Area of Operation **II** - Task **A**

Aircraft Flight Instruments & Navigation Equipment

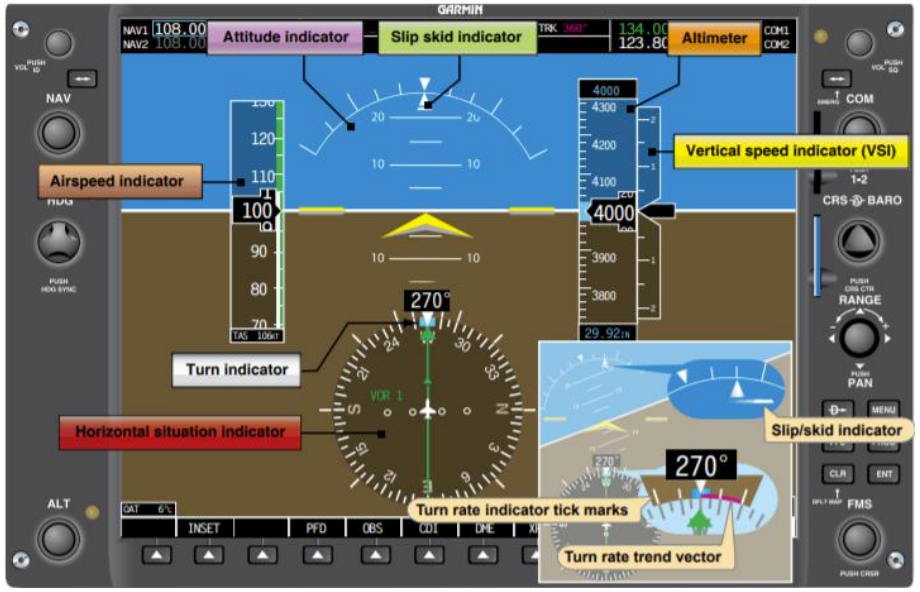
Key References:
- Instrument Flying Handbook
- AIM

Content

1. Introduction

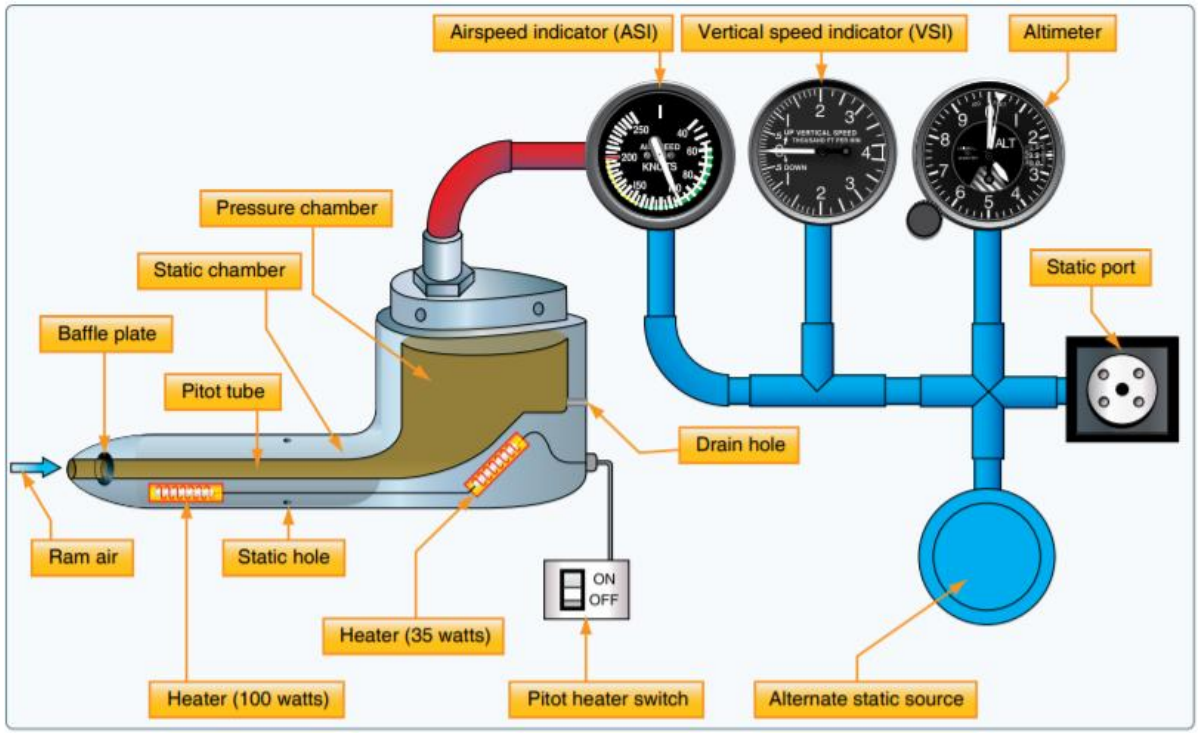
- **What**: Learn about the aircraft's equipment used on Instrument Flying and navigation systems
- **Why**: Instrument Flying relies on aircraft's equipment and navigation systems, and knowing how they work, as well as their limitations, is critical for safe flying.

- **Instruments**
  - Airspeed, Attitude, Altimeter, Turn Coordinator (+ Turn Rate), HSI/HDG, Vertical Speed Indicator (VSI)
- **Navigation Types**
  - Ground based: VOR, DME, NDB
  - Satellite based: GNSS (GPS)



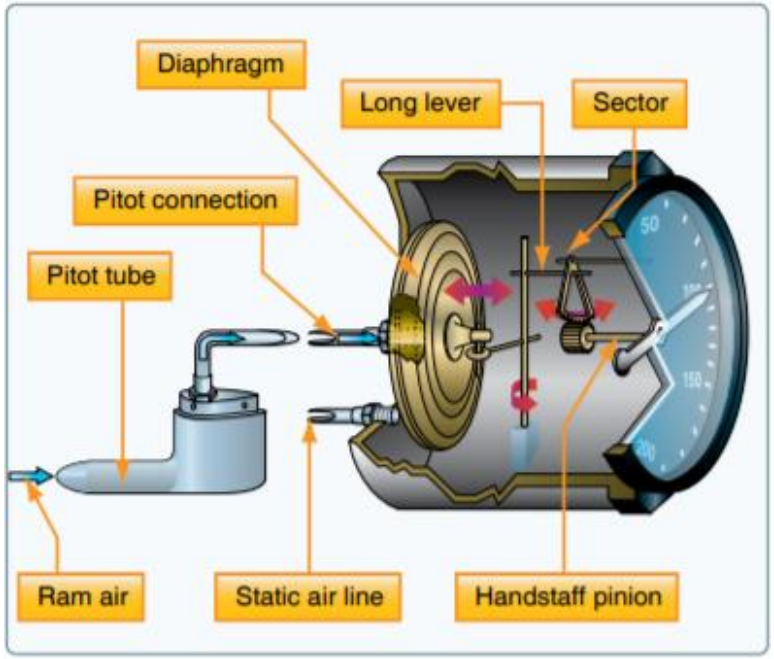
2. Instruments | Pitot-Static

- **Airspeed Indicator, Altimeter and VSI (Vertical Speed Indicator)**
- **How it Works**
  - Altitude calculated by expansion/contraction of an aneroid (Static Port) *// Not Corrected for non-standard temperature*
  - VSI calculated by the flow of a "calibrated leak" between the VSI casing and the Static source
  - Airspeed calculated by pressure differential (diaphragm) between the Pitot and Static port *// Not true airspeed*
  - *G1000 does not use diaphragm/aneroid wafers, all is handled by the ADC (solid state components)*
- **Potential Problems**
  - Subject to position errors (air flow)
  - Pitot blockage: act as altimeter (increases w/ altitude), or goes slowly to zero if drain hole is open
    Action ➔ Pitot heat on
  - Static port blockage: altitude remains unchanged, Airspeed shows increasing as the airplane descends (pilot will tend to pull back, reduce power ☠). VSI zero.
    Action ➔ Alternate static (altitude will read higher)



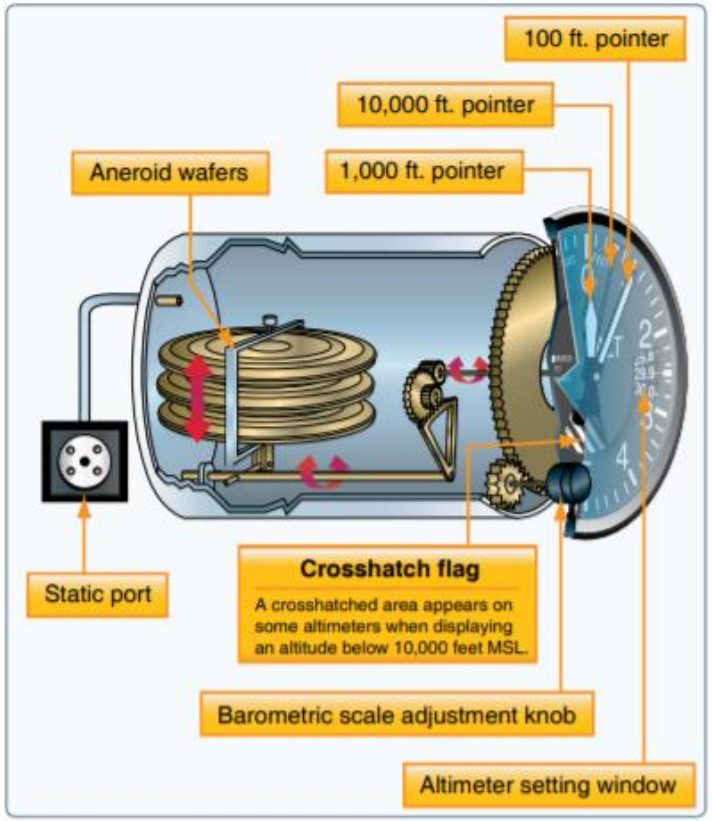
2. Instruments | Pitot-Static

Airspeed Indicator



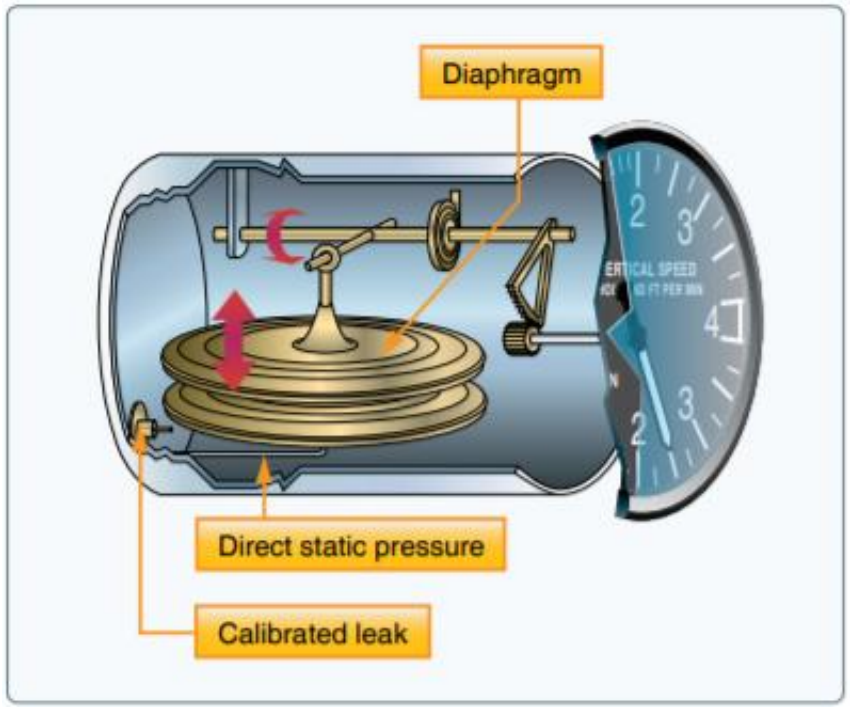
Limitations
- Blockages
- Does not calculate True airspeed
  (True Airspeed = 2% IAS for each 1,000ft MSL)

Altitude Indicator



Limitations
- Does not correct for non-standard temperature
- Requires reference pressure on the Kollsman Window
- **Alternate Static reads higher altitude**

