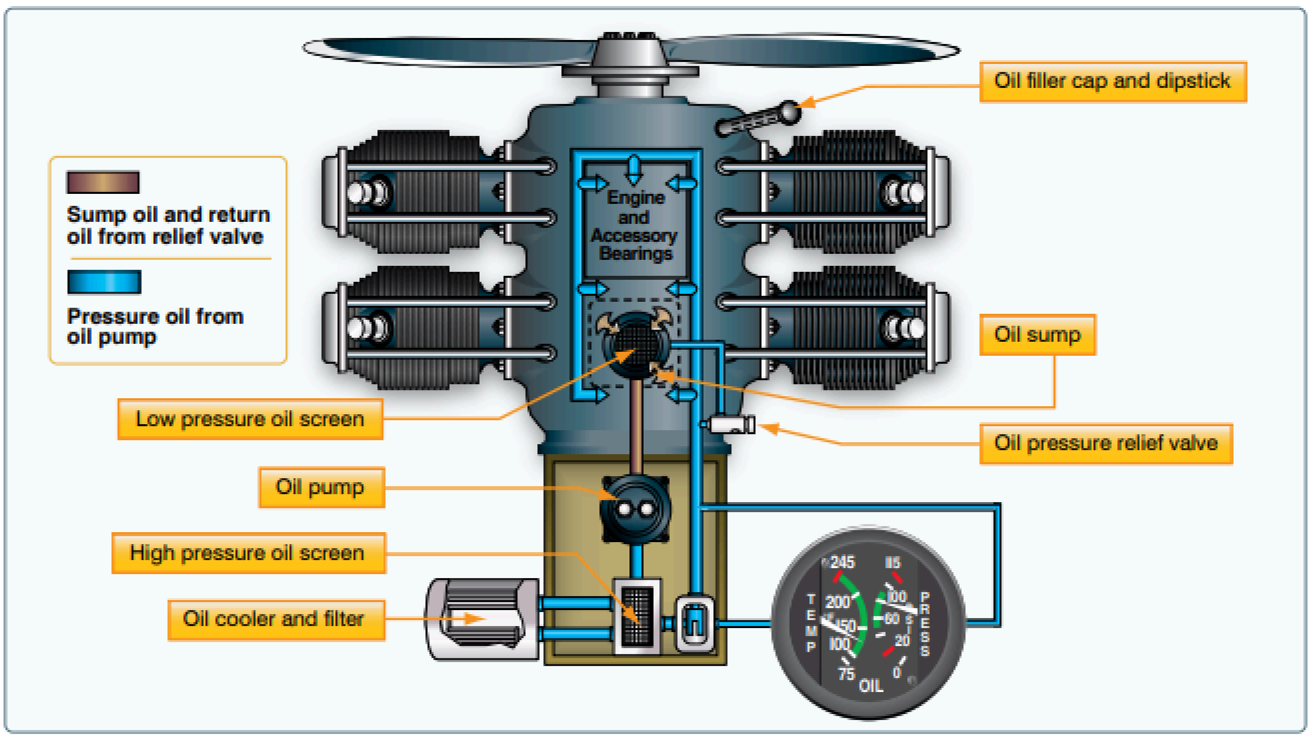


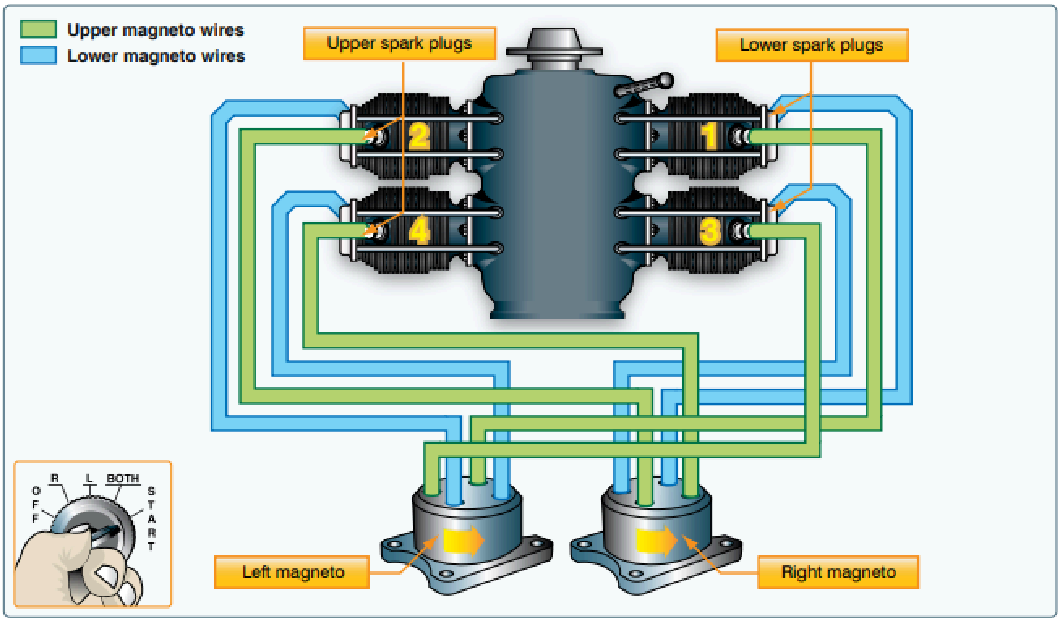
- **Coordinated Flight -** In order to correct for these tendencies, pilots must use the rudder pedals to manage the amount of sideslip or skidding as the pilot rolls the airplane or maintains a turn. Flying with no skid or sideslip is called *coordinated flight.* The instrument which gives the pilot direct information about this is called the *turn coordinator*, however **pilots can also learn to sense when they are being pushed away from the turn or towards the turn.**



