II.A. Aircraft Flight Instruments & Navigation Equipment

References: Instrument Flying Handbook (FAA-H-8083-15), POH/AFM

Objectives: The student should develop knowledge of the elements related to the operation of flight instruments as well as the characteristics and operation of navigation equipment.

Key Elements:
1. Pitot/Static Errors
2. Compass Corrections
3. VOR Navigation

Elements:
1. **Flight Instruments**
   a. Pitot Static Systems
   b. Altimeter
   c. Vertical Speed Indicator
   d. Airspeed Indicator
   e. Air Data Computer
   f. Gyro Systems
   g. Attitude Indicator
   h. Heading Indicator
   i. Turn Indicator
   j. Attitude & Heading Reference System
   k. Magnetic Compass
   l. RMI & HSI
2. **Navigation Equipment**
   a. VOR
   b. DME
   c. ILS
   d. ADF & NDB
   e. GPS
3. **Anti-Ice/Deicing**

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 can describe the different flight and navigation instruments and their operation, as well as potential errors associated with the instruments.

Instructors Notes:

Introduction:

Attention
Interesting fact or attention-grabbing story

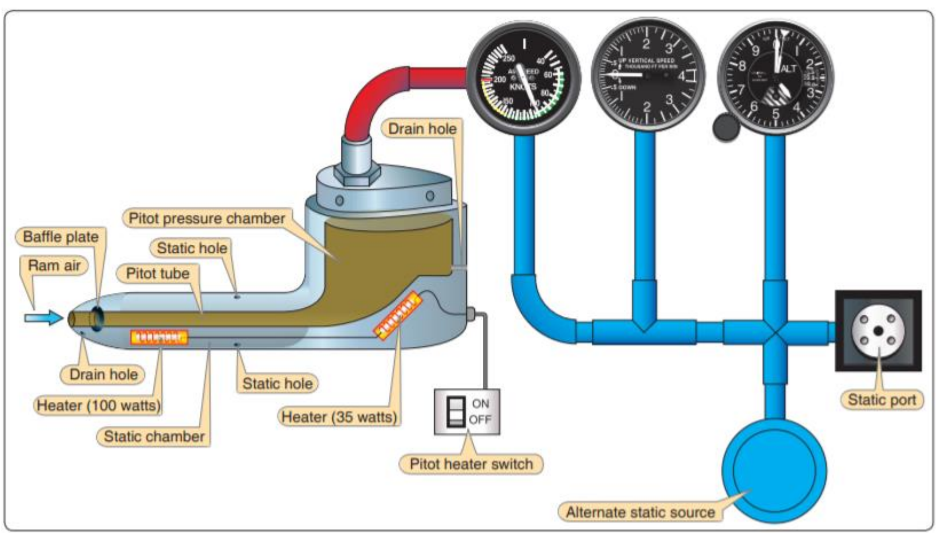
Overview
Review Objectives and Elements/Key ideas

What
An explanation of how your flight instruments and navigation instruments parts and operation, the errors associated with them, as well as their proper use.

Why
A thorough understanding of the operation of the flight instruments is necessary in order to understand the errors and potential problems associated with them. An understanding of the different types of navigation equipment is important for proper use in flight.

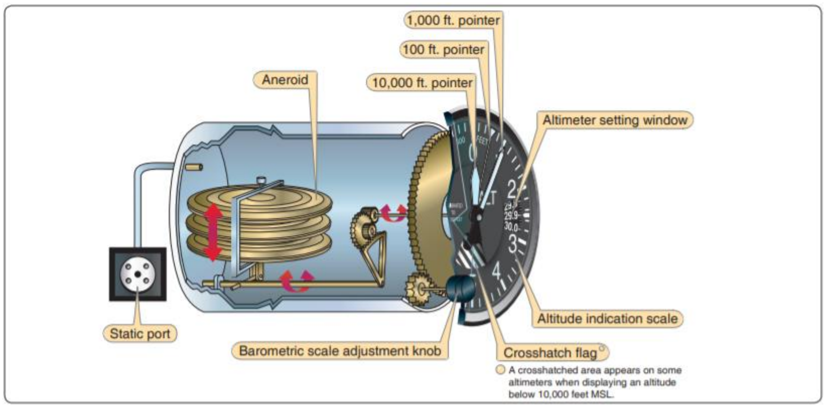
How:

1. **Flight Instruments**
   A. Pitot-Static System
      i. System Basics
         a. Used to determine the height, and speed of movement through the air
         b. Three instruments operate on the pitot/static system: Altimeter, VSI, Airspeed Indicator
         c. Two types of pressure are measured: Static (still air) and Pitot (ram air) pressure
            - Static Pressure - measured at a flush port where air is not disturbed
               a Pressure of the air that is still, measured perpendicular to the aircraft surface
               b Used in the Altimeter, VSI, and Airspeed Indicator
            - Pitot Pressure - measured through a tube pointed into the relative wind
               a Used in the Airspeed Indicator



      ii. Altimeter
         a. Measures the pressure of the ambient air and displays it as feet above a selected pressure level
         b. Operation
            - Primary Components – Instrument case, aneroid wafer, gear/linkage, adjustable scale

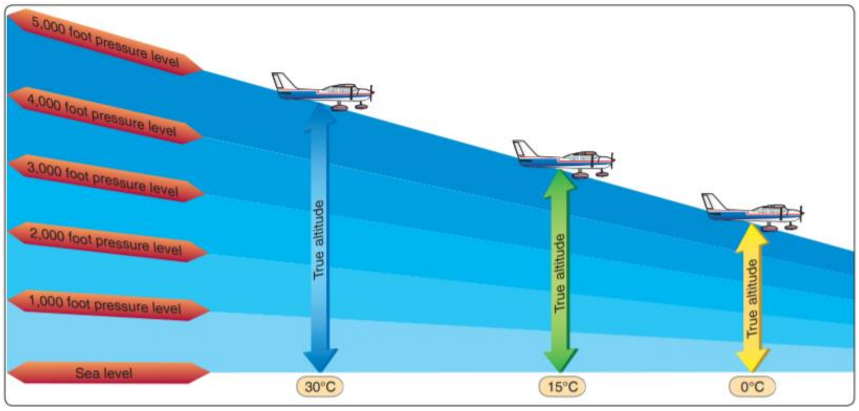
- The instrument case is connected to the static port
- Inside the instrument case is an Aneroid
    - a Aneroid defined: Operating by the effect of outside air pressure on a diaphragm
- The aneroid compresses or expands based on pressure from the static port
    - a As pressure increases, the aneroid compresses
    - b As pressure decreases, the aneroid's natural springiness causes it to expand
- The change in thickness moves the gears/linkages to change the altitude displayed
- Adjustable barometric scale/Kollsman window allows you to set reference pressure
    - a Rotating the knob changes the barometric scale: 1" Hg = 1,000'
    - b Pressure altitude is indicated when set to 29.92" Hg
    - c Indicated altitude is shown when set to the local altimeter setting

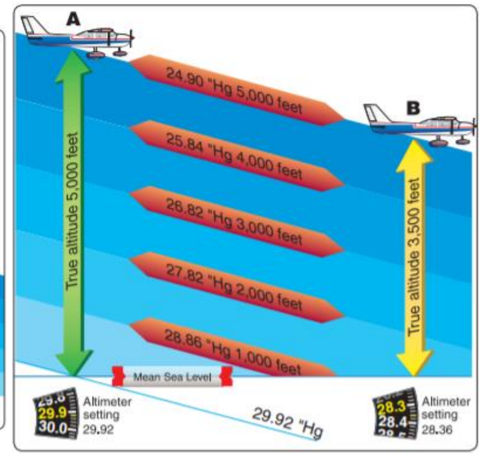


c. Errors

- Mechanical
    - a Should indicate within 75' of airport elevation when set to the local altimeter setting (> 75' error requires maintenance/calibration)
- Nonstandard Temperature (pictured below, left)
    - a In warmer than standard air, air is less dense and the pressure levels spread apart
        1. At 5,000' indicated, true altitude is higher than it would be if the air were cooler
        2. The pressure level for that altitude is higher than it would be at standard temp
    - b In colder than standard air, air is denser and pressure levels are closer together
        1. At 5,000' indicated, true altitude is lower than it would be if the air were warmer
        2. The pressure level for that altitude is lower than it would be at standard temp
        3. This can pose a risk in extremely cold conditions, corrections may be necessary

a. See VIII.A.10 Non-Precision or VIII.B.10 Precision Approach for more info





- Nonstandard Pressure (pictured above, right)
  - a Transitioning from High pressure to Low pressure during flight
    1. The altimeter interprets decreasing pressure as though the airplane is climbing
       a. Indicated altitude slowly increases due to decreasing pressure
       b. To compensate, the pilot descends, therefore lowering true altitude
  - b The opposite occurs transitioning from Low to High pressure
- REMEMBER: From Hot to Cold, or High to Low, look out below!

