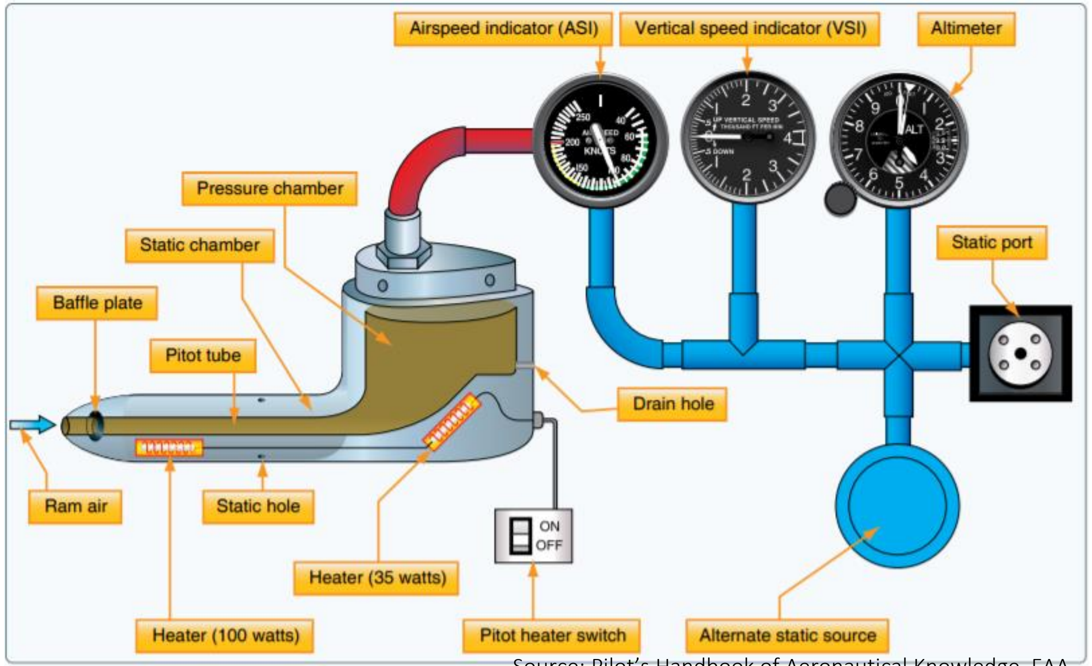
Flight Instruments & Navigation Equipment

THE BACKSEAT PILOT

Pitot-Static System

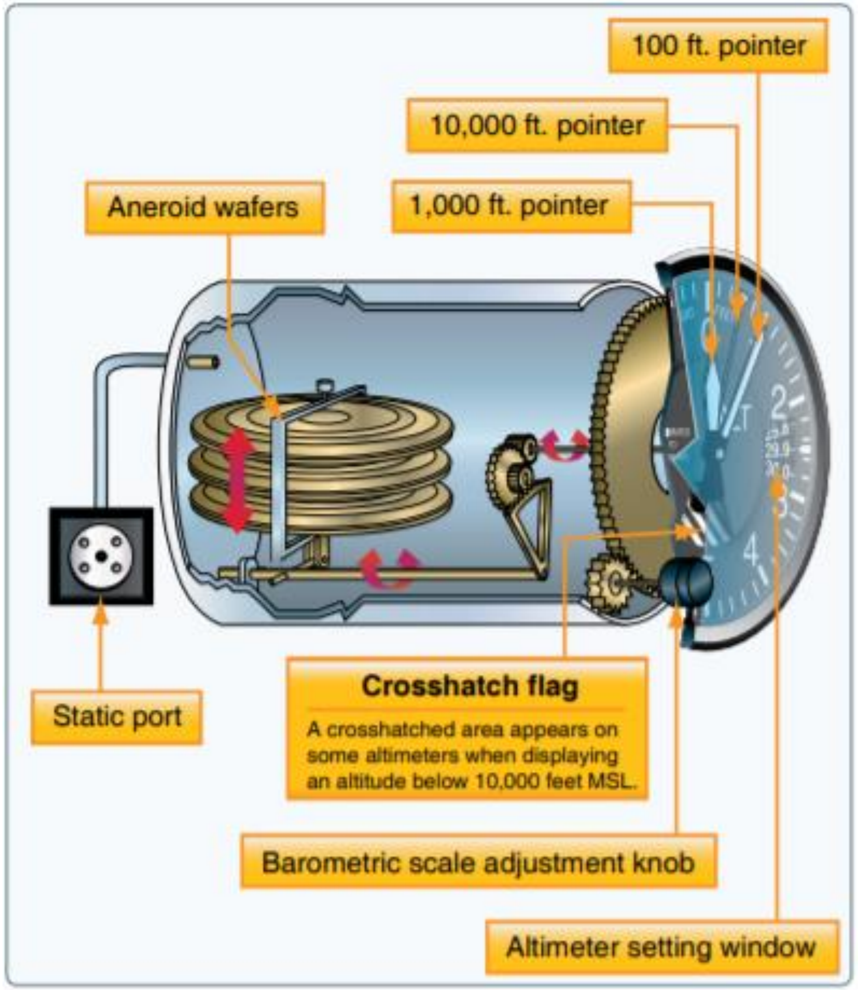
- Instruments
  - Airspeed Indicator, Altimeter, Vertical Speed Indicator
- How it Works
  - Static pressure
    - Pressure of the air that is still
    - Connects to all 3 instruments
  - Pitot pressure
    - Pointed into the relative wind; ram air pressure
    - Connects to the Airspeed Indicator



Source: Pilot's Handbook of Aeronautical Knowledge, FAA

Altimeter

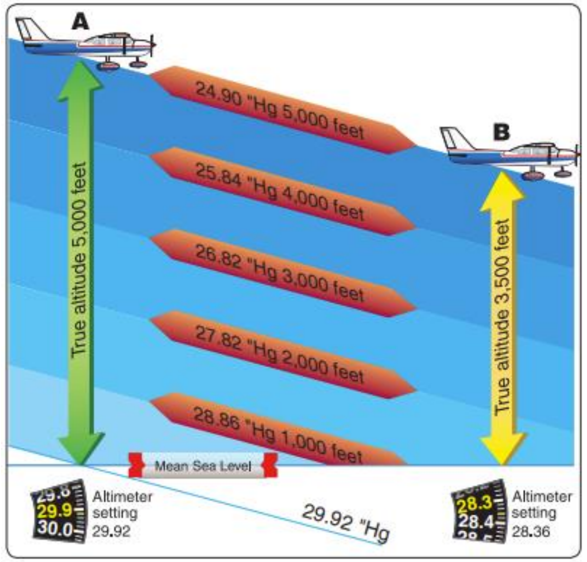
- Operation
  - Instrument case connected to the static port
  - Static pressure compresses/expands an aneroid
  - Compression/expansion changes the altitude displayed
  - Kollsman Window: Set reference pressure
- Mechanical Errors
  - Within 75’ of airport elevation

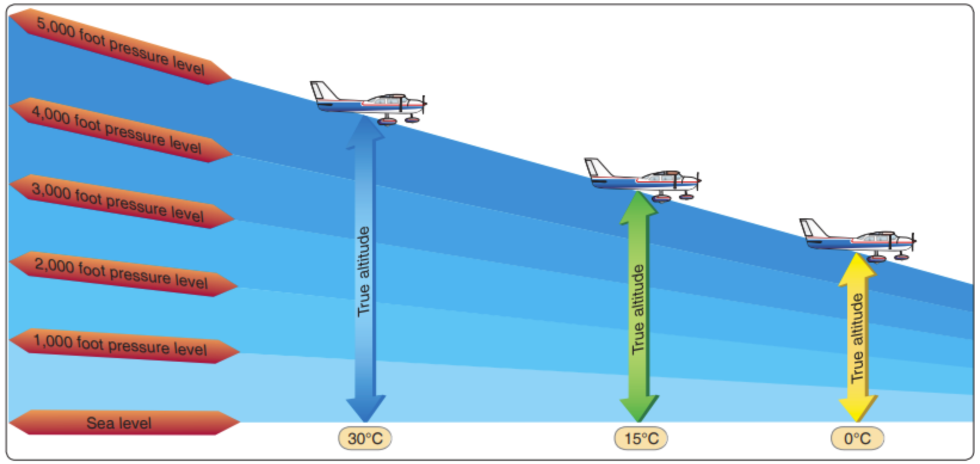


Source: Pilot’s Handbook of Aeronautical Knowledge, FAA

Altimeter

- Non-Standard Temperature
  - Warmer than Standard: Air is less dense, pressure levels are spread apart
  - Colder than Standard: Air is denser, pressure levels are closer together
- Non-Standard Pressure
  - High to Low: Altimeter interprets decreasing pressure as a climb
  - Low to High: Altimeter interprets increasing pressure as a descent
- From hot to cold, and high to low, look out below

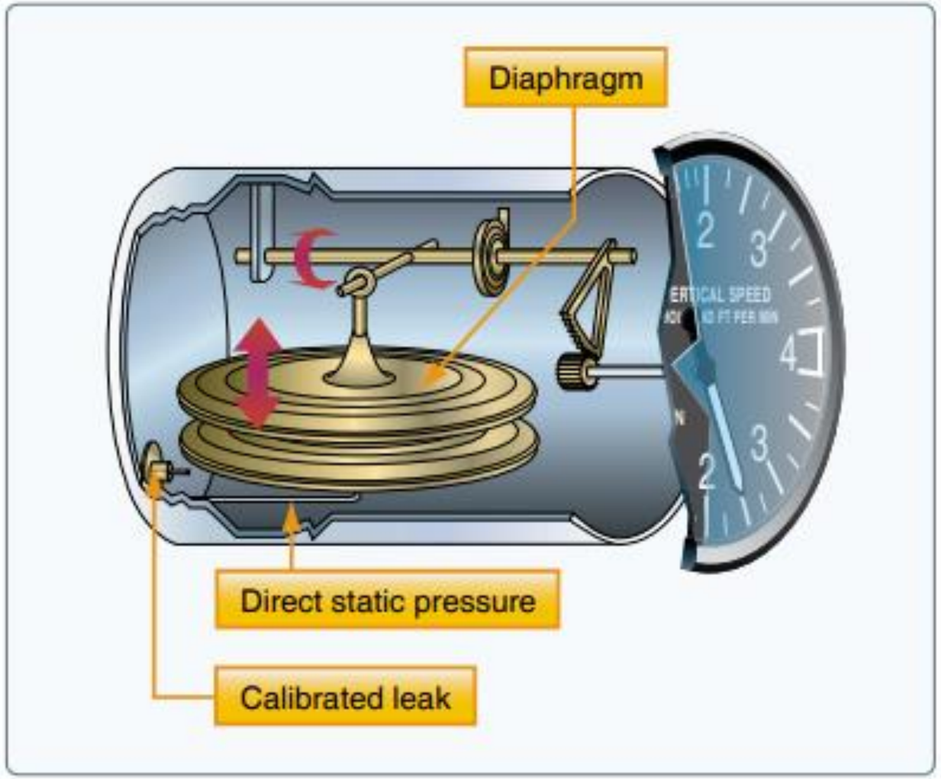




Source (both): Instrument Flying Handbook, FAA

Vertical Speed Indicator

- Differential pressure instrument
- Operation
  - Instrument case & aneroid vented to static system
  - Case: Slow pressure changes (calibrated leak)
  - Aneroid: Pressure changes are immediate
  - Pressure difference is reflected as vertical speed
  - Lags a few seconds behind actual pressure changes

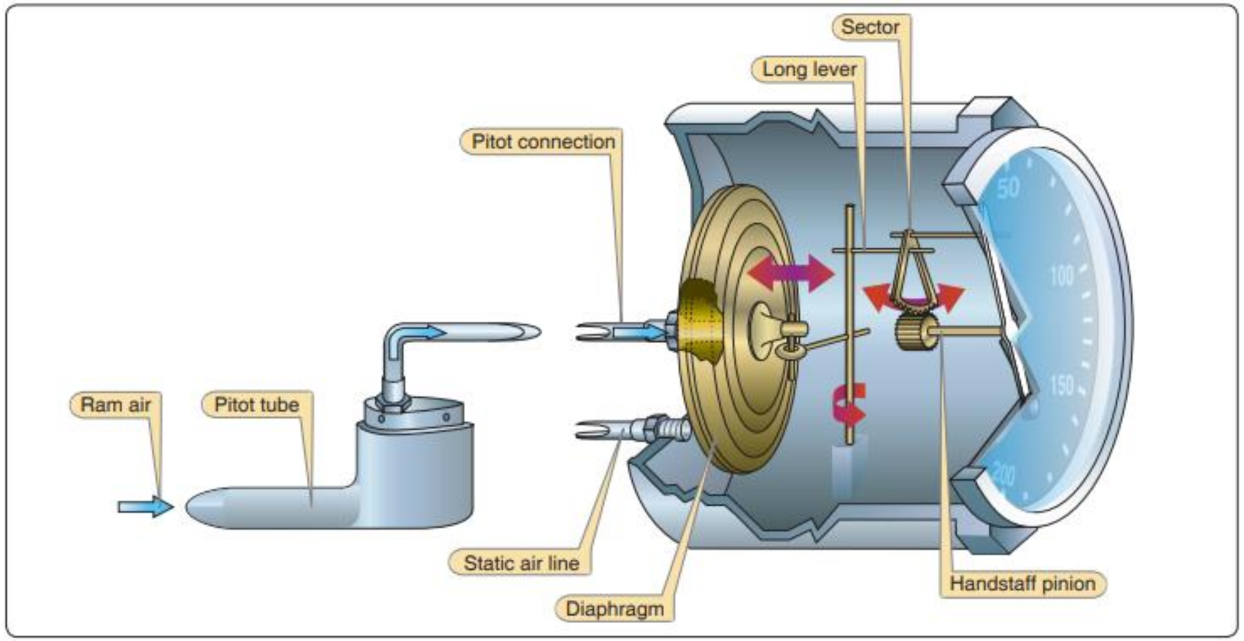


Source: Pilot's Handbook of Aeronautical Knowledge, FAA

Airspeed Indicator

- Measures Dynamic Pressure
  - Difference between static and ram air pressure

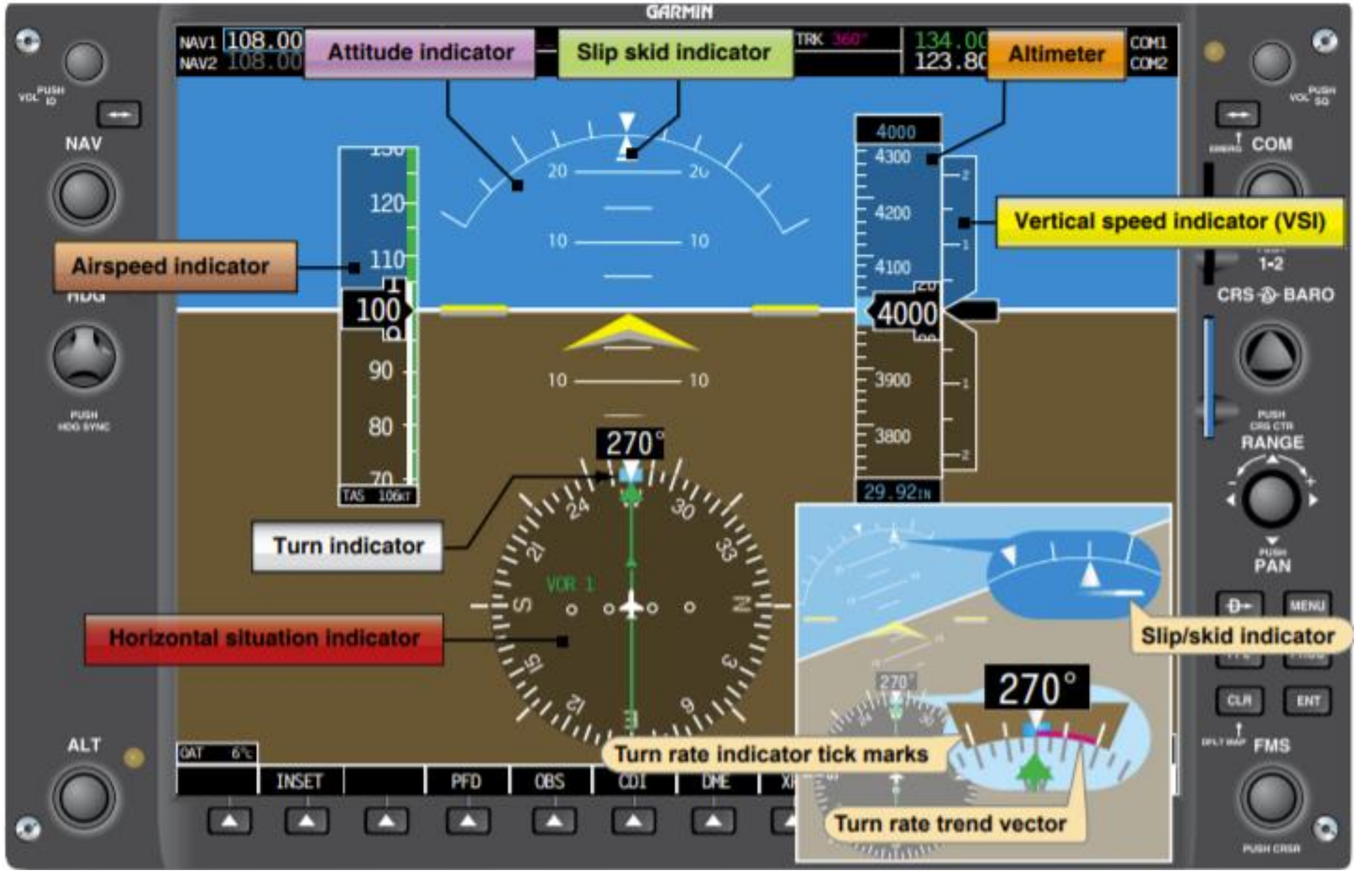
- Operation
  - Diaphragm receives pressure from the pitot tube
  - Instrument case receives pressure from the static port
  - Difference in static/ram pressure compresses and expands the diaphragm
  - Diaphragm movement changes airspeed