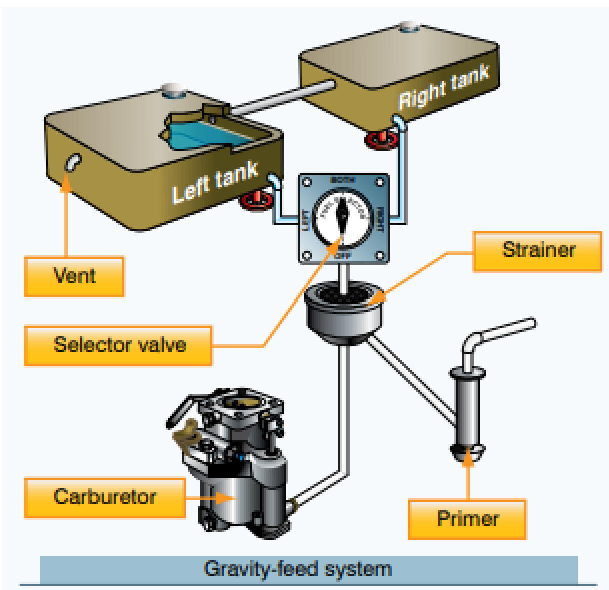
- **Airplane Piston Engines -** Most small training airplanes have *reciprocating* engines (*piston-powered* engines, similar to a car). Most of these are *air-cooled, horizontally-opposed* engines, with a *wet sump* oil system. Unlike a car, airplane engines usually generate their own spark (independent of the electrical system) using a *magneto ignition* system. Most airplanes have *dual* magnetos, leading to two spark plugs per cylinder, which fire simultaneously for more complete combustion.