iii. Vertical Speed Indicator - Indicates the rate of change in pressure

a. Primary Components – Instrument case, aneroid housed inside the case
- Both the aneroid and the inside of the instrument case are vented to the static system
  - a Case – Vented so that pressure changes are slow/delayed (calibrated leak)
  - b Aneroid – Pressure in the aneroid changes immediately

b. In a Climb (static pressure decreases)
- Case – pressure remains constant momentarily
- Aneroid – pressure decreases; the aneroid is compressed by higher pressure in the case
- VSI – Indicates a climb. The greater the pressure difference, the higher the indication

c. Descent (static pressure increases)
- Case – maintains current pressure momentarily
- Aneroid – pressure increases; aneroid expands due to lower pressure in the case
- VSI – indicates a descent

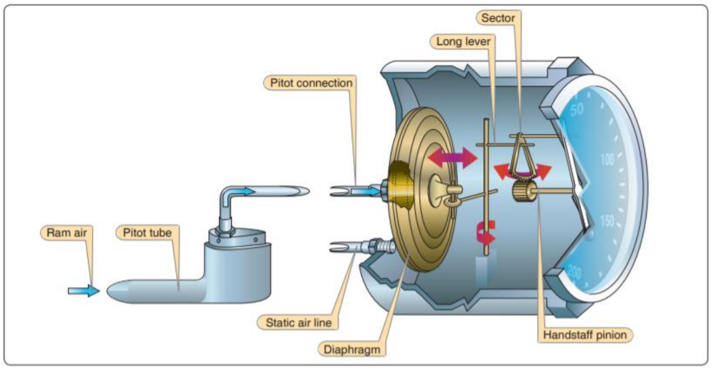
d. When the aircraft levels off, the pressure in the case and aneroid equalize

e. Pointer lags a few seconds behind actual change in pressure
- Still more sensitive than an altimeter and is useful

iv. Airspeed Indicator

a. A differential pressure gauge measuring the dynamic pressure of the air the aircraft is flying in
- Dynamic Pressure: the difference in the ambient static pressure and the ram air pressure

b. Primary Components – Instrument case, Diaphragm inside the case
   - Diaphragm receives pressure from pitot tube
   - Case is sealed and connected to the static port(s)



c. Accelerating
   - As ram air pressure increases or static pressure decreases, the diaphragm expands, and the gearing indicates a rise in airspeed
d. Decelerating
   - As ram air pressure decreases or static pressure increases, the diaphragm contracts and the gearing indicates a decrease in speed

v. ADC (Air Data Computer)
   a. Computer that receives and processes pitot/static pressure and temperature information
      - Uses this info to calculate very precise altitude, airspeed (IAS/TAS), and temperature
   b. Small, solid-state (no moving parts) systems (more accurate/reliable than older instruments)
      - Replaces wafers, aneroids, gearing, etc. with a single system (digital/no moving parts)
   c. Integrated glass cockpit/EFIS (electronic flight instrument system) display instrument indications

vi. Blocked Pitot-Static System
   a. General
      - Errors in the ASI and VSI almost always indicate a pitot blockage, static blockage, or both
      - Moisture, ice, dirt, insects, etc. can cause a blockage in either system
      - Always preflight the pitot tube and static ports
   b. Blocked Pitot System
      - Remember, the pitot system measures the difference between ram air pressure in the pitot tube and static air pressure from the static port
         a Static pressure is vented to instrument casing
         b Ram air is connected to a diaphragm in the case
      - Ram air blocked, with drain hole open
         a Air already in the system vents through the drain hole and remaining pressure in the pitot tube drops to match the outside (static) air pressure
         b Airspeed decreases to zero as ram air pressure and static pressure become equal
            1. Not an instantaneous drop, but happens quickly

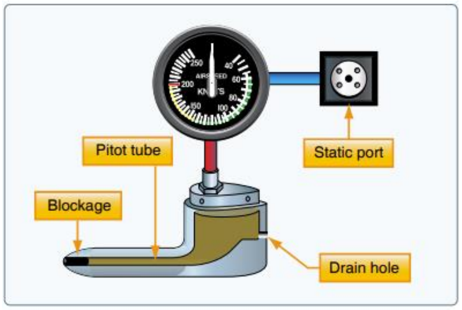


Figure 8-9. *A blocked pitot tube, but clear drain hole.*

- Ram air blocked, and drain hole blocked
  - a Big Picture
    1. Airspeed indicator acts like an altimeter
    2. Ram air pressure in the pitot tube is trapped
       - a. Accelerating/decelerating does not affect airspeed indications
    3. Static pressure changes with altitude
  - b In a climb
    1. Ram air pressure remains constant
    2. Static pressure decreases
    3. Diaphragm expands, just like would happen with an increase in ram air pressure/acceleration
    4. Airspeed increases as altitude increases
  - c In a descent
    1. Ram air pressure remains constant
    2. Static pressure increases
    3. Diaphragm contracts, just like would happen with a decrease in ram air pressure/deceleration
    4. Airspeed decreases as altitude decreases
  - d Airspeed acts like an altimeter, increasing in a climb and decreasing in a descent

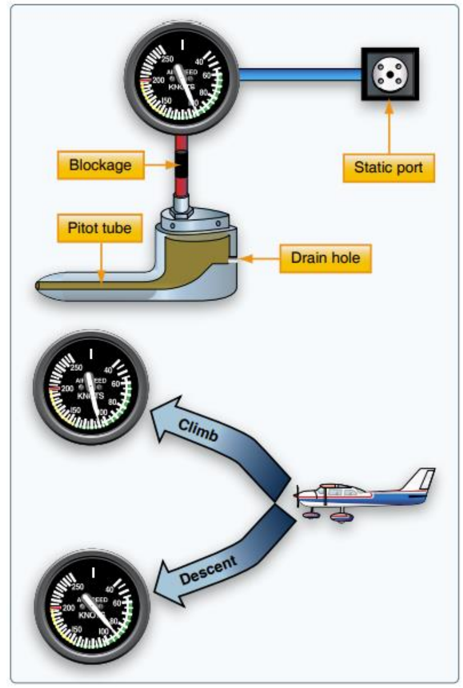


Figure 8-10. *Blocked pitot system with clear static system.*

c. Blocked Static System
- Static system blocked, with pitot tube open
  - a Airspeed operates but is inaccurate
    1. When above the altitude where the static port(s) were blocked, airspeed indicates lower than actual
       - a. Trapped static pressure is higher than normal for that altitude
    2. When operating at a lower altitude, airspeed indicates higher than actual
       - a. Trapped static pressure is lower than normal for that altitude
  - b Altimeter freezes at the altitude where the block occurred
  - c Vertical Speed shows a continuous zero indication

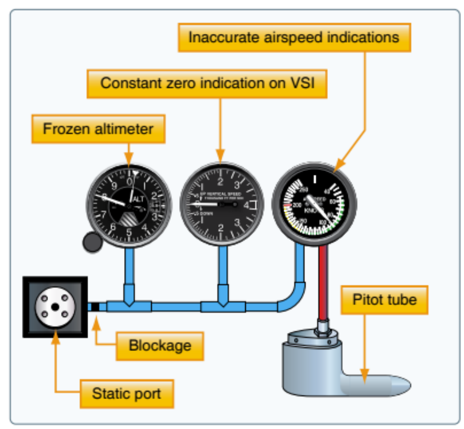
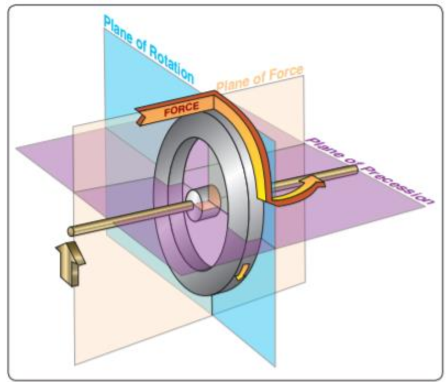


Figure 8-11. *Blocked static system.*

d. Alternate Static Source
- Provides alternate source of static pressure in the case the primary becomes blocked
- Normally inside the flight deck
  - a Pressure inside the flight deck is lower than exterior pressure due to venturi effect of the air flowing around the fuselage
- Instrument indications when the alternate static source is used:
  - a Altimeter indicates slightly higher than actual
  - b Airspeed indicates greater than actual
  - c Vertical speed shows a momentary climb and then stabilizes if altitude is constant