Source: Instrument Flying Handbook, FAA

Air Data Computer (ADC)

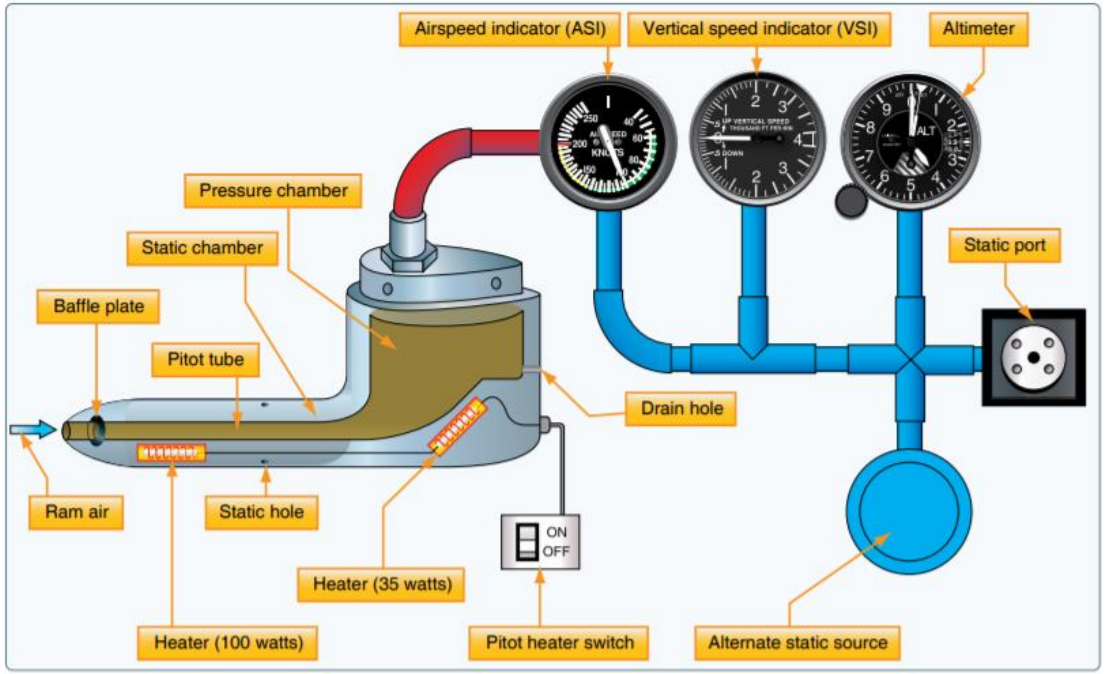
- Digital Pitot-Static system
- Operation
  - Computer receives pitot/static pressure and temperature information
  - Small, solid-state systems replace wafers, aneroids, gearing, etc.
  - More accurate and reliable
  - Displays instrumentation on glass cockpit



Source: PHAK, FAA

Blocked Pitot-Static System

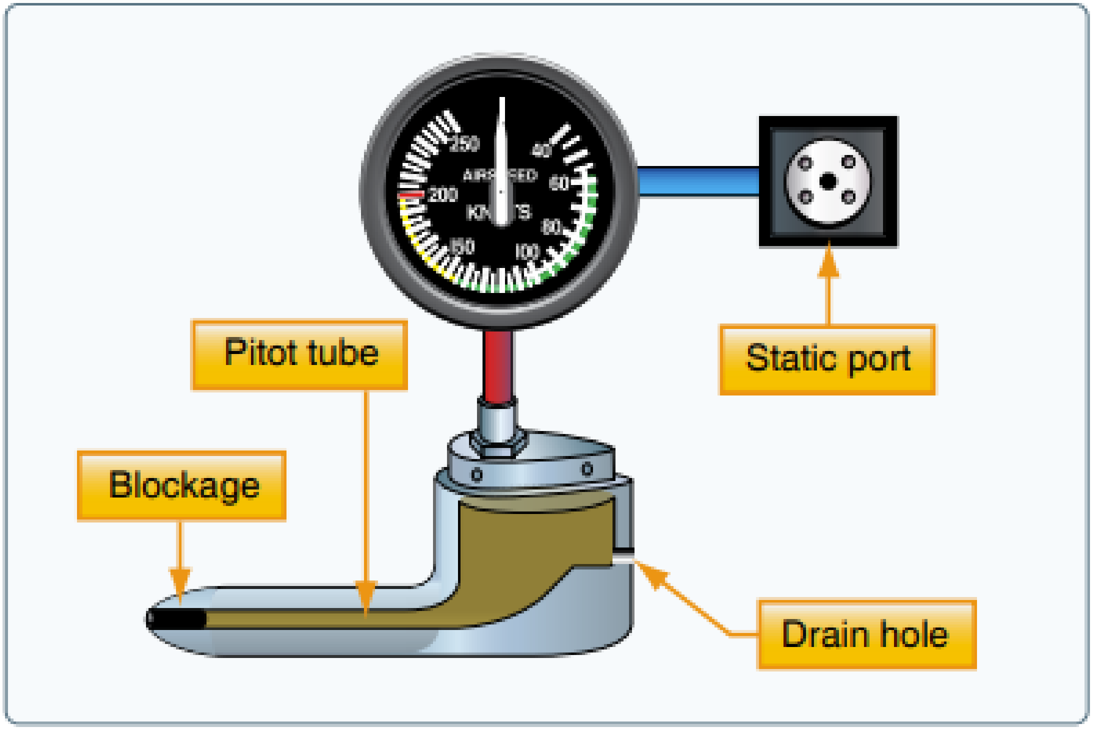
- Airspeed & Vertical Speed Indicator errors almost always indicate pitot-static blockage
- Moisture, ice, dirt, insects, etc. can cause a blockage of either system
- Always preflight the pitot tube and static ports



Source: PHAK, FAA

Pitot System: Ram Air Blocked, Drain Open

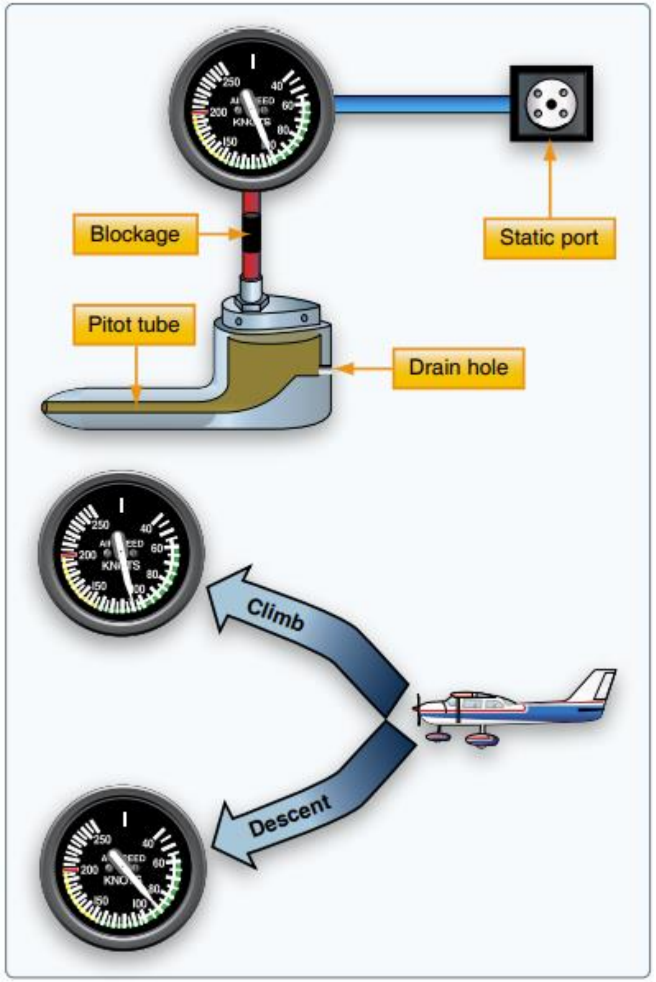
- Air already in the system vents through the drain hole
- Ram air pressure drops to match outside (static) air pressure
- Airspeed quickly decreases to zero as pressures equalize



Source: PHAK, FAA

Pitot System: Ram Air & Drain Blocked

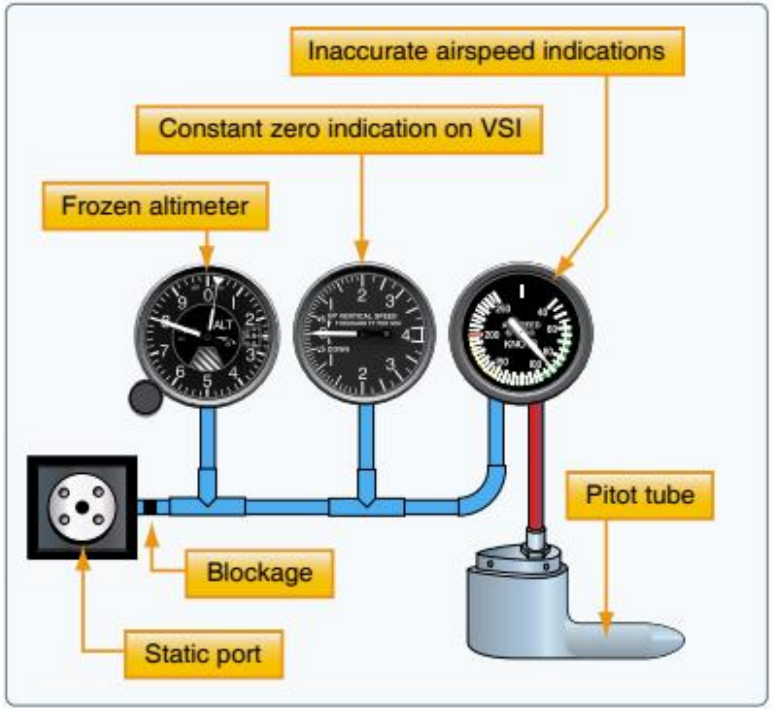
- Ram air pressure in the pitot tube is trapped
- Static pressure changes with altitude
- In a Climb
    - Ram air pressure remains constant
    - Static air pressure decreases
    - Airspeed increases
- In a Descent
    - Ram air pressure remains constant
    - Static air pressure increases
    - Airspeed decreases
- Airspeed Indicator acts like an Altimeter



Source: PHAK, FAA

Static System: Static Blocked, Pitot Open

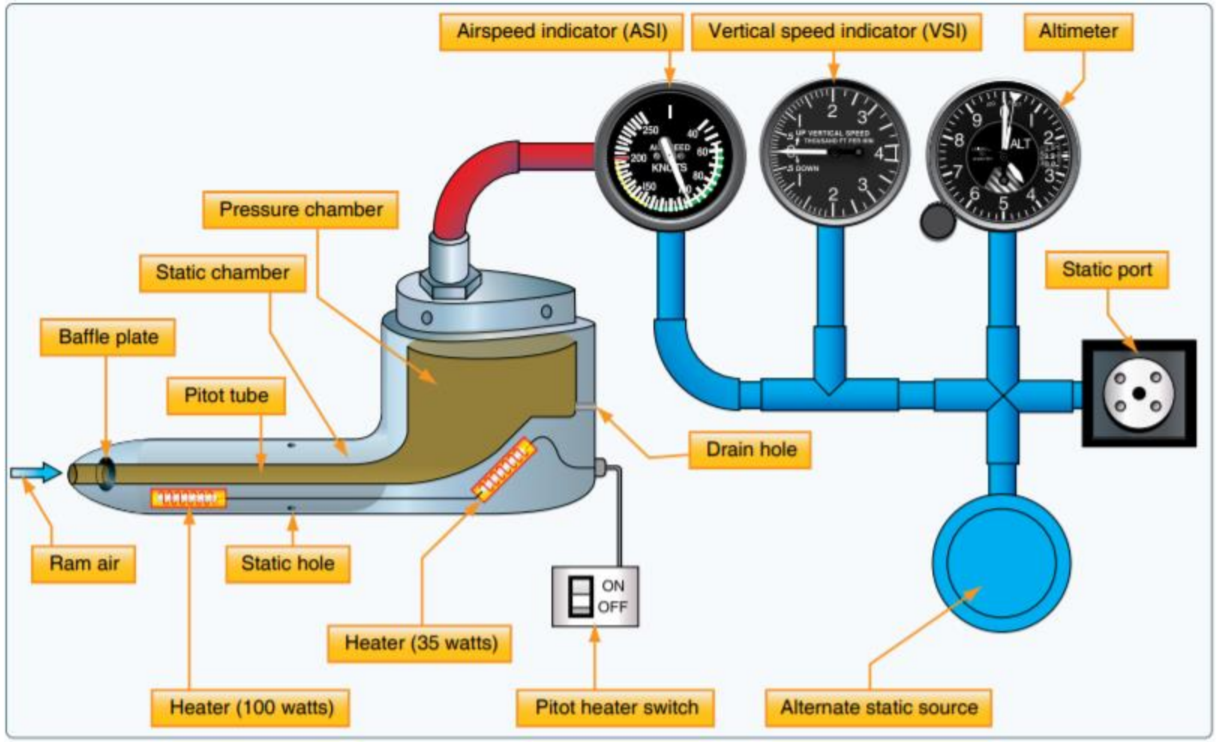
- Airspeed Indicator
  - Operates but is inaccurate
  - Above Blockage Altitude: Airspeed indicates lower than actual
    - Trapped static pressure is higher than normal for that altitude
  - Below Blockage Altitude: Airspeed indicates higher than actual
    - Trapped static pressure is lower than normal for that altitude
- Altimeter
  - Freezes at the blockage altitude
- Vertical Speed Indicator
  - Shows zero



Source: PHAK, FAA

Alternate Static Source

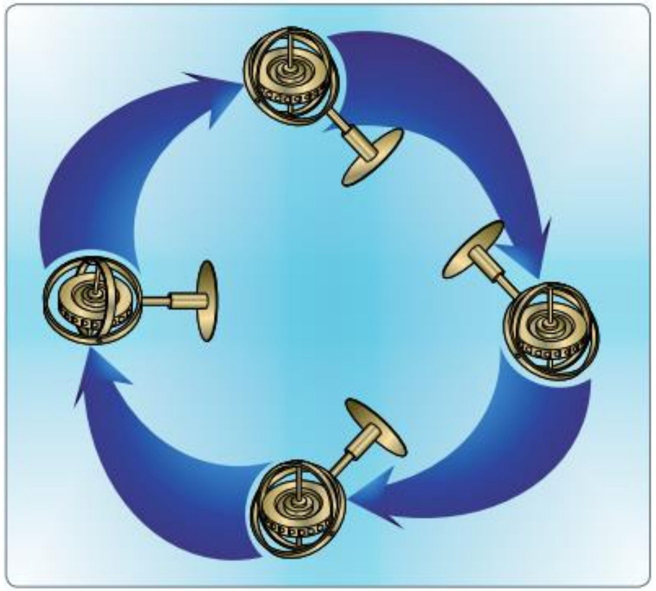
- Provides alternate source of static pressure in case the primary is blocked
- Normally inside the flight deck
  - Flight deck pressure is lower than outside static pressure
- Instrument Indications
  - Altimeter: Slightly higher than actual altitude
  - Airspeed: Greater than actual airspeed
  - Vertical Speed: Momentary climb then stabilizes