VSI

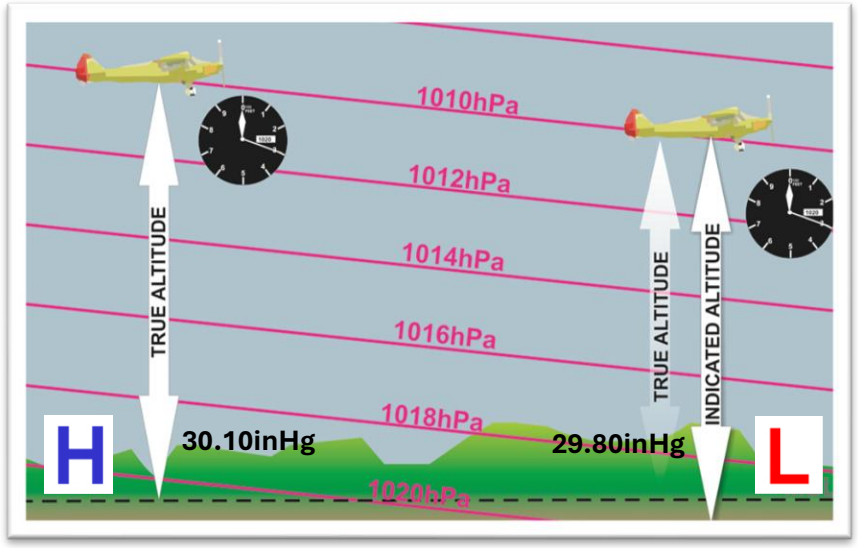


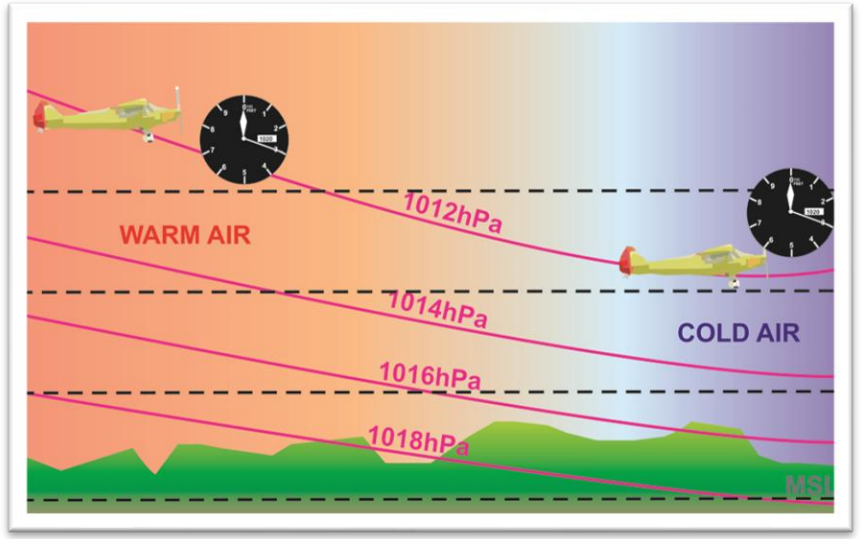
Limitations
- Lags more than the altimeter
- 6-9 second lag until stabilizes
- Jumps (then stabilizes back) when turning Alternate Static

2. Instruments | Pitot-Static

- **Effects on Altimeter**
  - When air is colder than standard ➔ the aircraft is at lower altitude than altimeter indicates
    - *Rule of thumb: Altitude = 4% lower for every 10°C below ISA at low altitudes*
  - When flying from higher to lower pressure area without adjusting the altimeter:
    - The aircraft will be at lower altitude than altimeter indicates
  - **High to Low** or **Hot to Cold ➔ Look out Below**
    - The higher you are, the higher the error will be (more air below you)

The altimeter is calibrated assuming standard atmosphere

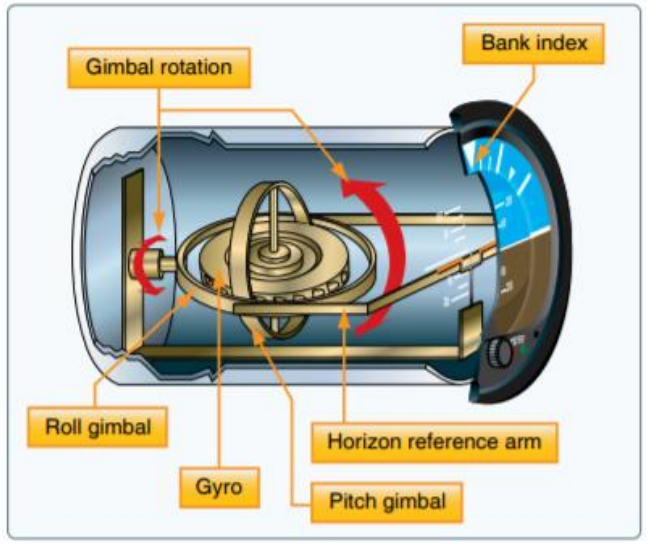




2. Instruments | Gyroscopic

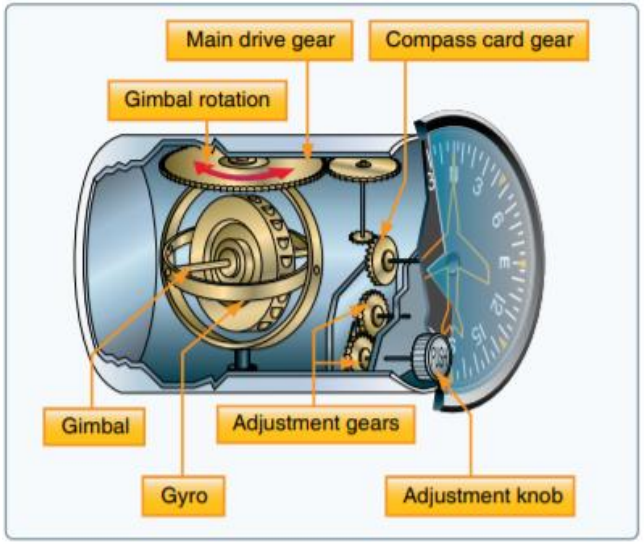
- **Attitude Indicator, Heading Indicator, Turn Coordinator**
- **How it Works:** *Spinning discs mounted in a way to take advantage of the Gyroscopic properties*
  - Power Sources: Electrical (turn coordinator) or Vacuum (attitude and heading indicators)
  - Rigidity in Space: Gyro remains in a fixed position in space (attitude and heading indicators)
  - Precession: Any applied force is felt 90º from that point in the direction of rotation (turn coordinator)

Attitude Indicator



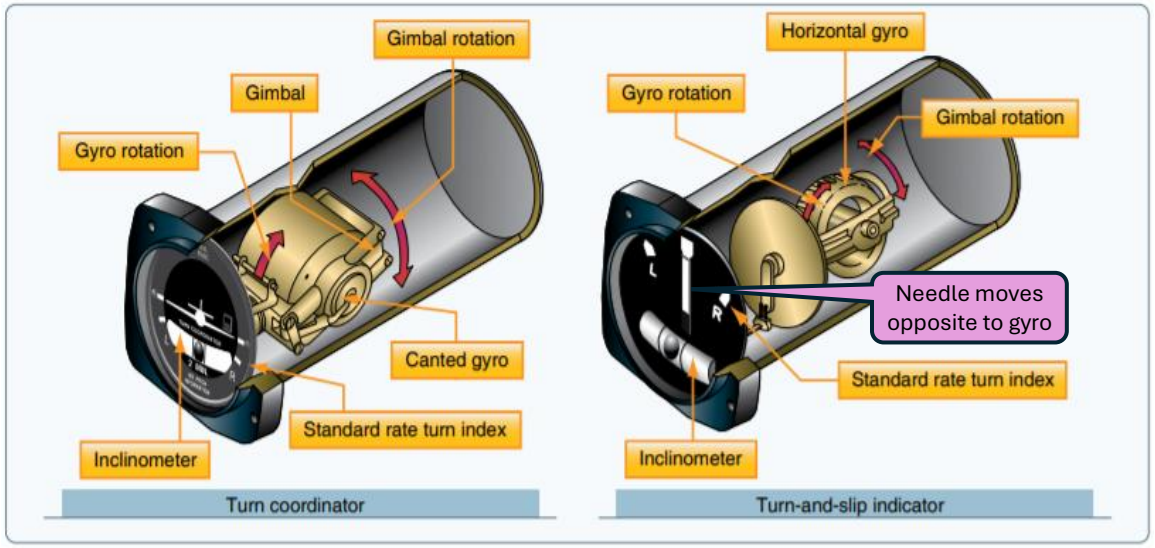
Errors
- Slight nose up during rapid acceleration (and vice versa)
- Possibility of a small bank and pitch error after a 180º turn
- Tumble when bank >100º or pitch >60º

Heading Indicator



Errors
- Precession results in heading drift (+Earth rotates at 15º per hour)
- Check and reset the heading indicator every 15 minutes

Turn Coordinator (or Turn-and-Slip Indicator, less common)



How does it work
- Yawing produces a force in the horizontal plane tilting the gyro left or right. Spring returns to neutral.
- Turn-and-Slip: Gyro is vertical (senses YAW), shows Rate/Direction of turn (does not show bank/roll)
- Turn Coordinator: Gyro is tilted 30º (senses YAW and ROLL). Shows initially "Rate of Roll" and then RoT

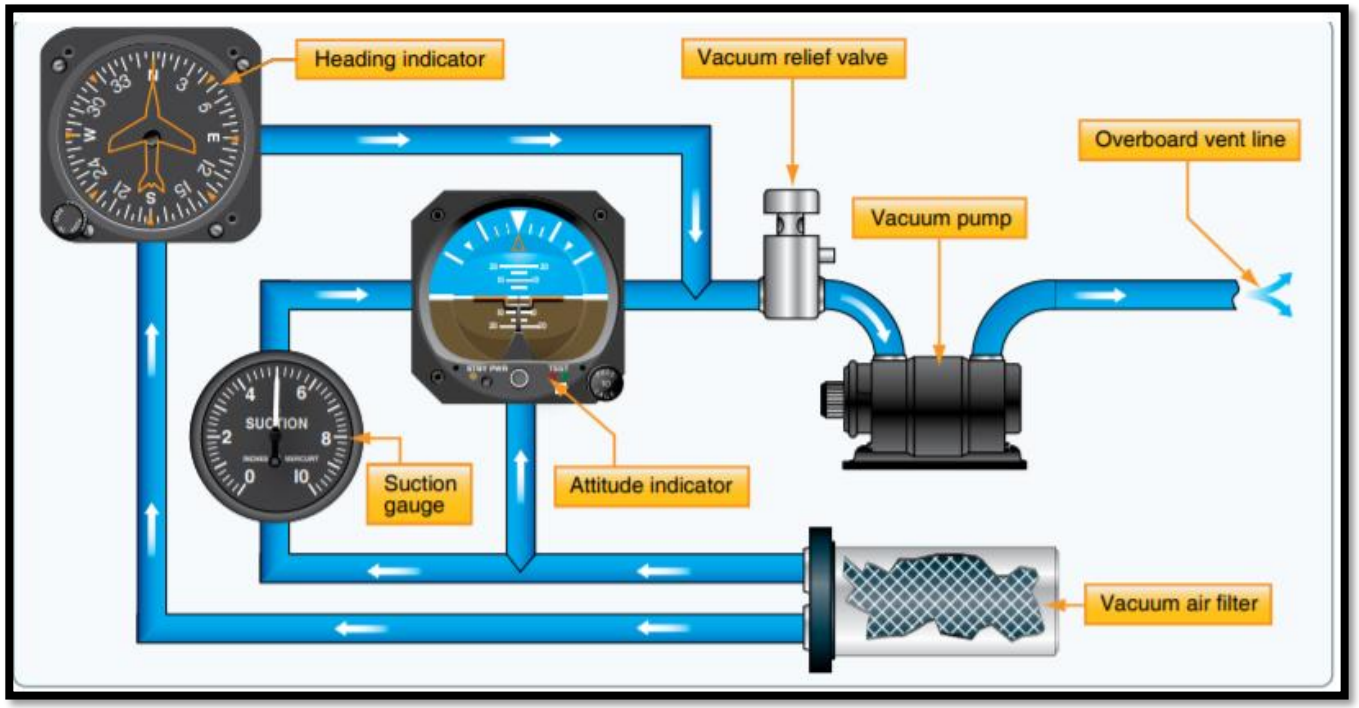
2. Instruments | Gyroscopic

Vacuum System (C172S G1000)

