Flight Instruments and Avionics

Objective

To understand the basic flight instruments used for flight, their limitations and biases, plus common failure modes.

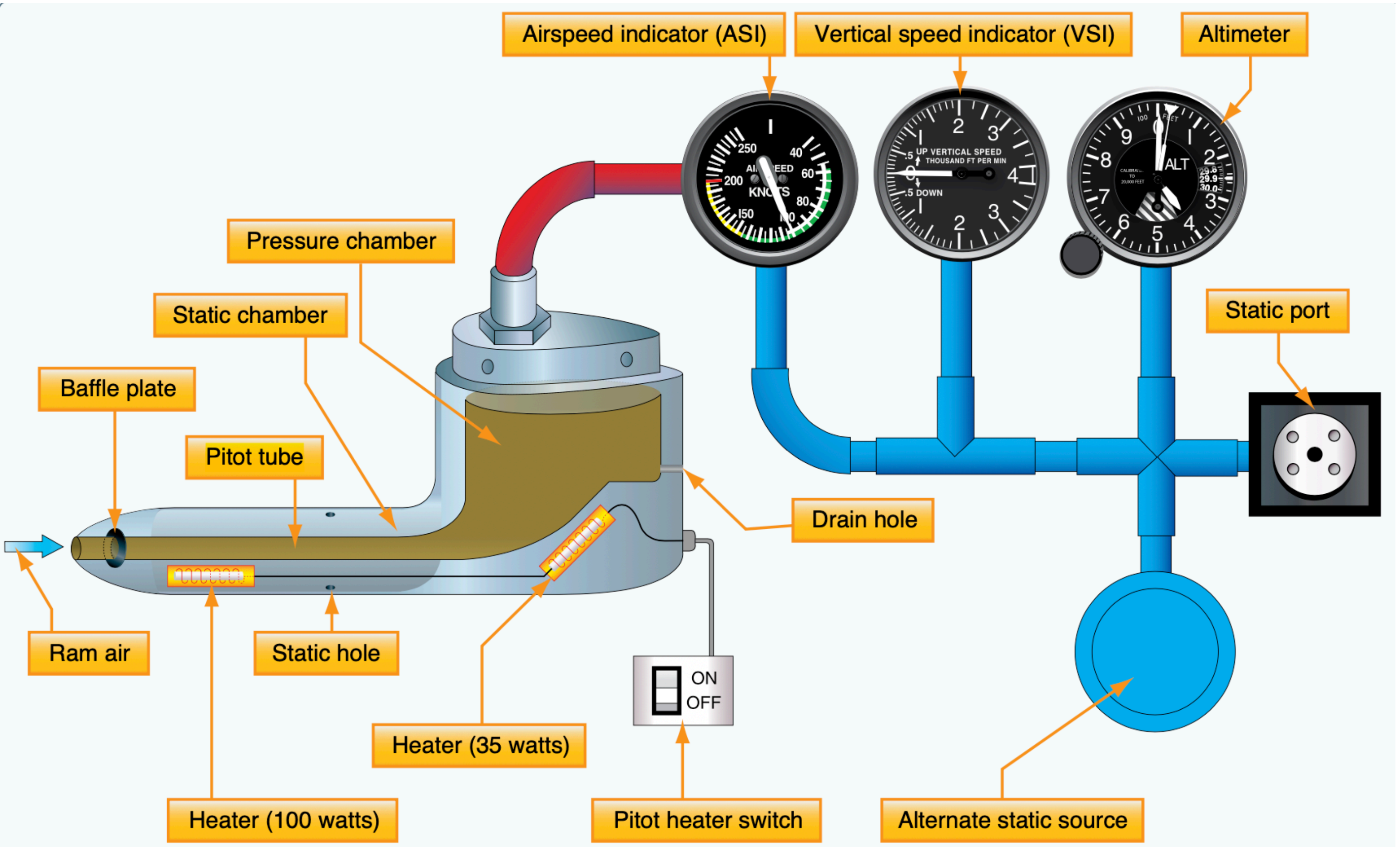
Motivation

To a give a student an intuitive understanding of the operation of the flight instruments, and a sense of how they will behave if they malfunction.

Overview

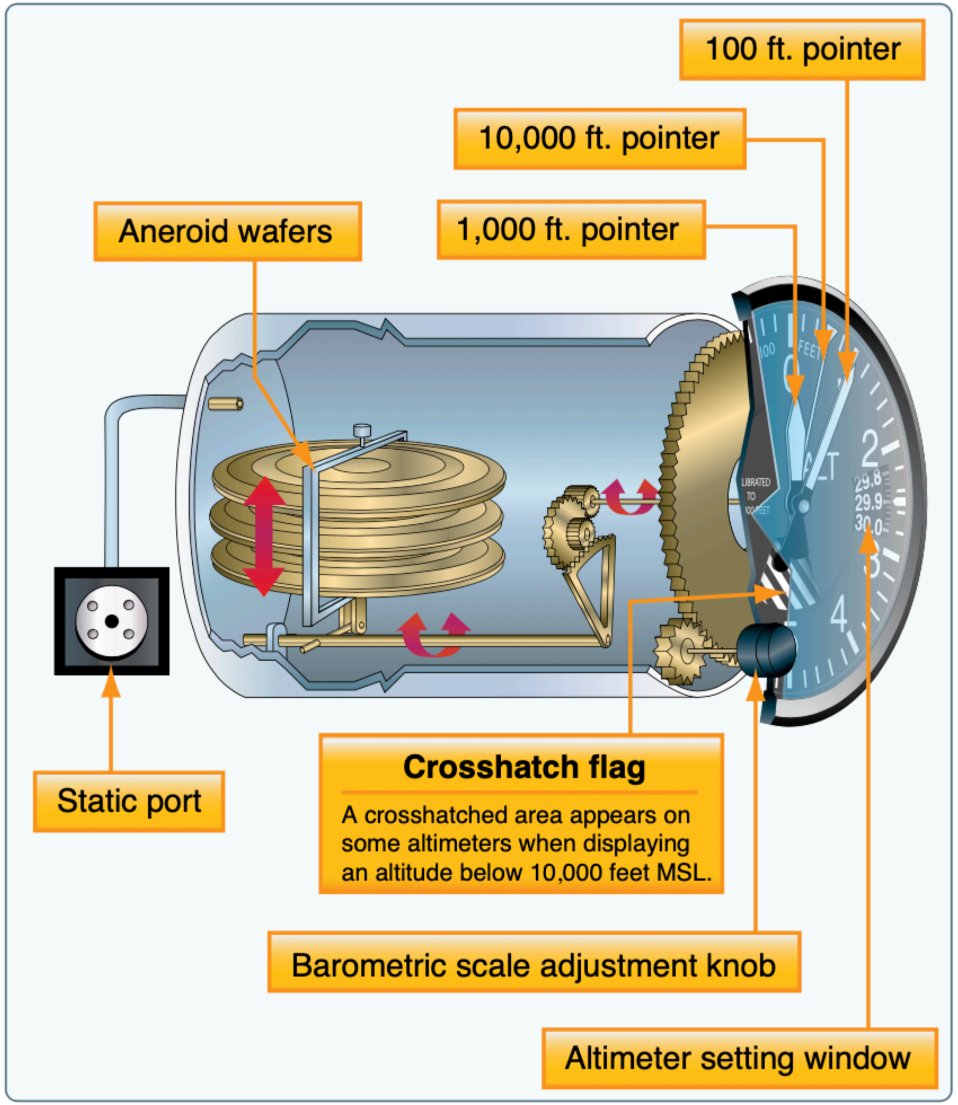
- Pitot-Static instruments
  - Altimeter
  - Vertical Speed Indicator
  - Vertical Speed Indicator
  - Airspeed indicator
- Pitot-static port blockages
- Inclinometer
- Gyroscopic and vacuum Instruments
  - Attitude Indicator
  - Directional Gyro/Heading Indicator
  - Horizontal Situation Indicator (HSI)
- AHRS and EFIS Systems
- Vacuum System Failures
- Magnetic Compass
  - Compass errors

SMOKING PROHIBITED
MANEUVERING SPEED 105 KIAS
WARNING
TURN COORDINATOR
VERTICAL SPEED
AVIONICS
MAP LIGHT DIM
MAGNETOS
FUEL PUMP
LIGHTS
BCN
LAND
TAXI
NAV
STROBE
PITOT HEAT
ALT BAT
RADIO LT
PANEL LT
GLARESHIELD LT
PEDESTAL LT
THROT PUSH OPEN
MIX PULL LEAN
ALT STATIC AIR PULL ON
CABIN AIR PULL ON
AVOID SLIPS WITH FLAPS EXTENDED