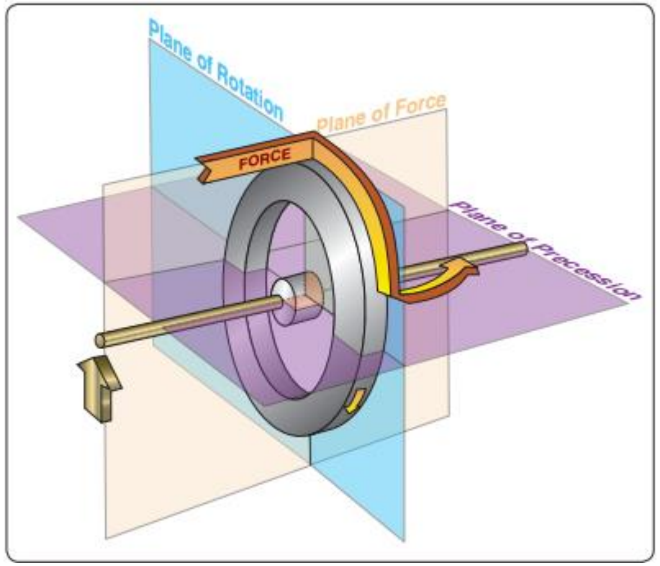


Source: PHAK, FAA

Gyroscopic System

- Instruments
  - Attitude Indicator, Heading Indicator, Turn Coordinator
- Gyroscope
  - Small wheel with its weight concentrated around its periphery
  - Rigidity: Gyro is rigid in space – case and aircraft rotate about it
    - Attitude & Heading instruments
  - Precession: A force is felt 90-degrees from the point of application in the direction of rotation
    - Rate instruments

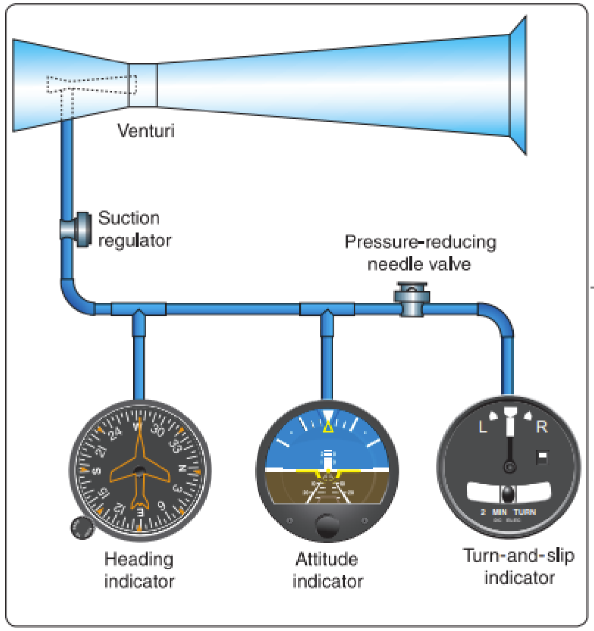




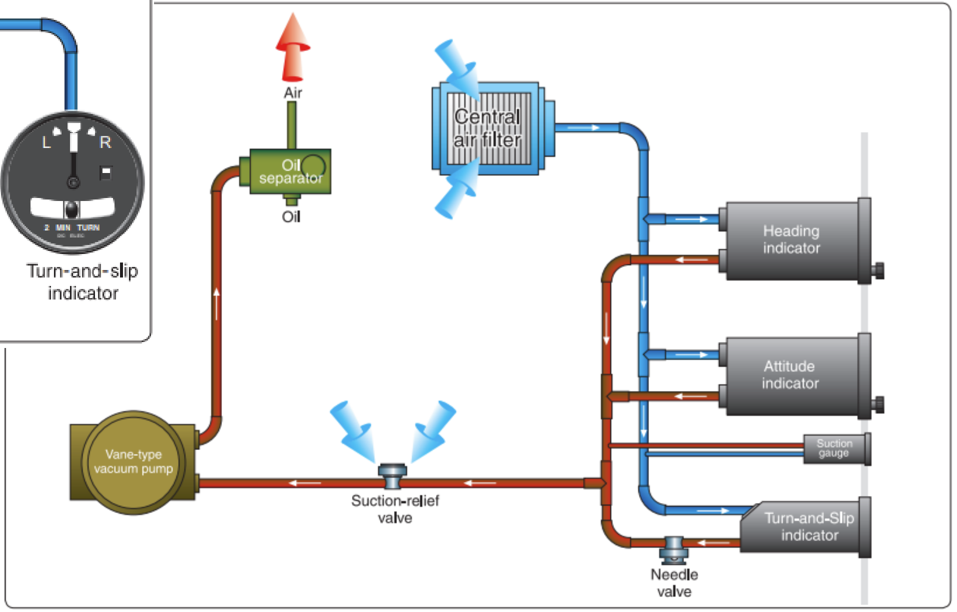
Source: PHAK, FAA

Gyroscopic System

- Power Sources
  - Electrical
  - Vacuum
  - Venturi Tube
  - Wet-Type Vacuum
  - Dry-Air Pump
  - Pressure



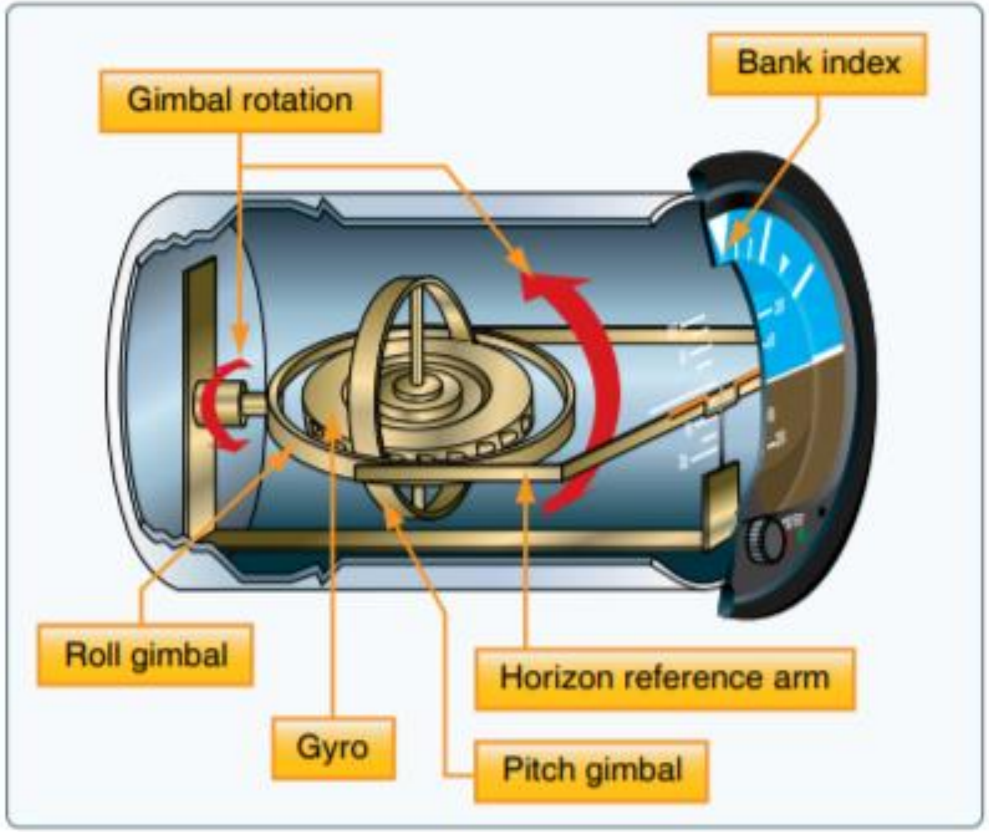
Venturi Tube System



Wet Type Vacuum Pump – Source (both): Instrument Flying Handbook, FAA

Attitude Indicator

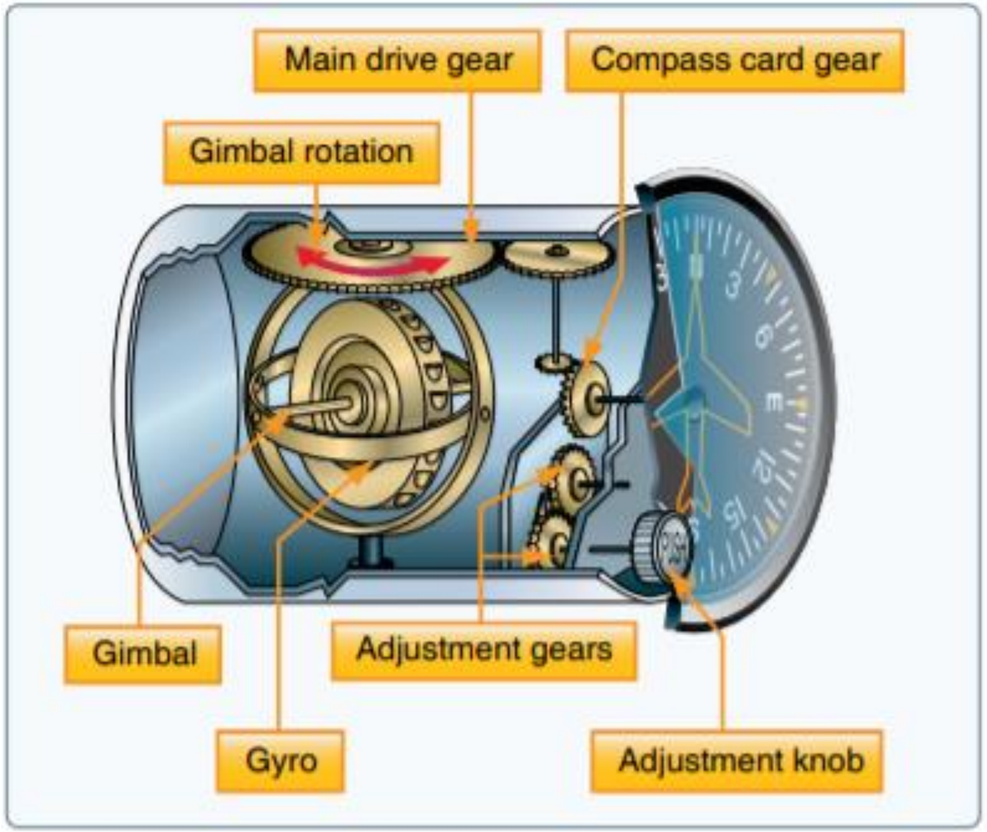
- Operation
  - Brass wheel with a vertical spin axis
  - Double gimbal allows pitch & roll about the gyro
  - Horizon disk attached to gimbal
  - Airplane pitches & rolls around horizon disk
- Errors
  - Nose up during rapid acceleration
  - Small bank & pitch error after a 180º turn
  - Precession & tilting



Source: PHAK, FAA

Heading Indicator

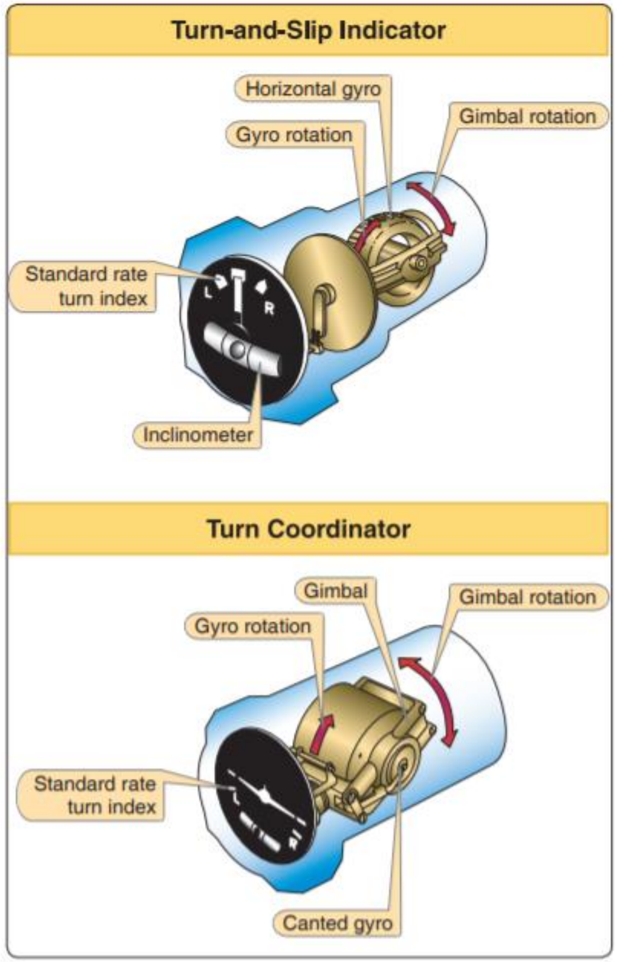
- Operation
  - Senses rotation about the vertical axis
  - Double gimbal
  - Heading is set to match the compass
  - Rigidity maintains position
- In-Flight Maintenance
  - Earth’s rotation – Match to compass every 15 mins



Source: PHAK, FAA

Turn and Slip Indicator

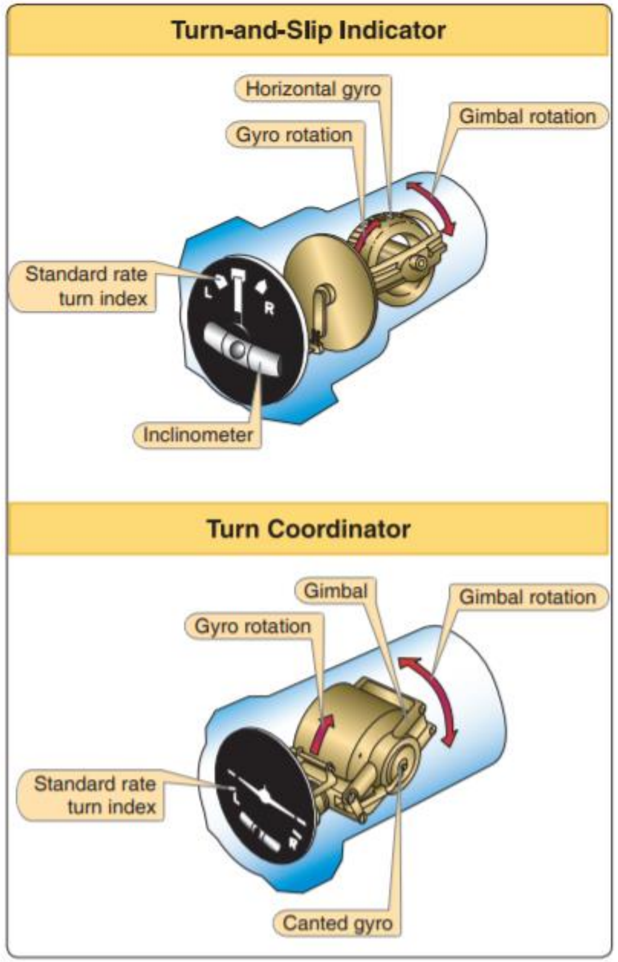
- Basics
  - Displays turn direction and turn rate
  - Operates on principal of Precession
  - Doghouse-shaped markings indicate standard rate turn
- Operation
  - Gyro mounted in a single gimbal
  - Yawing produces a force in the horizontal plane
  - Precession causes the gyro/gimbal to rotate about gimbal axis
  - Pointer deflects to indicate rate of turn
- Limitation
  - Only senses rotation about the vertical axis