B. Gyroscopic System (Attitude Indicator, Heading Indicator, Turn Coordinator)
  i. Gyro Basics
    a. Gyro: A small wheel with its weight concentrated around its periphery
    b. Two characteristics of gyroscopes: Rigidity and Precession
      - Rigidity: The gyro remains rigid in its case and the aircraft rotates about it
        a Attitude and heading instruments operate on this principle
        b When spun at a high speed, the wheel becomes rigid, resisting any tilt/turn in any direction other than around its spin axis
      - Precession (pictured, right): A force is felt 90º from the point of application in the direction of rotation
        a Rate instruments (turn indicator, turn coordinator) operate on this principle
        b Gyro precesses (rolls over) proportionate to the rate the plane rotates about its axis



    c. Power Sources
      - Electrical Systems
      - Pneumatic Systems
        a Driven by a jet of air striking buckets in the wheel
        b Vacuum pump evacuates air in the instrument, filtered air is blown onto the wheel
        c Venturi Tube System – No vacuum pump, but a venturi tube is used to create suction
      - Wet-Type Vacuum Systems – generally for aircraft that operate at relatively low altitudes
        a Steel vane air pumps are used to evacuate air from the instrument cases
        b Vanes in the pumps are lubricated with oil which is discharged with the air (hence, wet)
      - Dry-Air Vacuum Pump Systems – generally for aircraft that operate at higher altitudes
        a At high altitudes the air is less dense and more air is required in the instruments
        b Air pumps that do not mix oil with the discharge air are used in high flying (hence, dry)
      - Pressure Indicating Systems (twin engine airplane has two systems)
        a A gyro pressure gauge measures any pressure drop across the instruments
        b If an engine/pump fail, a check valve isolates the system and uses the other side's air
  ii. Attitude Indicator
    a. Operation
      - A small brass wheel with a vertical spin axis spun by a stream of air or an electric motor
      - Mounted in a double gimbal - allows the aircraft to pitch and roll about the gyro
        a Double Gimbal: The axes of the two gimbals are at right angles to the spin axis of the gyro, allowing free motion in two planes around the gyro (pitch and roll)
      - To function properly, the gyro must remain upright while the aircraft pitches/rolls
        a Gyro bearings have little friction, but even this small amount causes precession/tilt
        b An erection mechanism applies a force to counter tilt and keep the gyro upright

- Older instruments have pitch/bank limits at which the gyro tumbles, becoming unreliable
  - a At these limits, the gyro hosing contacts the gimbals causing the gyro to tumble
  - b A caging mechanism can lock the gyro vertical, preventing tumble
  - c Newer instruments are designed to eliminate tumble all together
- A horizon disk is attached to the gimbals so it remains in the same plane as the gyro
  - a The airplane pitches and rolls around the horizon disk
- A small aircraft is displayed relative to the horizon and can be raised or lowered as needed

b. Errors
- Free from most errors, but:
  - a There may be a slight nose-up indication during rapid acceleration (and vice versa)
  - b There is the possibility of a small bank angle and pitch error after a 180^{o} turn
  - c Both errors are quite small and correct within a minute or so of straight-and-level

iii. Heading Indicator

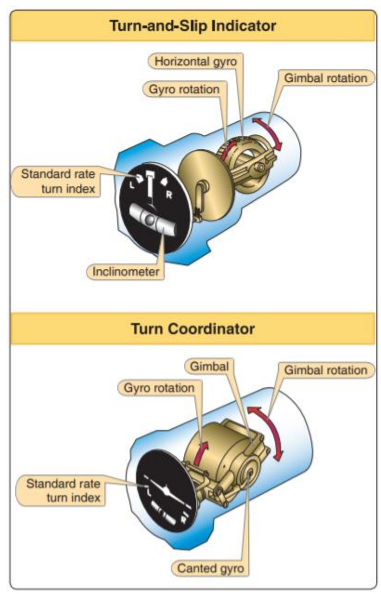
a. Operation (almost always air driven) – Senses rotation about the vertical axis
- Mounted in double gimbal axis (like the attitude indicator), but the spin axis is horizontal

b. Heading

- Unless slaved, heading is manually set to match the compass
  - a Rigidity causes it to maintain this position in space
  - b Heading turns with rotation about the vertical axis
- Reset heading to match the compass every 15 min
  - a Earth rotates approx. 15^{o} per hour while the gyro maintains its position relative to space

iv. Turn Indicator - operate on precession

a. Turn-and-Slip Indicator (pictured below)



- Basics
  - a Displays direction and rate of turn
  - b Operates on precession
  - c Dog-house shaped markings indicate standard rate turn (3^{o} per second)
- Operation
  - a Gyro is powered by air or an electric motor
  - b Small gyro mounted in a single gimbal
    1. Spin axis is parallel to lateral axis; gimbal axis is parallel to longitudinal axis
  - c Yawing produces a force in the horizontal plane
    1. Precession causes the gyro and its gimbal to rotate about the gimbal axis
    2. Restrained in this rotation by a calibration spring
    3. Rolls over just enough to cause the pointer to deflect until aligning with the standard rate markings
- Limitation

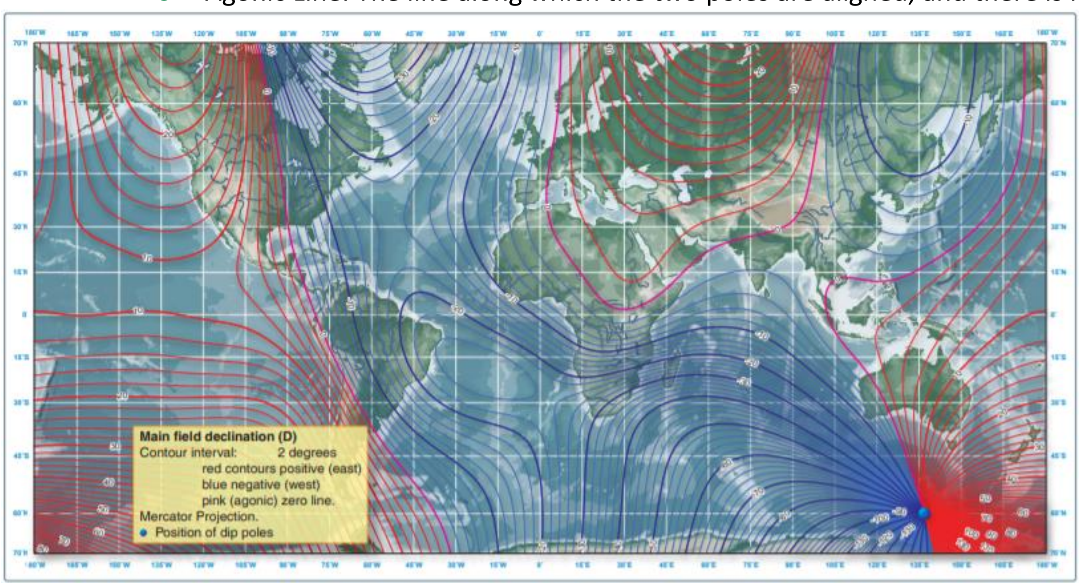
            a Sense rotation only about the vertical axis
            b No rotation around the longitudinal axis which in normal flight occurs before the aircraft begins turning
    b. Turn Coordinator (pictured)
        - Basics
            a Shows turn direction, rate of bank, then once stabilized, rate of turn
            b Operates on precession
            c Miniature aircraft display
            d Dashes indicate standard rate
        - Operation
            a Powered by air or an electric motor
            b Operates like the Turn and Slip Indicator, but the gimbal frame is angled up about 30°
                1. Allows it to sense both roll and yaw
    c. Inclinometer
        - Basics
            a Part of the turn-and-slip indicator and turn coordinator
            b Black glass ball sealed in a curved glass tube filled partially with liquid
            c Shows the relationship between bank angle and rate of yaw (slip/skid)
                1. Or the relative strength of gravity and the force of inertia caused by a turn
        - Indications
            a Straight-and-Level: No inertia acting on the ball, remains centered between the 2 wires
            b Turning
                1. Ball Centered: Bank matches rate of turn, coordinated flight
                2. Ball Inside the Turn: Bank angle too steep – Force of gravity > Inertia
                    a. Slipping turn (too much bank for the rate of turn)
                3. Ball Outside the Turn: Bank Angle too Shallow – Inertia > Force of Gravity
                    a. Skidding turn (rate of turn is too great for the angle of bank)

v. AHRS (Attitude and Heading Reference System)
    a. Traditional gyro instruments are being replaced by AHRS
    b. Same pitch, roll, yaw data but new sensors and technology feeding the instruments/displays
        - Small solid state (no moving parts) systems integrating a variety of technology
        - Consists of inertial sensors, rate gyros, magnetometers, even satellite reception in some
    c. Single system eliminates need for separate attitude, heading, turn coordinator gyros
        - Superior reliability and accuracy vs older instruments - Reduces cost and maintenance
    d. Typically integrated with an EFIS (electronic flight information system)/glass cockpit