Pitot-Static instruments

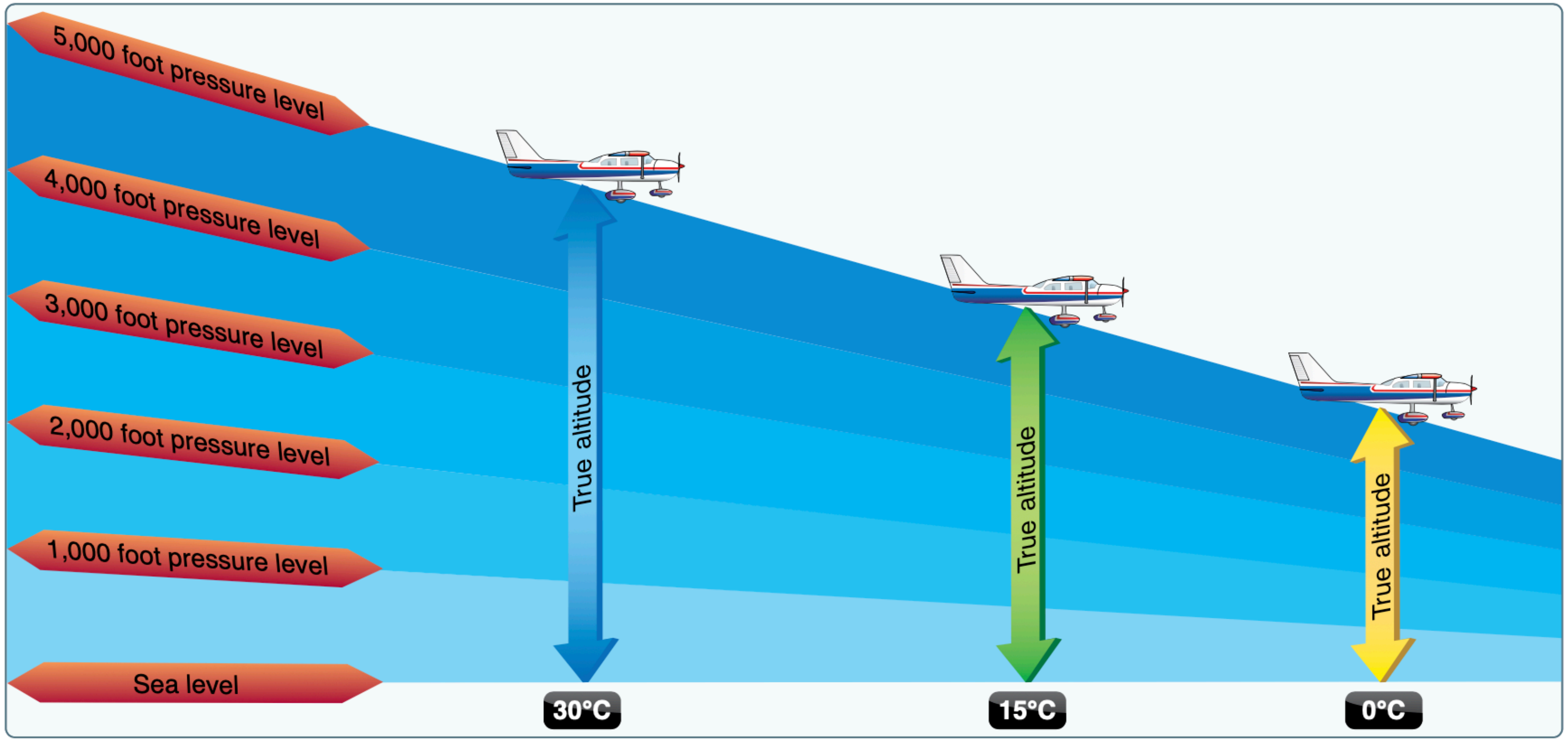
- Static port: Ambient air pressure
- Pitot tube: Ram air pressure, in the relative wind flow



Altimeter

- Converts barometric pressure into altitude
- Calibrated to the lapse rate of the standard atmosphere (2° per 1000', 1" Hg per 1000')
- Calibrated to the temperature of the standard atmosphere (15° @ S.L.)
- Kollsman window allows for calibrating the atmosphere indicator up and down
    - Window does have a set range

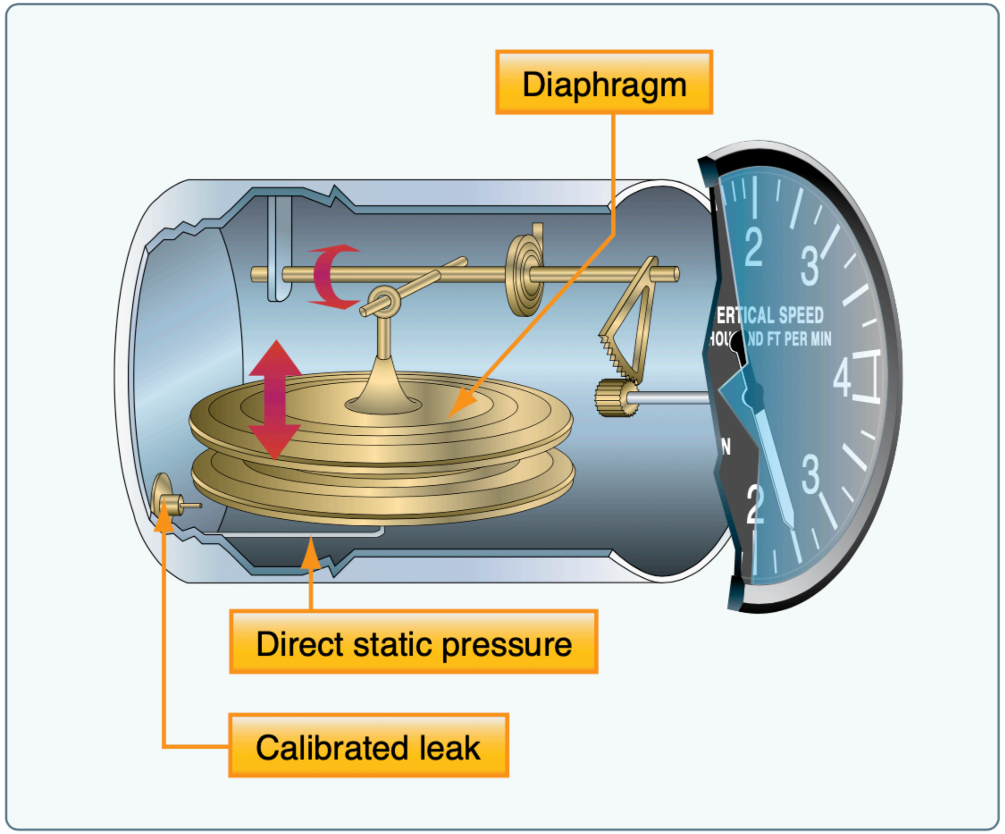
Nonstandard Temperature Errors



- Colder temperatures: "Compress" the column of air below, altimeter reads higher
- Hotter temperature: "Expand" the column of air below, altimeter reads lower

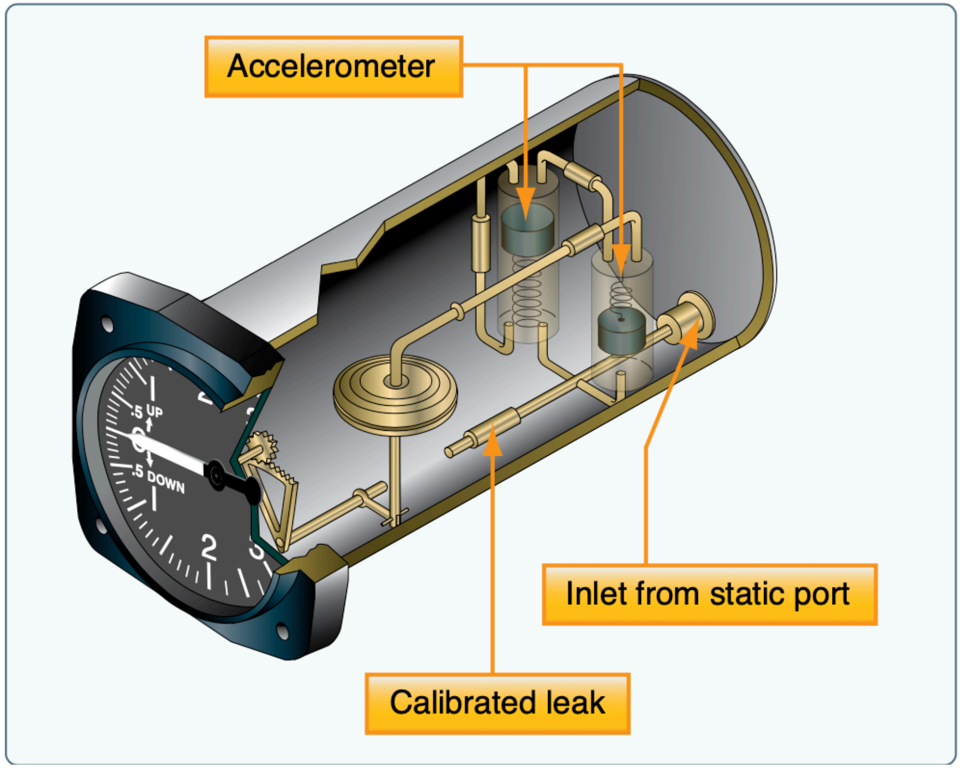
Types of Altitude

- **Indicated** altitude: Read from the altimeter
- **True** altitude: Vertical distance from mean sea level
- **Absolute** altitude: Vertical distance above terrain (AGL)
- **Pressure** altitude: Read from altimeter when set to 29.92"
    - Height in the standard atmosphere where the ambient pressure is found
- **Density** altitude: Pressure altitude corrected for nonstandard temperature



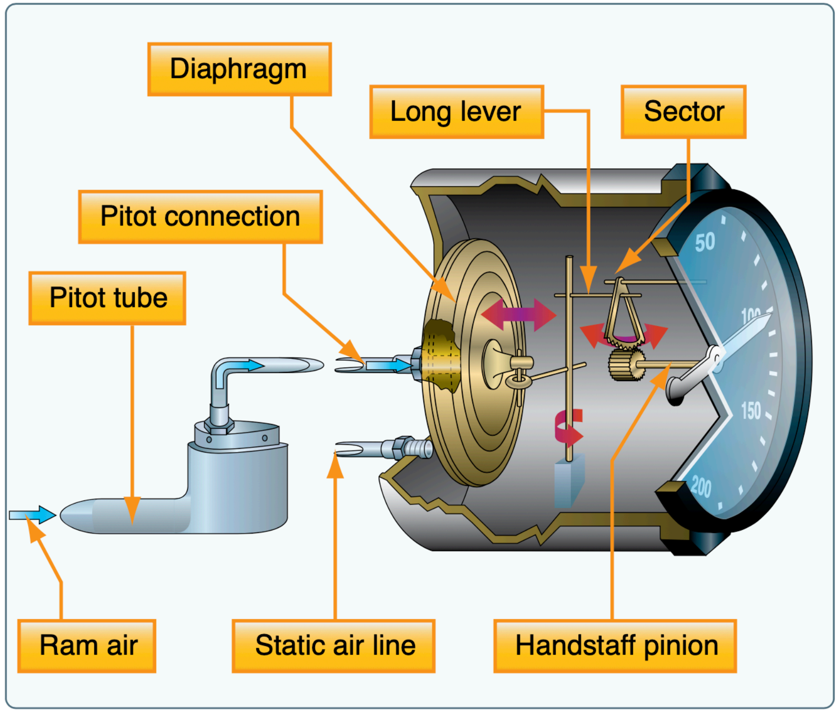
Vertical Speed Indicator

- Rate of change of the altitude/ambient pressure
- Will lag considerable with pressure alone