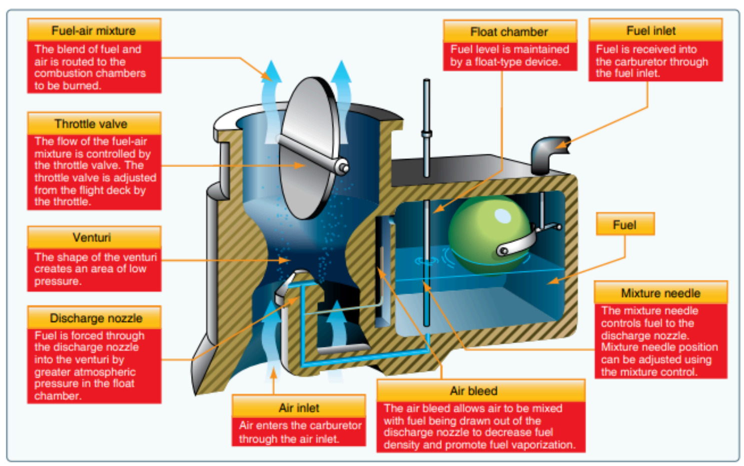






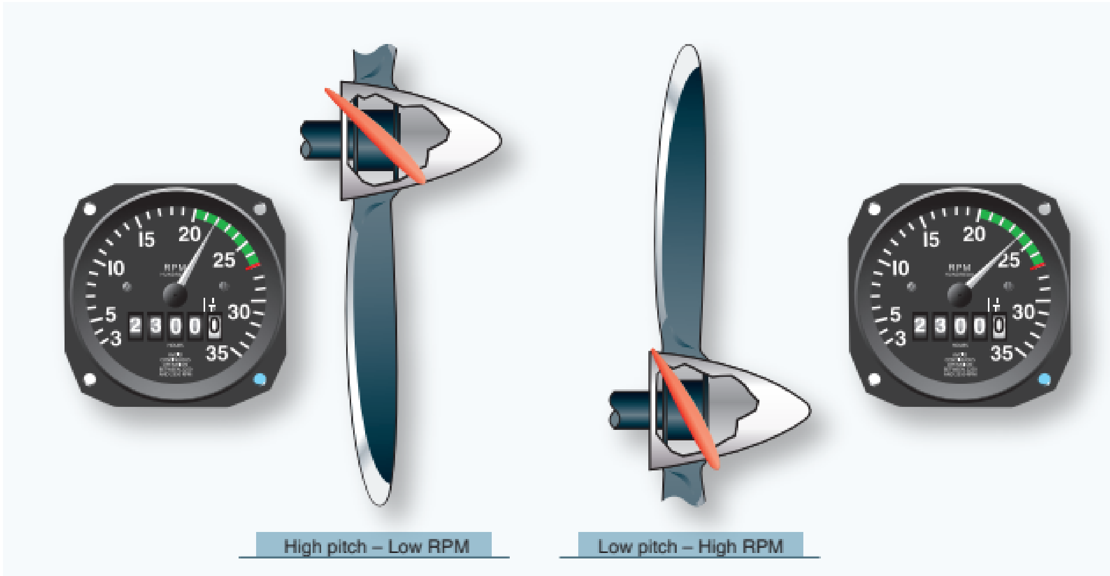
- **Fuel System** - Many training planes have a simple, *gravity-fed* fuel system. Generally these engines also introduce fuel using a *carburetor*, which atomizes (finely disperses) fuel using the *venturi effect*.