Source: Instrument Flying Handbook, FAA

Turn Coordinator

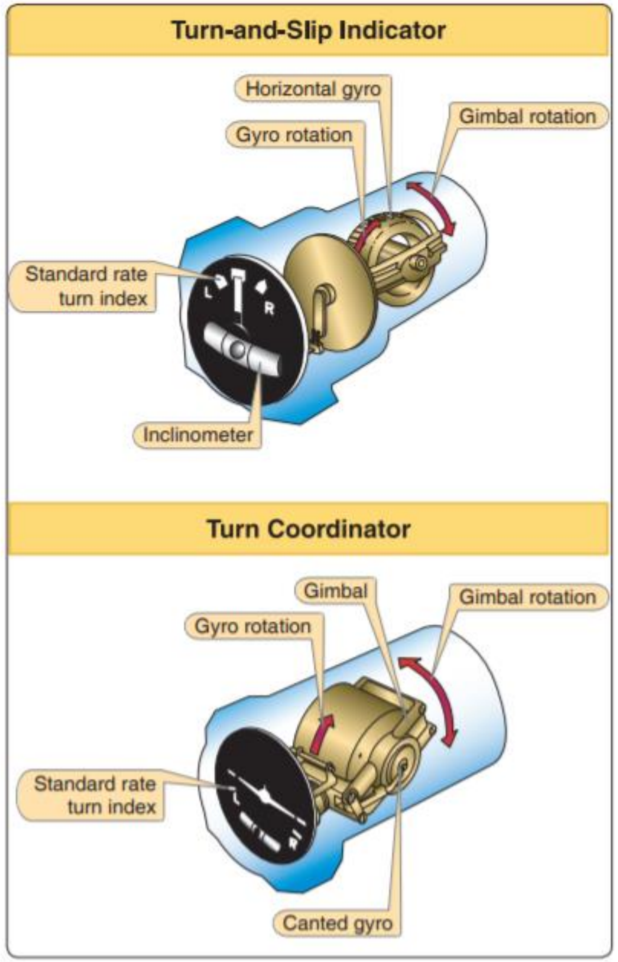
- Basics
  - Displays turn direction, rate of bank, and, when stabilized, rate of turn
  - Operates on principal of Precession
  - Miniature aircraft (rather than a needle)
  - Dashes indicate standard rate turn
- Operation
  - Powered by an air or electric motor
  - Like the turn-and-slip indicator but gimbal frame is angle up 30-degrees
    - Allows it to sense roll and yaw



Source: Instrument Flying Handbook, FAA

Inclinometer / Coordination Ball

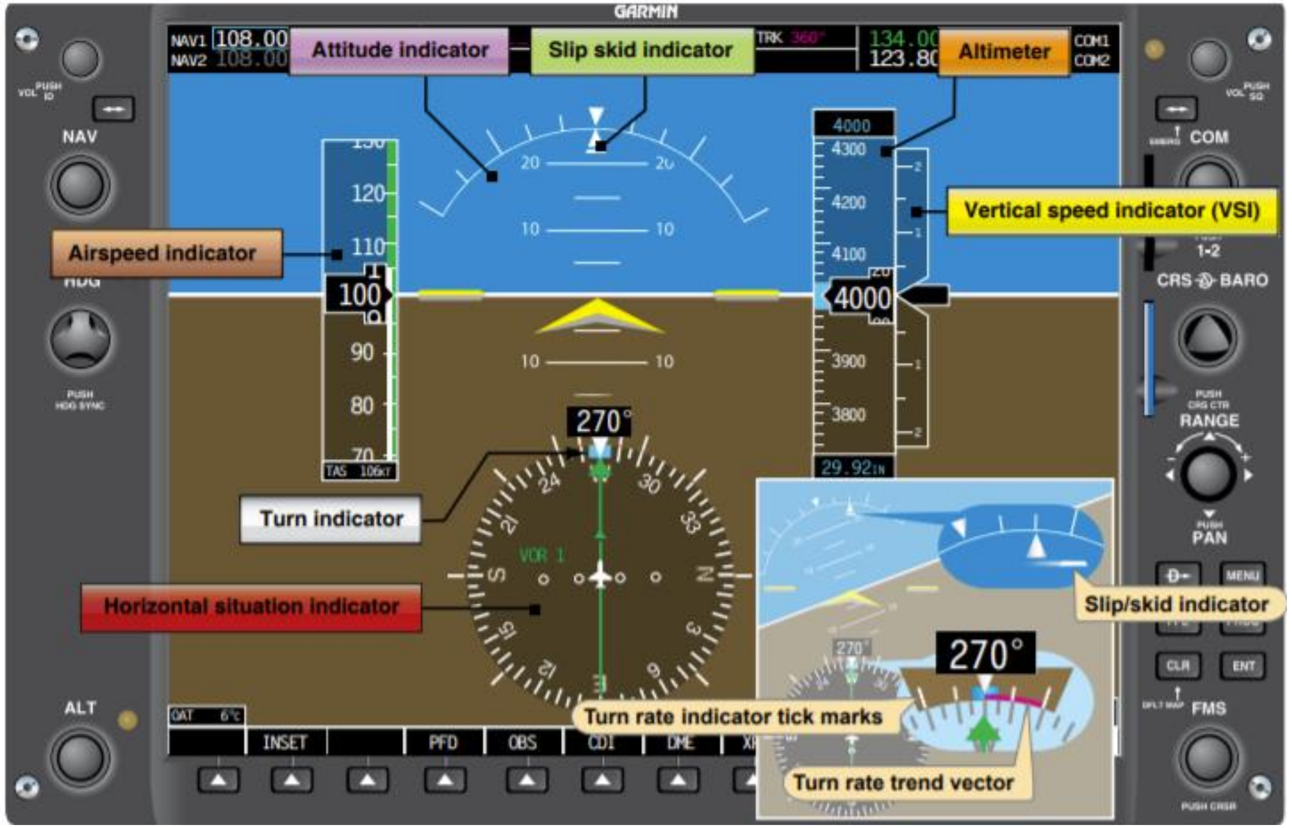
- Basics
  - Part of Turn Indicator & Turn-and-Slip Indicator
  - Glass ball sealed in curved glass tube with liquid
  - Measures relationship between bank angle and yaw (coordinated flight)
- Indications
  - Centered: No inertia, coordinated flight
  - Ball Inside the Turn: Bank angle too steep (slipping turn)
  - Ball Outside the Turn: Bank angle too shallow (skidding turn)



Source: Instrument Flying Handbook, FAA

Attitude & Heading Reference System (AHRS)

- Digital Gyroscopic System
- Operation
  - Solid-state systems – no moving parts
  - Inertial sensors, rate gyros, magnetometers, satellite reception
  - Superior reliability & accuracy
  - Displayed on glass cockpit

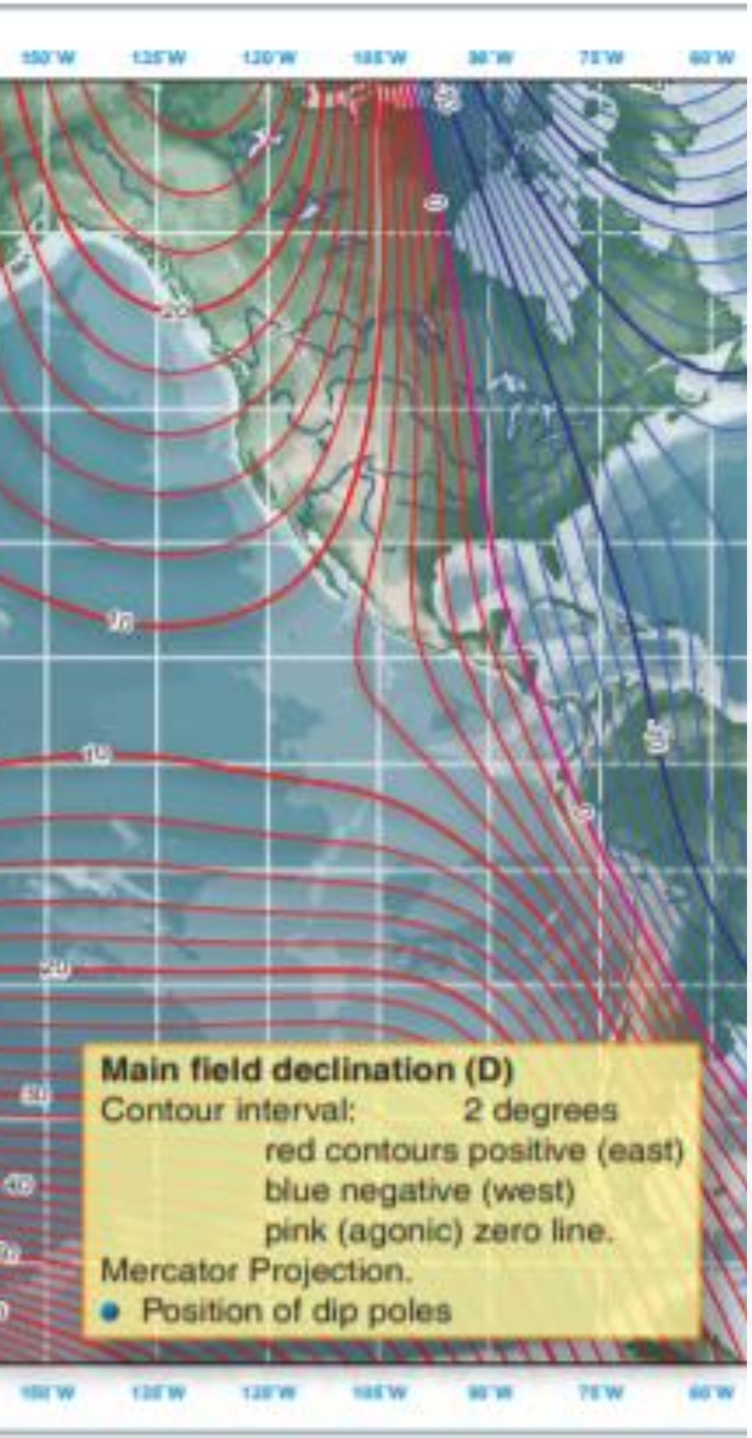


Source: PHAK, FAA

Magnetic Compass

- Operation
  - 2 magnets attached to a metal float in a clear compass fluid
  - Compass card is wrapped around the float and displays headings
  - Lubber line indicates current heading
  - Pilot always sees the compass from its backside
- Technique
  - Move the desired heading to the lubber line

Source: Instrument Flying Handbook, FAA



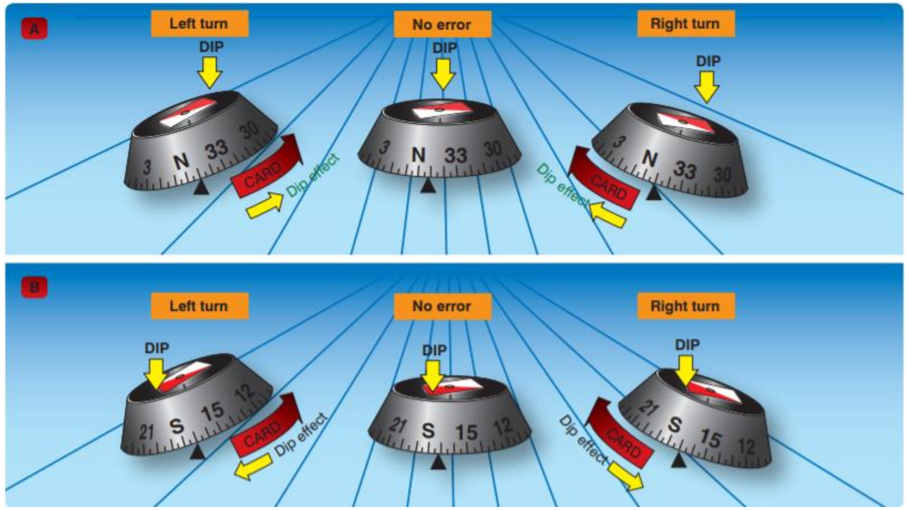
Magnetic Compass Errors

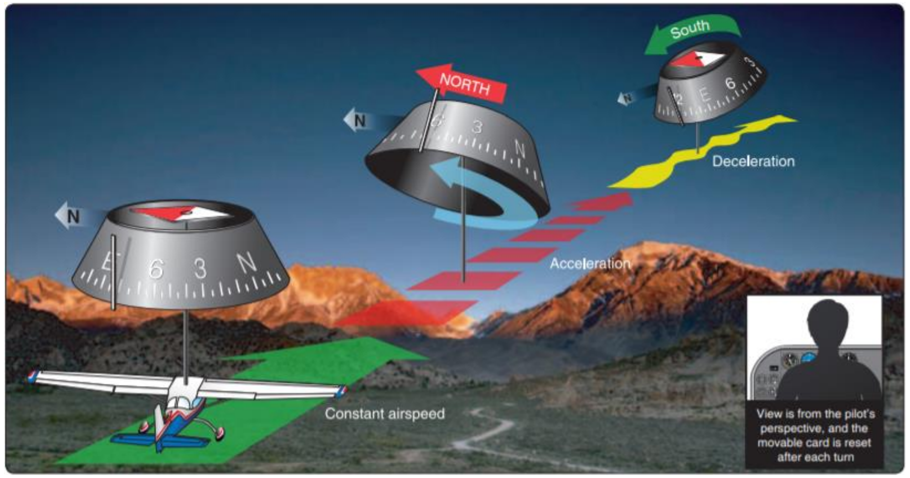
- Variation
  - Difference between magnetic & true North
  - Isogonic line: Lines connecting points with the same magnetic variation
  - Agonic line: Line along which the two poles are aligned – No variation
- Deviation
  - Magnetic fields within the aircraft
  - Degrees of deviation is displayed on compass correction card
- Compass Course
  - True course corrected for Variation & Deviation
  - True Course ± Variation = Magnetic Course
  - Magnetic Course ± Deviation = Compass Course
  - East is least, West is best

Source: Instrument Flying Handbook, FAA

Magnetic Compass Errors

- Dip Errors
  - Lines of magnetic flux
    - Perpendicular at the poles
    - Parallel at the surface
  - Northerly & Southerly Turning Errors
    - Turns from a Southerly Direction: Compass Leads
    - Turns from a Northerly Direction: Compass Lags
    - UNOS: Undershoot North, Overshoot South
  - Acceleration Error
    - Aft of compass tilts up when accelerating and down when decelerating
    - ANDS: Accelerate North, Decelerate South
- Oscillation Error
  - Combination of all other errors & airplane movement
  - Use the average

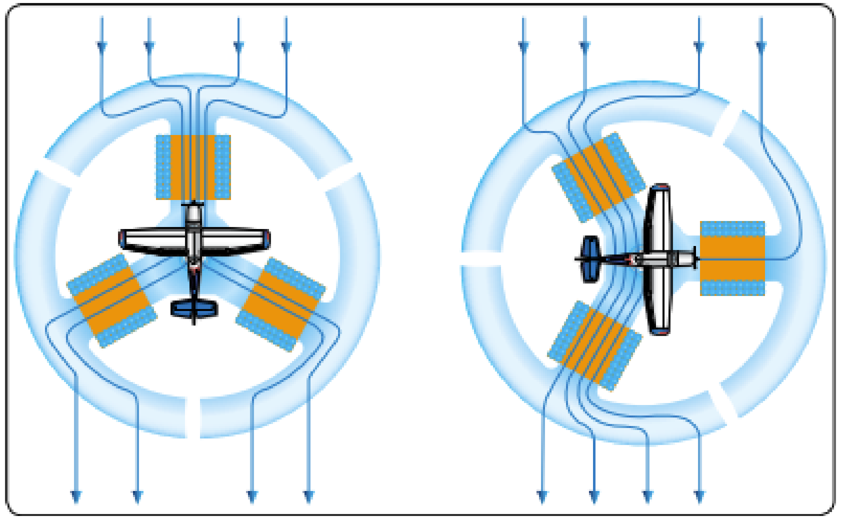




Source (both): Instrument Flying Handbook, FAA

Radio Magnetic Indicator (RMI)