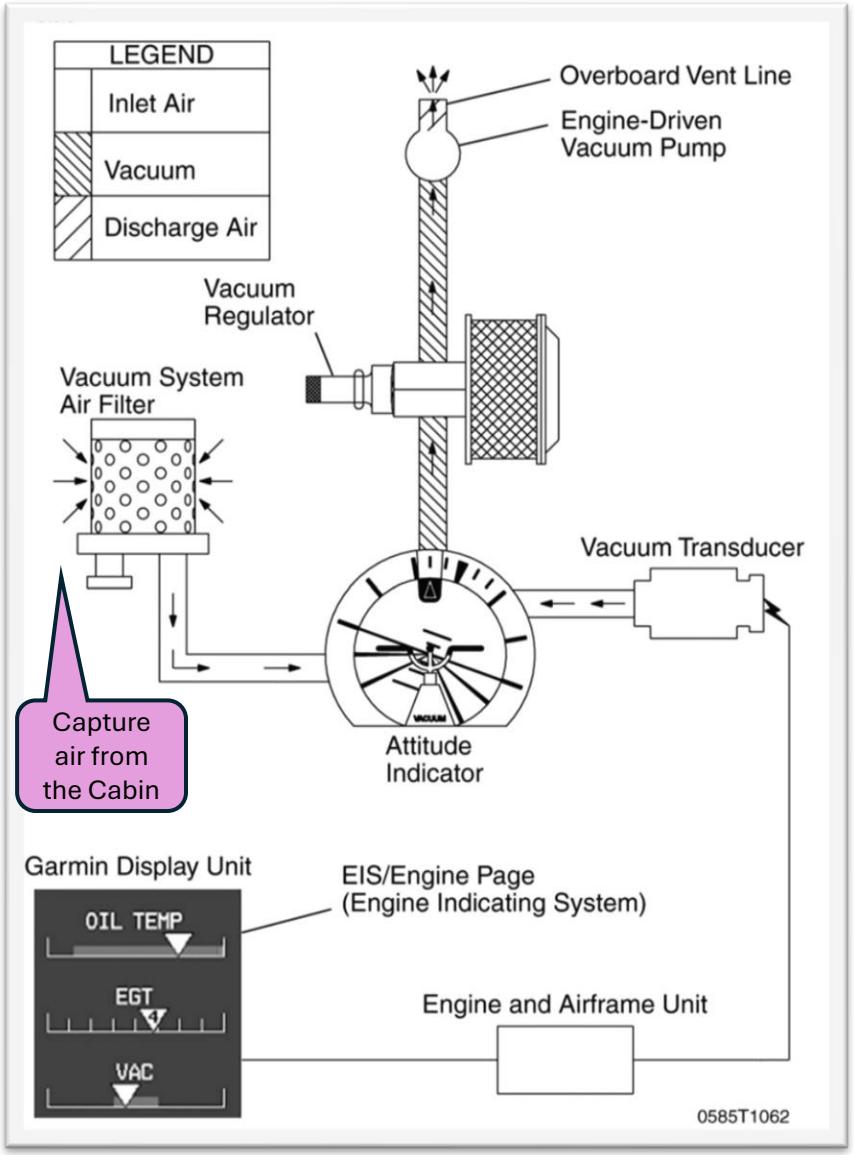
- 1 Air Filter, 1 Vacuum regulator
- 1 Engine-driven vacuum pump
- Standby Attitude Indicator
- Vacuum transducer ➔ "Green" pump pressure 4.5-5.5 inHg
  - LOW VACUUM annunciator goes off if below 3.5inHg

New C172S comes w/ GI-275 (standalone backup instrument w/ all the PFD functions). It has its own ADAHRS (ADC+AHRS) and 60min optional battery

Generic Vacuum System

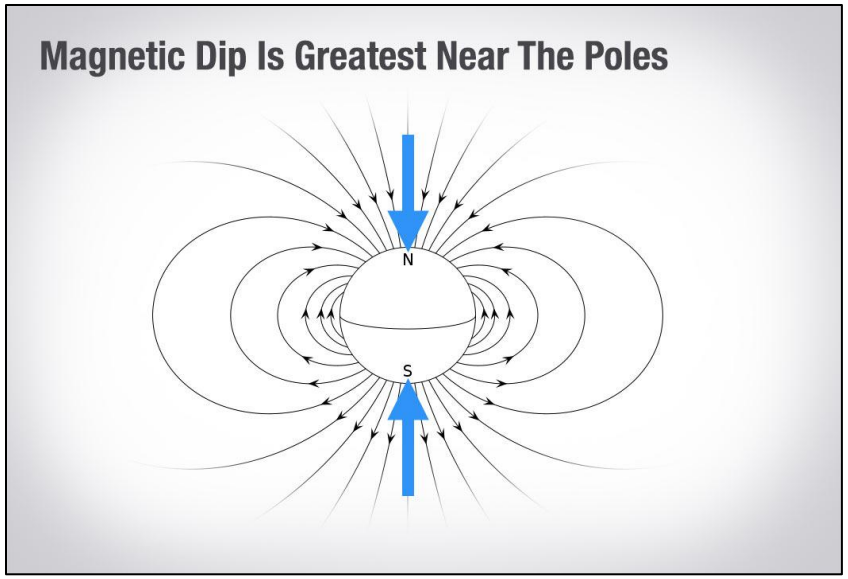


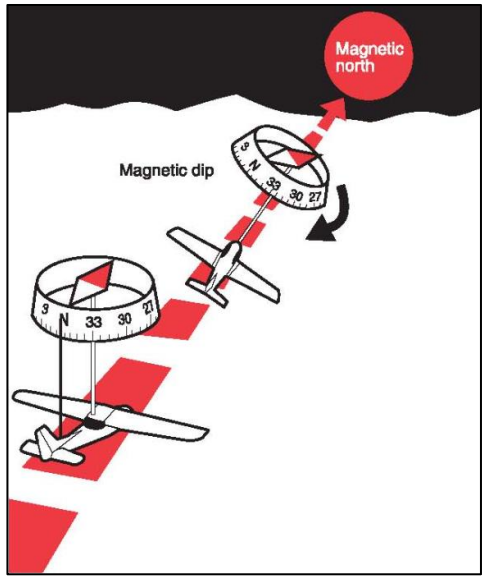
C172S Vacuum System (Backup Attitude Indicator)

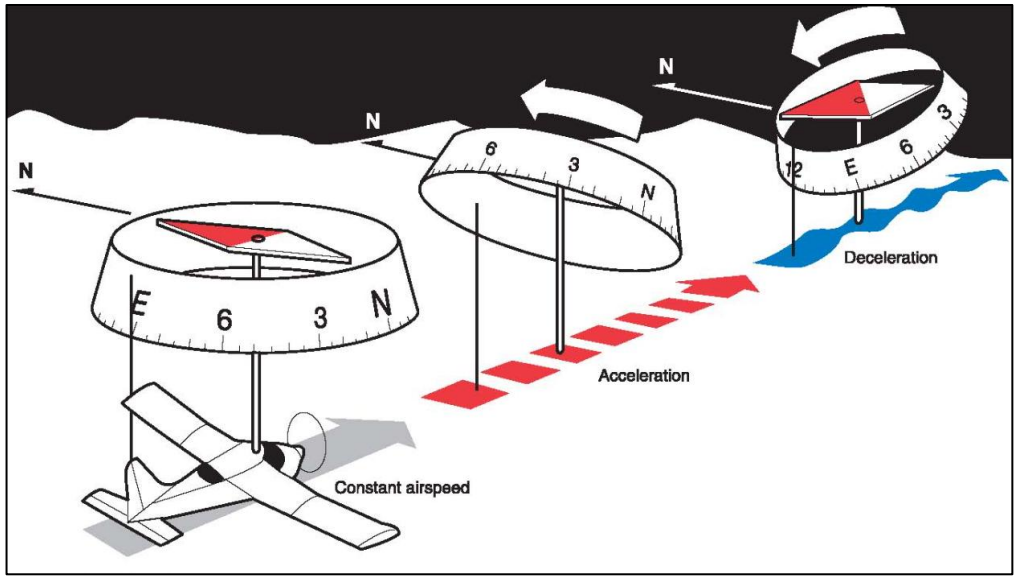


2. Instruments | Magnetic Compass

- **Compass Errors**
  - Variation: difference between magnetic north (compass) and true north
  - Deviation: interference w/ aircraft's equipment. Corrected by the compass card.
  - Magnetic dip: earth's magnetic flux is 3D, so the compass will try to dip to align
  - Turning: to the N (compass lags), to the S (it accelerates). UNOS → **15^0 + Half of the Latitude**
  - Acceleration: when flying on **E/W heading**, compass needle points towards the North when accelerating. ANDS
  - Oscillation: float assembly bouncing around
  - *NOTE: limitations – steep bank (>18^0) shows erratic readings*

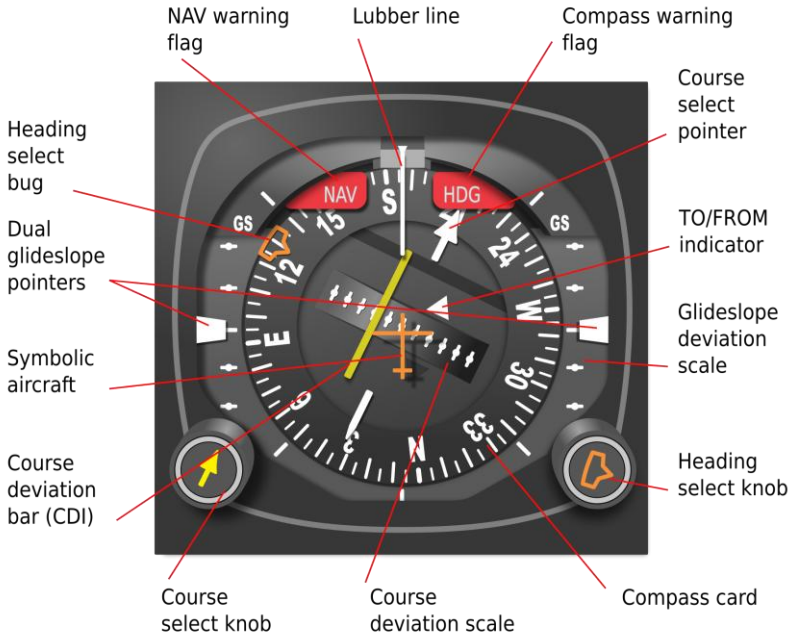






2. Instruments | RMI & HSI

- **RMI (Radio Magnetic Indicator)**
  - Bearing indicator (ADF, VOR, both) overlayed on a heading indicator
  - Heading (Compass Card) is automatically rotated by a Flux Valve (earth's magnetic field)



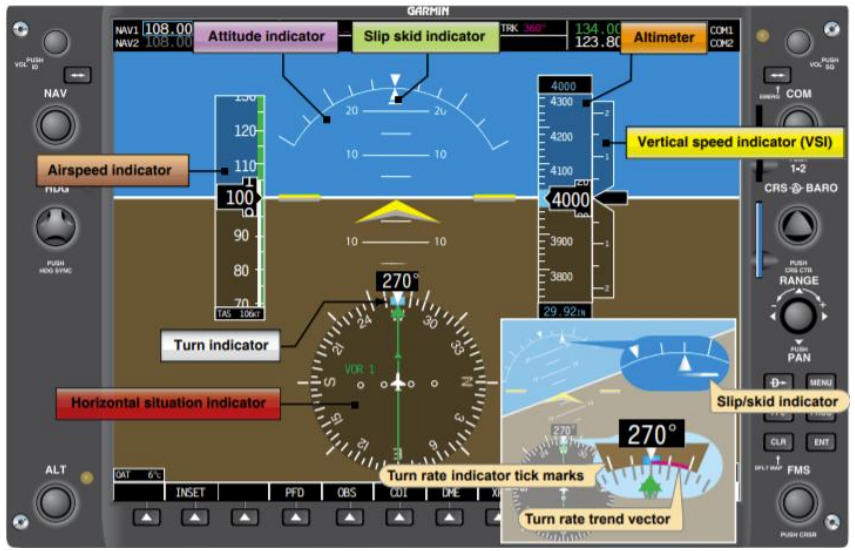
- **HSI (Horizontal Situational Indicator)**
  - Combines a heading indicator with a Navigation source (e.g. VOR, ILS, etc)
  - Compass card automatically aligns to magnetic north (flux valve)
  - Shows deviation from selected radial/bearing