Instantaneous Vertical Speed Indicator (IVSI)

- Accelerometer weights help lead the indication before pressure changes



Airspeed indicator

- Airspeed = (Ram air pressure - static pressure)
- Operates with a diaphragm

Types of Airspeed

- Indicated airspeed (IAS): Read from altimeter
- Calibrated airspeed (CAS): Calibrated for position/instrument errors
  - At slow airspeeds this may be several knots off
- True airspeed (TAS): CAS corrected for altitude and nonstandard temperature
- Ground speed (GS): Actual speed over the ground
  - TAS adjusted for wind

IAS vs CAS

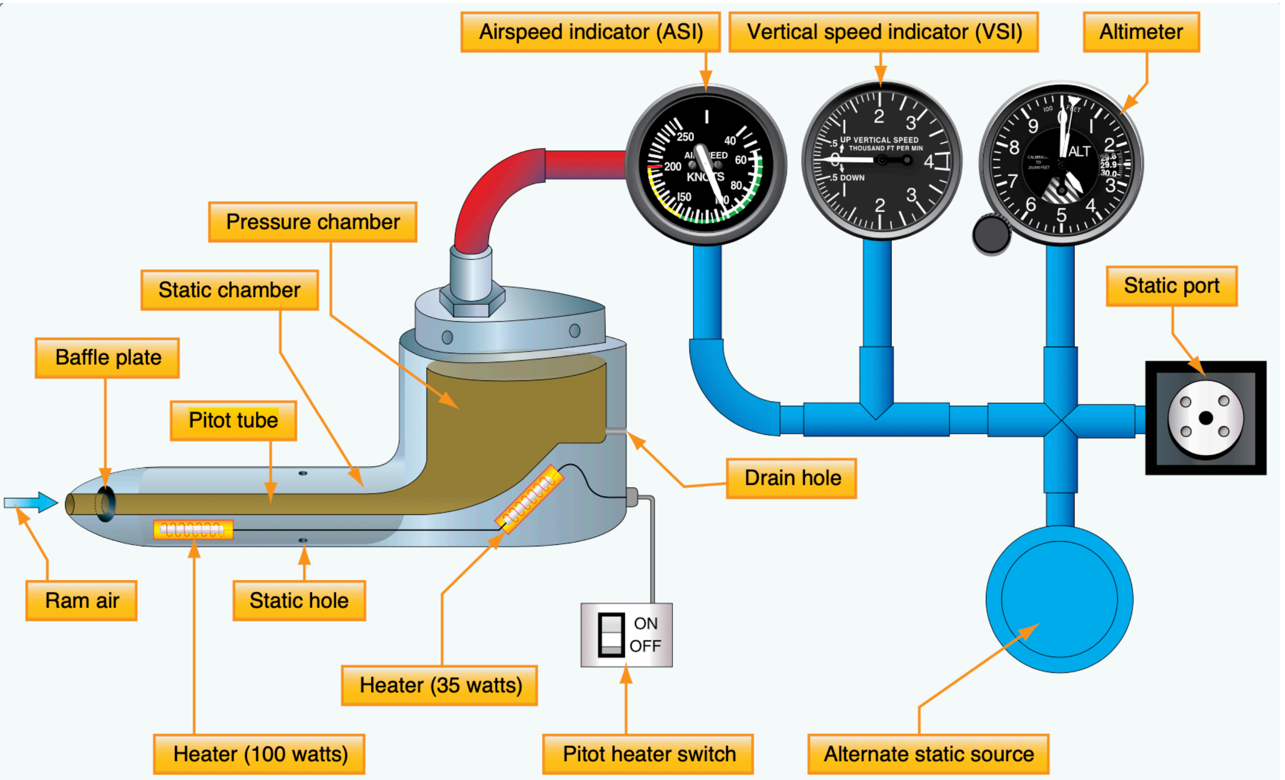
CONDITIONS:
Power required for level flight or maximum power descent.

FLAPS UP													
KIAS	50	60	70	80	90	100	110	120	130	140	150	160	170
KCAS	61	65	72	80	89	99	109	118	128	138	147	157	167
FLAPS 20°													
KIAS	40	50	60	70	80	90	95	---	---	---	---	---	---
KCAS	54	58	63	71	80	89	94	---	---	---	---	---	---
FLAPS FULL													
KIAS	40	50	60	70	80	90	95	---	---	---	---	---	---
KCAS	52	57	63	71	80	90	95	---	---	---	---	---	---

Figure 5-1. Airspeed Calibration (Sheet 1 of 2)

Airspeed Indicator Markings

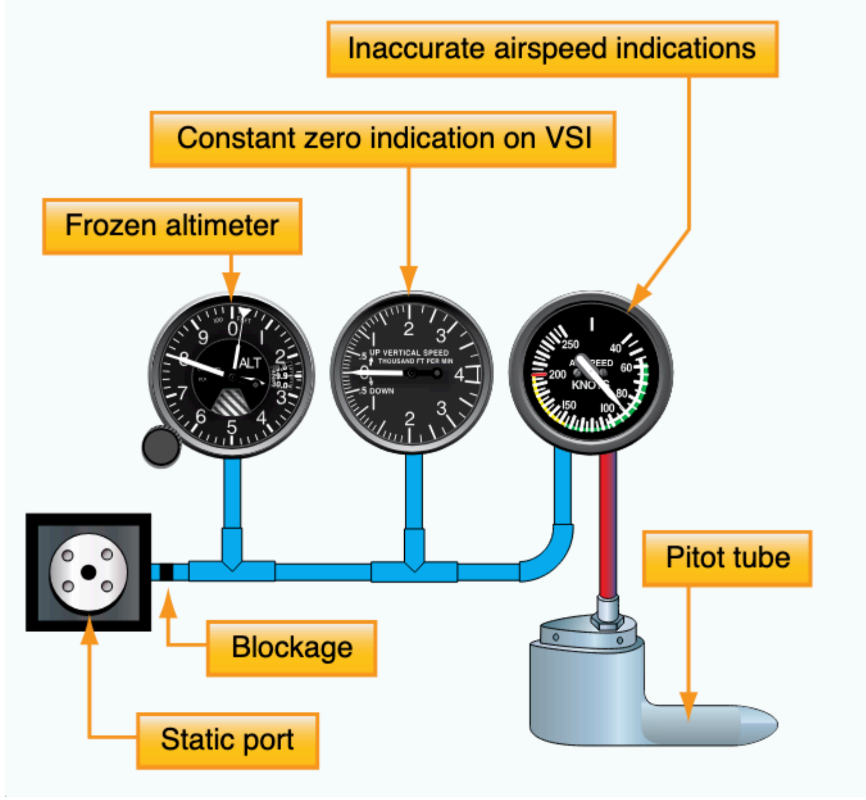
- V_{S0}: Stall speed in landing configuration
- V_{S1}: Stall speed in clean configuration
- V_{FE}: Flap extension speed (full flaps)
- V_{N0}: Maximum structural cruising speed (smooth air only)
- V_{NE}: Never exceed speed
- Note V_A is not marked



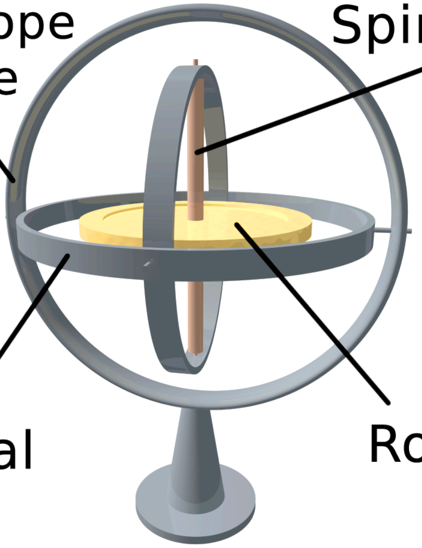
Pitot Blockages

- Ram air block: Airspeed reads 0
- Ram air + drain hole blocked:
  - Airspeed reads whatever it was when it was blocked
  - If you descend it'll read lower, higher if ascending