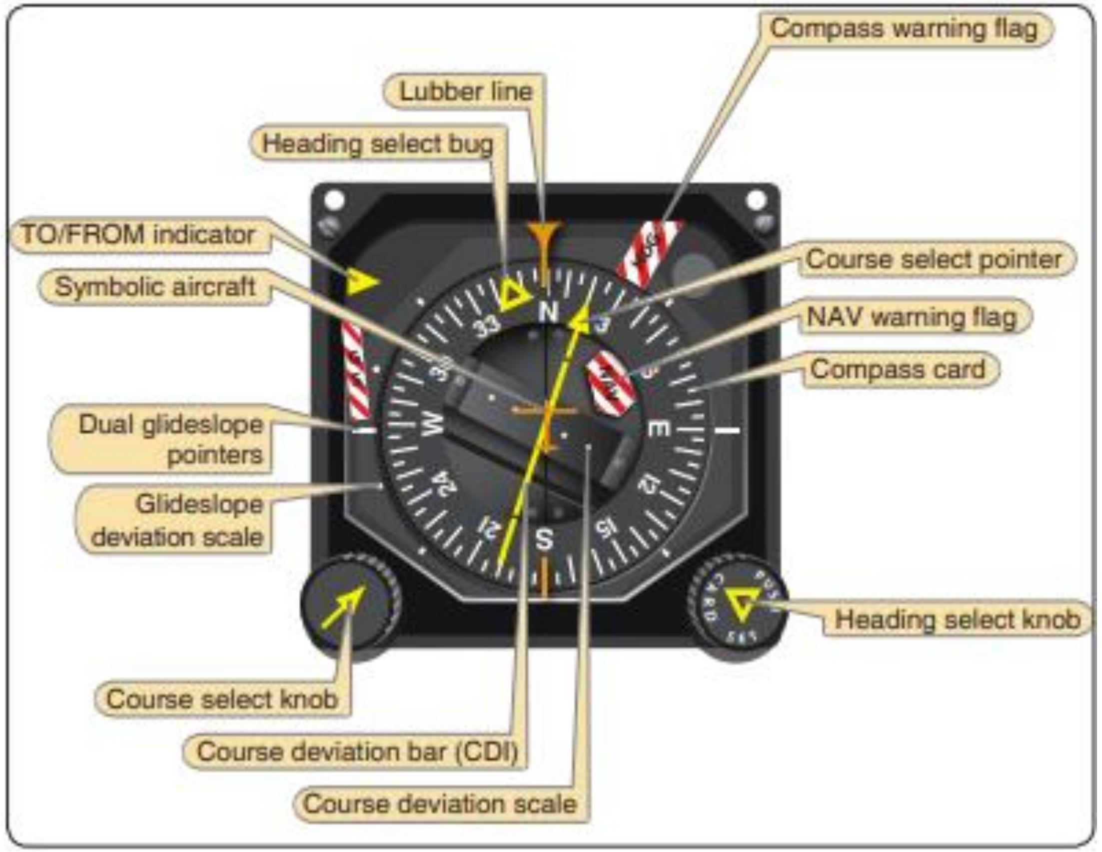
- Operation
  - Bearing indicator overlayed on a heading indicator
  - Flux valve: Automatically rotates the compass card of the RMI using Earth's magnetic fields
  - Bearing indicators are driven by an ADF or VOR



Source: PHOAK, FAA

Horizontal Situation Indicator (HSI)

- Heading indicator + Navigation Signals
  - RMI on steroids
- Operation
  - Flux valve uses magnetic fields to drive heading indications
  - Navigation is displayed over the heading indicator



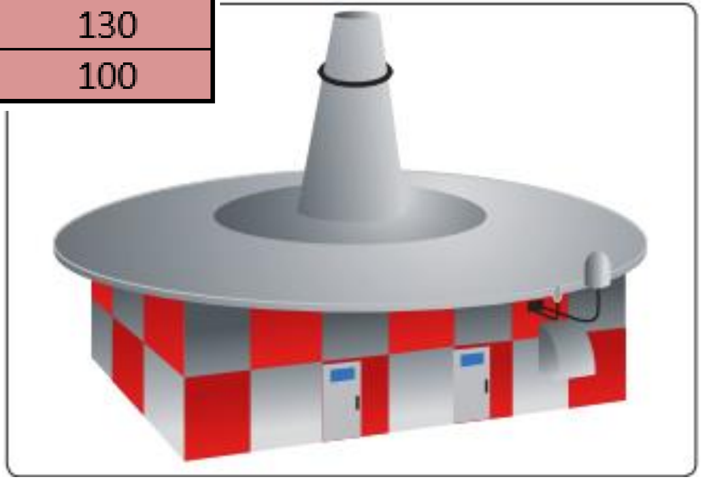
Source: Instrument Flying Handbook, FAA

VOR

- What is it?
  - VHF Omnidirectional range
  - Radials projected in all directions referenced to magnetic north
  - Radial: Line of magnetic bearing extending outward from the VOR
  - Terminal, Low, High class

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

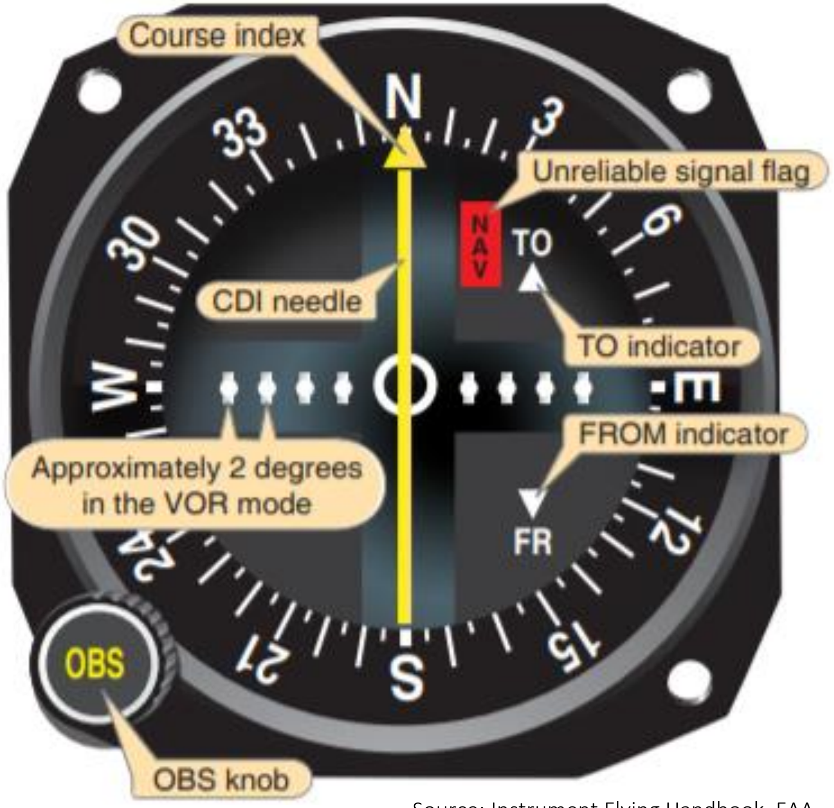
- Types of VORs
  - VOR
  - VOR / DME: VOR + Distance Measuring Equipment
  - VORTAC: VOR + TACAN



Source: Instrument Flying Handbook, FAA

VOR

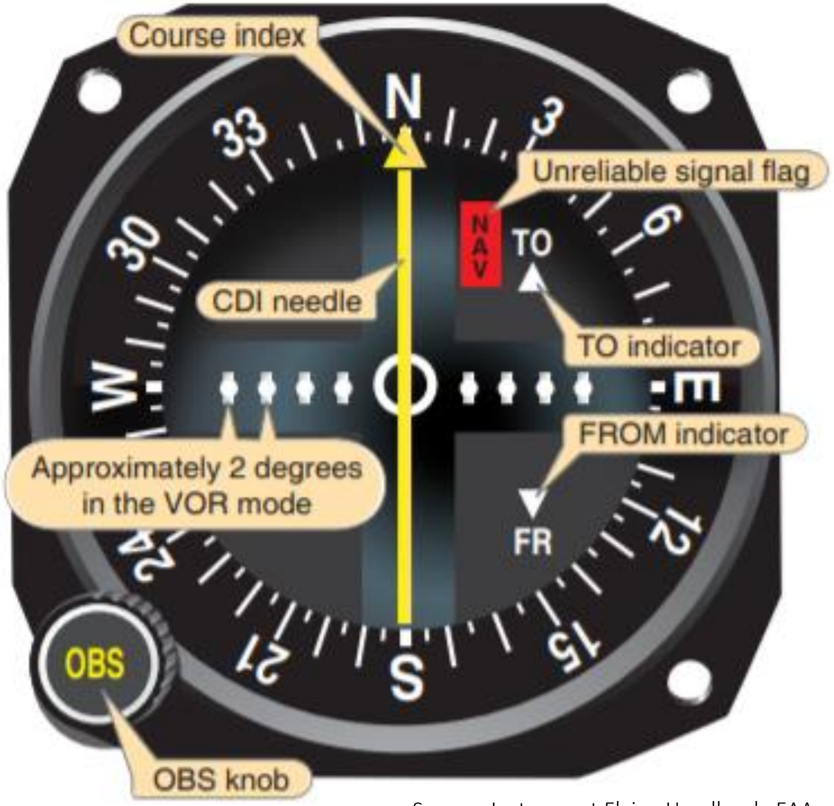
- Ground Components
  - VOR station
- Aircraft Components
  - Antenna – Picks up signal
  - Receiver – Processes signal
  - VOR Instrument – Displays signal
- VOR Instrument
  - Omnibearing Selector (OBS): Dial used to select the desired radial
  - Course Deviation Indicator (CDI): Indicates position relative to the selected course
  - To/From Indicator: Displays whether the selected course takes the aircraft to or from the VOR
  - Flags: Indicates unusable/unreliable signals



Source: Instrument Flying Handbook, FAA

VOR Basics

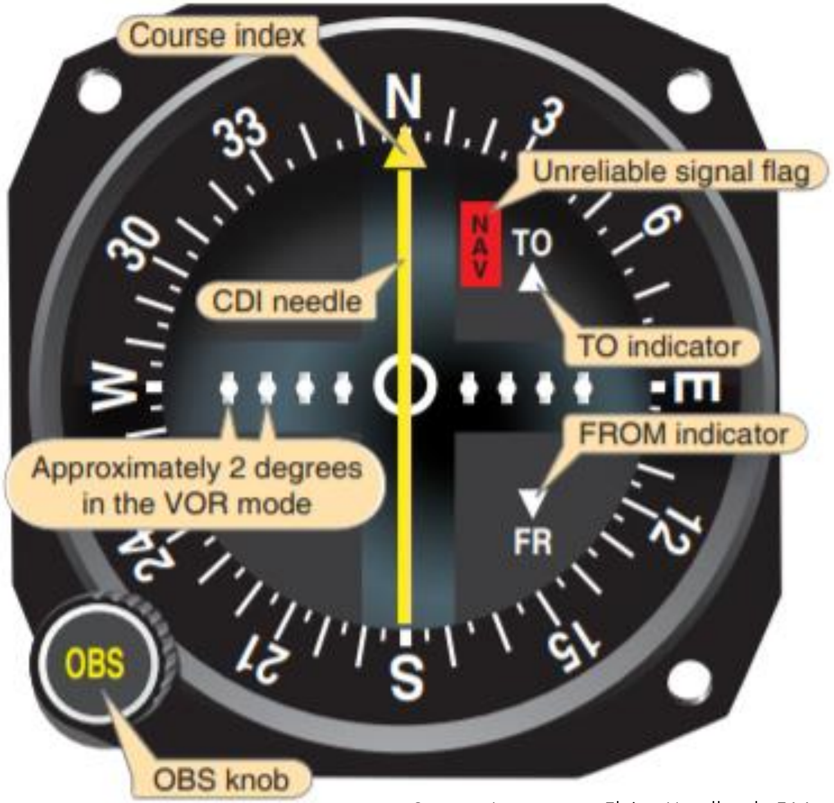
- Tune, Identify, Monitor (TIM)
  - Tune the VOR frequency on the receiver
  - Verify with morse code/voice/display
  - Monitor the identification
- Orientation
  - Rotate the OBS to center the needle
  - Note To/From
    - To: Course to fly to the VOR
    - From: Radial the aircraft is currently on
- Navigating To a VOR
  - Rotate OBS until TO appears, center the CDI, fly the course
- Navigating From a VOR
  - Center the needle with a FROM indication, fly the course
  - Whether To or From, adjust heading for wind



Source: Instrument Flying Handbook, FAA

VOR Checks

- FAR 91.171
  - IFR operations require the VOR to be checked withing the last 30 days
- Types of Checks
  - FAA Test Facility
  - Certified Airborne Checkpoint
  - Certified Ground Checkpoint
  - Dual VOR check
- Chart Supplement contains checkpoints
- Ground checks require ± 4 degrees
- Airborne checks require ± 6 degrees

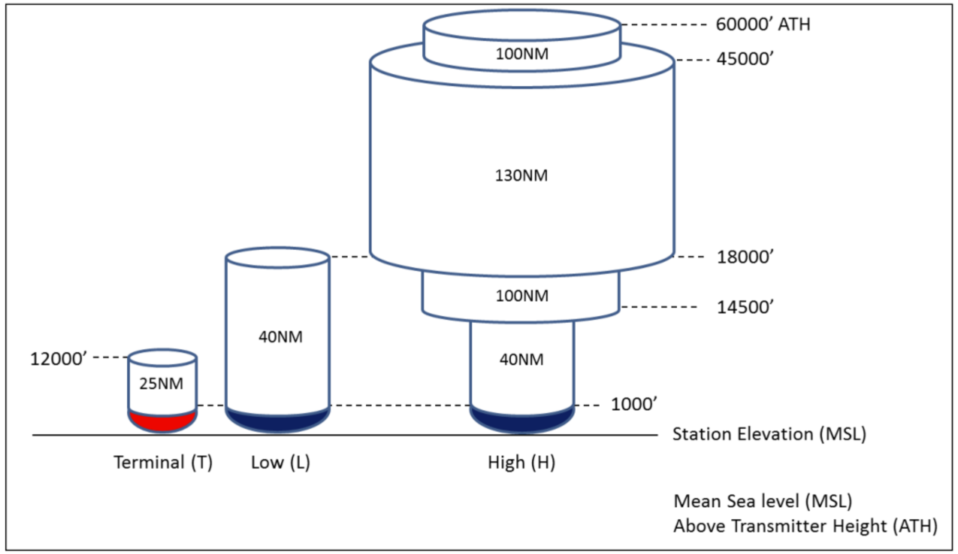


Source: Instrument Flying Handbook, FAA

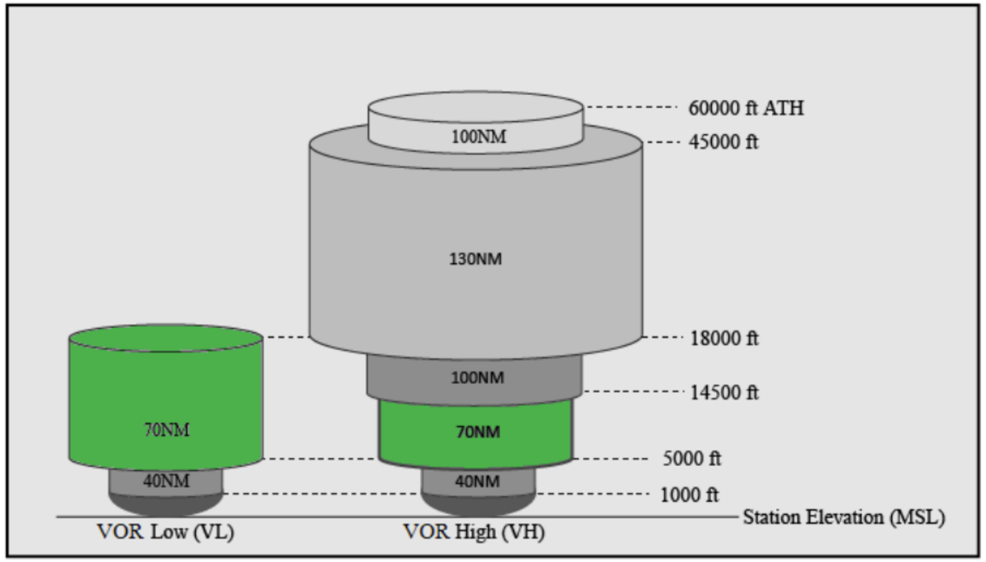
VOR MON (Min Op Network)

- What is it?
  - NAS is transitioning to PBN
  - Reducing number of VORs (from 896 to 590)
  - New service volumes – Designed to enable near continuous VOR signal at/above 5,000’ AGL

LEGACY SERVICE VOLUMES



NEW MON SERVICE VOLUMES



Source (both pictures): FAA

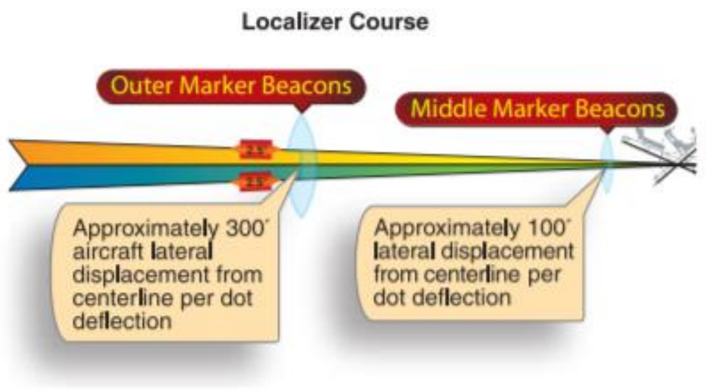
Mean Sea level (MSL)
Above Transmitter Height (ATH)