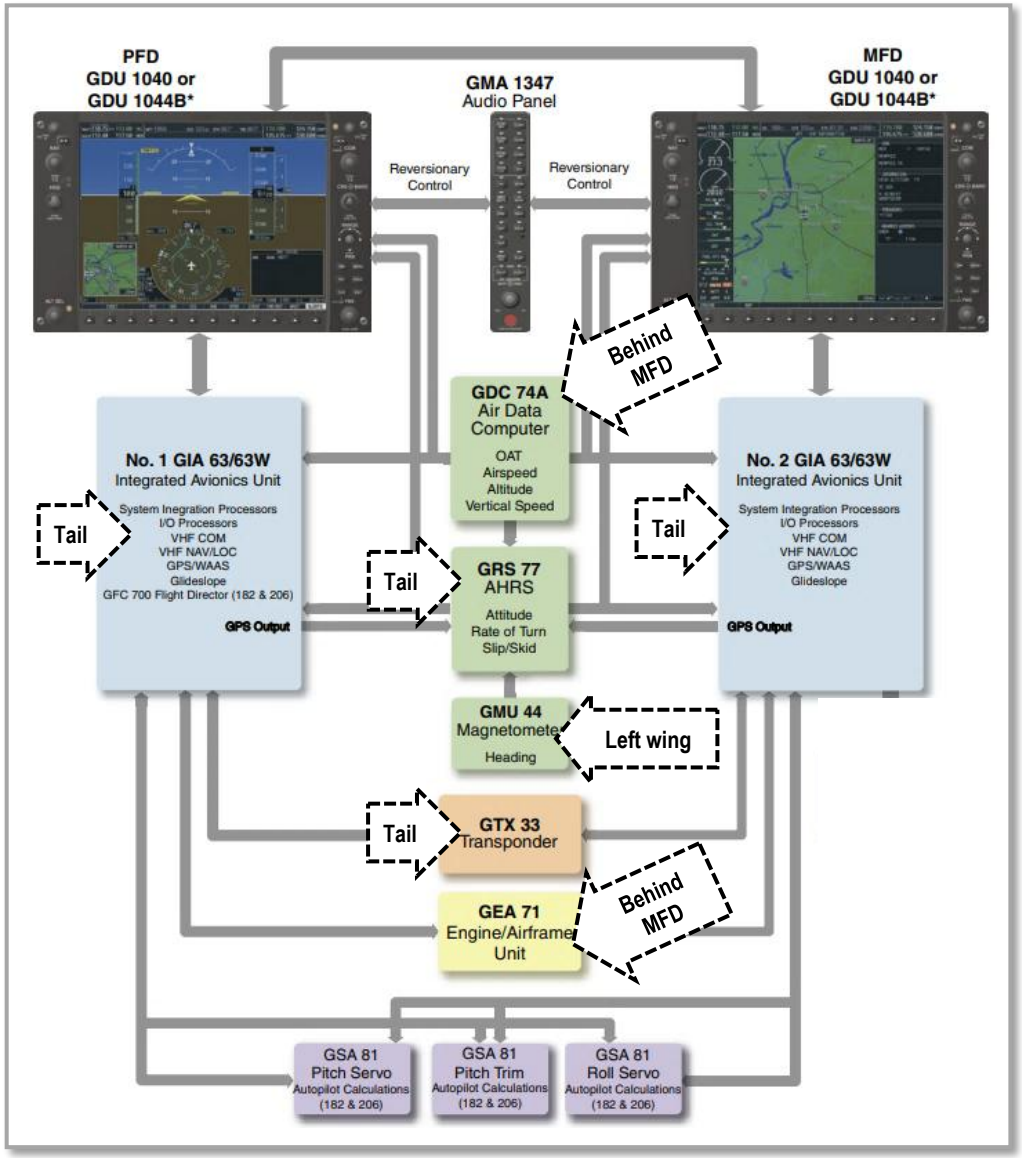
2. Instruments | PFD

G1000

- GDU (Graphic Display Unit): PFD and MFD
- GIA (Integrated Avionic Unit): 2 units, one associated to each GDU
  - *GPS receiver, COMM/NAV receivers and connect all systems*
- ADC (Air Data Computer): Airspeed, Altitude, VSI, OAT. Behind the MFD
- AHRS: Attitude, Rate-of-Turn, Slip/Skid. Solid-state (or MEMS) gyro/accel.
- Magnetometer (GMU):
  - *Detects magnetic field info and send to the AHRS for Heading*
- Autopilot Servos (GSA)
- Autopilot (GFC700)
- Audio Panel
- Transponder
- Eng/Airframe unit

Note: G3X Touch works with LRUs in multiple configs



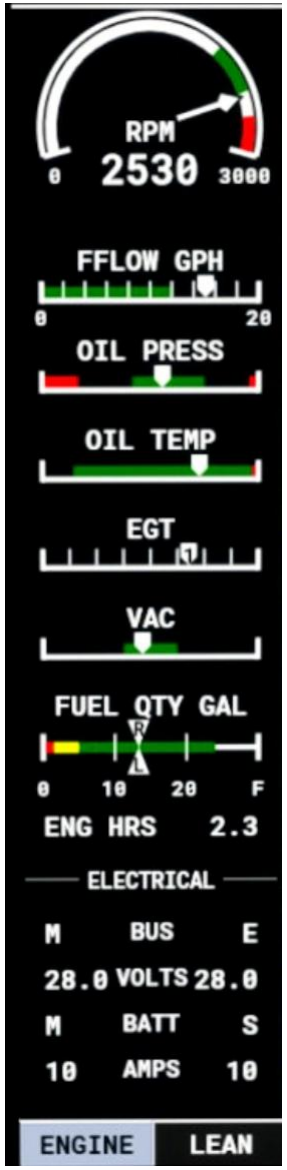


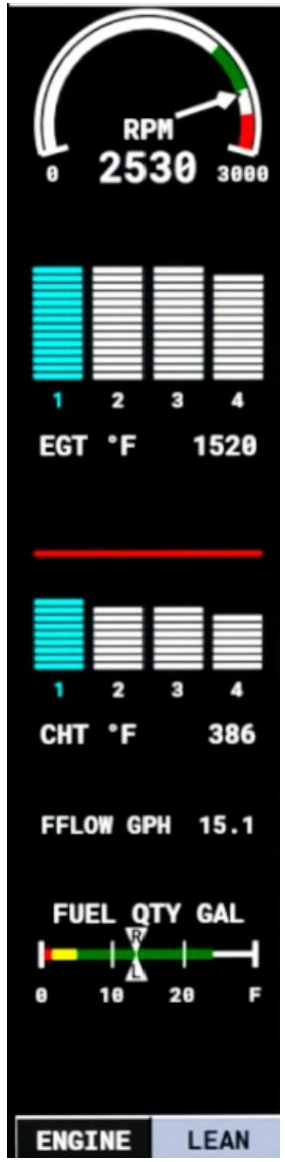
2. Instruments | Engine Information System

- **EIS**
  - Monitoring Instrument that provides information about the aircraft's engine, fuel and electrical systems
  - <u>System can include</u>:
    - LCD Displays
    - Warning signals (messages, blinking lights, etc)
    - Alarms
    - Sensors

  - **C172S**
    - **EGT**: Exhaust Gas Temperature *(1250F-1650F)*
    - **CHT**: Cylinder Head Temperature *(200F-500F)*

GI-275

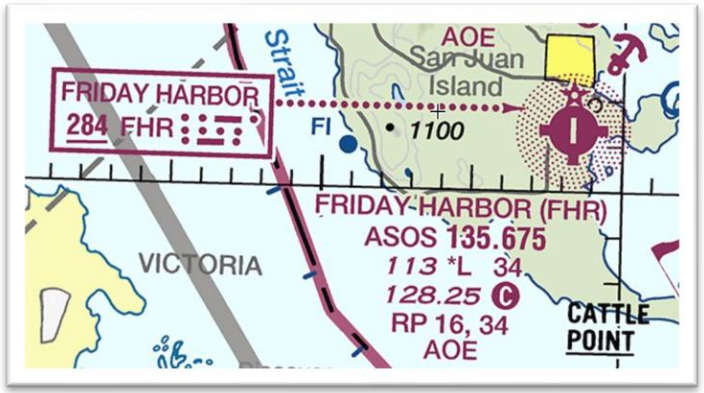




3. Navigation | ADF (Automatic Direction Finder) & NDB

AIM 1-1-2

- **What**
  - Points to a station (being decommissioned)
  - NDB operates between 190-535 KHz and transmit radio energy in all directions
  - Volumes (radial dist.): HH (75nm), H (50nm), MH (25nm), Compass loc. (15nm)
- **Components**
  - NDB (Ground), ADF (Aircraft)
    - ✓ *ADF = Automatic Direction Finder (2 antennas, Receiver and Instrument)*
    - ✓ *ADF operates between 530-1700 kHz and can be tuned to AM stations*
  - Limitations: subject to interference
- **Instrument**
  - Fixed Card (top)
  - Movable Card (middle)
  - RMI (Radio Mag Indicator, bottom)



Relative Bearing
135º

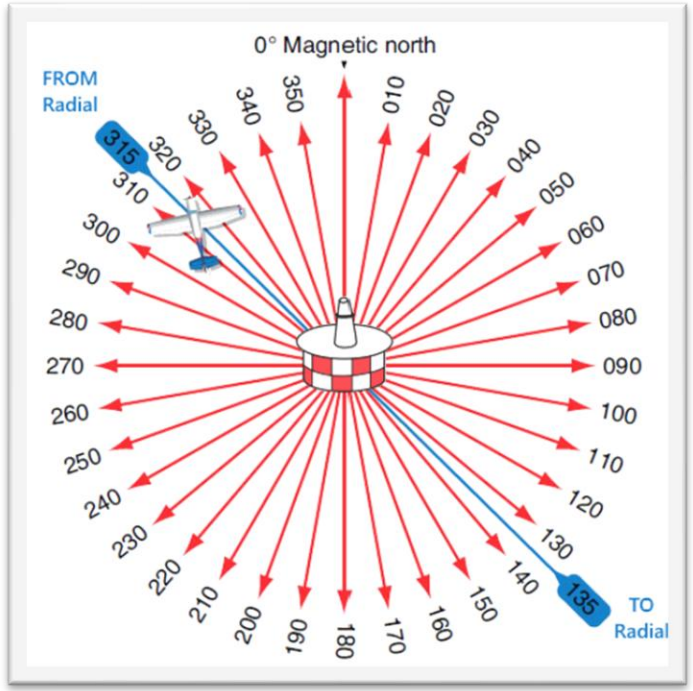
Magnetic Hdg
45º
+
Relative Bearing
135º
=
Mag Bearing
180º

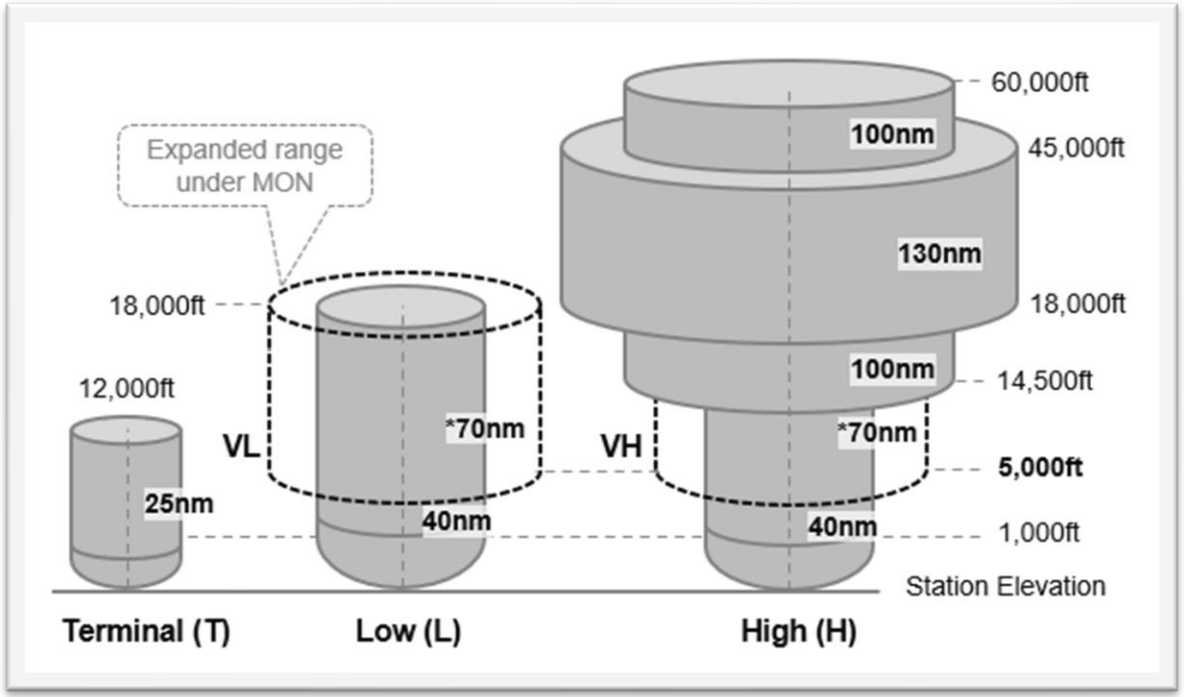
Automatically update hdg (Fluxgate)

