Private Pilot (ASEL) Ground School Course

Lesson 08 | Aircraft Flight Instruments

Lesson Overview

Lesson Objectives:

- Develop an understanding of how the flight instruments work on an aircraft.
- Develop an understanding of how modern cockpits display information digitally.

Lesson Completion Standards:

- Student demonstrates satisfactory knowledge of aircraft flight instruments by answering questions and actively participating in classroom discussions.

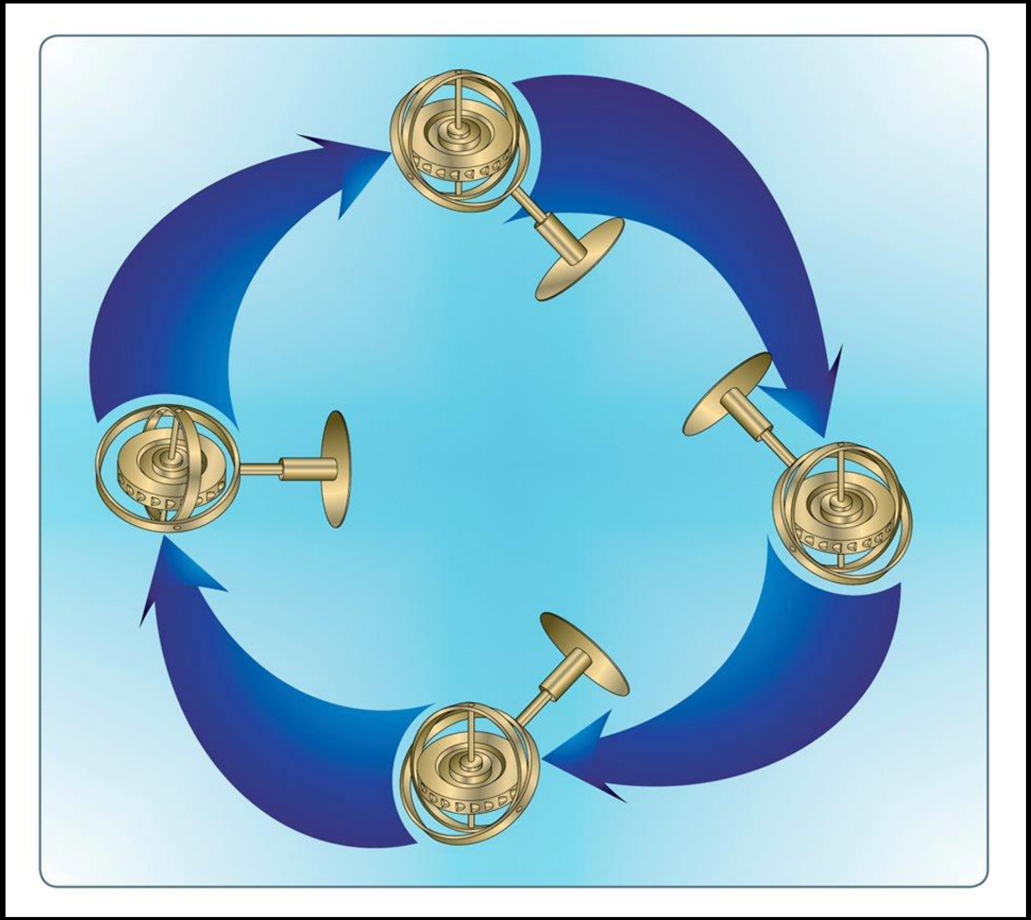
Gyroscopic Instruments

Aircraft Flight Instruments

Gyroscopic Instruments

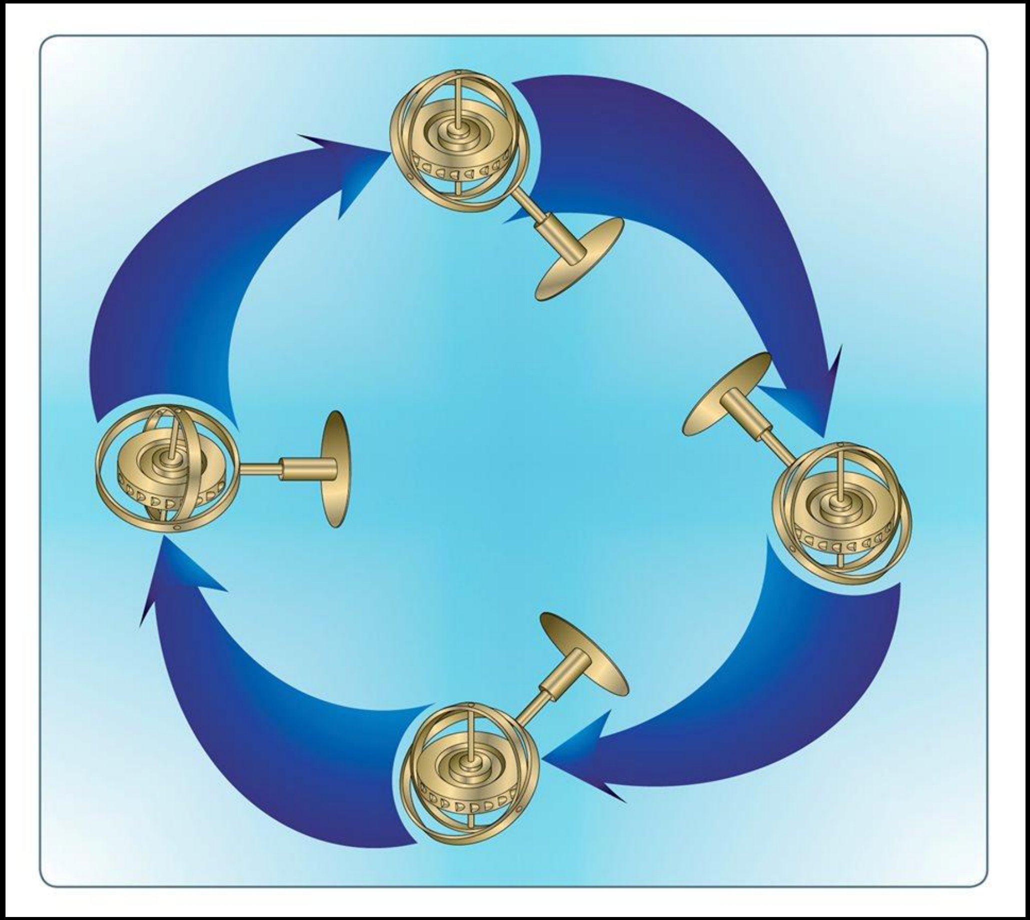
- Attitude Indicator, Heading Indicator, Turn Coordinator

Gyroscopic Systems



- The two characteristics of gyroscopes are rigidity in space and precession
- These systems include attitude, heading, and rate instruments, along with their power sources