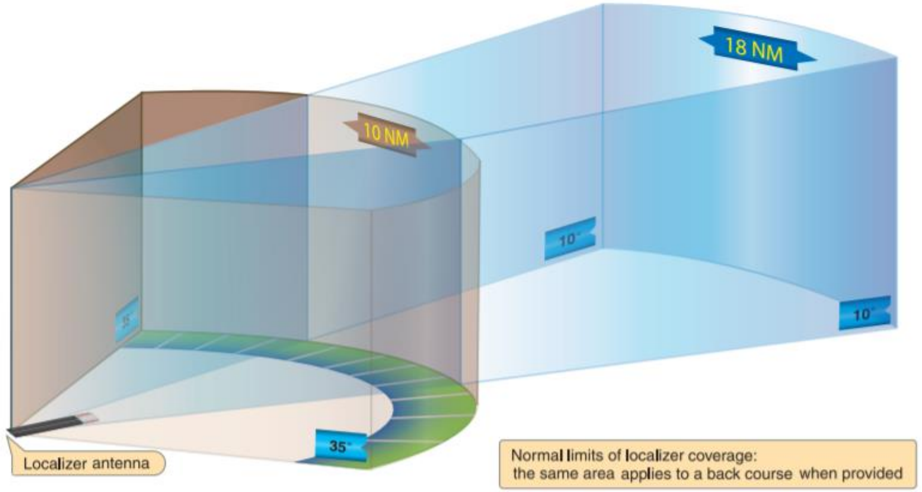
Distance Measuring Equipment (DME)

- Function
  - Provides *slant range* distance from a station
  - Timed RF pulses between aircraft & ground equipment are converted to nautical miles
- Ground Equipment
  - VOR/DME, VORTAC, ILS/DME & LOC/DME
- Aircraft Equipment
  - DME Antenna & Receiver
  - Pilot Controls (on/off, frequency, modes, altitude)
- Errors
  - DME signals are line-of-sight
  - Slant range distance: Straight line distance from the aircraft to the ground facility
    - Error is smallest at low altitudes and long range
    - Negligible if 1 mile (or more) away for each 1,000’ above the facility

Instrument Landing System (ILS)

- What is it?
    - Electronic system providing horizontal & vertical guidance to a runway
- Types
    - Cat I: Descent no lower than 200’ AGL
    - Cat II: Descent no lower than 100’ AGL
    - Cat III: No decision height minimums
    - Cat II & III require special certification and equipment

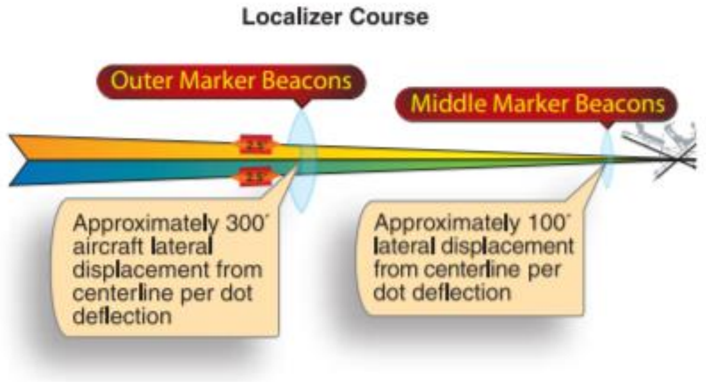


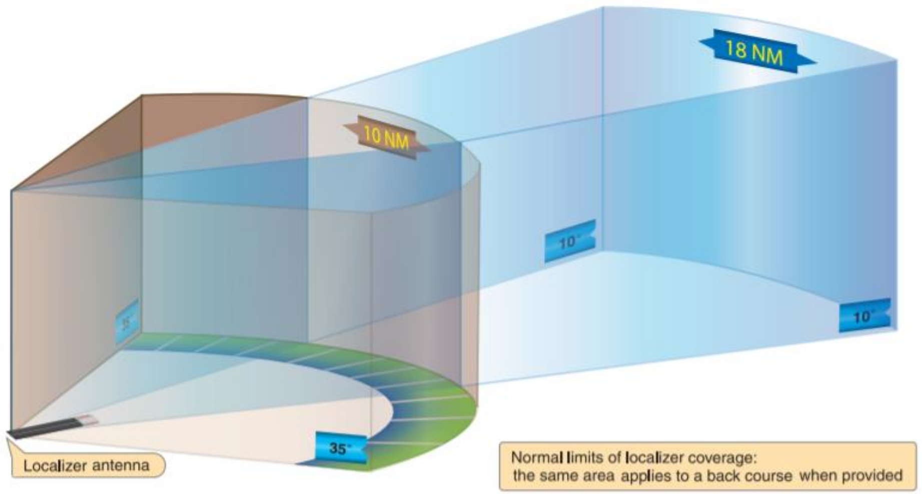


Source (both): Instrument Flying Handbook, FAA

ILS Ground Components

- Localizer: Horizontal guidance
  - Projects a front and back course
  - Narrow course – 5 degrees
  - Projects 18 NM & 4,500’ above the antenna
  - 108.1 – 111.95 MHz
- Glideslope: Vertical guidance
  - Generally, a 3-degree glidepath
  - Only projects a front course
  - 1.4 degrees thick
  - Tied to localizer frequency

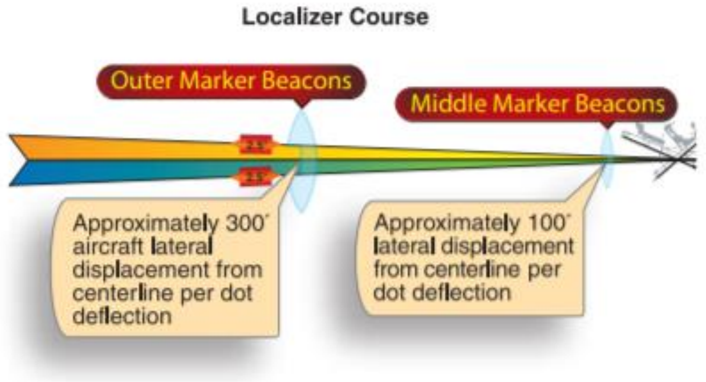


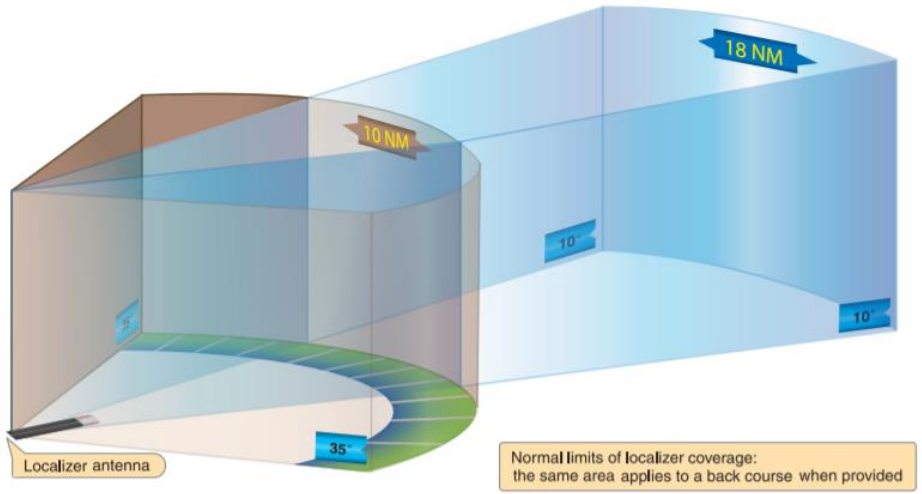


Source (both): Instrument Flying Handbook, FAA

ILS Ground Components

- Marker Beacons: Range information
  - Outer (OM): 4-7 NM out / Glideslope intercept
  - Middle (MM): 3,500’ out / 200’ above threshold
  - Inner (IM): Decision height on a Cat II approach
  - Compass Locator: Collocated with OM / MM

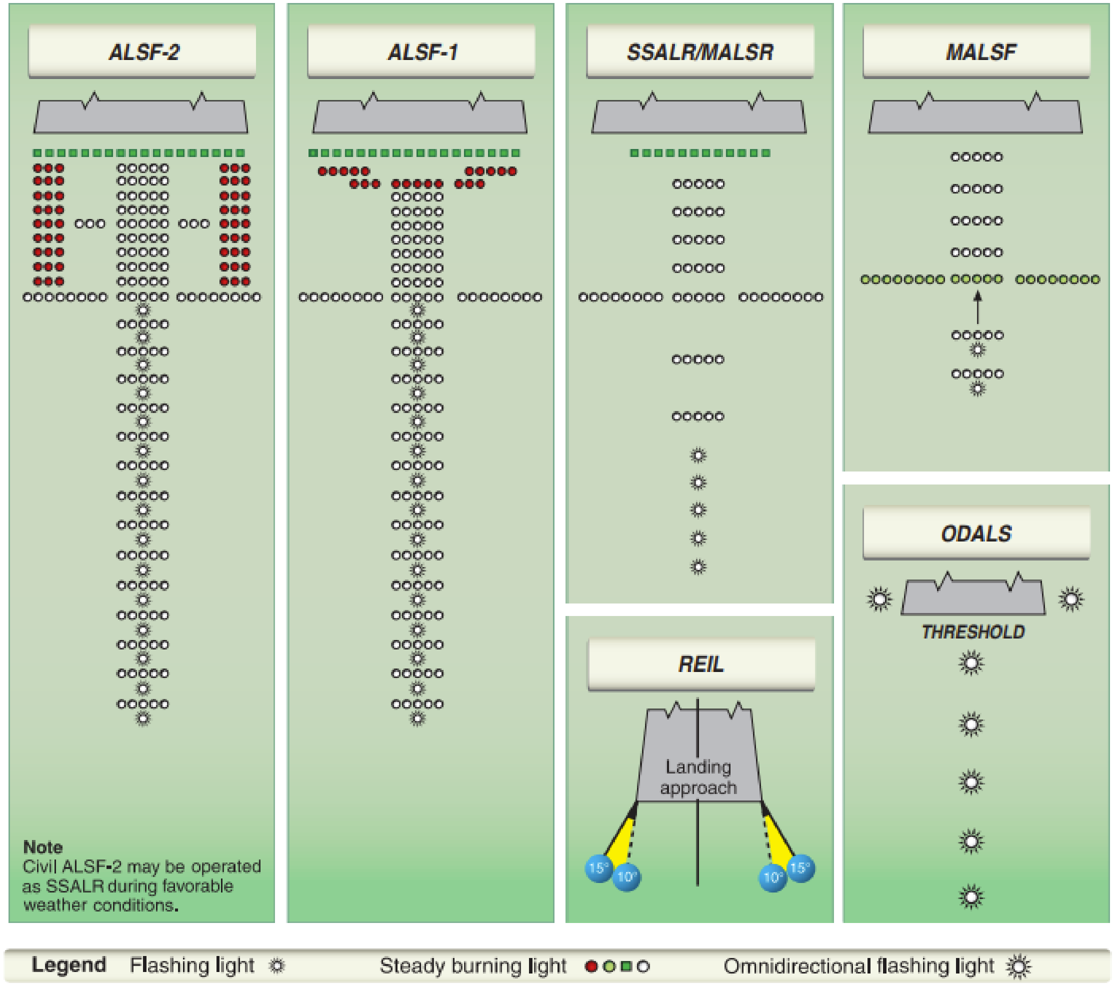




Source (both): Instrument Flying Handbook, FAA

ILS Ground Components

- Approach Lights
  - Transition from instrument to visual flight
  - Visual identification of the ALS must be instantaneous
- Types of Approach Lights
  - ALSF – Approach light system with sequenced flashing lights
  - SSALR – Simplified short approach light system with runway alignment indicator lights
  - MALSR – Medium intensity approach light system with runway alignment indicator lights
  - REIL – Runway end identification lights
  - MALSF – Medium intensity approach light system with sequenced flashing lights (and runway alignment)
  - ODALS – Omnidirectional approach light system



Source: Instrument Flying Handbook, FAA

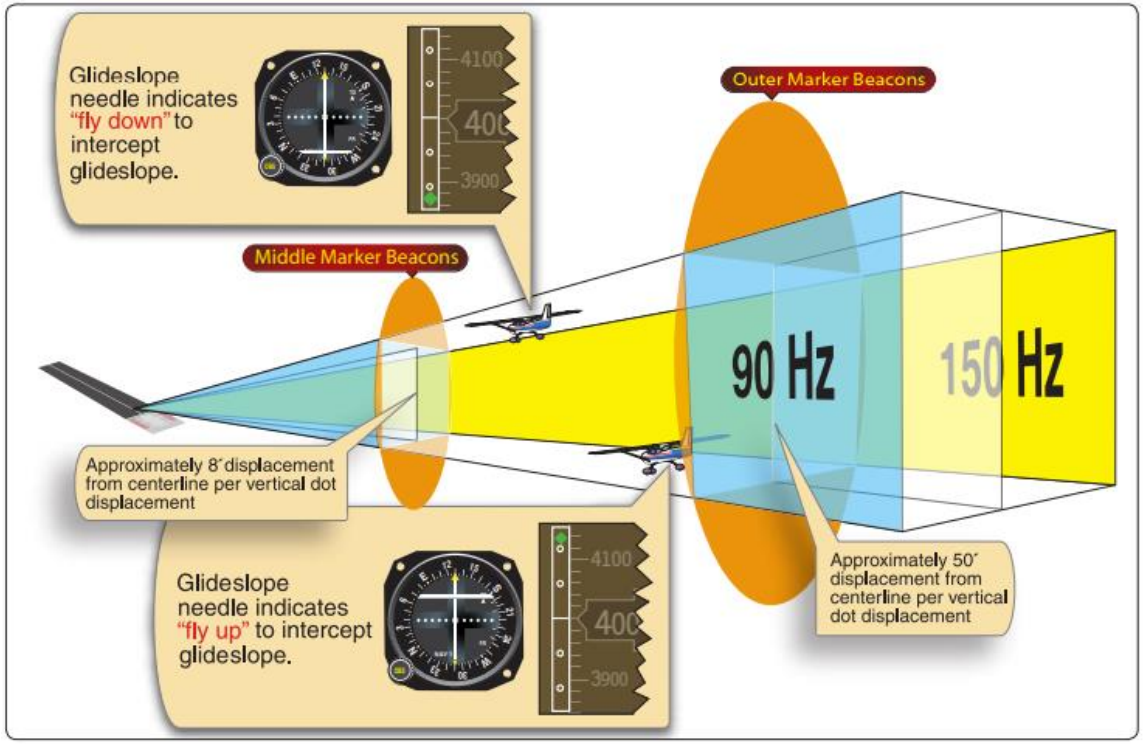
ILS Airborne Components: LOC

Source: Instrument Flying Handbook, FAA

- Receiver
  - Same as a VOR receiver
- Navigation
  - Navigation: Functions the same as a VOR, but more sensitive
  - Rotating the OBS has no effect
  - Directional Indications when inbound on the front course / outbound on the back course
  - Opposite indications when outbound on the front course / inbound on the back course
- Flying
  - Center the LOC, fly the inbound course
  - Apply drift corrections as the course moves off center

ILS Airborne Components: Glideslope (GS)

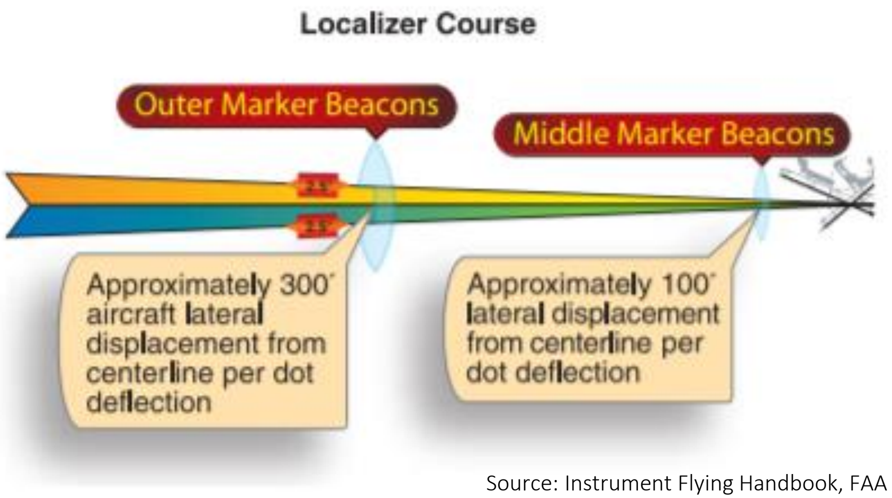
- Receiver
  - Auto tuned with the localizer frequency
- Navigation
  - Horizontal needle on vertical, five-dot deflection indicates position
  - Needle represents the glideslope
  - On Glidepath: Needle centered
  - Above Glidepath: Needle is below center
  - Below Glidepath: Needle is above center
- Flying
  - Set pitch & power as GS is intercepted
  - Small pitch adjustments to keep centered
  - Divide attention