C. Magnetism
    i. Magnetic Compass
        a. Operation
            - Two small magnets attached to a metal float sealed inside a bowl of clear compass fluid
            - A card is wrapped around the float and visible from the outside with a lubber line
                a Lubber Line: The reference line used in a magnetic compass or heading indicator

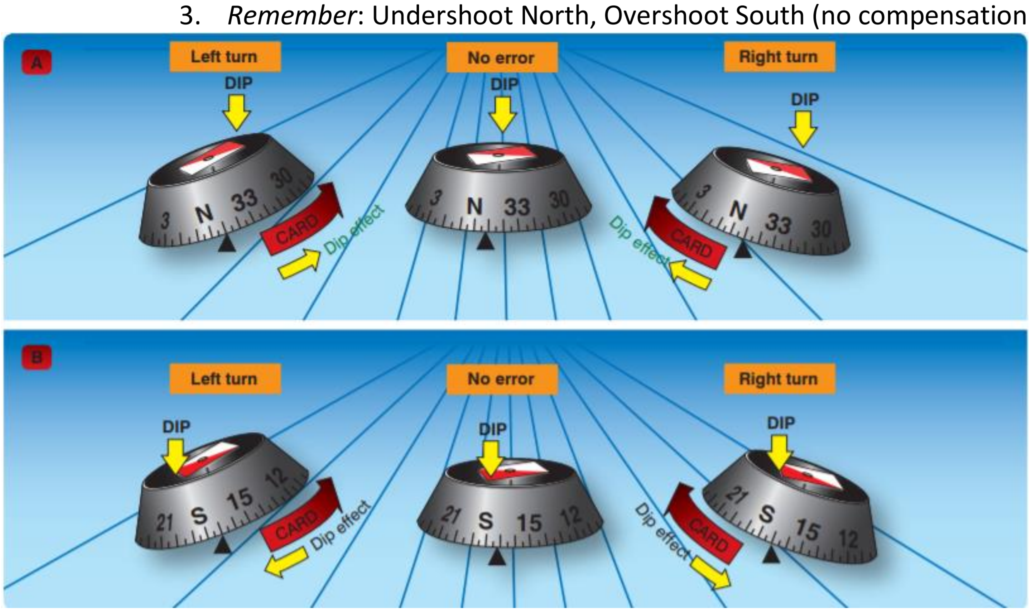
- The float/card has a steel pivot in the center riding inside a spring loaded, glass jewel cup
  - a The jewel and pivot mount allow the float to rotate and tilt up to approximately 18°
- Magnets align with Earth's magnetic field and direction is read opposite the lubber line
  - a The pilot always sees the compass card from its backside (the card stays stationary and the pilot turns around it)
    1. For this reason, headings appear backward on the compass
    2. When flying N, E is shown L of the lubber line vs R in actuality
  - b Technique: Don't turn toward the heading as displayed on the compass, instead move the desired heading to the lubber line

b. Errors
- Variation
  - a Caused by the difference in the locations of the magnetic and geographic north pole
    1. The magnetic north pole is not collocated with the geographic north pole
    2. They're approximately 1300 miles apart
  - b Isogonic Lines: Lines used to connect points with the same magnetic variation
  - c Agonic Line: The line along which the two poles are aligned, and there is no variation

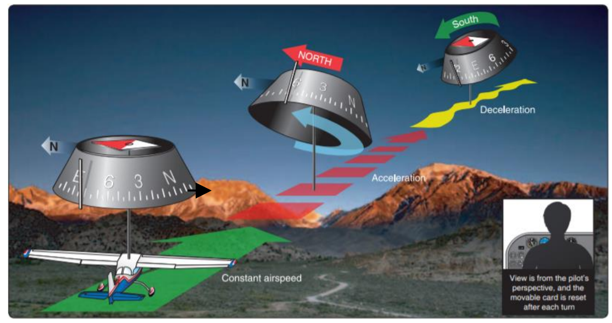


- Deviation
  - a Caused by local magnetic fields within the aircraft
    1. Not affected by geographic location (like variation)
  - b Degrees of deviation is shown on a compass correction card
    1. Different on each heading; can be minimized by "swinging the compass"
  - c Compensator units (magnets that compensate for deviation) can also help
- Finding the Compass Course – True Course corrected for Variation and Deviation
  - a True Course ± Variation = Magnetic Course
  - b Magnetic Course ± Deviation = Compass Course
  - c Remember: East is Least, West is Best
    1. East: Subtract variation from true course; West: Add variation to true course

- Dip Errors
  - a What's Going On
    1. Lines of magnetic flux leave at the magnetic N pole and enter at magnetic S pole
       - a. At both poles the lines are perpendicular to the surface
       - b. Over the equator the lines are parallel to the surface
    2. Magnets align with these fields and near the poles they dip/tilt the float and card
  - b Northerly and Southerly Turning Errors (basically, the compass pulls toward the North)
    1. Starting a turn from a Southerly heading (turning to a Northerly direction):
       - a. Compass Leads – initially shows a more aggressive turn in the same direction
       - b. As the aircraft banks, the compass card tilts with it, and the magnetic field pulls the card in the direction of the turn (toward the North)
       - c. Undershoot Northerly headings to compensate (30°- N; 20°- 030/330; 10°- 060/300)
    2. Starting a turn from a Northerly heading (turning to a Southerly direction):
       - a. Compass Lags – initially shows a turn in the opposite direction
       - b. As the aircraft banks the compass card tilts with it, and the magnetic field pulls the card opposite the direction of turn (back toward the North)
         - i. Overshoot Southerly headings to compensate (30°- S; 20°- 150/210; 10°- 120/240)
    3. *Remember*: Undershoot North, Overshoot South (no compensation needed



for E/W)
  - c Acceleration Error (only applicable on East and West headings)
    1. Due to the pendulous-type mounting, the aft end of the compass tilts up when accelerating and down when decelerating

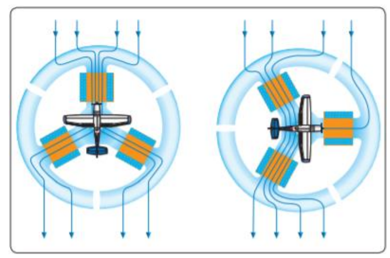


2. On an E or W heading, acceleration appears as a turn to the North, and deceleration indicates a turn toward the South
3. *Remember*: ANDS – Accelerate North, Decelerate South

- Oscillation Error
  - a Oscillation is a combination of all the other errors as well as the movement of the plane
    1. Compass card swinging back and forth around the heading being flown
  - b Use the average indication

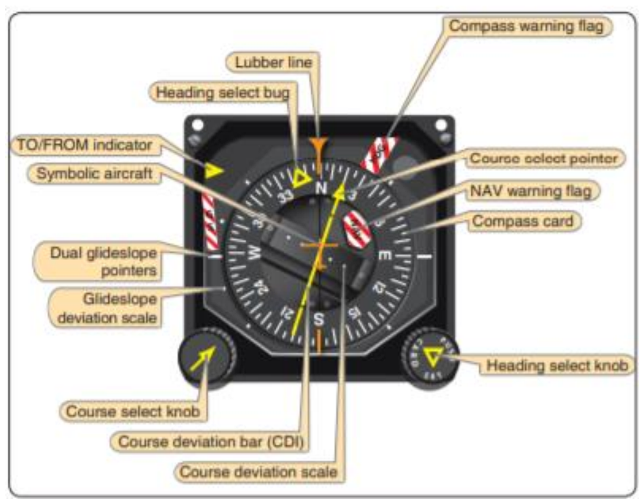
ii. RMI & HSI
Will be discussed in more detail below with Navigation instruments. This section is to focus on the magnetic properties of the heading instruments

a. RMI (pictured below, left)
   - Bearing indicator(s) overlayed on a heading indicator (but doesn't use a gyro)
   - A flux valve automatically adjusts heading as you turn
     - a Flux valve (pictured right): small, segmented ring made of soft iron that readily accepts lines of magnetic flux. As heading changes, current in the flux valve changes, rotating the RMI's heading