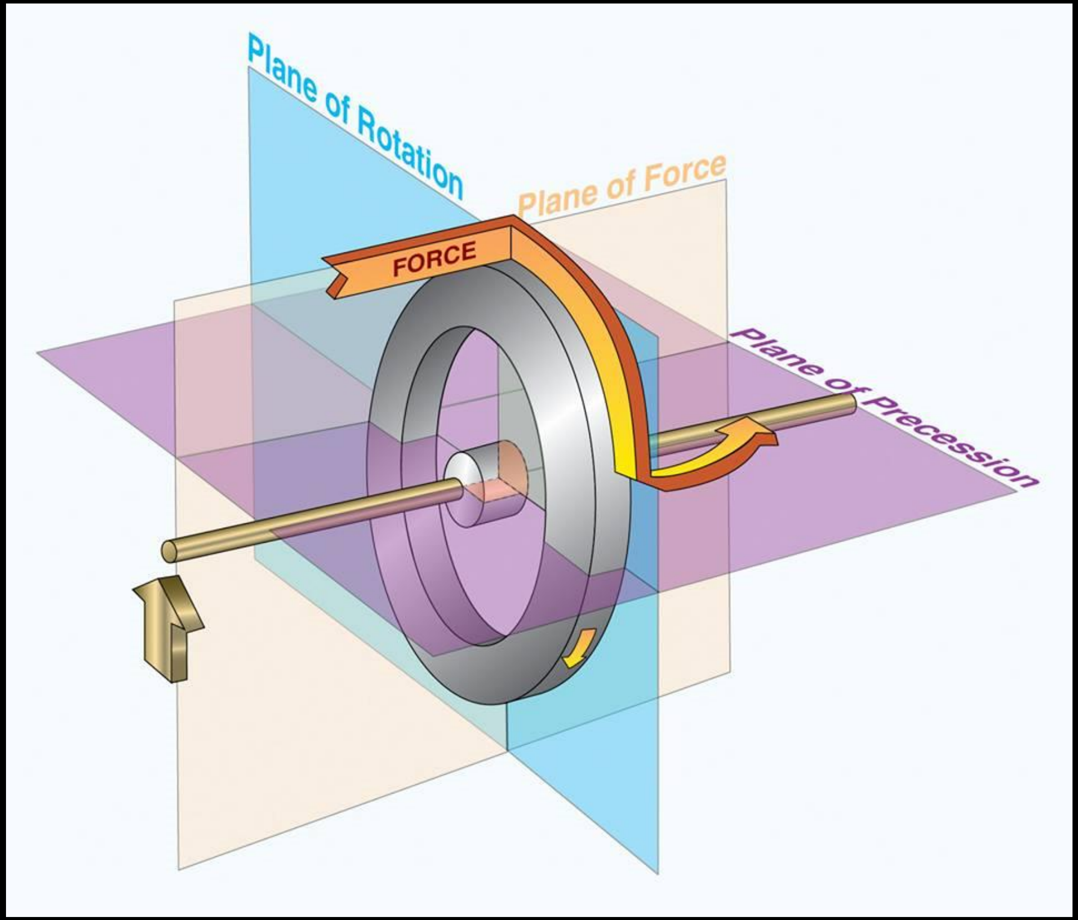
Gyroscopic Systems



- Include a gyroscope that is a small wheel with its weight concentrated around its periphery
- When this wheel is spun at high speed, it becomes rigid and resists tilting or turning in any direction other than around its spin axis
- Attitude and heading instruments operate on the principle of rigidity
- The gyro remains rigid in its case and the aircraft rotates about it

Rate Indicators Precession

- Rate indicators, such as turn indicators and turn coordinators, operate on the principle of precession
- The gyro precesses (or rolls over) proportionate to the rate the aircraft rotates about one or more of its axes