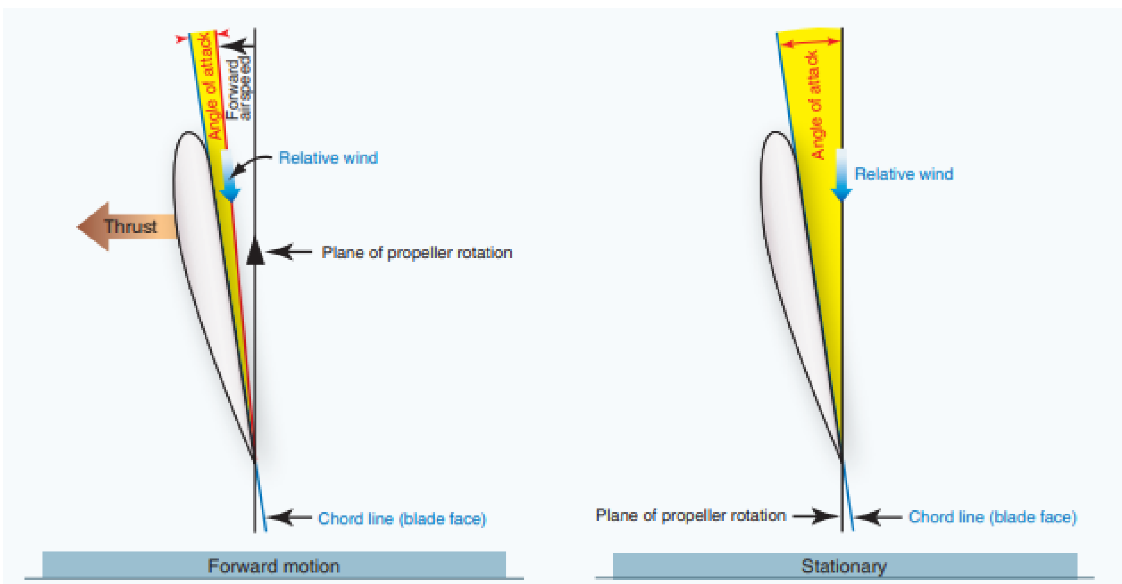


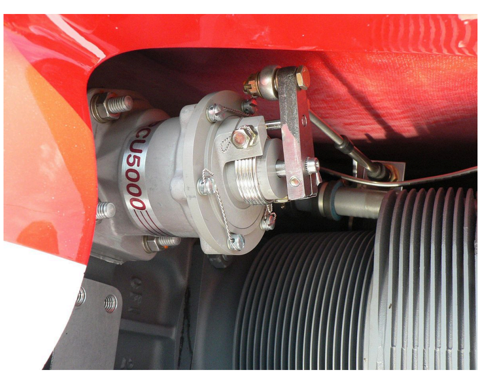


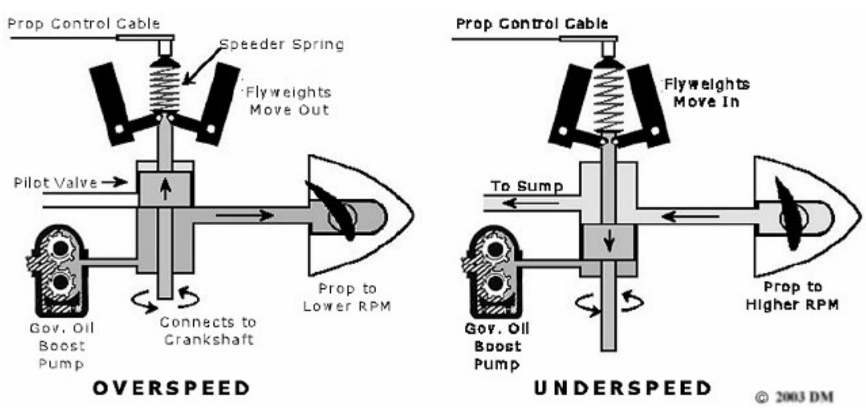
- **Constant Speed Propellers** - Many training airplanes have *fixed-pitch* propellers, which are simply rotating, curved airfoils (wings). Like all wings, these operate at some *angle of attack*. This is not adjustable in flight, and has to be chosen at the time of manufacture. Because drag varies greatly depending on angle of attack, being able to change AoA dynamically is useful. Therefore, some airplanes have *constant-speed propellers*, which continuously vary the AoA in order to maintain a fixed engine speed.
  - **Principle of Operation** - Constant-speed propellers use a *governor*, which is configured to maintain a specific RPM by adjusting a *speed spring*. The governor controls the propeller pitch by directing engine oil to the propeller hub, or releasing engine oil.

- **Governing Range** - The range of propeller blade pitch movement is limited by the high and low pitch stops. Depending on airspeed, this may cause the engine to turn slower or faster than the configured engine RPM.