   - Bearing indicators for tracking NDB/ADF or VOR
     - a ADF: Head = bearing to station, Tail = bearing from station
     - b VOR: Head = bearing to station, Tail = the radial currently crossing, or on

b. Horizontal Situation Indicator (HSI) (pictured below, right)
   - Heading indicator + navigation signals/glideslope
     - a Takes the RMI to the next level
     - b Flux valve drives heading
   - Gives an indication of location with relationship to a selected navaid and course



2. Navigation Equipment

A. VOR - Very High Frequency Omni-Directional Range

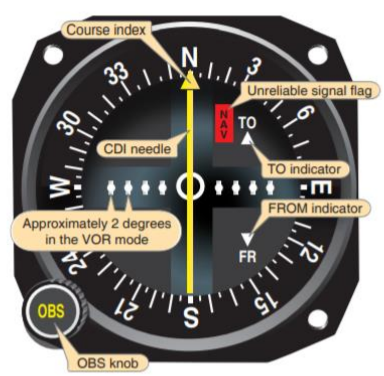
i. What is it?
   a. Omni means all
      - An *omni*directional range is a VHF radio transmitting ground station that projects straight line courses (or radials) from the station in *all* directions
         a It can be visualized from the top as being similar to the spokes from the hub of a wheel
   b. The radials projected are referenced to magnetic north
      - A radial is defined as a line of magnetic bearing extending outward from the VOR station
      - The accuracy of course alignment with radials is excellent (± 1°)
   c. VOR ground stations transmit within a VHF frequency band of 108.0 – 117.95 MHz
      - Because the equipment is VHF, the signals are subject to line-of-sight restrictions
         a Range varies in proportion to altitude
   d. The distance the radials are projected depends on the power of the transmitter

Class	Altitudes	Radius (Miles)
T	12,000' and Below	25
L	Below 18,000'	40
H	Below 14,500'	40
H	14,500 – 17,999'	100
H	18,000' – FL 450	130
H	FL 450 – 60,000'	100

   e. VORs are classed according to operational use in 3 classes with varying normal useful ranges:
      - T (Terminal); L (Low Alt); H (High Alt)

ii. Three types of VORS
   a. VOR – The VOR by itself. Provides magnetic bearing information to and from the station
   b. VOR/DME –DME (Distance Measuring Equipment) is installed with the VOR (more info below)
   c. VORTAC – Military tactical air navigations (TACAN) equipment is installed with a VOR
      - DME is always an integral part of a VORTAC

iii. VOR Components – Ground and Aircraft
   a. Ground - The VOR station itself; transmits on an assigned frequency
   b. Aircraft - Antenna, Receiver, and VOR navigation instrument
      - Antenna – Picks up the VOR signal
      - Receiver – Processes the signal into navigation information
      - VOR Instrument – Displays the navigation information
         a OBS (Omnibearing Selector, or course selector
            1. Dial that is rotated to select the desired radial and/or determine the radial on
         b CDI (Course Deviation Indicator) Needle
            1. Indicates the aircraft position in relation to the selected course/radial
            2. Full scale deflection = 12° or more off the selected course (each dot = 2°)



         c To/From Indicator
            1. Shows whether the selected course takes the aircraft To or From the VOR
            2. Does not indicate whether the aircraft is currently heading To or From the VOR

- d Flags
  1. OFF flag indicates an unusable/unreliable signal

c. VOR Basics
- Tune, Identify, Monitor (TIM)
  - a Tune and listen for the station's Morse code ID or a voice stating the name and VOR
  - b If the VOR is out of service, the ID is not transmitted (should not be used for navigation)
- Orientation – Radial/To or From the station
  - a Rotate the OBS to center the CDI needle - note the course and the To or From indication
    1. The VOR only relays direction from the station and has the same indications regardless of the aircraft's heading
    2. The To indication displays the course to fly to the VOR
    3. The From indication displays the radial the aircraft is currently on
  - b Using a second VOR can provide an exact location at the intersection of the two radials
- Navigation
  1. Track To a VOR - Rotate the OBS until TO appears, center the CDI, fly the course
     a. Correct for wind to maintain course
  - b Track From a VOR - Center the needle with a From indication, fly the course indicated
- See more in VII.A. Intercepting and Tracking Navigation Systems

iv. VOR Checks

a. FAR 91.171: No person may operate under IFR using the VOR system of radio navigation unless the VOR equipment has been operationally checked within the preceding 30 days…

b. The best assurance of maintaining an accurate VOR receiver is periodic checks and calibrations

c. Types of Checks (checkpoints are listed in the Chart Supplement)
- FAA VOR Test Facility (VOT)
- Certified Airborne Checkpoints
- Certified Ground Checkpoints located on airport surfaces
- Dual VOR check

d. The check verifies the VOR radials received are aligned with the radials the station transmits

e. IFR tolerances required are ± 4° for ground checks and ± 6° for airborne checks

v. VOR MON (Minimum Operating Network)

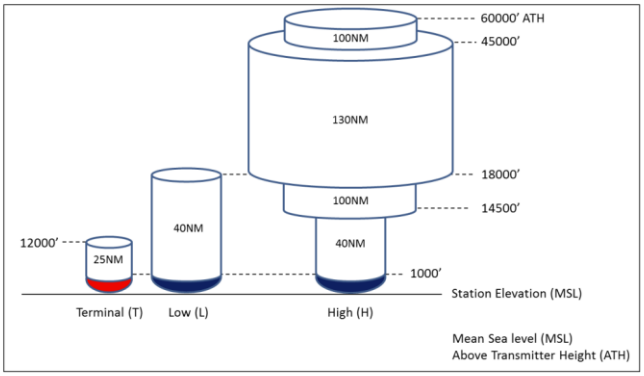
a. National Airspace System is transitioning to performance-based navigation (PBN)
- Number of VORs is being reduced (going from 896 to 590 by 2030)
- Two new, larger service volumes will enable near continuous navigation above 5,000' AGL

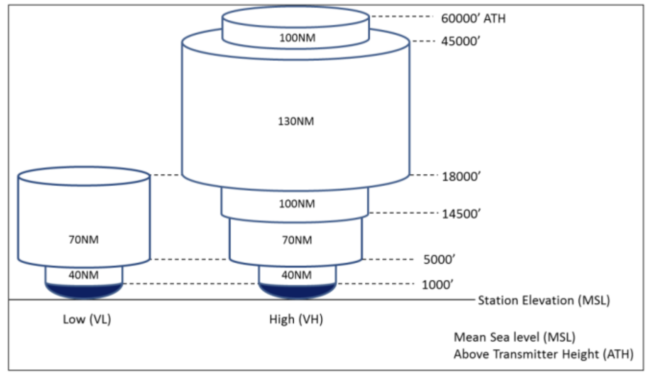
b. Designed to enable aircraft, having lost GPS, to revert to conventional navigation procedures

c. New Service Volumes
- Low: 70 nm from 5,000' to 18,000'

- High: 70 nm from 5,000’ to 14,500’