3. Navigation | VOR (VHF Omni-Directional Range) AIM 1-1-3

What:

- Allow the pilot to fly magnetic courses or identify radials by using stations as reference (radio signal emitted from the ground)
- 3 Classes: Terminal, Low, High ➔ Based on Service Volumes
- Different variations: VOR, VOR/DME (VOR+DME), VORTAC (VOR + TACAN)



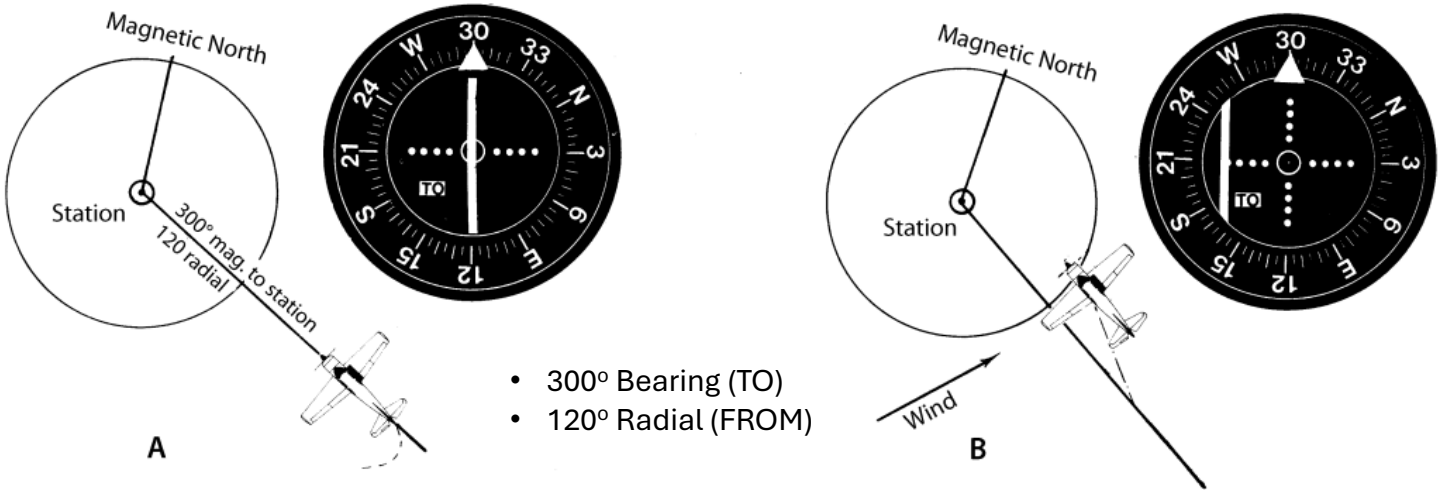


Service Volumes expanded under MON

3. Navigation | VOR (VHF Omni-Directional Range) AIM 1-1-3

How it Works

- Station: emits a rotating signal (30 times/sec) + ref signal when crossing 360 radial
- Aircraft Receiver: calculates difference between both signals to find its radial
- 108.0 to 117.95 MHz *(excl LOC frequencies of 108.10-111.95 w/ odd tents)*
- Limitations: Line-of-Sight, Cone of confusion, Reverse Sensing
- Minimum Operational Network (MON): VOR within 100nm (>5000ft)
  - ✓ *Reduction from 896 to 590 VORs, expanding service volumes*



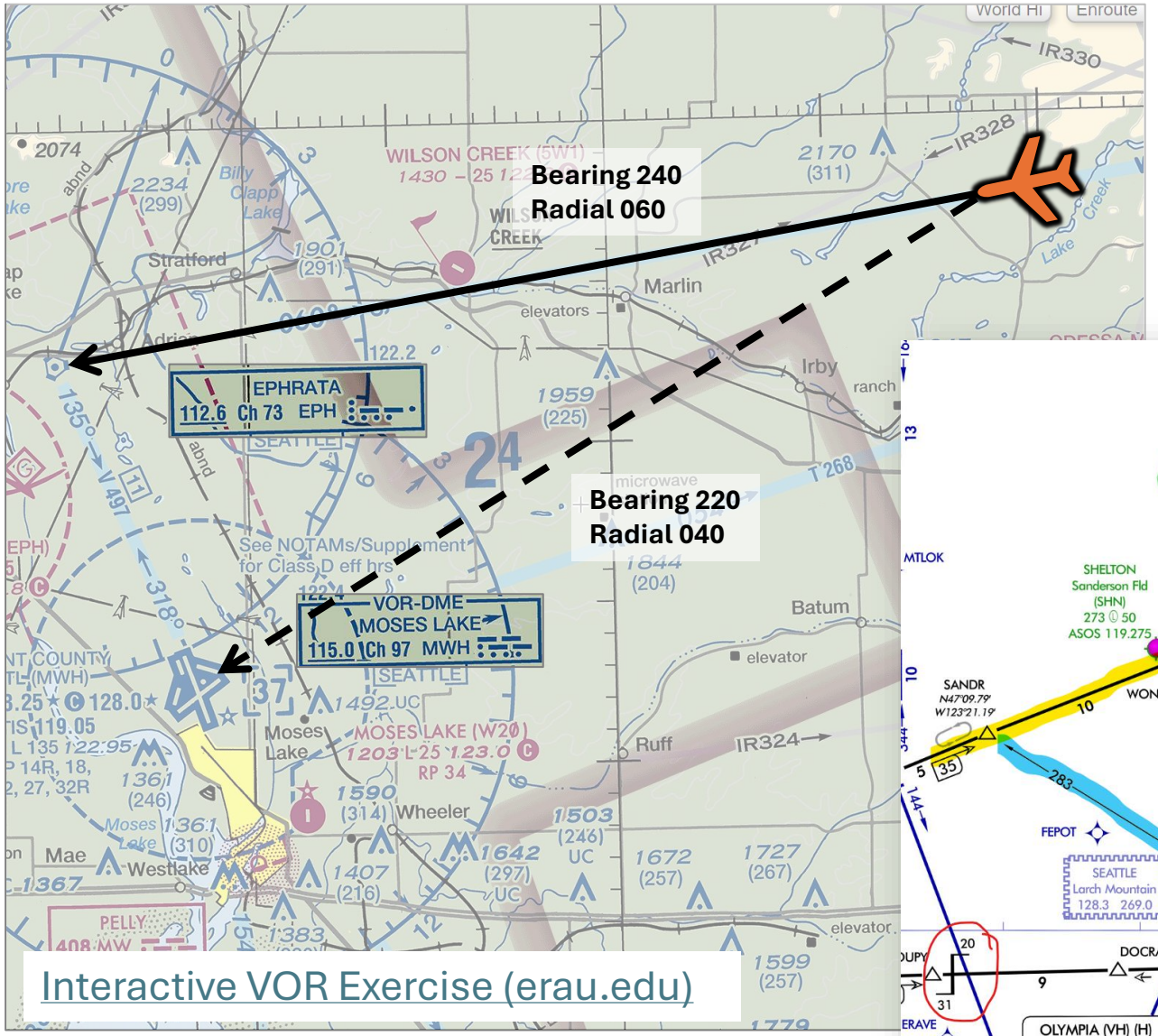
- 300° Bearing (TO)
- 120° Radial (FROM)

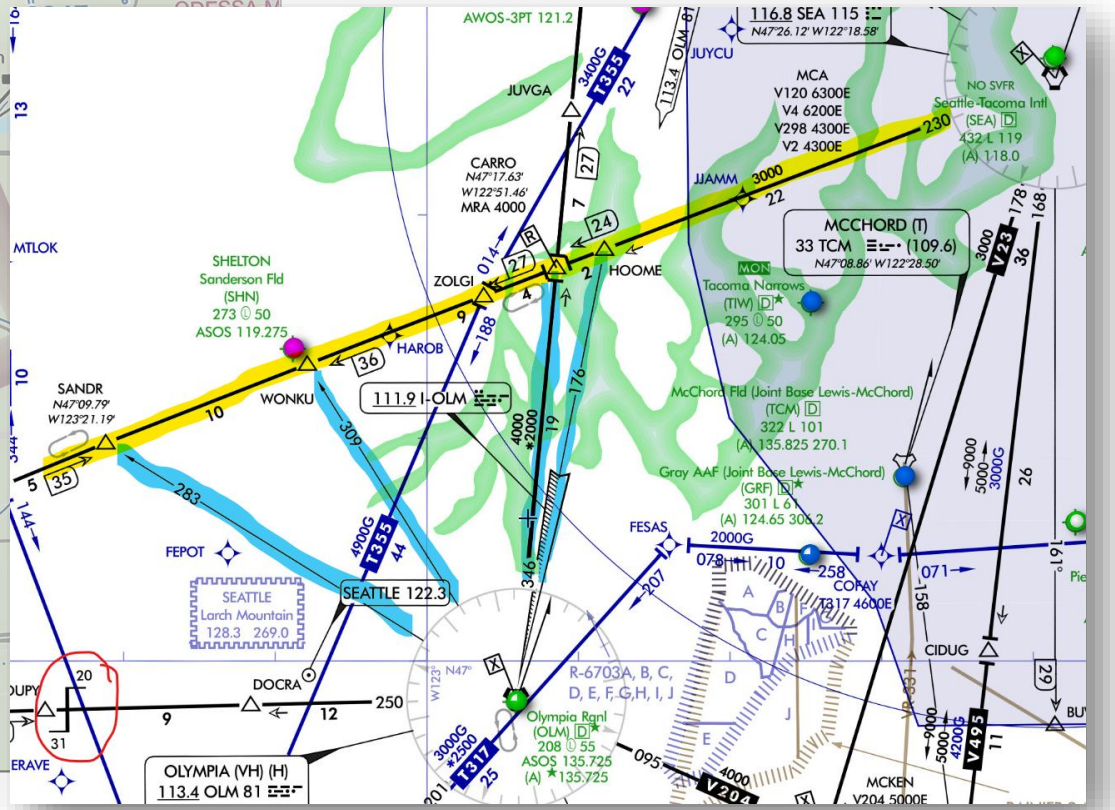
VOR Receiver Checks (§91.171)

Every 30 days for IFR Navigation

- VOT (360 From) ➔ ±4°
- Dual VOR ➔ ±4°
- Ground Checkpoint ➔ ±4°
- Repair Station ➔ ±4°
- VOR Airborne Checkpoint ➔ ±6°
- Above landmark within 20nm of a VOR, low altitude ➔ ±6° of selected radial
- Record:
  - ✓ *Date*
  - ✓ *Error*
  - ✓ *Place*
  - ✓ *Signature*