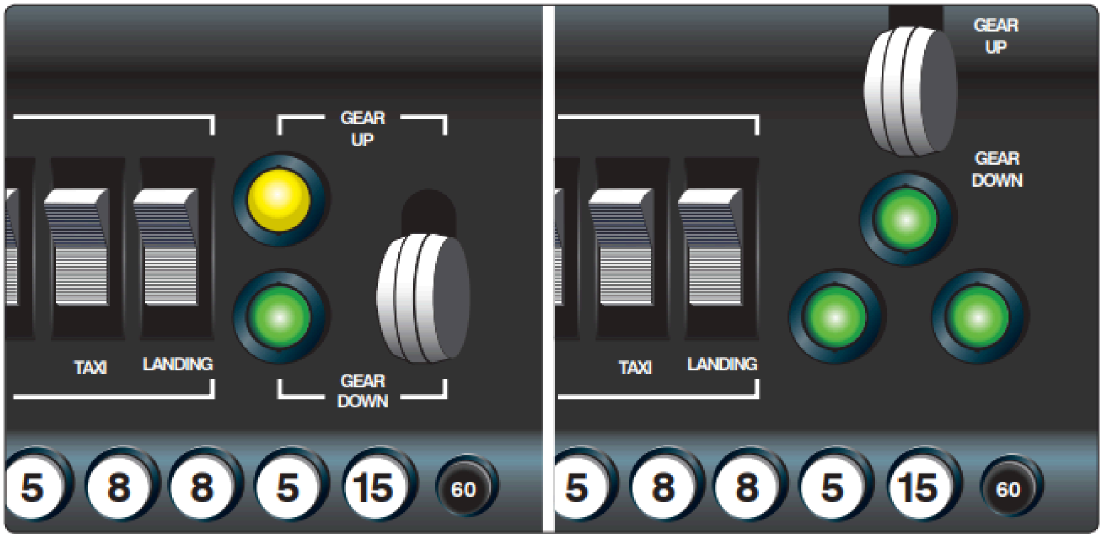


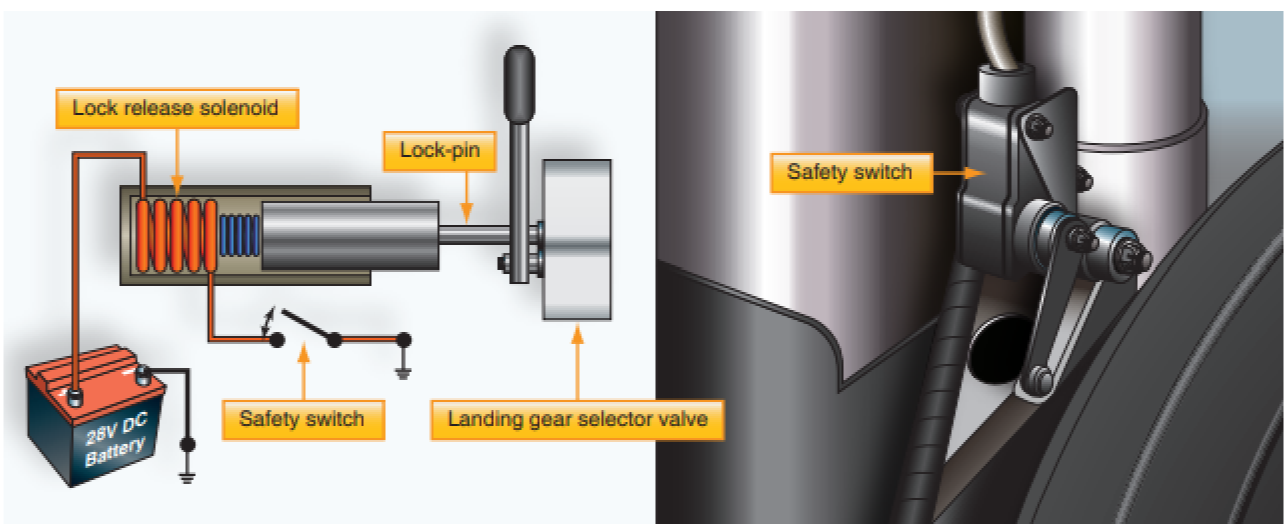






- **Retractable Gear Systems -** Some airplanes have *retractable landing gear* systems, which retract the landing gear into the fuselage to reduce drag during flight. These systems generally have a *landing gear position switch*, *landing gear position indicators*, *safety switches* (which operate the indicators), *emergency release systems*, and a series of mechanical or hydraulic connections to the actual landing gear.