Source: Instrument Flying Handbook, FAA

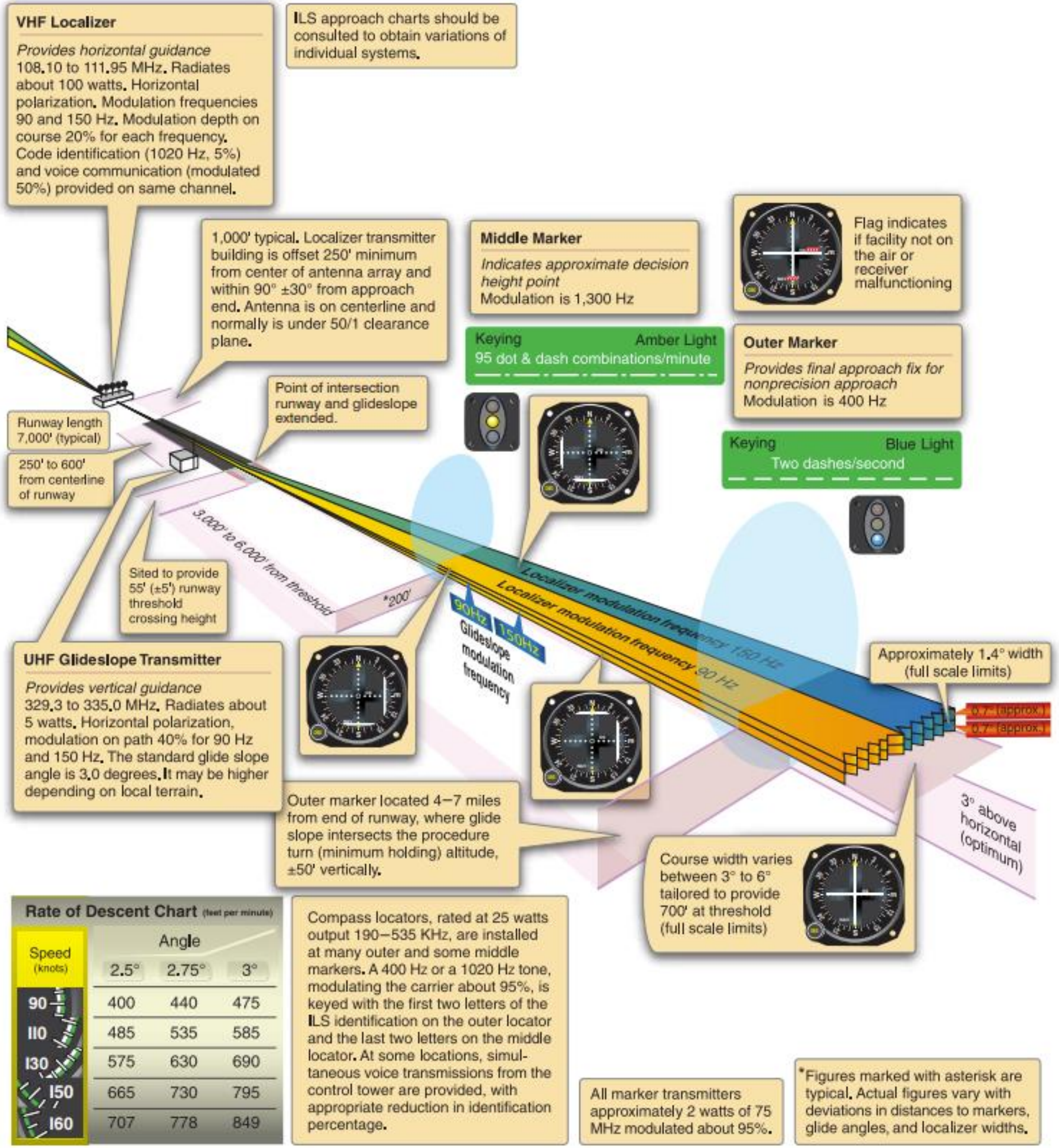
ILS Airborne Components

- Marker Beacons
  - OM: Low pitch, Continuous dashes, Purple/blue
  - MM: Intermediate tone, Dots/dashes, Amber
  - IM: High pitch, Continuous dots, White
  - BCM: High pitch, Two dots, White
- DME
  - Used on some approaches for waypoints/location
- Compass Locators
  - Transition from enroute NAVAIDS to ILS system
- DME collocated with Glide Slope Transmitter
  - Provides distance to touchdown information



Source: Instrument Flying Handbook, FAA

ILS Airborne Components

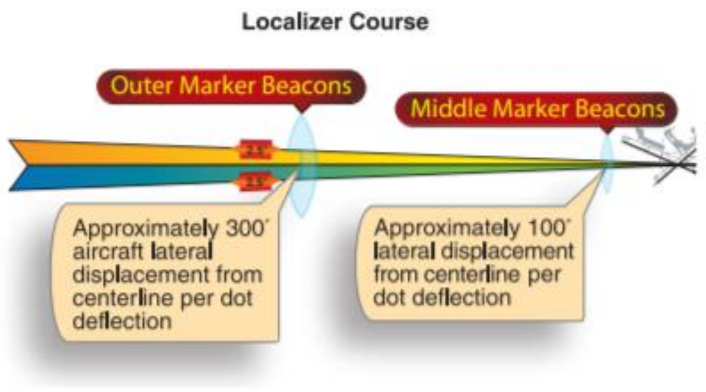


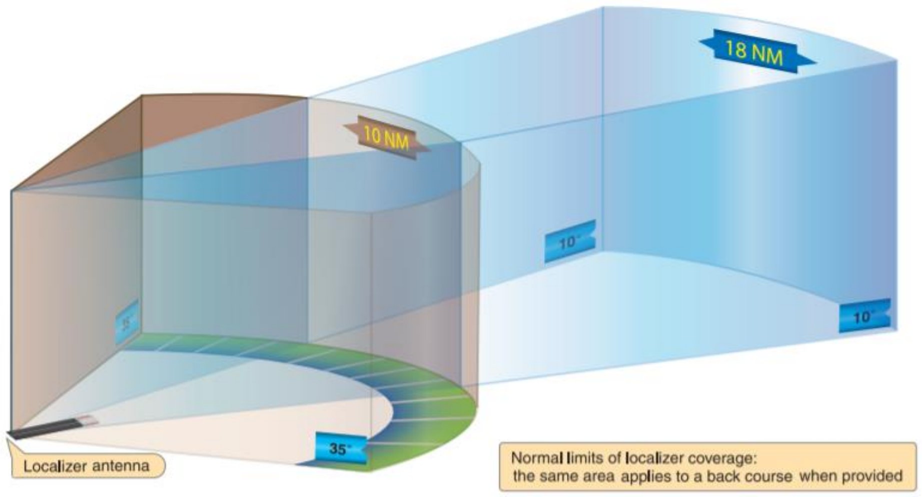
Speed (knots)	Angle 2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Source: Instrument Flying Handbook, FAA

ILS Errors

- Reflection
  - Surface vehicles & aircraft below 5,000’ AGL may disturb the signal
- False Courses
  - GS facilities inherently produce additional courses at higher vertical angles
  - Lowest occurs at 9-12^{o}
  - Could lead to confusion and very high descent rates
  - Fly the altitudes shown on the approach chart





Source (both): Instrument Flying Handbook, FAA

ADF & NDB

- Nondirectional Radio Beacon (NDB)
  - Ground-based radio transmitter that transmits radio energy in all directions
- Automatic Direction Finder (ADF)
  - Needle points to the NDB ground station to determine relative bearing
- Magnetic Heading + Relative Bearing = Magnetic Bearing
  - Mary Had Roast Beef, Mary Barfed (MH + RB = MB)
- Ground (NDB) Components
  - NDB ground station
- Airborne (ADF) Components
  - 2 antennas
  - Receiver
  - Indicator instrument

Source: Instrument Flying Handbook, FAA

ADF Indicator Instruments

- Fixed Card ADF
  - Always indicates 0 at the top
  - Needle indicates RB to the station
  - Pilot must determine MB
- Movable Card ADF
  - Pilot can rotate MH to the top of the instrument
  - Head of the needle indicates MB to the station
  - Less work for the pilot
- Radio Magnetic Indicator (RMI)
  - Automatically rotates to display aircraft heading (flux valve)
  - Can have two needles – ADF / VOR
  - ADF: Head indicates MB to station / Tail indicates MB from station
  - VOR: Indicates radial relative to the station

Source: Instrument Flying Handbook, FAA

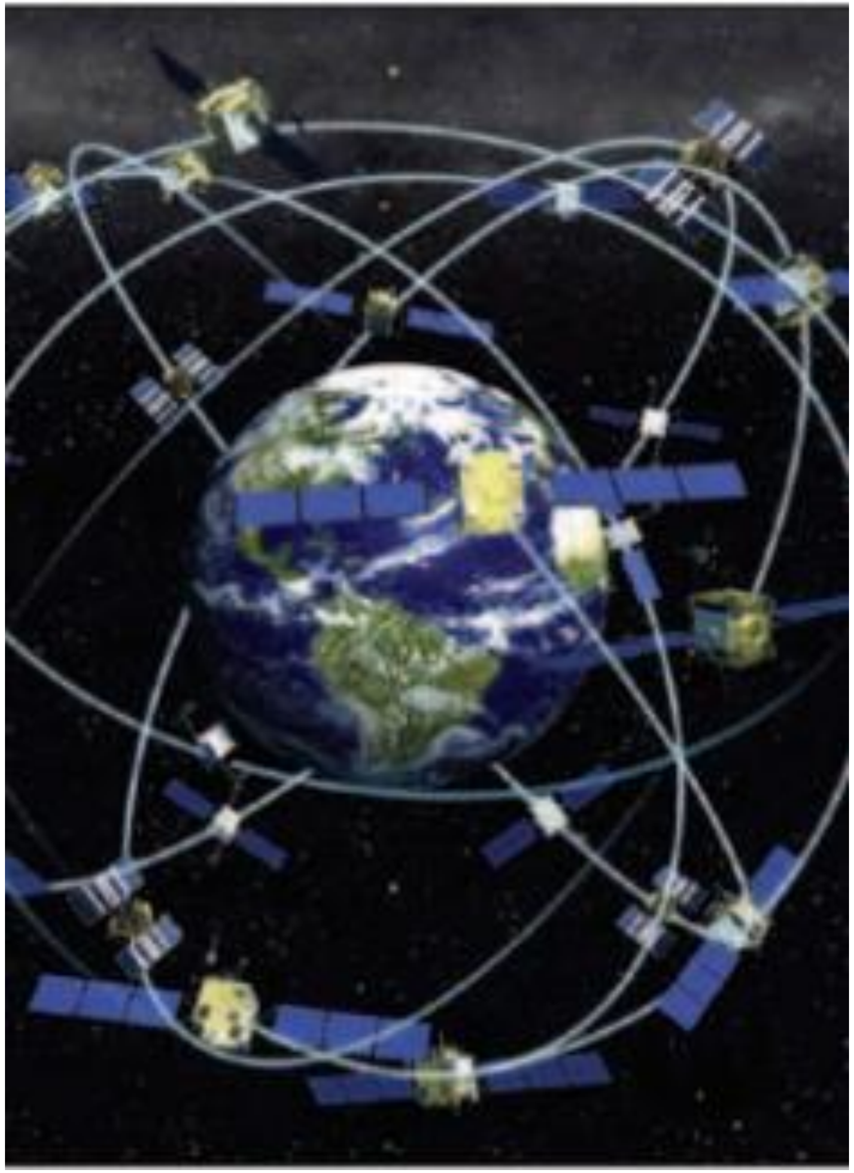
NDB & ADF Basics

- Fixed Card ADF
  - Visualize the ADF dial in terms of the longitudinal axis
  - Relate RB to MH to determine MB
- Movable Card ADF
  - Rotate aircraft heading to the top of the instrument
  - Turn toward the head of the needle
  - Reset aircraft heading after each turn
- Radio Magnetic Indicator (RMI)
  - Turn toward the head of the needle
- Station Passage
  - Approaching the station, the needle becomes more sensitive
  - Abeam when needle points 90^{o} off your track
  - Passage time interval varies with altitude

Source: Instrument Flying Handbook, FAA

Global Positioning System (GPS)

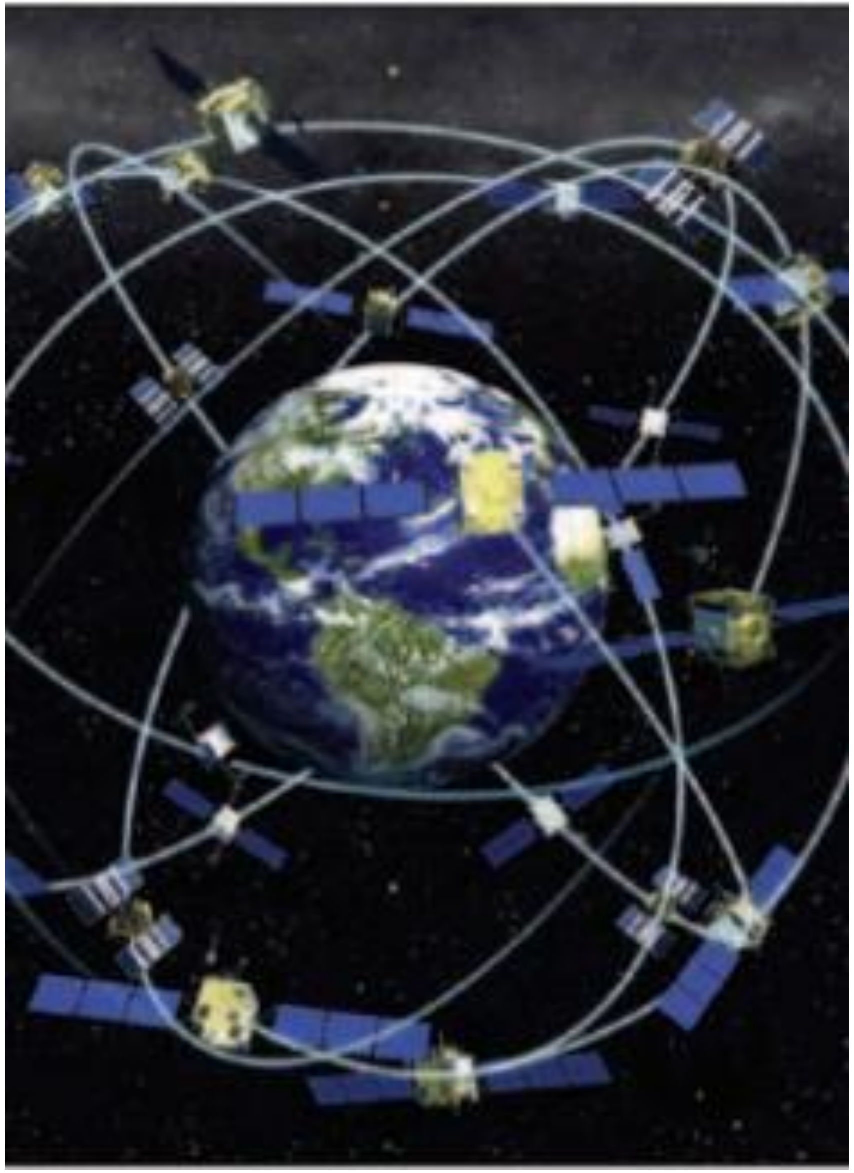
- Space Segment
  - 24 satellite constellation 11,000 NM above earth
  - 5 satellites in view at any time (12-hour orbits)
  - Transmit a unique code to GPS receivers
  - UHF – unaffected by weather but subject to line-of-sight
- Control Segment
  - Master control station
  - 5 monitoring stations
  - 3 ground antennas
- User Segment
  - All components associated with the GPS receiver
  - Receiver utilizes satellite signal/code to provide position, velocity, and precise timing to the users



Source: Instrument Flying Handbook, FAA

Global Positioning System (GPS)