3. Navigation | VOR (VHF Omni-Directional Range)

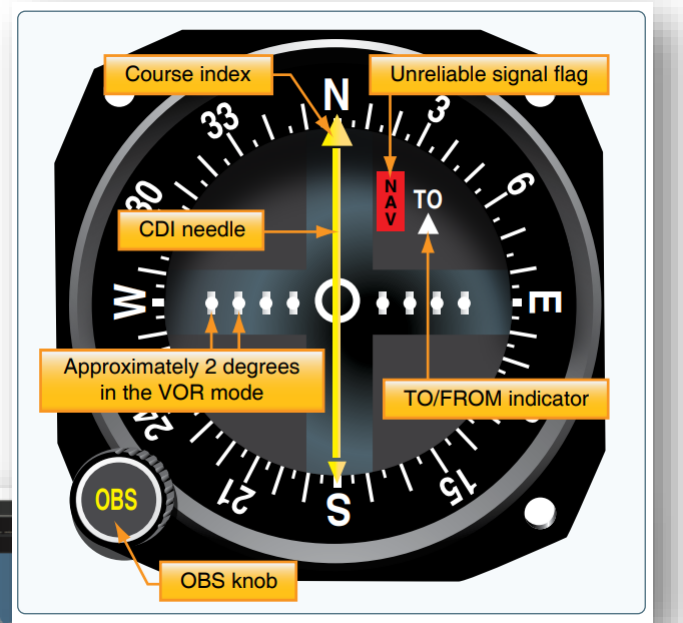




3. Navigation | VOR (VHF Omni-Directional Range)

Steps for VOR Navigation

1. Tune to the VOR frequency and identify it
2. Turn the OBS to determine the bearing you are in (needle centered w/ TO indication)
3. Turn the aircraft until your heading aligns to the VOR course selected
4. If you want to cross the VOR in a different radial, turn the OBS to the desired bearing
5. Turn the airplane to intercept the radial that leads to the desired bearing
6. Change station at the changeover point
7. Wind correction:
   - If drifting, turn 10º into the wind
   - Adjust WCA depending on the results (under/over-shoot)



Avoid reverse sensing

- If flying to the VOR, flag w/ TO
- If flying from the VOR, flag w/ FROM
- *Note: no reverse sensing in the G1000*

Flying heading 030 towards the 240 radial (intercept) and fly bearing 060

3. Navigation | DME (Distance Measurement Equipment)

AIM 1-1-7

What

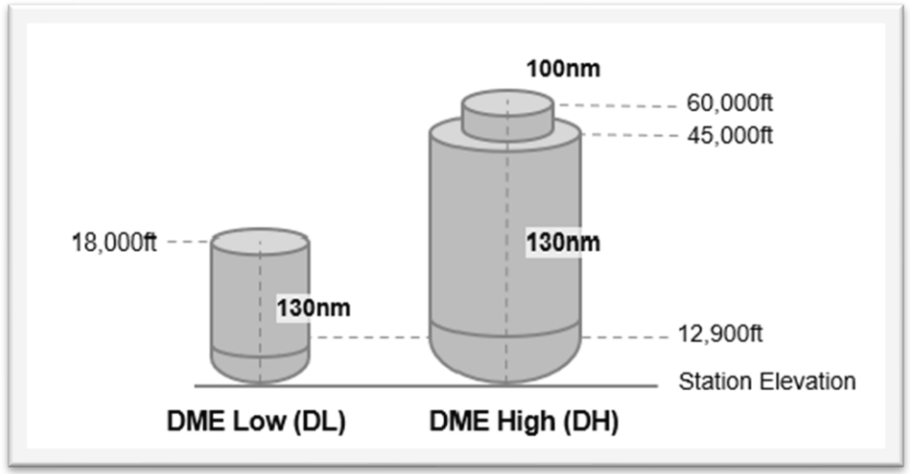
- Provides distance from a station
- 2 classes: Low and High depending on Service Volume

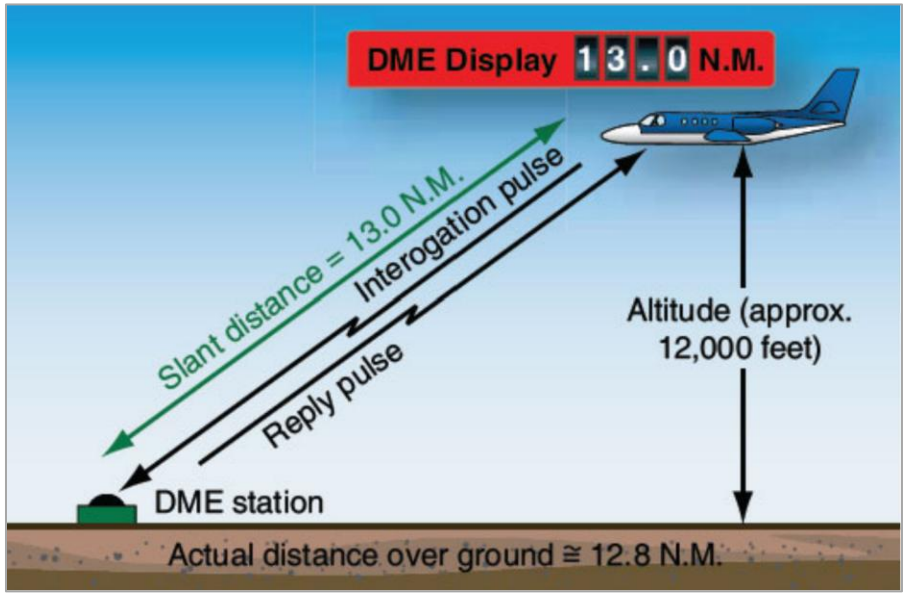
How it Works

- Airplane interrogates, station responds ➔ Receiver calculates distance
- UHF: Operates in the 962-1213 MHz frequencies (paired w/ VOR freq)
- Limitations:
  - Line-of-sight
  - Slant Range
    - ✓ *The higher you are and the closer you are →the higher the error*
    - ✓ *Negligible 1nm horizontal per 1000ft alt*

- DME receiver can be replaced by a RNAV system (G172 doesn't have a DME)
- DME receiver (or RNAV) is required above FY240 (FAR 91.205)

Service Volumes expanded under MON



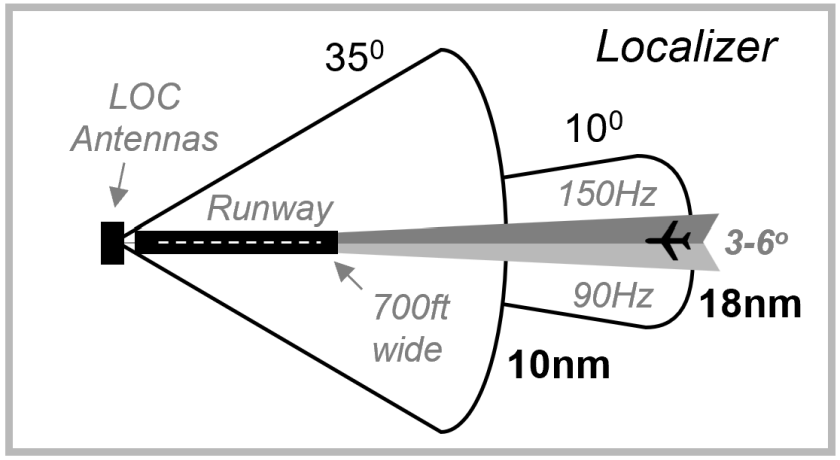


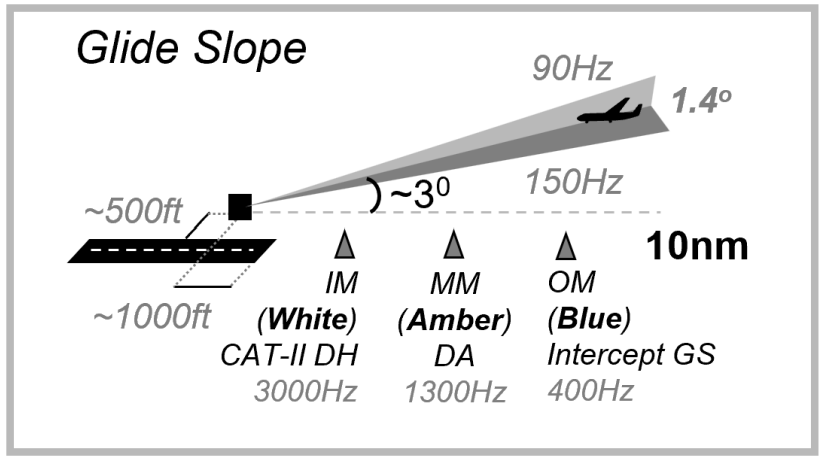
3. Navigation | ILS (Instrument Landing System) AIM 1-1-9

What: Electronic system providing horizontal & vertical guidance for landing

How it Works

- Localizer (LOC, VHF), Glide Slope (GS, UHF), Marker Beacons and ALS
  - *LOC frequencies: 108.1 – 111.95 MHz with odd tenths only*
  - *Glideslope: Generally 3º glide path, 1.4º thick, tied to the LOC frequency*
- Minimums (DH/RVR): CAT-I (200ft/1800-2400), CAT-II (100ft/1200), CAT-III (up to 0) **CAT II & III requires specific certification and equipment*
- Limitations: subject to obstruction, interference (surface vehicles/aircraft can disturb the signal), and false echoes for GS





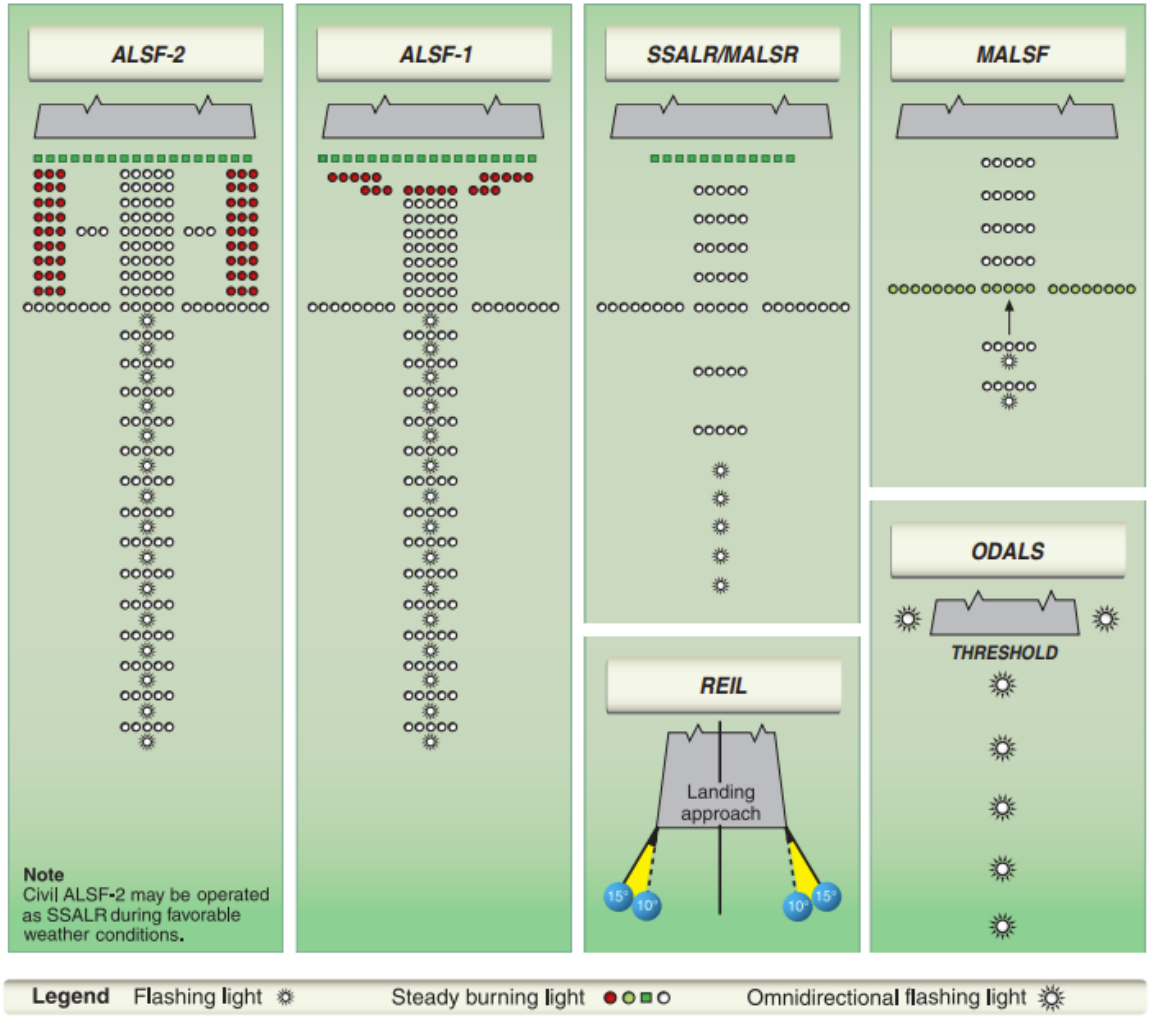
Marker Beacon

- **Outer (OM):** 4-7 NM out/GS intercept
  - Blue/Purple, low pitch, dashes
- **Middle (MM):** 3,500' out/200'
  - Amber, intermediate pitch, dots/dashes
- **Inner (IM):** DH on a Cat II approach
  - White, high pitch, dots
- **Compass Locator**: With OM/MM