PIPER CHEROKEE SERVICE MANUAL

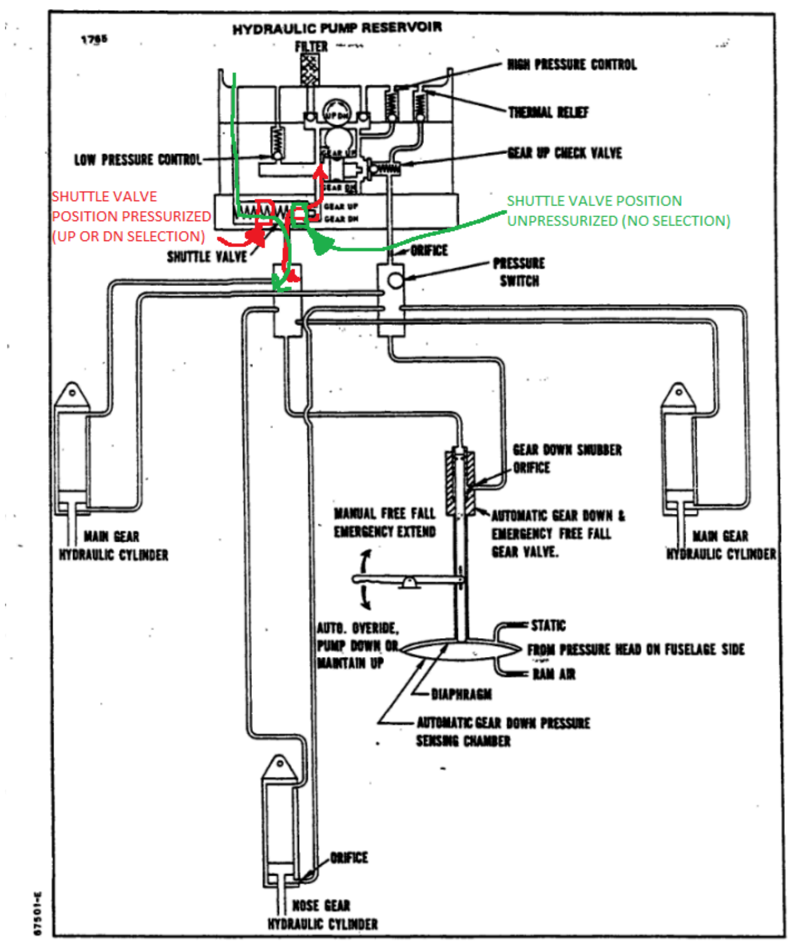
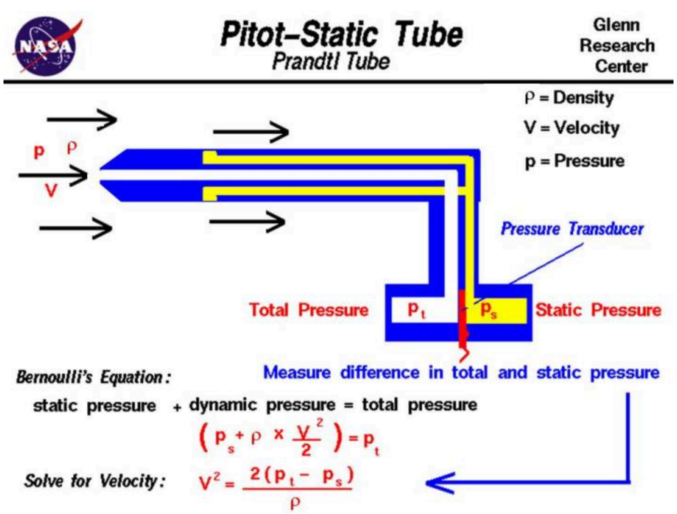
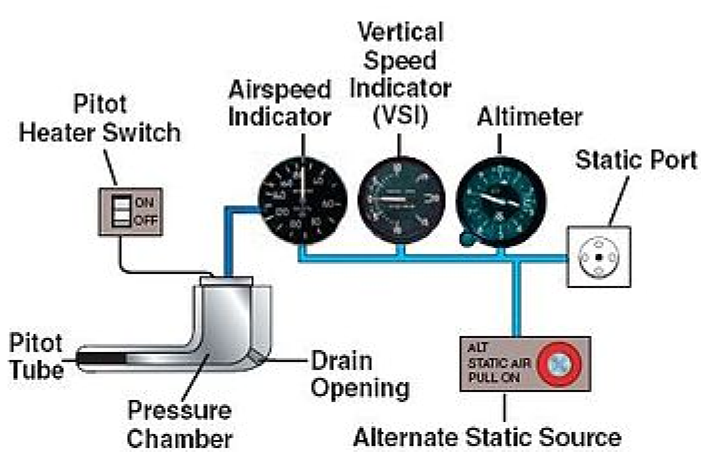