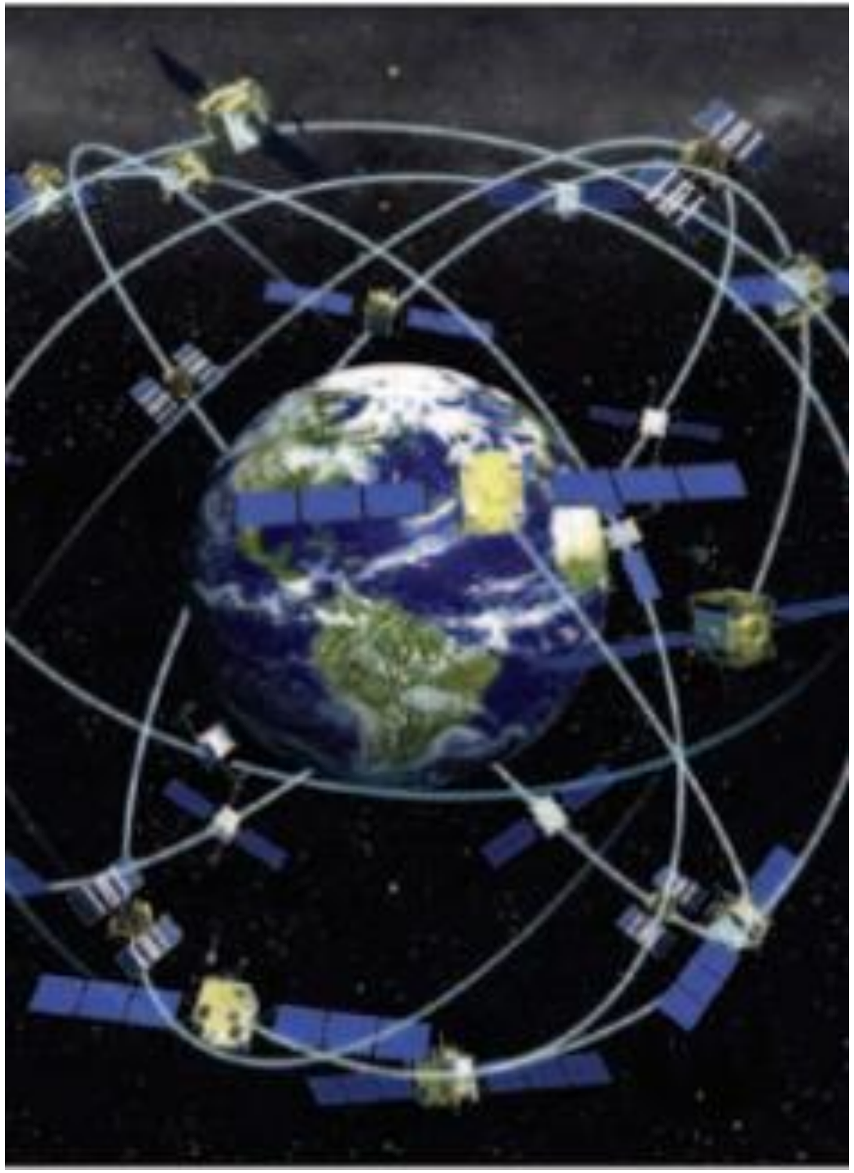
- Solving for Location
  - Receiver uses 4 best positioned satellites for a 3-D fix
  - Satellites broadcast course/acquisition (CA) code
  - Receiver uses CA code to compute satellite distance
  - Receiver triangulates position using several satellite's signals
- Navigating
  - As simple as selecting a destination & tracking the course
    - Can add SIDs, routes/airways, STARs, approaches, holds, etc.
  - Course deviation is linear – no change in sensitivity



Source: Instrument Flying Handbook, FAA

GPS RAIM

- Receiver's ability to verify satellite signal integrity
- Requires minimum of 5 satellites
  - Or 4 and a barometric altimeter
- 2 Types of RAIM messages
  - Not enough satellites in view
  - Potential error exceeds limits for the phase of flight
- Alternate Means of Navigation
  - Un-augmented GPS equipment must be equipped with an alternate means of navigation
  - No need to monitor alternate equipment if using RAIM
  - Active monitoring of the nav equipment is required if RAIM fails

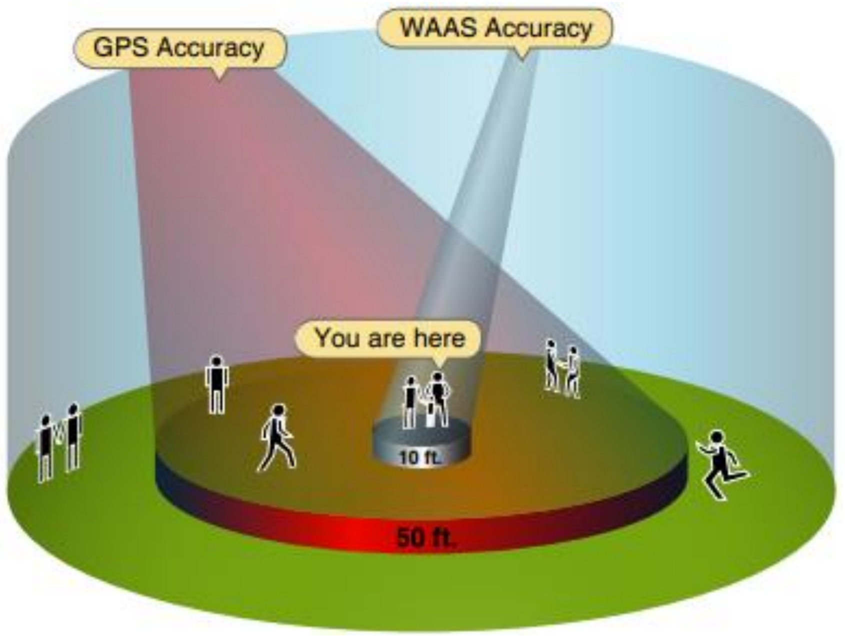


Source: Instrument Flying Handbook, FAA

GPS Substitution

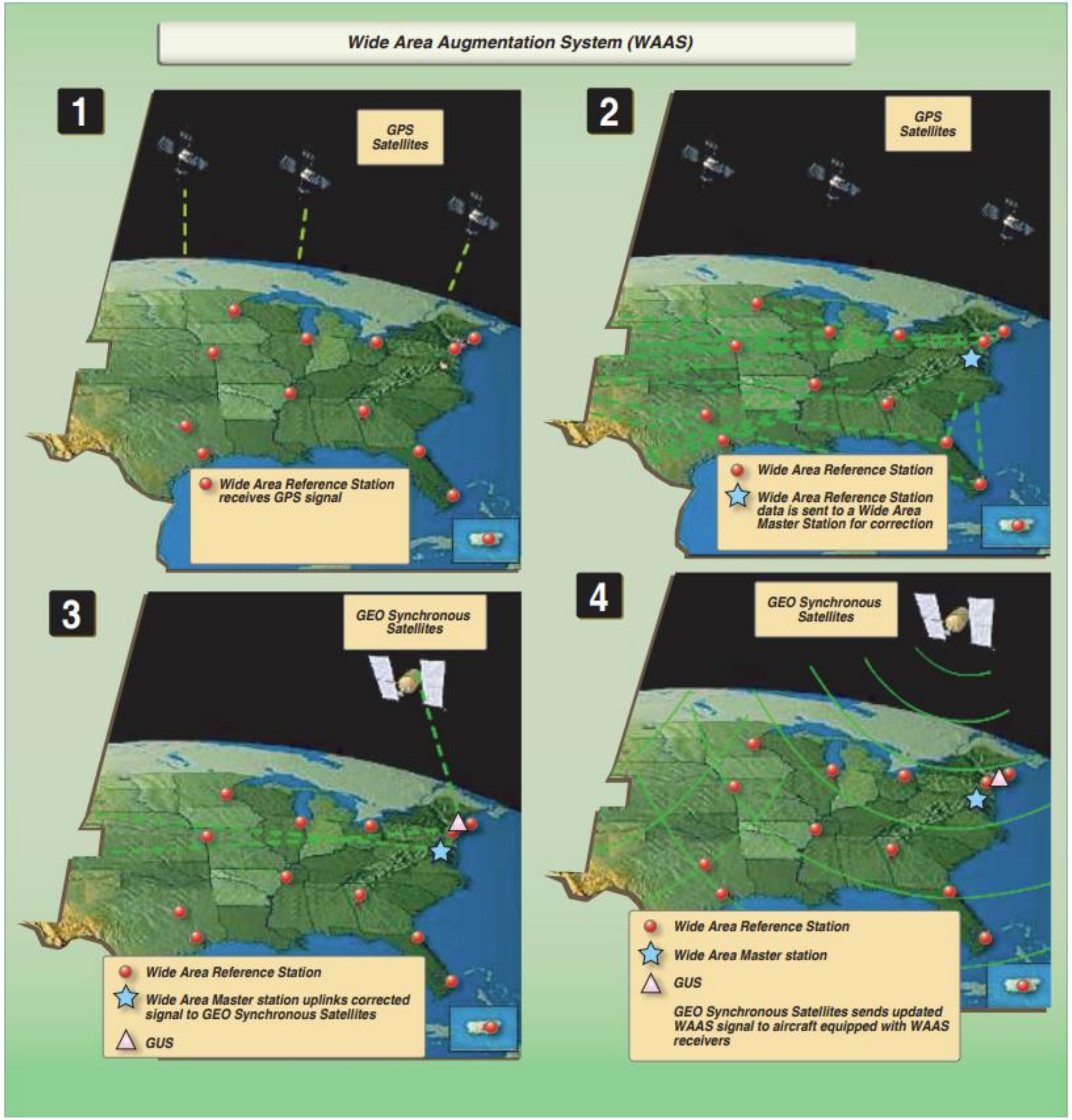
- May be used as a substitute for ADF & DME for following operations:
  - Determining position over a DME fix
  - Flying a DME arc
  - Navigation to/from an NDB or Compass Locator
  - Determining position over an NDB or Compass Locator
  - Determining position over a fix defined by an NDB or Compass Locator bearing crossing a VOR/LOC course
  - Holding over an NDB / Compass Locator

Wide Area Augmentation System (WAAS)

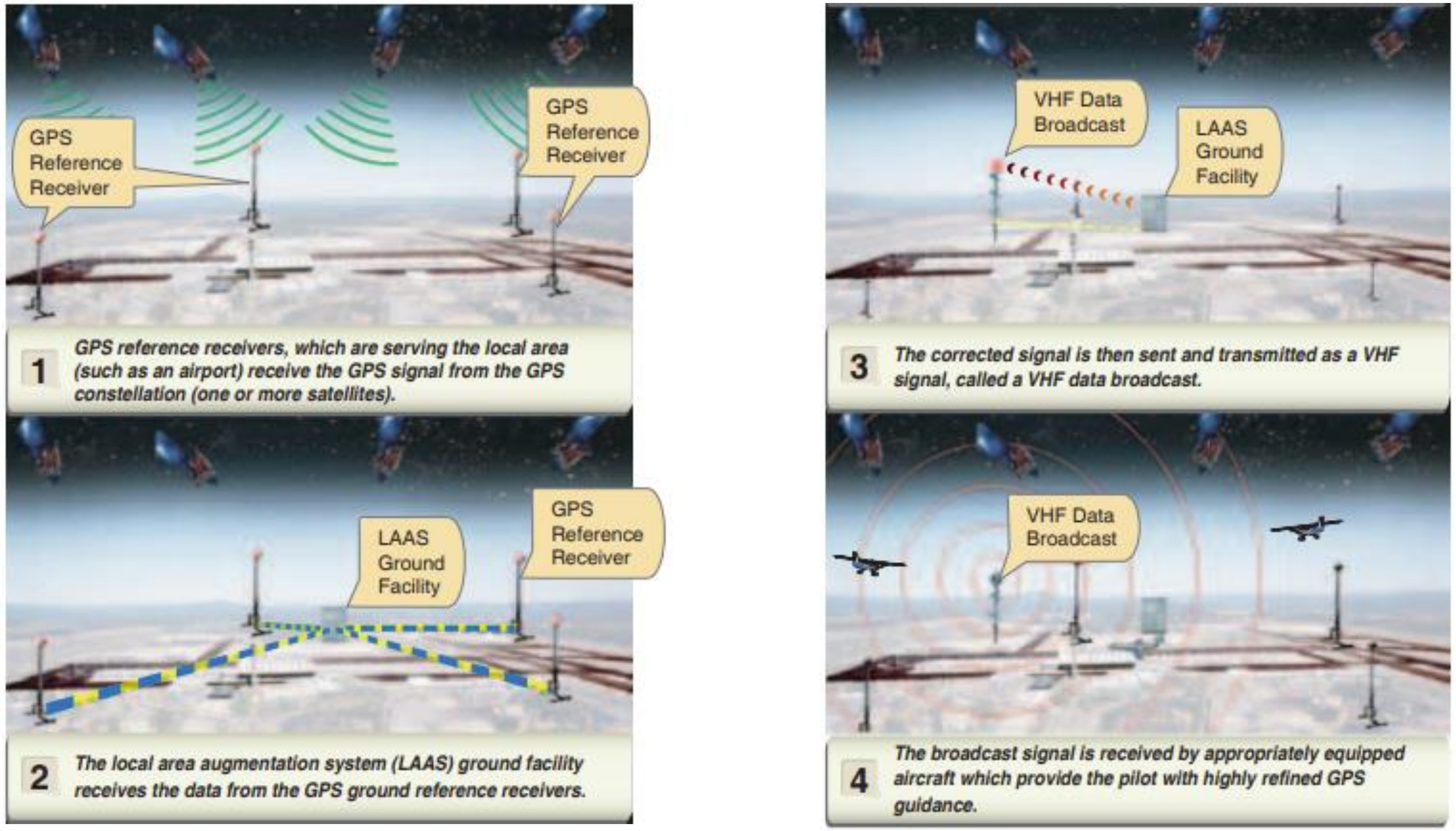


- Improves accuracy, integrity and availability of GPS signals
  - Real-time satellite monitoring
  - Ground stations measure and correct variations in signals
- Capabilities
  - Navigation system from takeoff through Cat I approaches
  - Electronic glidepath independent of ground equipment or barometric aiding
  - Approaches without the cost of installing a ground station
  - Eliminates cold temperature effects, incorrect altimeter settings or lack of an altimeter source
- Approach with Vertical Guidance
  - WAAS generated glidepath similar to an ILS

Wide Area Augmentation System (WAAS)



Source: Instrument Flying Handbook, FAA

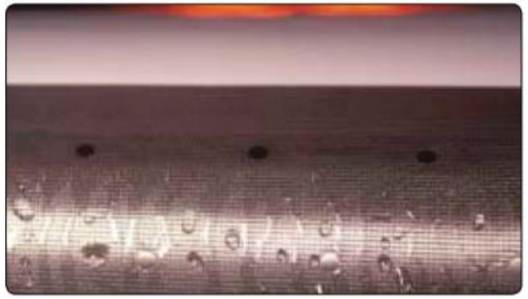


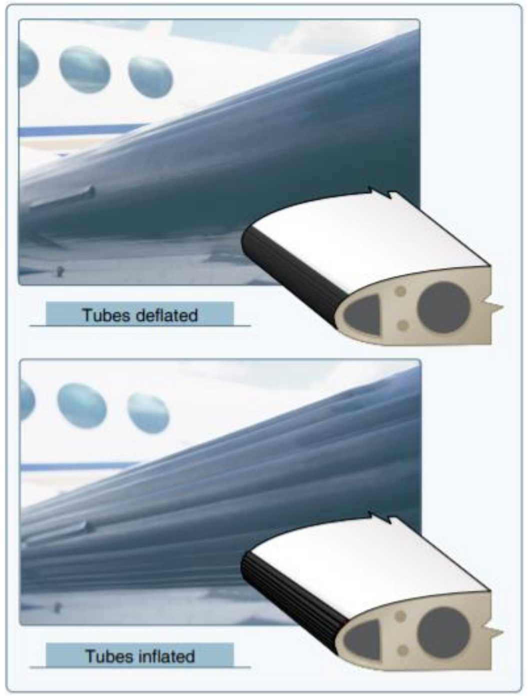
Local Area Augmentation System (LAAS)

- WAAS with more ground augmentation
- Real-time correction of GPS signal
  - Receivers around the airport send data to a central location
  - Correction message is transmitted to users
  - Corrects GPS signals providing CAT I level and above

Anti-Ice / Deice

- Weeping Wing
  - Anti-ice mixture is excreted through tiny holes in the wing
- Heated Surfaces
  - Jet aircraft use hot engine bleed air to prevent ice build-up
- Boots
  - Bleed air is used to inflate leading edge “boots” to remove ice
- Pitot Heat
  - Electrically heated pitot mast to prevent icing
- Windshield Defrost
  - Heat ducted to the windshield to remove light icing
- Big Picture
  - Avoid icing. If in icing, leave as soon as possible





Questions?