LEGACY SERVICE VOLUMES	NEW SERVICE VOLUMES

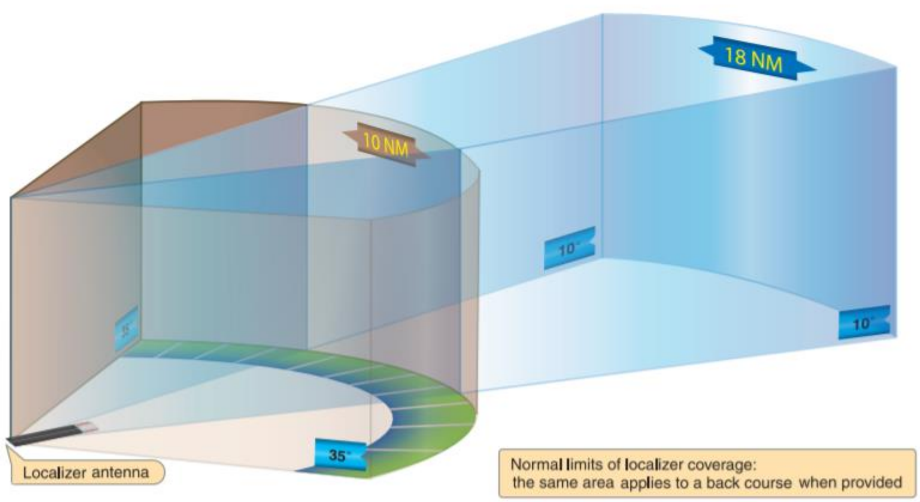




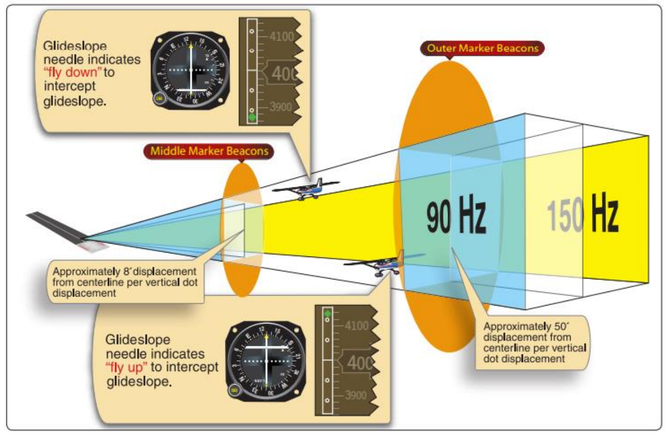
B. Distance Measuring Equipment (DME)
   i. Function – provides slant range distance from a station
      a. With VOR and DME, a pilot can determine bearing and distance TO or FROM a station
      b. Can be used to determine position along a radial or fly a constant distance from a station
   ii. How it Works
      a. The aircraft DME transmits interrogating RF pulses which a DME antenna on the ground receives
      b. The signal triggers ground receiver equipment to respond back to the interrogating aircraft
      c. The aircraft DME measures the elapsed time between the sent signal and the reply signal
         - The time measurement is converted into NMs from the station
      d. Some receivers provide ground speed by monitoring the rate of change of position to the station
      e. DME operates on UHF frequencies between 962 MHz and 1213 MHz
   iii. Components
      a. Ground Equipment - VOR/DME, VORTAC, ILS/DME, and LOC/DME
      b. Airborne Equipment - Antenna and Receiver
      c. Pilot Controllable Features
         - Channel (frequency) Selector: To select the proper channel/frequency desired
         - On/Off/Volume: Can be used to identify the DME (Morse code plays 1x for every 3-4x VOR)
         - Mode Switch: Cycles between Distance, GS and time to station
         - Altitude: Some receivers correct for slant range error
   iv. Errors
      a. DME signals are line-of-sight
      b. Slant Range Distance
         - The mileage readout is the straight-line distance from the aircraft to the ground facility
         - Not the same as the distance from the station to the point on the ground below the aircraft
         - This error is the smallest at low altitudes and long range

            a Greatest when over the DME station, when it will display altitude above the station
            b Negligible if 1 mile or more away from the facility for each 1,000’ above facility elevation

C. Instrument Landing System (ILS) – Detailed picture in the Instrument Flying Handbook (Chap. 9)
  i. Electronic system providing both horizontal and vertical guidance to a specific runway
    a. Used to execute a precision instrument approach procedure
  ii. Three Types of ILS Approaches
    a. Category I: Provide for approach to a height above touchdown of not less than 200’
    b. Category II: Provide for approach to a height above touchdown of not less than 100’
    c. Category III: Provide lower minimums for approaches without a decision height minimum
      - II and III require special certification for the pilots, as well as ground/airborne equipment
  iii. Ground Components
    a. Localizer: Provides horizontal (left/right) guidance along the centerline of the runway
      - Radiates a course to the runway and a course in the opposite direction (front/back course)
      - Localizer course is very narrow, normally 5°
        a A full-scale deflection shows when 2.5° to either side of the centerline
        b Course narrows (more sensitive) closer to the runway (see Localizer Course pic below)
      - Guidance is given from 18 nm from the antenna up to 4,500’ above antenna elevation
      - Operates on frequencies between 108.1 and 111.95 MHz (odd tenths only)



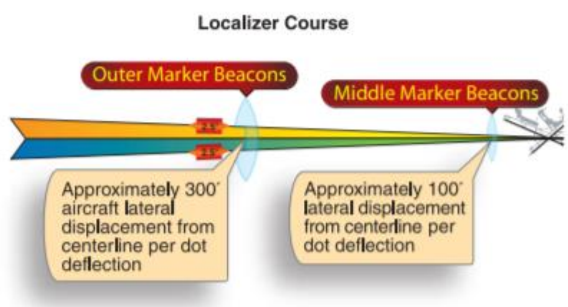
    b. Glide Slope: Provides vertical guidance to the runway touchdown point, usually a 3° glide slope
      - Basically, a localizer on its side
        a The projection angle is normally 2.5-3.5° above the horizontal
      - Only radiates a signal in the direction of the final approach (front course)



- Normally 1.4° thick path (at 10 nm, this is 1,500', narrowing to just a few feet at touchdown)
  - a Intersects the MM at about 200' and the OM about 1,400' above runway elevation
- Equipment is housed in a building approximately 750-1,250' down from the approach end of the runway, and 400-600' to one side of the centerline
- Tied to localizer frequency
  - a Localizer auto tunes the glideslope

c. Marker Beacons: Provide range info along the approach path

- A low powered transmitter that directs its signal upward in a small, fan shaped pattern. Used along the flightpath when approaching an airport for landing, marker beacons indicate, both aurally and visually, when the aircraft is directly over the facility
- 2 VHF marker beacons, Outer/Middle, are normally used in an ILS system
  - a A third beacon, Inner, is used where Category II ops are certified
- Outer Marker (OM) – On localizer front course 4-7 miles from the airport
  - a Indicates where one should intercept the glidepath on the localizer (if at the proper alt)



- Middle Marker (MM) – About 3500' from the threshold on the front course
  - a Position where the glide-slope is about 200' above landing threshold
- Inner Marker (IM) – Located on the front course between the MM and threshold
  - a Indicates the decision height on a Category II ILS approach
- Compass Locator
  - a Low powered NDBs which are received and indicated by the ADF receiver
  - b When used in conjunction with an ILS front course, the compass locator facilities are collocated with the outer and/or MM facilities

d. Approach Lights: Assist in the transition from instrument to visual flight

- Visual stage of the instrument approach
  - a Landing is continued with reference to runway touchdown zone markers
- Visual identification of the ALS must be instantaneous, so it's important to know the type
  - a ALSF, SSALR, MALSR, REL, MALSF, ODALS, also VASIs

iv. Airborne Components

a. Localizer

- Receiver and Controls
  - a Same as a VOR receiver

- b Most receivers switch between VOR/LOC automatically by the frequency input
- c Tune/identify frequencies, set course

- Navigation
  - a Functions the same way as a VOR receiver, but more sensitive
    1. Needle indicates if the aircraft is left/right of centerline
  - b Rotating the OBS has no effect on the operation of the localizer needle
    1. Still useful to select the LOC inbound course
  - c Course Indications
    1. When inbound on the front course, or outbound on the back course, course indications remain directional (normal)
    2. When outbound on the front course, or inbound on the back course, heading corrections should be made opposite the needle deflection
       a. Fly away from the needle
       b. Exception: Aircraft has reverse sensing capability and it is in use
       c. Back course signals should only be used with a published back course approach
  - d Flying
    1. Once reaching LOC centerline, maintain the inbound heading until the CDI moves off center
    2. Apply small drift corrections (reducing as the course narrows) to center the course
    3. Establish drift early as the course gets more sensitive through the approach

b. Glide Slope
- Receiver and Controls
  - a Glide slope is tuned automatically to the proper frequency when the localizer is tuned
  - b Each localizer frequency is paired with a corresponding glide slope frequency
- Navigation
  - a Display can vary based on equipment
  - b Generally, horizontal needle overlaying reference dots
    1. Standard vertical five-dot deflections indicate position
    2. Needle represents the glideslope
    3. On glidepath when the horizontal needle is through the middle dot
    4. Above glidepath when the needle is below middle
    5. Below glidepath when the needle is above
  - c Much more sensitive than the localizer (1.4^{o} from full up to full down deflection)
- Flying
  - a Set the approximate pitch and power settings as the glideslope is intercepted
  - b Use small pitch adjustments to keep the horizontal needle centered as discussed above
    1. ½ to 1^{o} changes
  - c Divide attention to keep the localizer and glideslope needles through the center dot
    1. Also scan to maintain airspeed, monitor descent/DA, etc.

c. Marker Beacon Receiver
- OM - Low-pitch tone, Continuous dashes at the rate of 2 per second, Purple/blue light

- MM - Intermediate tone, Alternate dots/dashes at 95 combinations per minute, Amber light
- IM - High-pitched tone, Continuous dots at the rate of 6 per second, White light
- BCM (Back Course Marker) - High pitched tone, Two dots at 72-75 per minute, White light
- Sensitivity: High/Low. Low provides best position indication and should be used on approach

d. DME Receiver
  - Provides another way to identify waypoints/location on the approach

v. Other components (not specific components but may be incorporated for safety and utility)
  a. Compass Locators: Provide transition from en route NAVAIDS to the ILS system
    - Assist in holding procedures, tracking the localizer course, identifying marker beacon sites
  b. DME collocated with Glide Slope Transmitter: Provides distance to touchdown information

vi. Errors
  a. Reflection: Surface vehicles/aircraft below 5,000' AGL may disturb the signal
  b. False Courses: Glideslope facilities produce additional courses at higher vertical angles
    - Angle of the lowest of false causes occurs at approximately 9-12^{o}
    - Flying a false course could lead to confusion as well as very high descent rates
    - False courses can be countered by flying the altitudes shown on the approach chart