Static Port Blockages



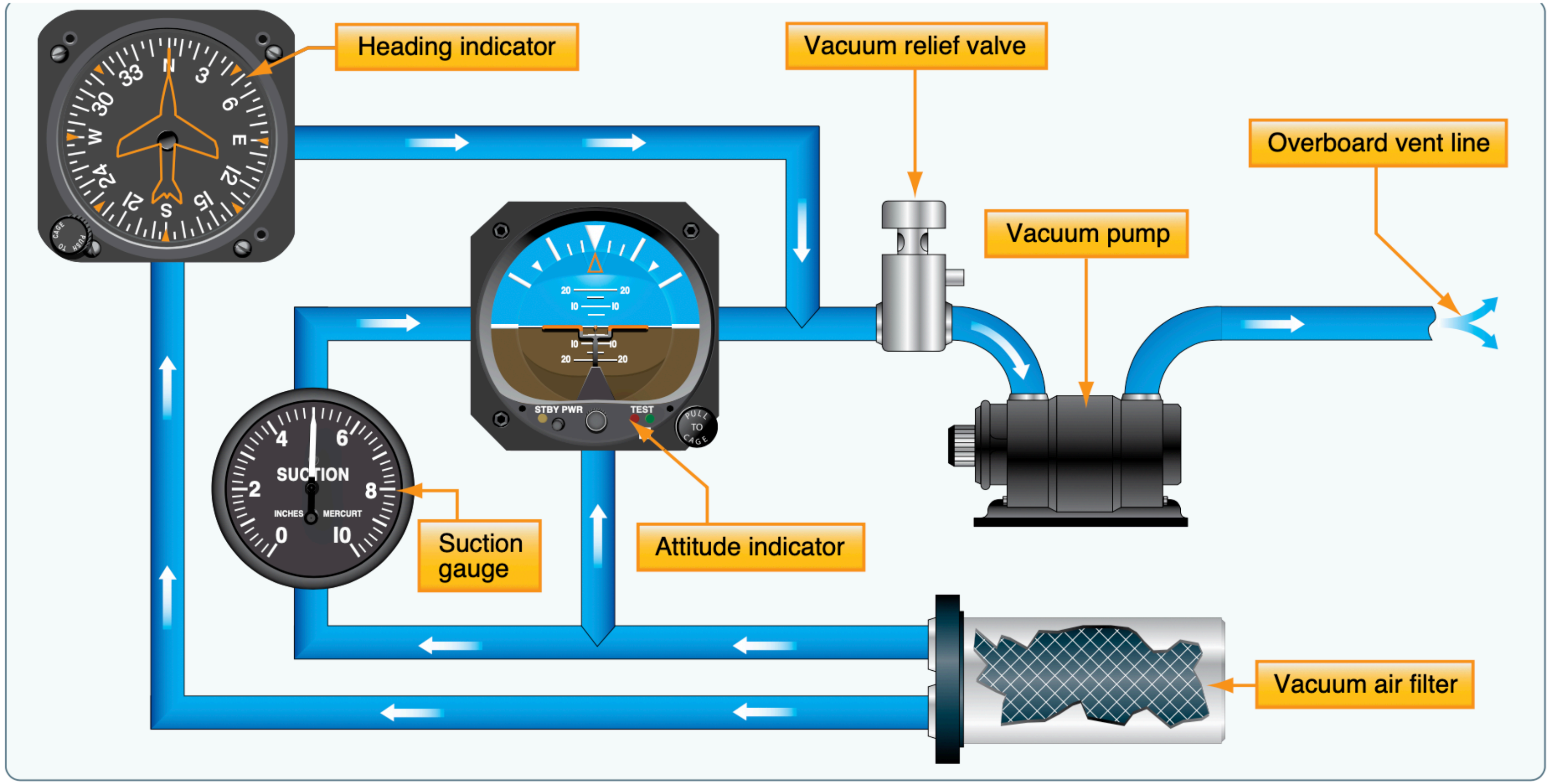
- Most airplanes have an alternate static course
  - This will vent into the cockpit, which may have slightly lower pressure
- VSI will show no climb or descent
- A blocked static port will cause errors in the airspeed indicator
  - Recall Airspeed = RAM pressure - static pressure
  - Airspeed is accurate at altitude where blockage occurred
  - Above the altitude, airspeed reads low
  - Below the altitude, airspeed reads high



Gyroscopic Instruments

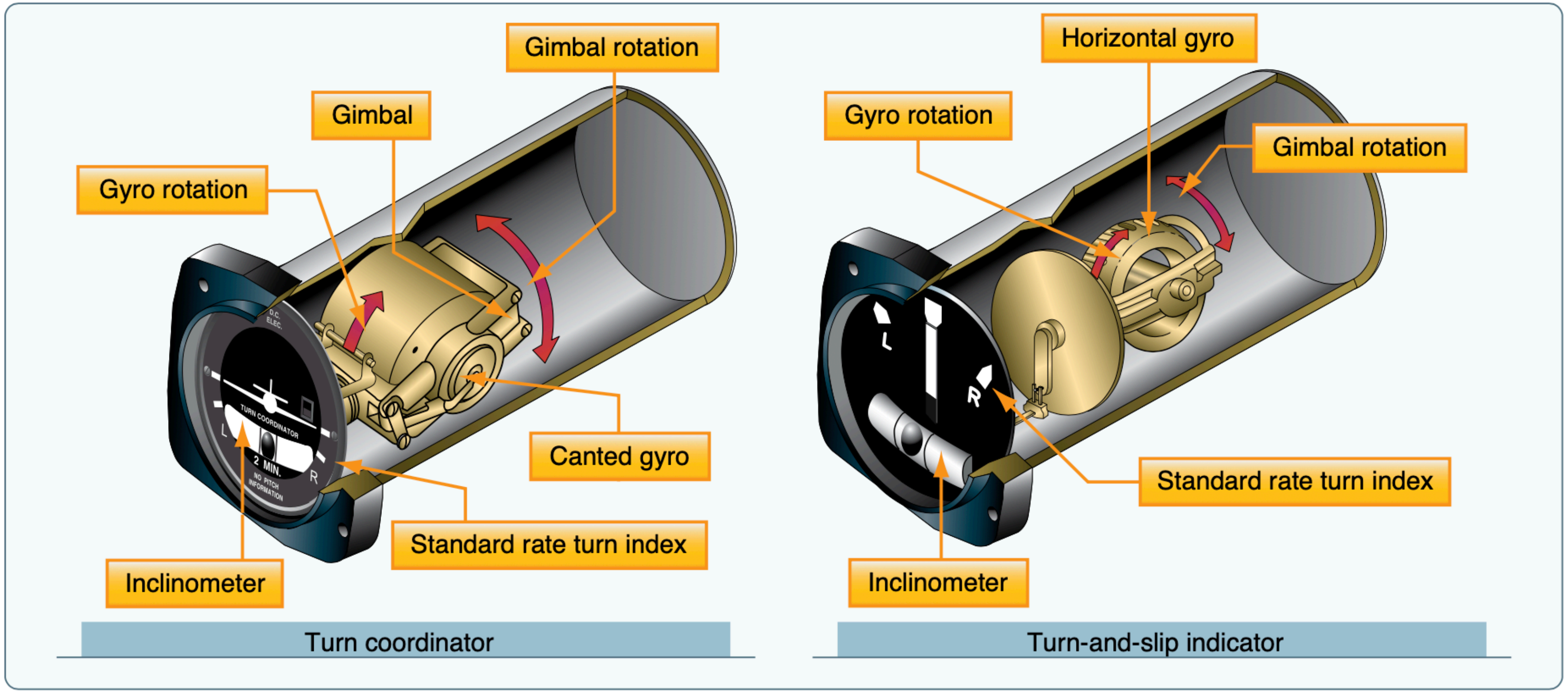
- Operate on the principle of gyroscopic stability
- Corollary: Bicycle wheel stability at low vs high speeds
- Mechanical flight instruments use a spinning rotor
  - Vacuum pump (engine-driven or electric)
  - Pressure
  - Electrical motor
- Aircraft rotates around the gyro

Vacuum Instruments

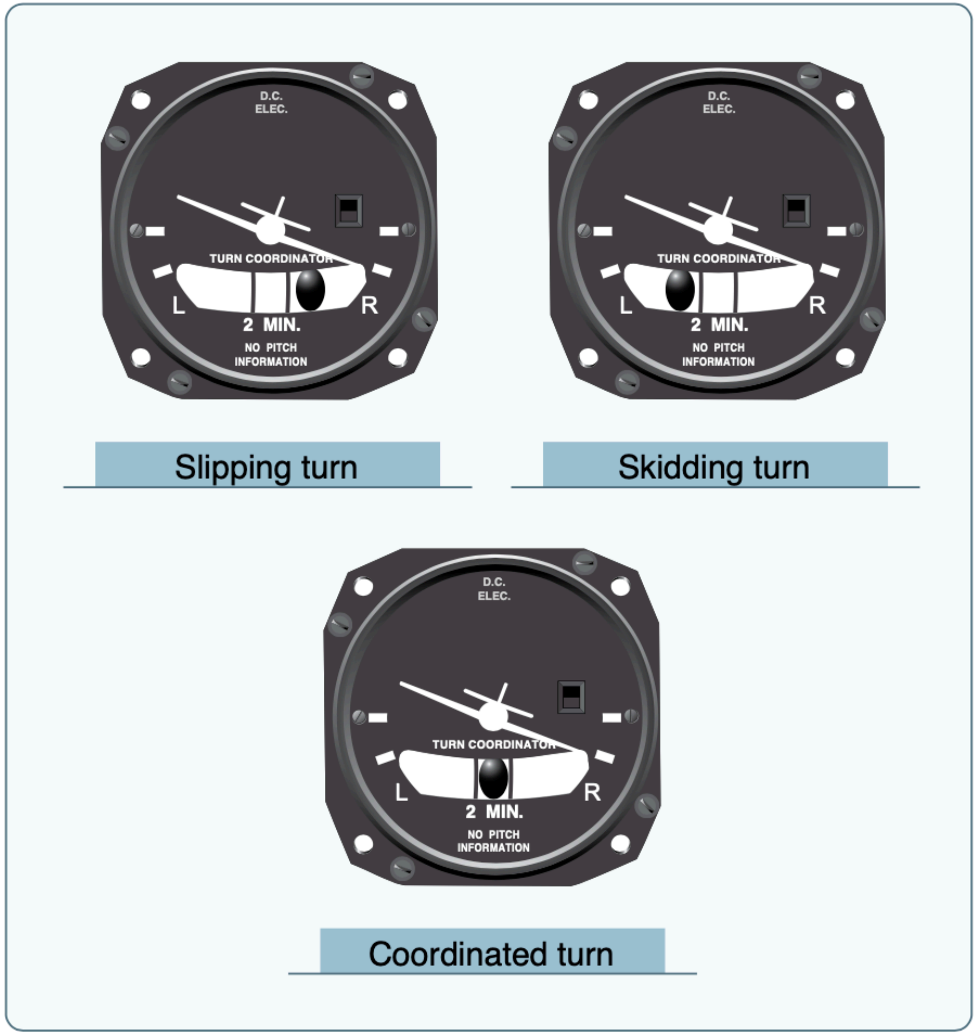


- In a standard "six pack":
  - Vacuum-driven gyroscopic system drive the attitude and heading indicators
  - Sometimes the turn coordinator