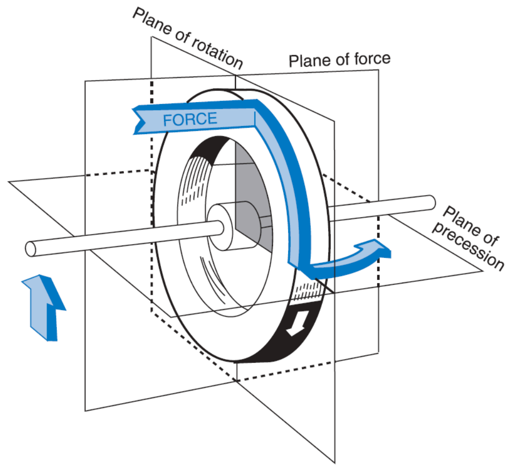
Figure 6-1. Schematic Diagram of Hydraulic System

- **Pitot Static System** - Airplanes sense airspeed by means of the *pitot tube*, which is pressurized by the oncoming airstream during flight. Airspeed can be measured by comparing this pressure (the *dynamic* pressure) to the un-captured airstream (the *static* pressure). The *pitot-static system* refers to the systems which are connected to the pitot and static tubes and lines.
    - Instruments like the *altimeter* and *vertical speed indicator* depend only on static pressure.





- **Gyroscopic and Vacuum Instruments** - The *gyroscopic* instruments rely on the gyroscopic principles of *precession* and *rigidity in space* in order to display airplane attitude, rate of turn, etc.
  - **Vacuum System** - Many older airplanes use a vacuum pump to create a suction which draws air through the gyros and causes them to spin.
  - **Electrical Gyros** - Some gyros are electrically powered.
  - The traditional vacuum-powered instruments are the *attitude indicator* and the *directional gyro* (By relying on *rigidity in space*).
  - The traditional electrically-powered instruments are the *turn coordinator*, which senses the rate of turn. (By measuring *precession*)



SECTION 7
AIRPLANE & SYSTEMS DESCRIPTIONS

CESSNA
MODEL 172P

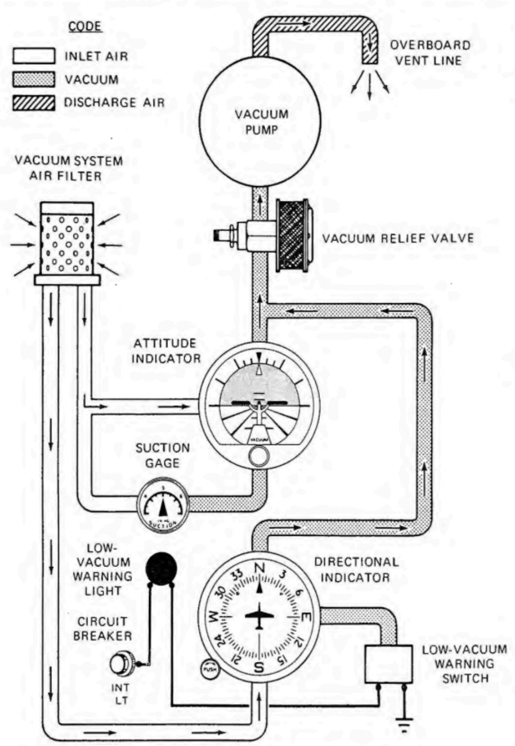


Figure 7-9. Vacuum System