D. Automatic Direction Finder (ADF) & Nondirectional Radio Beacon (NDB)
  i. NDB: Ground-based radio transmitter that transmits radio energy in all directions
    a. The ADF, when used with an NDB, determines the bearing from the aircraft to the station
  ii. ADF needle points to the NDB ground station to determine the relative bearing
    a. Relative Bearing: The number of degrees measured clockwise between the heading of the aircraft and the direction from which the bearing is taken
  iii. Magnetic Heading + Relative Bearing = Magnetic Bearing
    a. Mary Had + Roast Beef= Marry Barfed
    b. Magnetic Heading: The direction an aircraft is pointed with respect to magnetic North
    c. Magnetic Bearing: The direction to/from a station measured relative to magnetic North
  iv. NDB Components
    a. Ground equipment: the NDB (transmits between 190 to 535 kHz)
    b. Aircraft must be in operational range of the NDB - dependent on the strength of the station
  v. ADF Components
    a. The airborne equipment: 2 antennas, a receiver, and the indicator instrument
    b. Two Antennas
      - Sense Antenna: (Non-directional) Receives signals nearly equally from all directions
      - Loop Antenna: (Bidirectional) Receives signals better from two directions
      - When the two are combined, the ADF can receive a radio signal well in all directions except for one, thus resolving all directional ambiguity

c. Indicator Instrument
- 3 kinds: Fixed card, Movable Card, or the RMI with 1 or 2 needles
- Fixed Card ADF (or relative bearing indicator, RBI) (top picture)
    - a Always indicates 0 at the top; Needle indicates RB to the station
    - b Pilot must calculate MB based on MH and RB
    - c Ex with Picture: RB of 135° + current MH = RB
        1. In this case, RB to the station is 135° to the right
        2. If heading was 045°, RB = 180°
- Movable Card ADF (middle picture)
    - a Pilot can rotate MH to the top of the instrument
    - b Head of the needle indicates the MB to the station
    - c The tail indicates MB from the station
    - d Instrument provides MB, pilot doesn't have to calculate it
    - e Ex with Picture: RB is indicated by head of the needle
- RMI (bottom picture)
    - a Automatically rotates to display aircraft heading
    - b Can have two needles which can be used for navigation information from either ADF or VOR receivers
    - c ADF needle:
        1. Head indicates the MB To the station
        2. Tail indicates the MB From the station
    - d VOR needle: Indicates location radially with respect to the station
        1. Head of needle points the bearing TO the station
        2. Tail points to the radial the aircraft is currently on/crossing

vi. Using the NDB & ADF

a. Orientation (Fixed Card ADF)
- The ADF needle points TO the station, regardless of heading or position
    - a Therefore, the RB shown is the angular relationship between heading and the station measured clockwise from the nose of the aircraft
- Visualize the ADF dial in terms of the longitudinal axis
    - a When the needle points to 0°, the nose points directly to the station
    - b With the pointer on 210°, the station is 30° to the left of the tail
- The RB must be related to aircraft heading to determine direction TO/FROM
    - a Magnetic Heading + Relative Bearing = Magnetic Bearing

b. Movable Card
- Rotate aircraft heading to the top of the instrument
- Turn toward the head of the needle indicating the MB to the station
    - a Reset aircraft heading after each turn
- Crab into the wind to maintain the desired course

c. RMI
- Turn toward the head of the needle indicating the MB to the station
- Crab into the wind to maintain the desired course

d. Station Passage
- When close to the station, slight deviations from the track result in large needle deflections
    - a Increased sensitivity
    - b Establish proper drift and make small corrections as the needle deviates

- You are abeam when the needle points 90° off your track
- The time interval from first indications to passage varies with altitude
  - a A few seconds at low altitudes to 3 minutes at high altitudes

E. Global Position System (GPS)
  i. Satellite based navigation systems include
    a. GPS (Global Positioning System), WAAS (Wide Area Augmentation System), LAAS (Local…)
  ii. GPS
    a. The GPS system is composed of 3 major elements
      - The Space Segment
        - a Constellation of 24 satellites approximately 11,000 NM above the earth
          1. At any time, 5 are in view to any receiver (4 are necessary for operation)
          2. Each satellite orbits the Earth in approximately 12 hours
          3. Equipped with highly stable atomic clocks and transmit a unique code/nav message
        - b The satellites broadcast in the UHF range (so they are virtually unaffected by weather)
          1. Subject to line-of-sight references - Must be above the horizon to be usable
      - The Control Segment
        - a Consists of a master control station, 5 monitoring stations, and 3 ground antennas
        - b Distributed to allow continual monitoring/communications with satellites
          1. Updates are uplinked as necessary as satellites pass over the ground antennas
      - The User Segment
        - a Consists of all components associated with the GPS receiver
          1. Range from portable hand-held receivers to permanently installed systems
        - b The receiver utilizes the signals from the satellites to provide:
          1. Position, velocity, and precise timing to the user
    b. Solving for Location
      - The receiver utilizes the signals of at least 4 of the best positioned satellites to yield a 3D fix
        - a 3D - Latitude, longitude, and altitude
      - Satellites broadcast a course/acquisition (CA) code
        - a Contains information about the satellite's position/exact orbital location, the GPS system time, and the health/accuracy of the data transmitted
      - Receiver computes the distance the signal traveled
        - a Knowing the exact time the signal was sent and the speed at which it travels (about 186,000 miles per second) allows the receiver to calculate a pseudo-range distance
          1. Called a pseudo-range distance because it is not a direct measurement of distance, but a measurement based on time
      - Using the pseudo-range and position information, the receiver mathematically determines its position by triangulation from several satellites
    c. Navigating
      - VFR navigation with GPS can be as simple as selecting a destination and tracking the course

    a. Can program entire route – SIDs, routes/airways, STARs, approaches, holds, etc.
- GPS Tracking
    a. Course deviation is linear, no increase in sensitivity closer to waypoints (like VOR / LOC)
- It can be very tempting to rely exclusively on GPS, but never rely on one means of navigation

d. Receiver Autonomous Integrity Monitoring (RAIM)
- RAIM is the receiver's ability to verify the integrity of the signals received from the satellites
    a. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position
- RAIM requires a minimum of 5 satellites in view, or 4 and a barometric altimeter baro-aiding to detect an integrity anomaly
    a. Some receivers can isolate/remove a bad signal if 6 satellites in view (5 with baro-aiding)
- Generally, there are 2 types of RAIM messages
    a. There are not enough satellites in view to provide RAIM
    b. A potential error that exceeds the limits required for the current phase of flight
- Aircraft using un-augmented GPS navigation equipment under IFR must be equipped with an approved and operational alternate means of navigation appropriate to the route
    a. AIM 1-1-17(b)(2) – IFR Use of GPS
        1. GPS must be approved in accordance with TSO-C129, TSO-C196, TSO-C145, or TSO-C146 and installation must be in accordance with AC 20-138
            a. Un-augmented GPS (TSO-C129 or TSO C196) must be equipped with an alternate means of navigation suitable to the route of flight
    b. Monitoring of the alternate equipment is not required if the GPS receiver uses RAIM
    c. Active monitoring of the navigation equipment is required if the RAIM capability is lost
    d. Use other equipment, delay/cancel the flight if the loss of RAIM capability is predicted

e. GPS Substitution (AIM 1-2-3c.)
- GPS systems, certified for IFR en route and terminal operations, may be used as a substitute for ADF and DME receivers when conducting the following operations within the NAS:
    a. Determining the aircraft position over a DME fix
    b. Flying a DME arc
    c. Navigation TO/FROM an NDB/Compass Locator
    d. Determining the aircraft position over an NDB/compass locator
    e. Determining position over a fix defined by an NDB/Compass Locator bearing crossing a VOR/LOC course
    f. Holding over an NDB/Compass Locator