Turn Coordinator

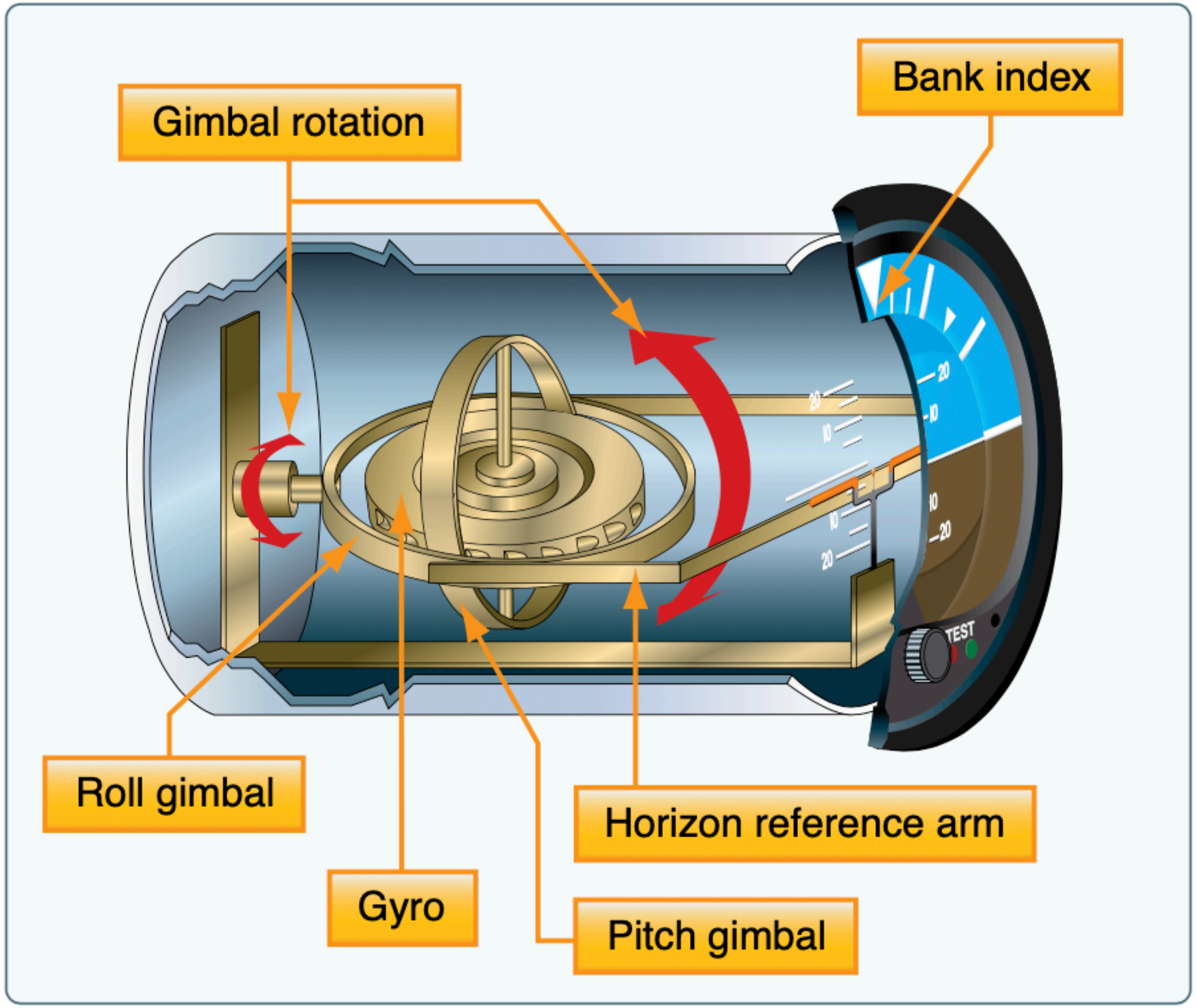


- 1-axis gyro
- Indicates rate of yaw/turn rate around the vertical axis
- No primary bank information



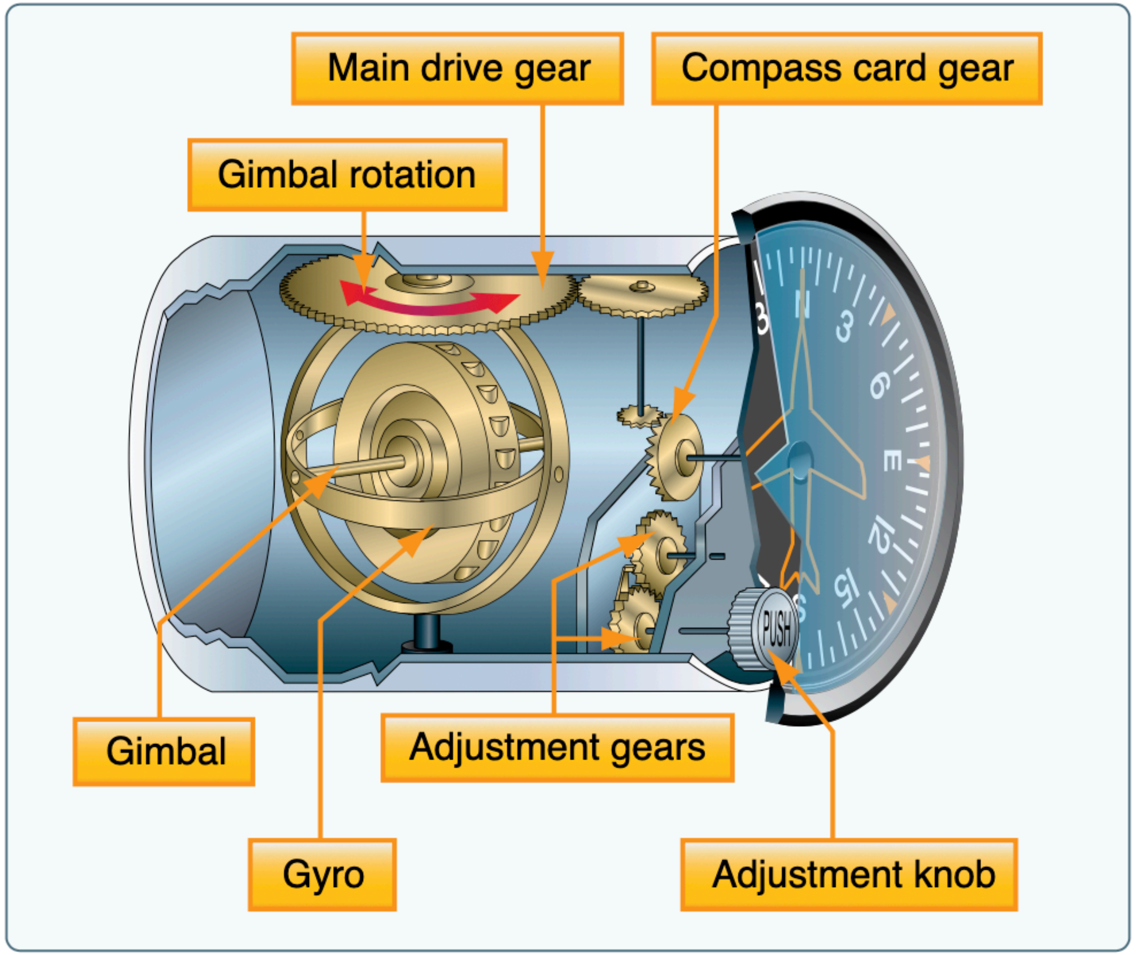
Inclinometer

- Indicates coordination of flight
- Not gyro or electrically operated
- Ball with mass in a fluid, like a level



Attitude indicator

- Indicates rotational position of the longitudinal (pitch) and lateral axis (roll)
- Adjustment knob to set horizon to level
- Pitch limit usually around 100-110°
- Bank limit around 60-70°



Directional Gyro/Heading Indicator

- Indicates rotational position about the vertical axis
- Must be continually calibrated with the magnetic compass
  - Earth rotates in space at a rate of 15° in 1 hour
  - Gyroscopic precession: gimbal is not frictionless, small forces cause position drift

Horizontal Situation Indicator (HSI)