3. Navigation | ILS (Instrument Landing System)

Approach Light Systems

- Transition to Visual Flight [AIM 2-1-1]
- **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 (& runway alignment)
- **ODALS**: Omnidirectional Approach Light System



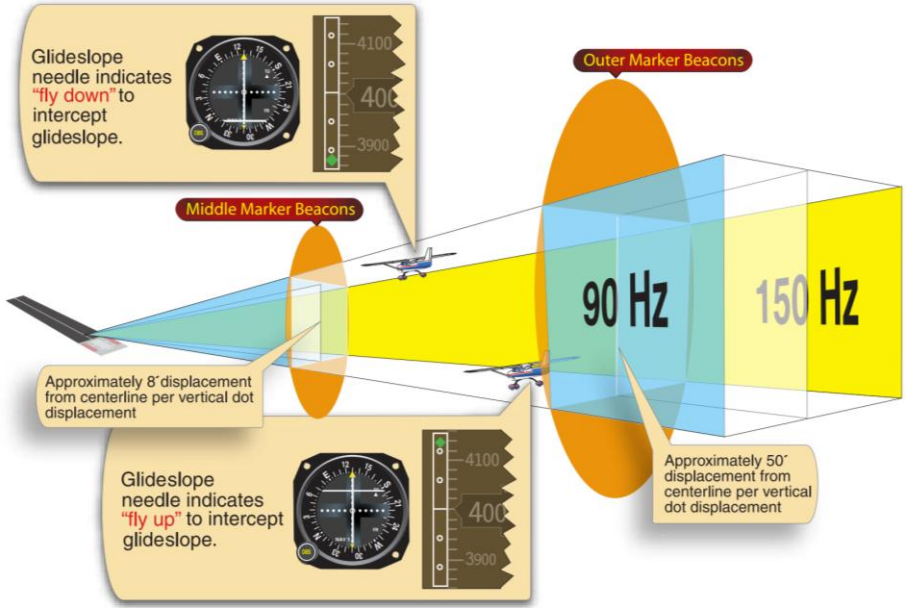
3. Navigation | ILS (Instrument Landing System)

Localizer Receiver

- Same as a VOR receiver
- Navigation:
  - Like a VOR, but more sensitive (2.5º full deflect. vs 10º)
  - Rotating the OBS has no effect
  - Back course has opposite sensing
- Flying
  - Center the LOC, fly the inbound course
  - Apply drift corrections

Glideslope Receiver

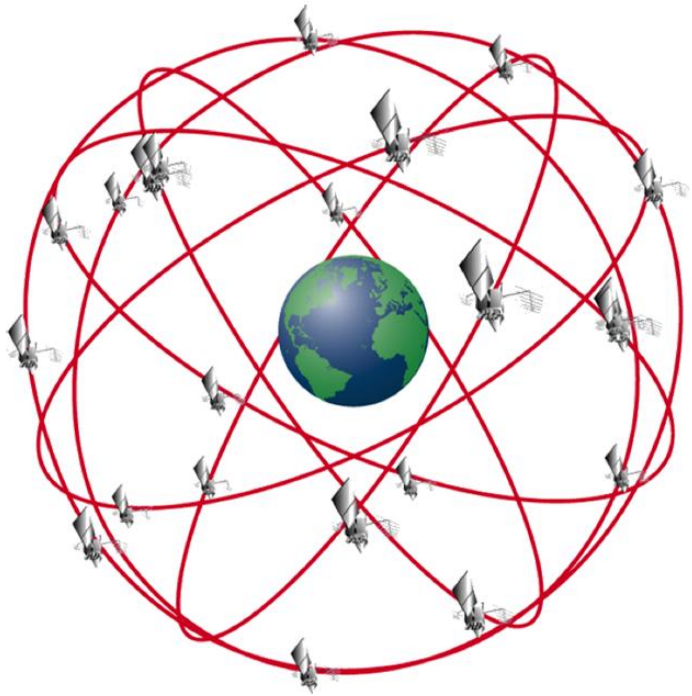
- Auto tuned with the localizer frequency
- Navigation:
  - Needle/diamond represent the glideslope
  - On Glidepath: Needle or diamond centered
- Flying
  - Set pitch & power as GS is intercepted
  - Small pitch adjustments to maintain slope

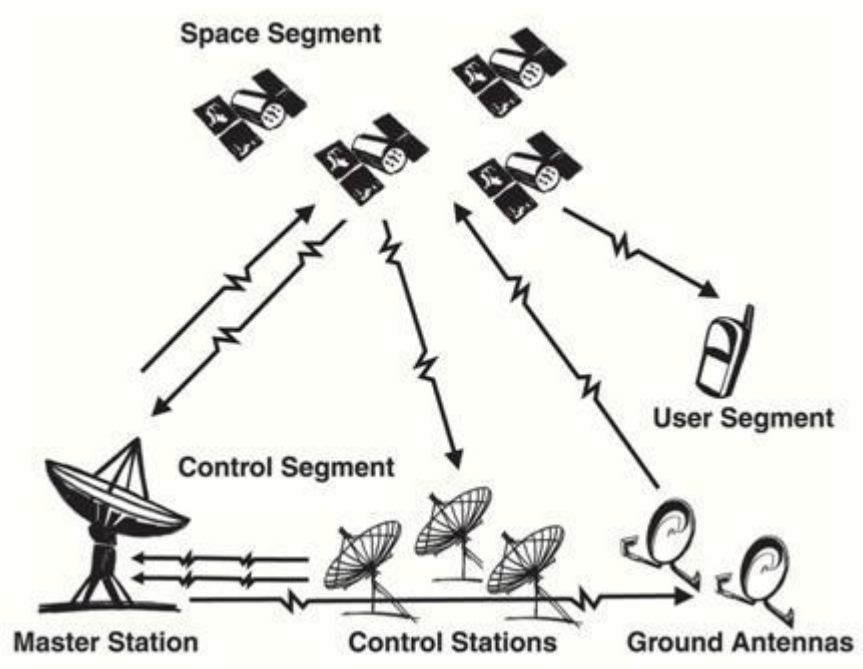


3. Navigation | GPS (Satellite-Based Radio Navigation)

GNSS (Global Navigation Satellite System) – AIM 1-1-17

- Types of systems: GPS (US), Galileo (EU), GLONASS (Russia), BeiDou (China)
- GPS Space Segment: constellation of min 24 satellites (current 31) orbiting earth at 11,000 miles
- GPS Control Segment: position/clock accuracy – 1 Master control station, 5 monitoring stations, 3 ground antennas
- Number of satellites required for triangulation: 3 (2D), 4 (3D), 5 (RAIM), 6 (fault exclusion)

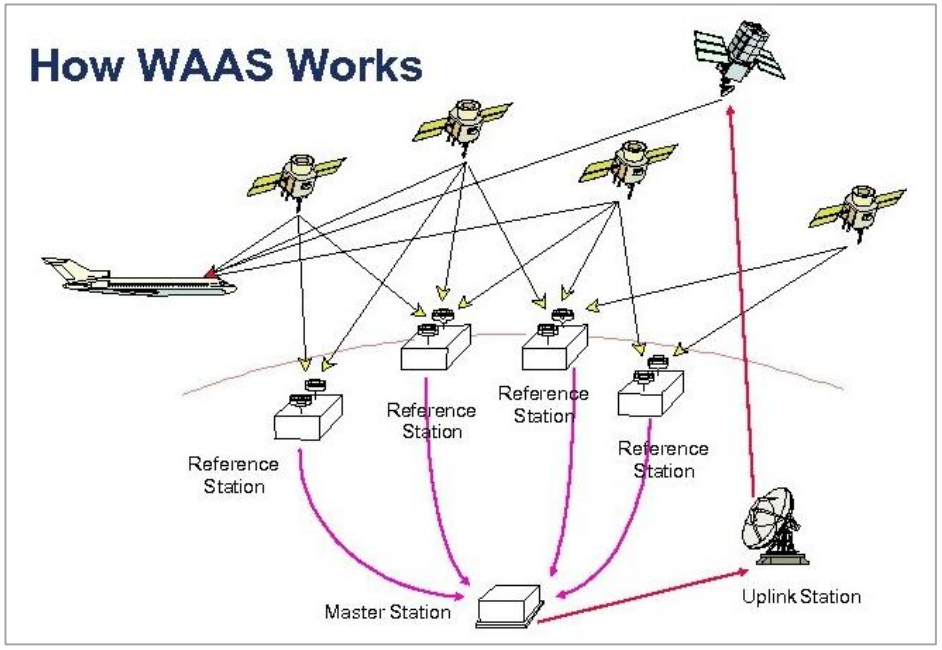




3. Navigation | GPS (Satellite-Based Radio Navigation)

SBAS (Satellite Based Augmentation System) – AIM 1-1-18

- Types of systems: WAAS (US), EGNOS (UE), SDCM (Russia, under dev.), etc
- WAAS (Wide Area Augmentation System): improves accuracy of GPS signal
  - ✓ *38 Stations (WRS): compare GPS signal w/ their own surveyed location*
  - ✓ *3 Master Stations (WMS): receive data from the WRSs, calculate the GPS errors and transmit to 6 ground uplink stations*
  - ✓ *3 Geostationary Satellites receive the signal from the uplink stations and broadcast to WAAS receivers, which correct the GPS signal*



3. Navigation | GPS (Satellite-Based Radio Navigation)

Using your GPS (multiple models available) in an MFD

- Steps: **(1)** Load Waypoints ➔ **(2)** Follow the Magenta CDI (like a VOR) ➔ **(3)** Check the moving maps (MFD)
- Be careful with the "Direct To" – GPS will not avoid terrain for you

3. Navigation | GPS (Satellite-Based Radio Navigation)

RAIM (Receiver Autonomous Integrity Monitoring) – AIM 1-1-17(a3)

- Required to ensure satellite signals meet integrity req ➔ Need at least 5 satellites (6, or 5 + baro aid, for fault exclusion)

GPS Equipment – AIM 1-1-18(c), AIM 1-1-17(b2a2), AIM 1-1-3(f3b2)

- TSO 129/196 (non-WAAS):
  - Can fly RNAV(GPS) approaches to LNAV minima (LNAV/VNAV with baro-aided systems)
  - When filing an alternate airport, at least one of them (destination or alternate) must have a non-GPS approach
  - Needs to confirm RAIM availability as part of pre-flight.
  - Under IFR, must be equipped with an alternate means of navigation (if lose RAIM, must revert to VOR navigation)
- TSO 145/146 (WAAS):
  - Can fly the approaches above, plus LPV, LP, and LNAV/VNAV minima w/o baro-aided system.
  - When filing an alternate airport, there are no restrictions on type of approach, both can be GPS
  - RAIM is not required (unless if lose WAAS signal).
  - WAAS users flying under Part 91 are not required to carry VOR avionics for IFR/GPS operations

GPS may be used as a substitute when:

- *Determining position over a DME fix and/or Flying a DME arc*
- *Navigating To/From an NDB or Compass Locator, or Holding over an NDB/Compass Locator*
- *Determining position over a fix defined by an NDB or Compass Locator bearing crossing a VOR/LOC course*
- *Can use GPS to fly a VOR approach as long as the VOR is operational and monitored [AIM 1-2-3 (c5)]*