iii. WAAS

FAA WAAS Quick Facts

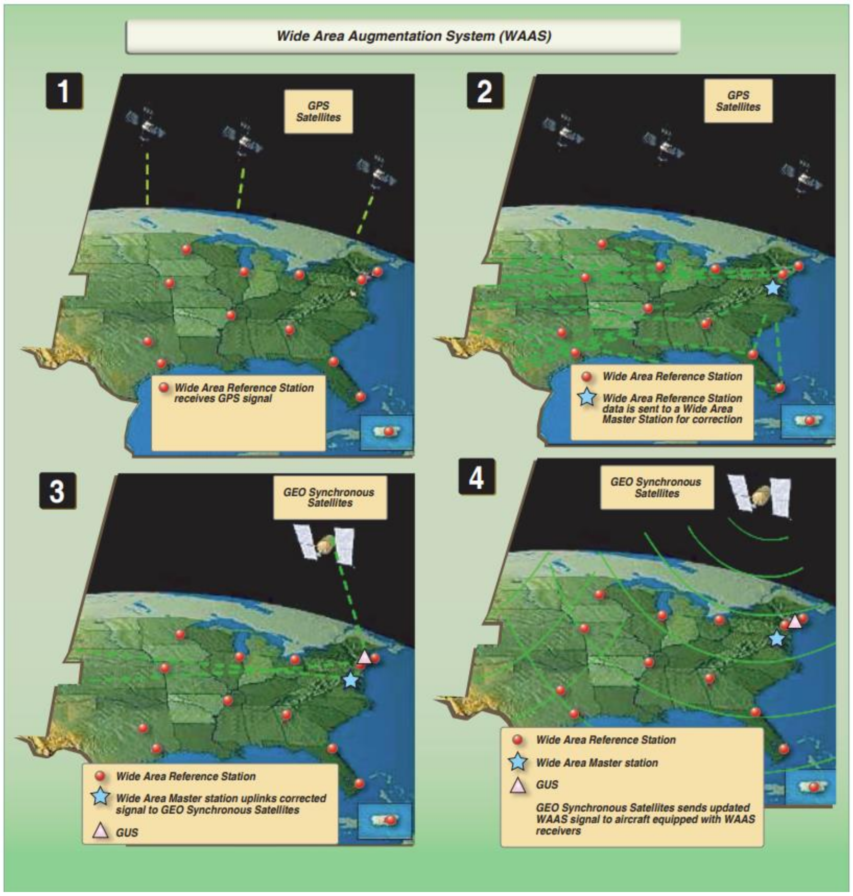
a. Designed to improve the accuracy, integrity, and availability of GPS signals
- Integrity is improved through real-time monitoring of the satellites

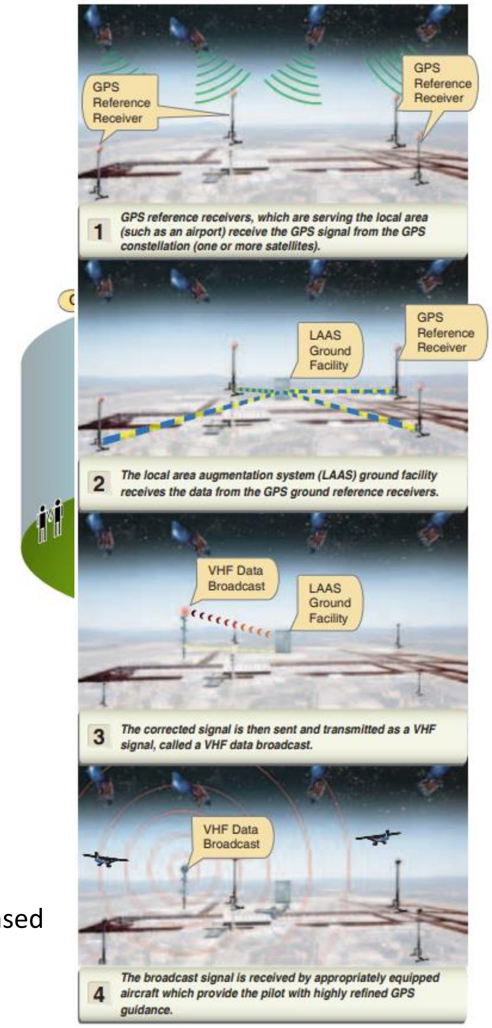
    a. Provides timely warnings when the signal is potentially hazardous/misleading
    b. WAAS certification required proving there is only an extremely small probability that an error would go undetected – equivalent of no more than 3 seconds of bad data per year
- Accuracy is improved by providing corrections to the satellites to reduce errors
    a. A network of ground-based stations measure small variations in satellite signals
    b. Measurements are routed to a master station
    c. Master station sends the correction message to a geostationary satellite
    d. Geostationary satellite broadcasts to WAAS receivers
- Performance improvements enable approach procedures with GPS/WAAS glidepaths
    a. WAAS requires a position accuracy of 25' or less at least 95% of the time
        1. Typically provides better than 1 meter laterally and 1.5 meters vertically
    b. Capable of Category 1 precision approach accuracy: 16 meters lateral/4 meters vertical

b. Capabilities
- Allows GPS to be used as the nav system from takeoff through Cat 1 precision approaches
- WAAS receivers support all basic GPS approach functions and provide additional capabilities
    a. Key benefit: Generate an electronic glidepath, independent of ground equip/baro-aiding
    b. Allows approach procedures to be built without the cost of installing a ground station
    c. Eliminates cold temperature effects, incorrect altimeter setting/lack of altimeter setting

c. New APV (Approach with Vertical Guidance) approaches can be flown with WAAS
- Basically, satellite-based approaches with a WAAS generated glidepath
- Like a Cat 1 ILS: Decision altitudes as low as 200', Visibility requirements as low as ½ mile

d. Can be further enhanced with LAAS





iv. LAAS (now more commonly referred to as GBAS – Ground Based Augmentation System)
   a. Similar to WAAS, but with more ground augmentation
   b. All-weather aircraft landing system based on real-time differential correction of the GPS signal
   c. Local receivers located around the airport send data to a central location at the airport
      - A correction message is then transmitted to users via a VHF Data Link
   d. A receiver on an aircraft uses this information to correct GPS signals, which then provides a standard ILS-style display to use while flying a precision approach
   e. LAAS aircraft landing at LAAS-equipped airports can conduct approaches to Cat I level and above

3. Anti-Ice/Deicing

A. General
   i. Different aircraft use different systems to deice/anti-ice primary surfaces (often the wings, tail, engines and sometimes the prop). These systems can vary greatly; examples include:
      a. Weeping Wing
         - The DA42, for example, uses the weeping wing system – an anti-ice mixture is stored in the nose and when turned on, it is excreted through tiny holes/pores in the wing. The fluid runs over the wing in flight (i.e., weeping wing). Used to prevent ice build-up in flight
      b. Heated Surfaces

- Jet aircraft often use hot engine bleed air vented to the wings/tail to prevent ice build-up

c. Boots
- Boots are also often used on turbo props/jets to remove ice from critical surfaces. Bleed air is used to inflate the leading edge "boots" in order to break up and remove ice

B. *The DA40 doesn't contain any specific deice or anti-ice equipment, but two pieces of equipment that can have an effect on ice build-up are the pitot-heat and windshield defrost:
   i. Pitot Heat
      a. Using pitot heat is absolutely necessary in the case of potential icing. Of course, make every attempt to get out of icing or get on the ground, but pitot heat can prevent a frozen pitot/static port and therefore unreliable instrument indications
   ii. Windshield Defrost
      a. Can be used to deice the windshield (if the icing is light)
      b. May provide needed visibility if trying to exit icing conditions, find an airport, and safely land

C. The bottom line: Avoid icing conditions. Don't fly. If in icing conditions, leave as soon as possible

Conclusion:
Brief review of the main points

PTS Requirements:
To determine that the applicant exhibits instructional knowledge of aircraft:
1. Flight instrument systems and their operating characteristics to include-
   a. pitot-static system.
   b. attitude indicator.
   c. heading indicator/horizontal situation indicator/radio magnetic indicator.
   d. magnetic compass.
   e. turn-and-slip indicator/turn coordinator.
   f. electrical system.
   g. vacuum system.
   h. electronic engine instrument display.
   i. primary flight display, if installed.
2. Navigation equipment and their operating characteristics to include–
   a. VHF omnirange (VOR).
   b. distance measuring equipment (DME).
   c. instrument landing system (ILS)
   d. marker beacon receiver/indicators.
   e. automatic direction finder (ADF).
   f. transponder/altitude encoding.
   g. electronic flight instrument display.
   h. global positioning system (GPS)
   i. automatic pilot.
   j. flight management system (FMS).
   k. multifunction display, if installed.

3. Anti-ice/deicing and weather detection equipment and their operating characteristics to include-
    a. airframe.
    b. propeller or rotor.
    c. air intake.
    d. fuel system.
    e. pitot-static system.
    f. radar/lightning detection system.
    g. other inflight weather systems.