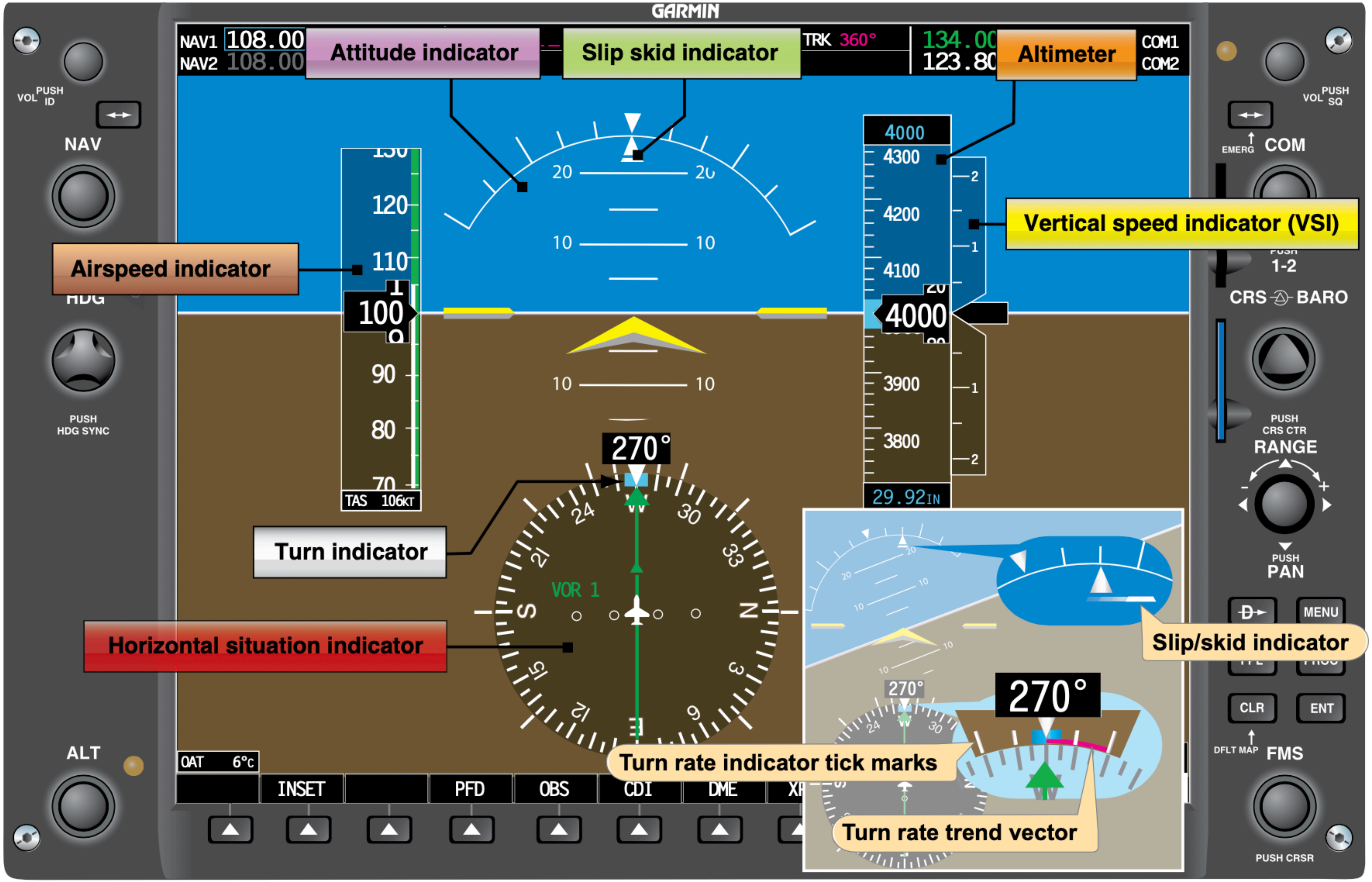
- Often overlay VOR CDI needles
- Some can be "slaved" to a magnetic sensing device
  - Eliminates the need to manually calibrate with the magnetic compass

Attitude and Heading Reference System (AHRS)

- No moving parts
- Uses accelerometers for roll/pitch/yaw information
- Use a magnetometer for heading information, often mounted on the wing
- Feeds modern glass-panel displays
- Less susceptible to mechanical failures

Vacuum System Failures

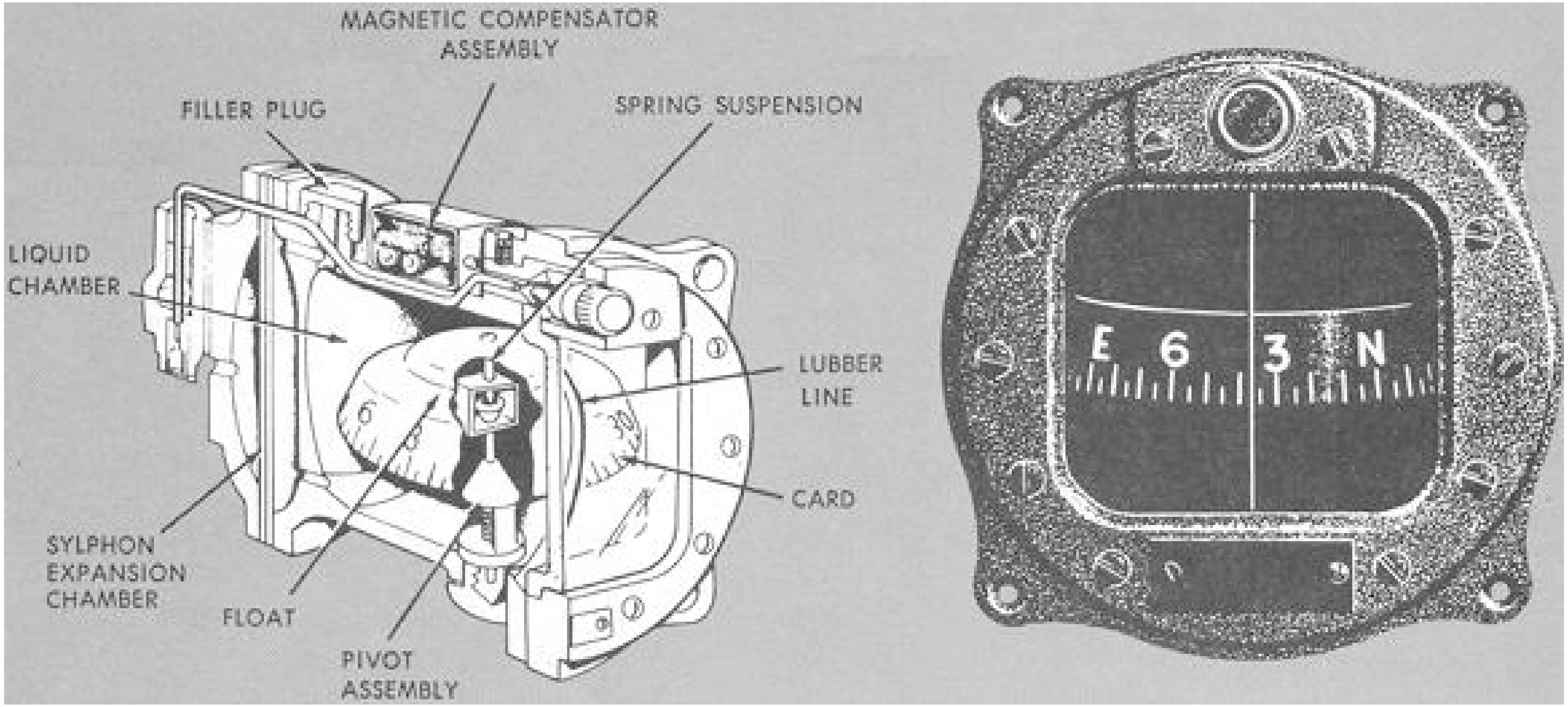
- A loss of vacuum pressure will result in a slow spin-down of gyros
- An attitude indicator will show a slow lean/dive
- Utilize a cross-checking scan



Attitude indicator
Slip skid indicator
Altimeter
Vertical speed indicator (VSI)
Airspeed indicator
Turn indicator
Horizontal situation indicator
Slip/skid indicator
Turn rate indicator tick marks
Turn rate trend vector

Magnetic Compass

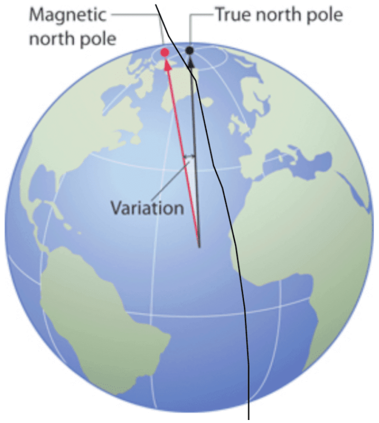
- Self-contained, no power needed
- Operates on the magnetic pull of the Earth

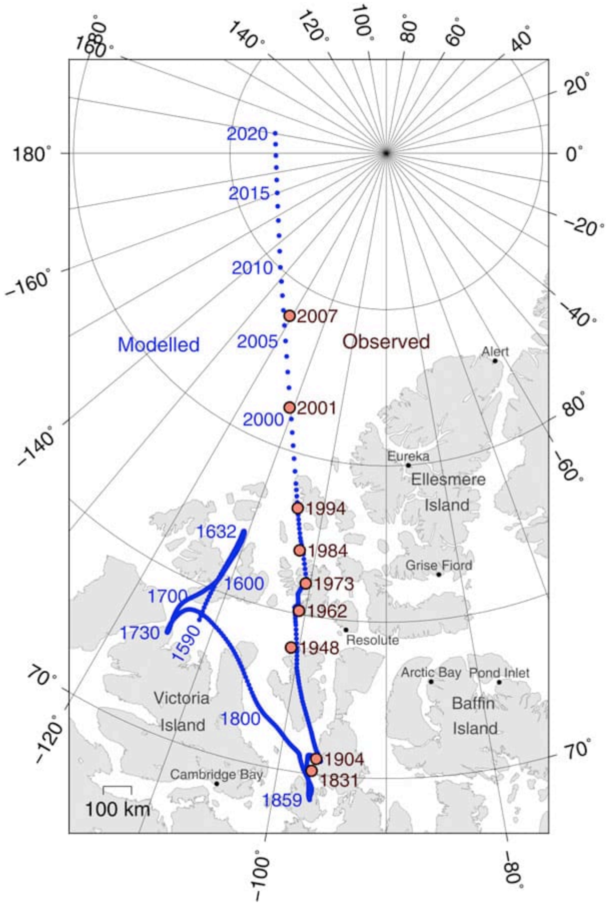

MAGNETIC COMPENSATOR ASSEMBLY
FILLER PLUG
SPRING SUSPENSION
LIQUID CHAMBER
LUBBER LINE
CARD
SYLPHON EXPANSION CHAMBER
FLOAT
PIVOT ASSEMBLY
E 6 3 N