3. Navigation | Transponder w/ Altitude Reporting

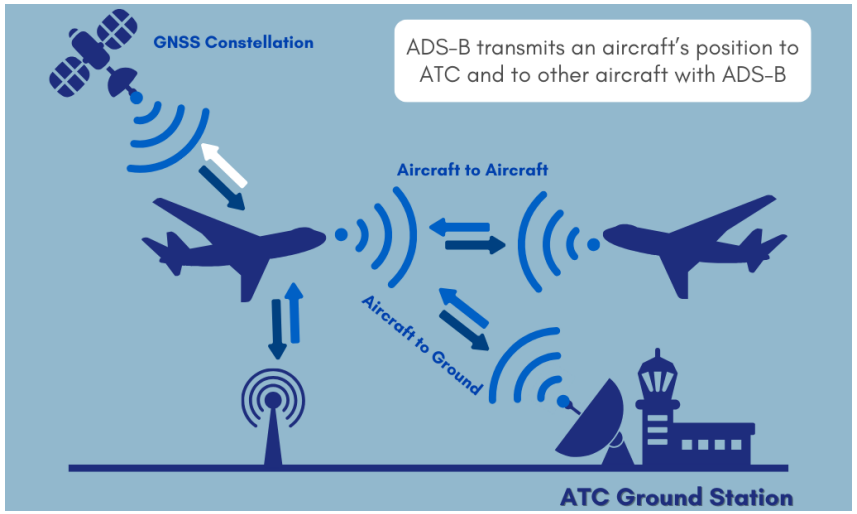
- **Allows ATC to see where the aircraft is**
  - Unique squawk code assigned by ATC to the aircraft can be monitored by them throughout the controlled airspace
  - Other codes: 7500 (hijack), 7600 (lost comms), 7700 (emergency), 1200 (VFR)
- **Modes and Functions**
  - Mode A: only transmits a four-digit squawk code and position ("Mode 3" is the equivalent for Military use)
  - Mode C: In addition to Mode A, it also transmits the aircraft's pressure altitude
  - Mode S (Select): In addition to Mode C, it also transmits speed, heading and ICAO address. TCAS and ADS-B.
  - Ident: Ident is a function of a transponder that, when activated, allows ATC to identify your aircraft on its radar screen.
  - Status: OFF, SBY (standby, not transmitting), ON (operating on Mode A/3), ALT (operating on Mode C)
- **Altitude Validation**
  - ACT must verify (by regulation) → inquire pilot's altitude, it must be within 300ft of what the controller sees
- **Maintaining**
  - Inspection required every 24 calendar months) [91.413]
  - If the aircraft has an operational transponder, it must be on and transmitting per 91.215(c)

3. Navigation | ADS-B

- **Automatic Dependent Surveillance Broadcast**
  - ADS-B Out: Broadcasts GPS location, altitude, groundspeed, and more to ground stations & other aircraft
  - ADS-B In: Pilots can see what controllers see, as well as weather (if installed)
    - ✓ *TIS-B (Traffic Information, 978MHz (UAT)/1090ES): ADS-B Out equipped aircraft + radar (~30nm, ±3,500ft)*
    - ✓ *FIS-B (Flight Information, 978MHz (UAT) only): weather products, clouds, icing, metar, airmet/sigmet, etc*

- **Requirements for ADS-B Out (91.225)**
  - Equipment satisfies 91.227 and 91.225(a)(1) and (b)(1) – note more options below 18,000ft MSL
  - Class A, B, and C airspace (and above Class B and C, up to 10,000ft MSL) and Inside Mode-C veil up to 10,000ft MSL
  - Class E airspace at and above 10,000ft MSL, excluding below 2,500ft AGL
    - ✓ *At and above 3,000ft MSL over the Gulf of Mexico within 12nm of the coast*

Use portable ADS-B In receivers if aircraft not equipped

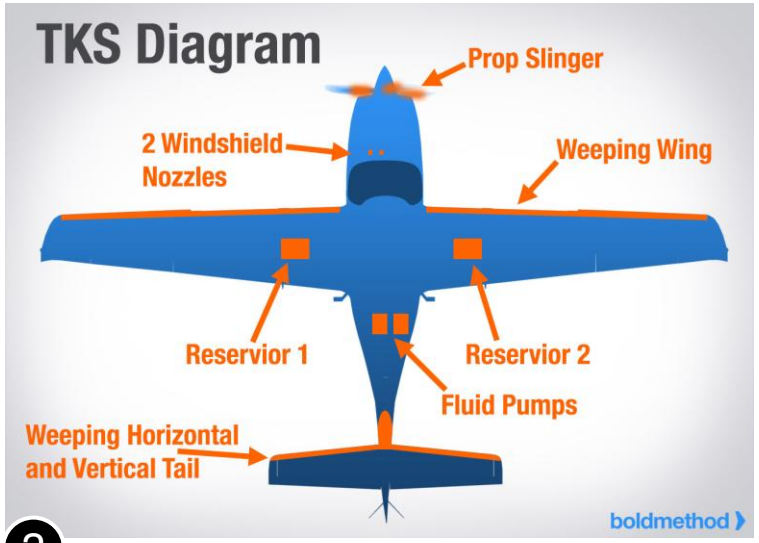


3. Navigation | Automatic Pilot & FMS

- **FMS (Flight Management System)**
  - Receives inputs from a variety of sensors and has a pre-loaded database of NAVAIDS, Airways, etc
  - Employs calculations to determine the action/guidance on all phases of flights (e.g. directs the auto-pilot)
- **Autopilot**
  - Single Axis (hold wings level), Two Axis (adds pitch control), Three Axis (adds yaw control)
  - Modes
    - **ROL/PIT** ➔ Maintain current bank/pitch attitude
    - **HDG** ➔ Maintain specified heading
    - **NAV** ➔ Follows the Navigation source
    - **APR** ➔ Navigation + GS on approaches
    - **ALT** ➔ Hold altitude
    - **VS** ➔ Recommended for Descent. Defines Vertical Speed (RPM)
    - **IAS** (or FLC) ➔ Recommended for Climb. Defines Airspeed (Kts)
    - **VNAV** ➔ follows descent paths (navigation)
- **Examples: GFC500, GFC700**

4. De-Ice and Anti-Ice

- **Anti-ice** prevents ice, **De-ice** removes ice
- **Airfoil**
  - ❶ Deice Boots ➔ Inflatable rubber boots bonded to the leading edge of the wing
    - Thermal Anti-Ice ➔ Hot air from the engine compressor
    - Weeping Wing ➔ Antifreeze weeps through small holes in the leading edge
- **Windscreen** and **Propeller**
  - Alcohol – Used to prevent ice build up on windscreen / propeller
  - Electric Heat – Wires imbedded in the windscreen / propeller anti-ice
- **TKS System** (Tecalemit-Kilfrost-Sheepbridge Stokes)
  - ❷ "Weeping wing", but a system that covers way more than the wing
- **C172S**
  - Flying into known icing condition is prohibited in the C172 by the POH
  - C172 does not have deicing, only minimal anti-icing
  - **Pitot heat** ➔ electrical heating element. Must be on if OAT <40°F (4.4°C)
  - **Windshield defrost** ➔ heated air routed to the top of the panel



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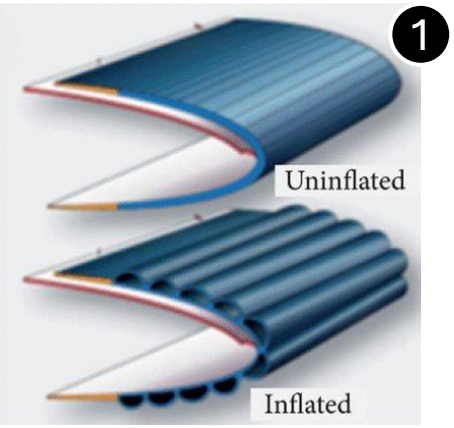
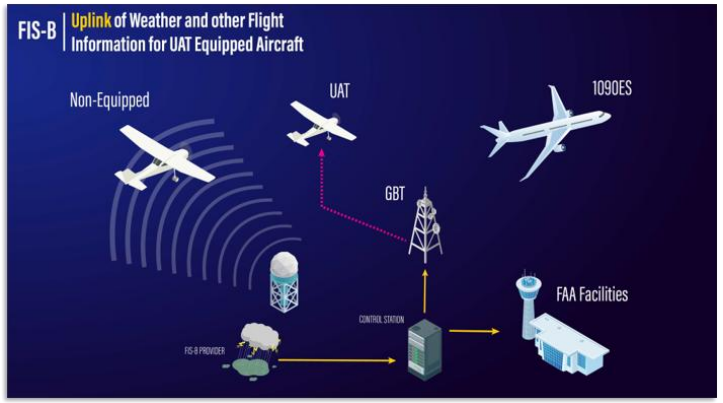
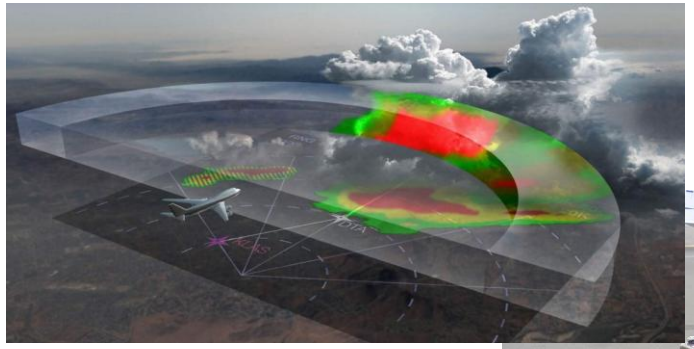
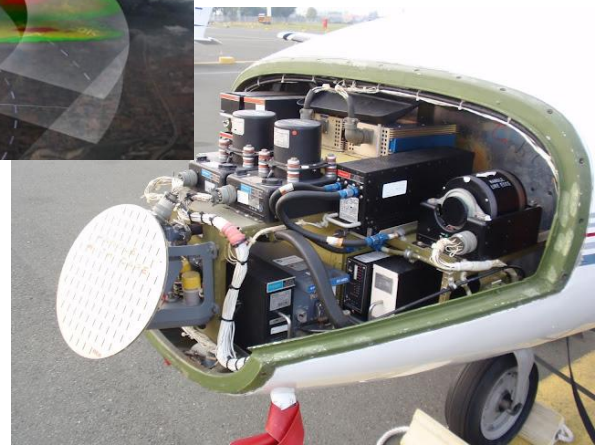


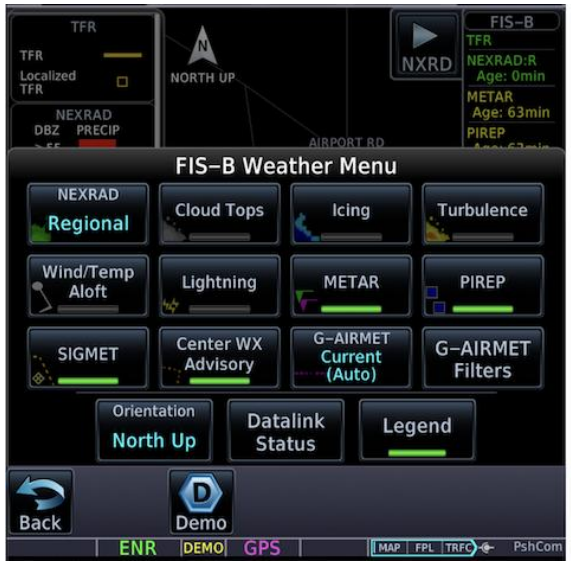
5. Inflight Weather Services & Equipment

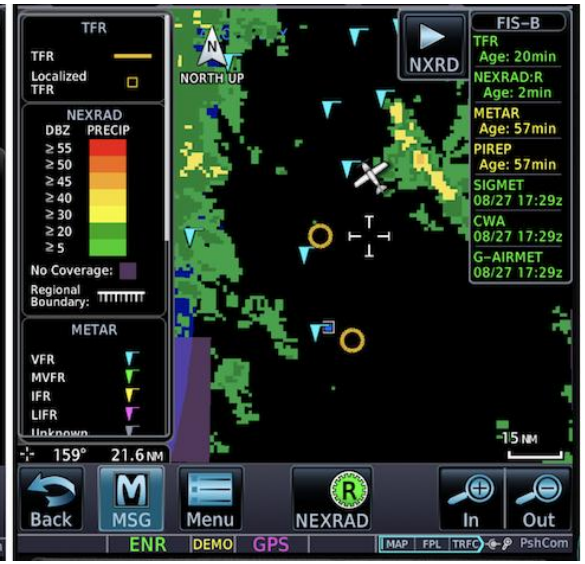
- **Weather Datalink**
  - FIS-B (Broadcasted by Ground Stations, 978MHz (UAT)): clouds, icing, metar, radar, airmet/sigmet, etc
  - Sirius XM: via satellite, requires subscription
- **Onboard Doppler Radar & Stormscope**
  - Radar works with UHF radios echoes
  - Lightning: Detects discharges within 200nm (WX-500 stormscope)











Questions?