Compass Errors and Variation

- Magnetic variation: Magnetic north vs true north
- Magnetic deviation: Magnetic fields from electrical equipment in an aircraft can cause errors
- Magnetic dip errors: North and south turning errors
- Acceleration errors: Accelerating on an east/west heading

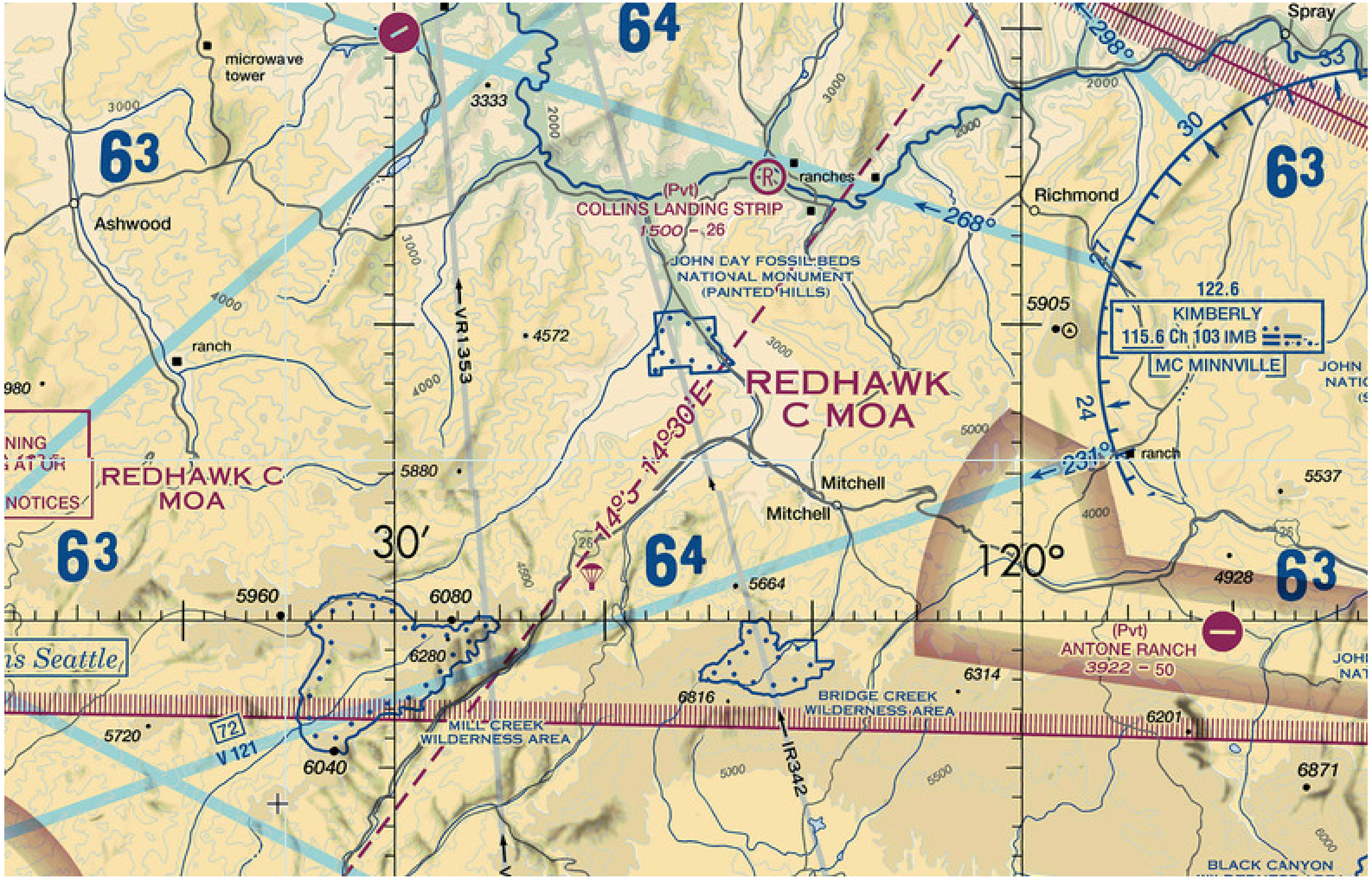
Magnetic Variation



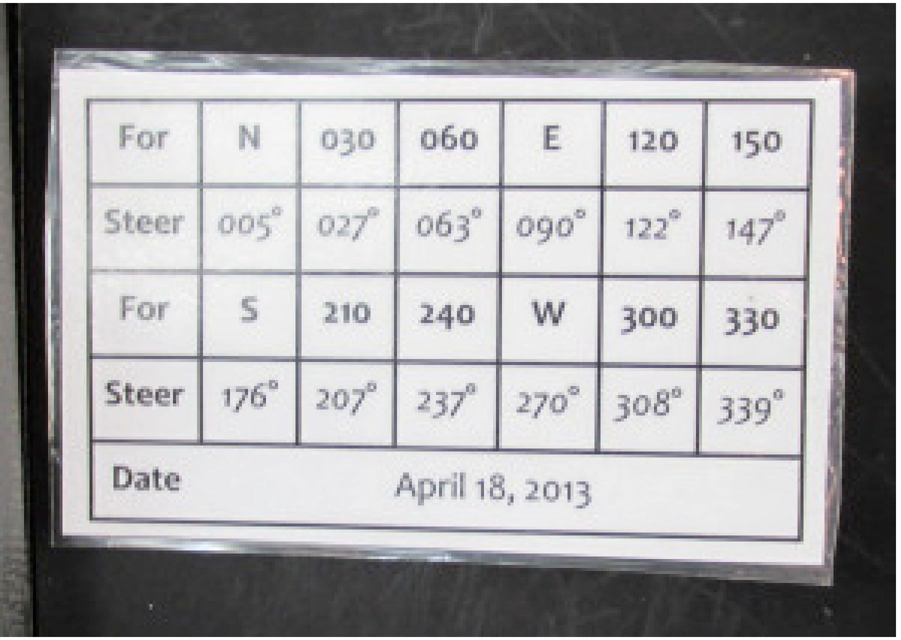


- True North and Magnetic north are not in the same spot
- The difference between true and magnetic is called variation
- This varies depending on your location on Earth

Isogonic Lines - Tells us Magnetic Variation

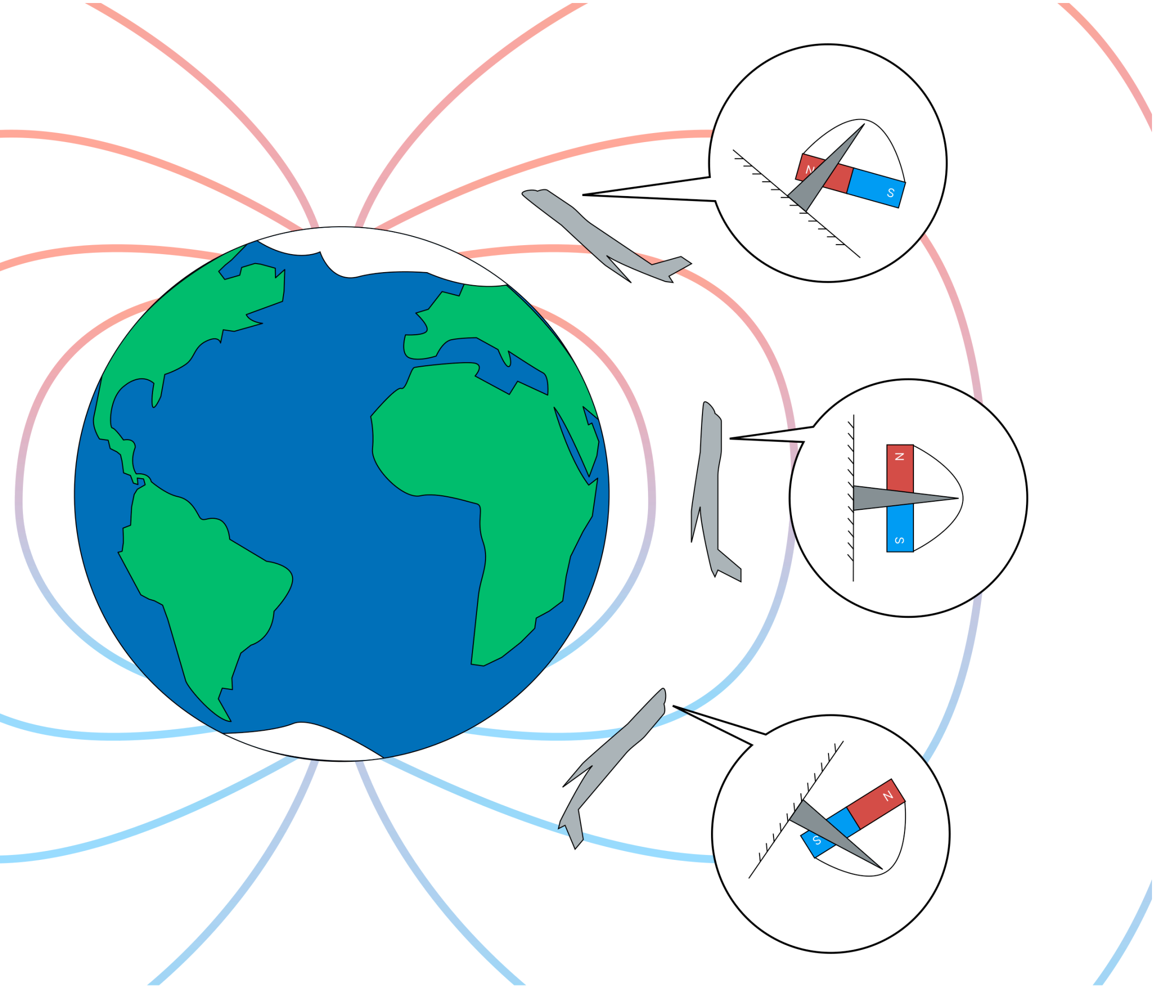


Magnetic Deviation



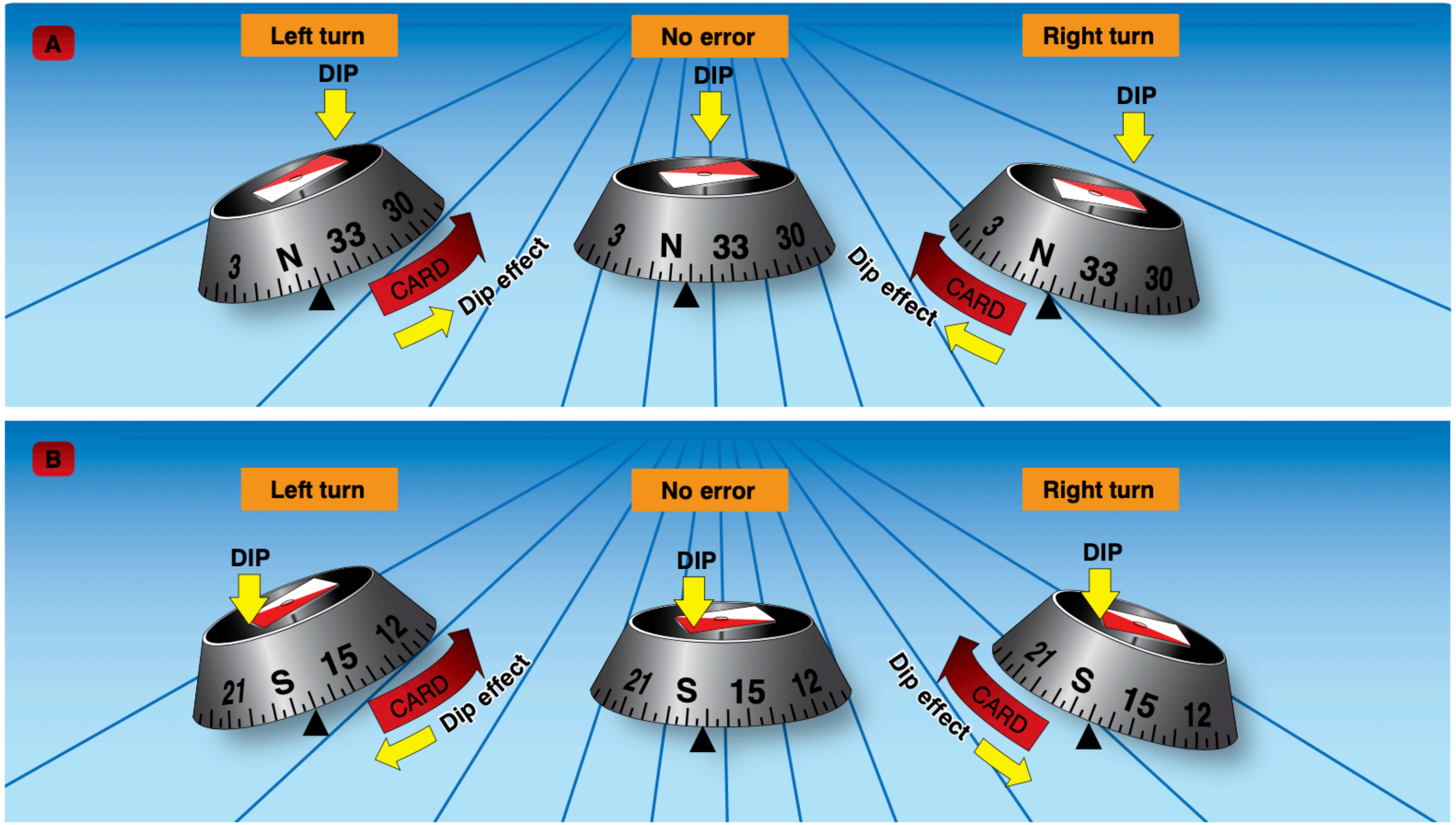
For	N	030	060	E	120	150
Steer	005°	027°	063°	090°	122°	147°
For	S	210	240	W	300	330
Steer	176°	207°	237°	270°	308°	339°
Date	April 18, 2013					

- The magnetic field for various electronic/magnetic/metallic components in the airplane can skew the direction of the compass
- The compass correction card gives you calibration to account for this
- Compass correction cards are specific to each airplane



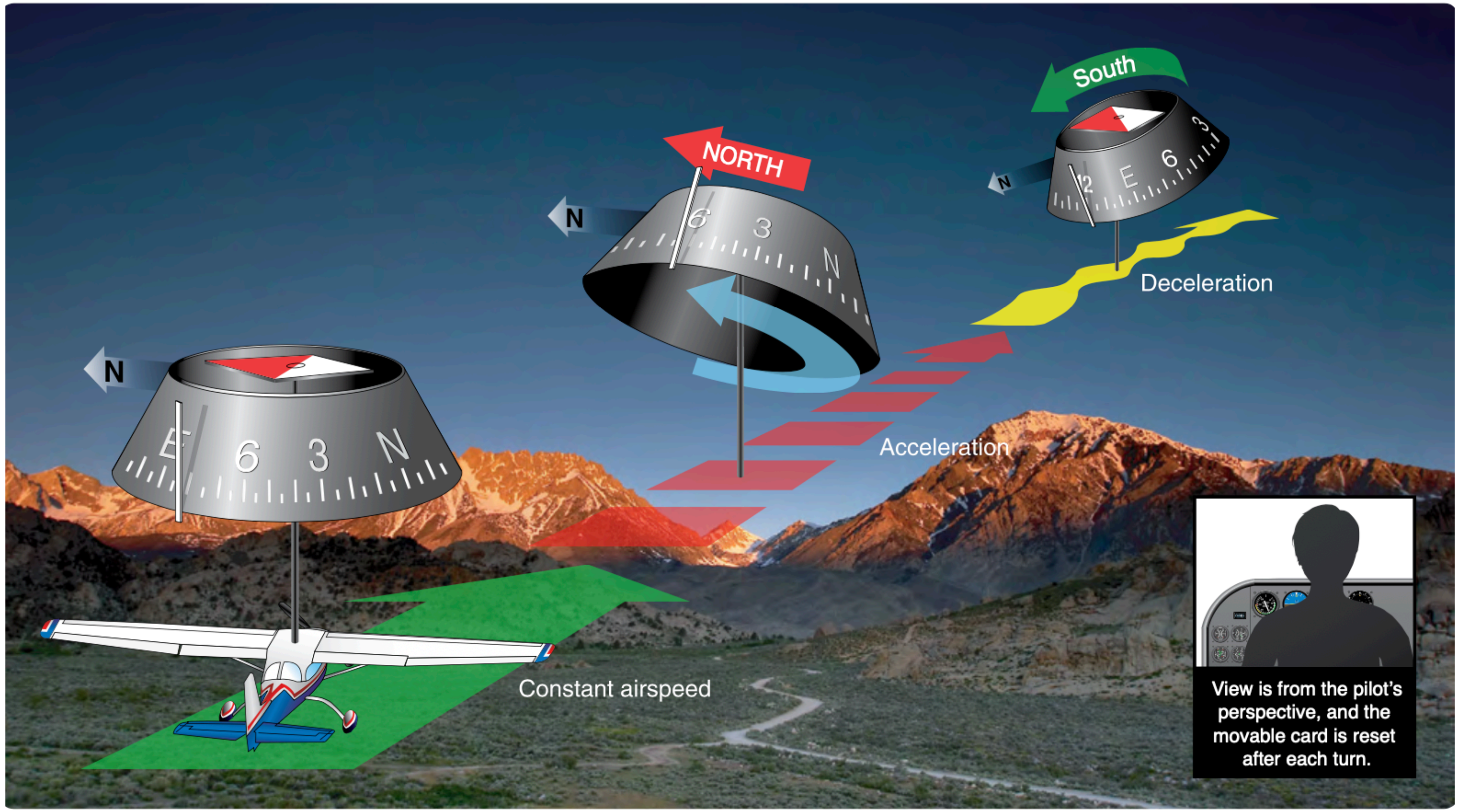
Magnetic Dip

- As you get closer to the poles the vertical component of the magnetic field get stronger (and the horizontal component gets weaker)
- Compasses can compensate for this when they are level
- When they are tilted though, the results may be skew



Magnetic Dip Errors

- When turning through a N or S heading
- North: compass card leads actual heading
- South: compass card lags actual heading
- "UNOS"
  - Undershoot North
  - Overshoot South



Acceleration Errors

- Compass card is not a uniform mass
  - It's a little heavier on the north side, to account for dip
- "ANDS"
  - Accelerate: North
  - Decelerate: South

Getting an Accurate Compass Reading

- Straight and level, unaccelerated flight
- Account for deviation using the compass correction card
- Know when to use true headings vs magnetic headings
- Magnetometer-based (electronic flight displays) systems won't have these errors

Summary

- Pitot-Static instruments
  - Altimeter
  - Vertical Speed Indicator
  - Vertical Speed Indicator
  - Airspeed indicator
- Pitot-static port blockages
- Inclinometer
- Gyroscopic and vacuum Instruments
  - Attitude Indicator
  - Directional Gyro/Heading Indicator
  - Horizontal Situation Indicator (HSI)
- AHRS and EFIS Systems
- Vacuum System Failures
- Magnetic Compass
  - Compass errors

Knowledge Check

If you were to lose electrical power to the avionics bus in your airplane, which instruments would stop working?

Knowledge Check

Flying in an airplane with a vacuum system, you notice that you heading indicator is starting to drift and the attitude indicator is leaning to the left. What might this indicate?

Knowledge Check

You're turning to a heading a 360° N using the magnetic compass. How would you ensure you roll out right on your heading?