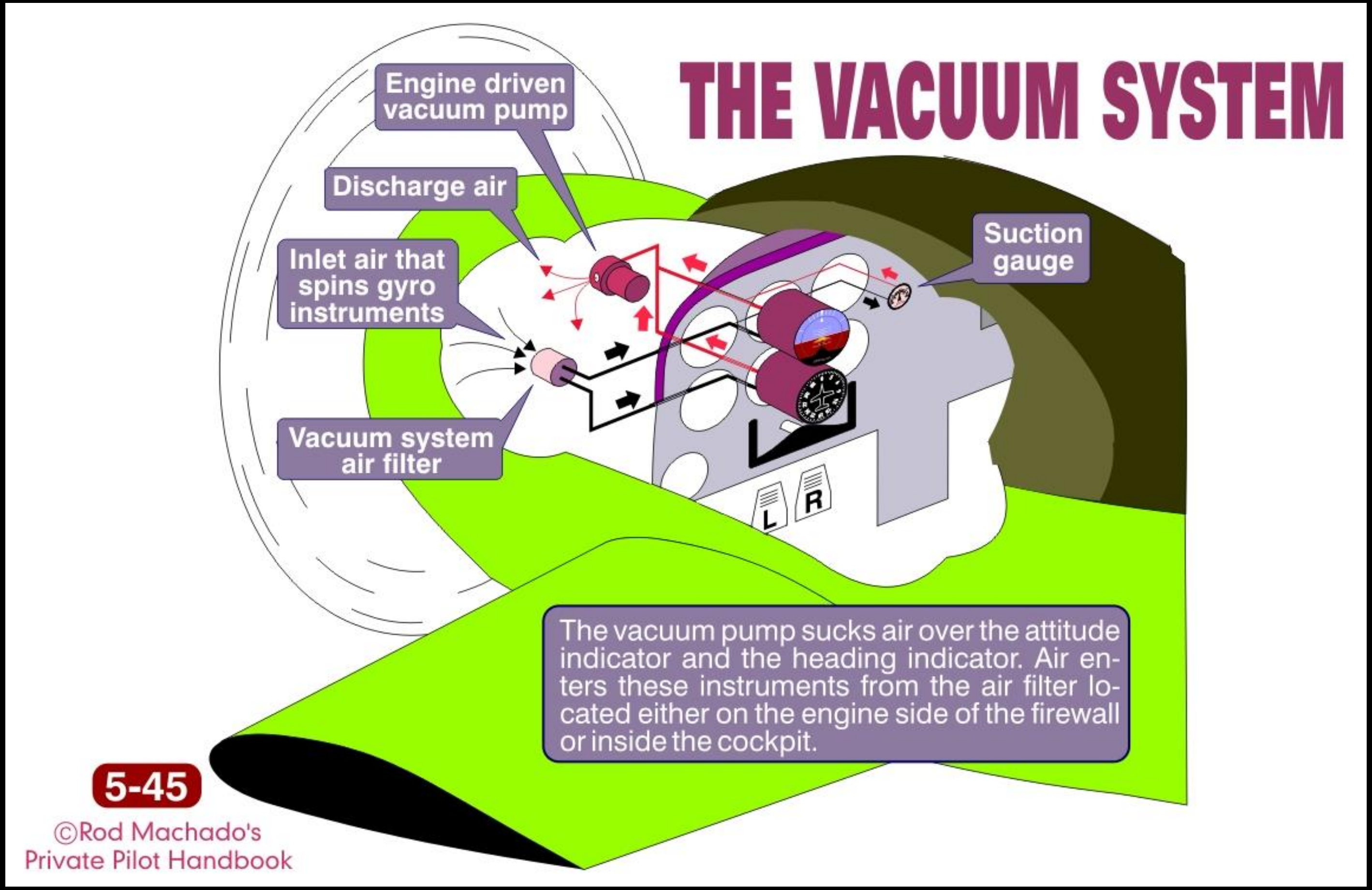


Gyroscopic Power Sources

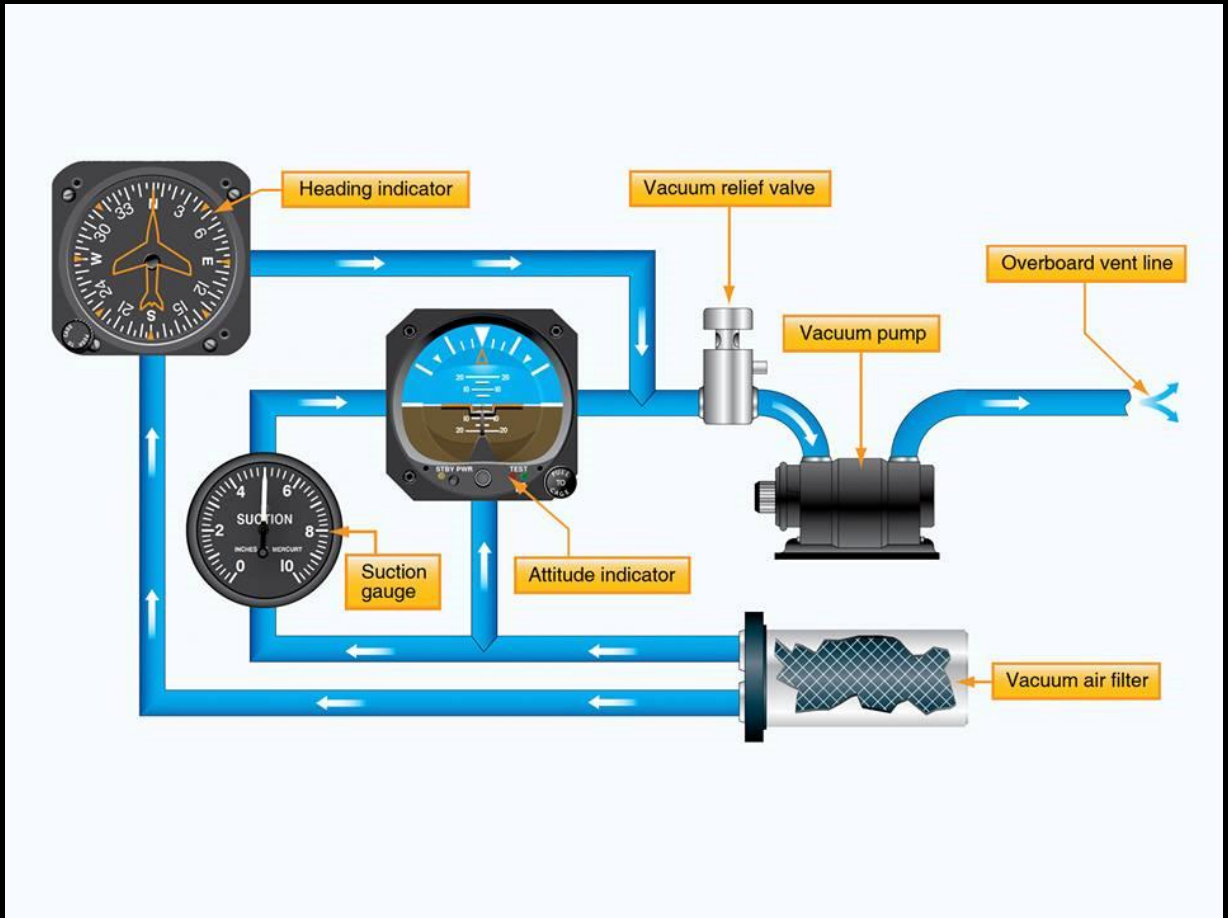
- Redundancy in the flight instruments provided so that any single failure does not deprive the pilot of the ability to safely conclude the flight
- Gyroscopic instruments are crucial for instrument flight so are powered by separate electrical or pneumatic sources:
  - Attitude Indicator - Vacuum System
  - Heading Indicator - Vacuum System
  - Turn Coordinator - Electric

Vacuum System

- Powers Attitude and Heading Indicators



Pneumatic System

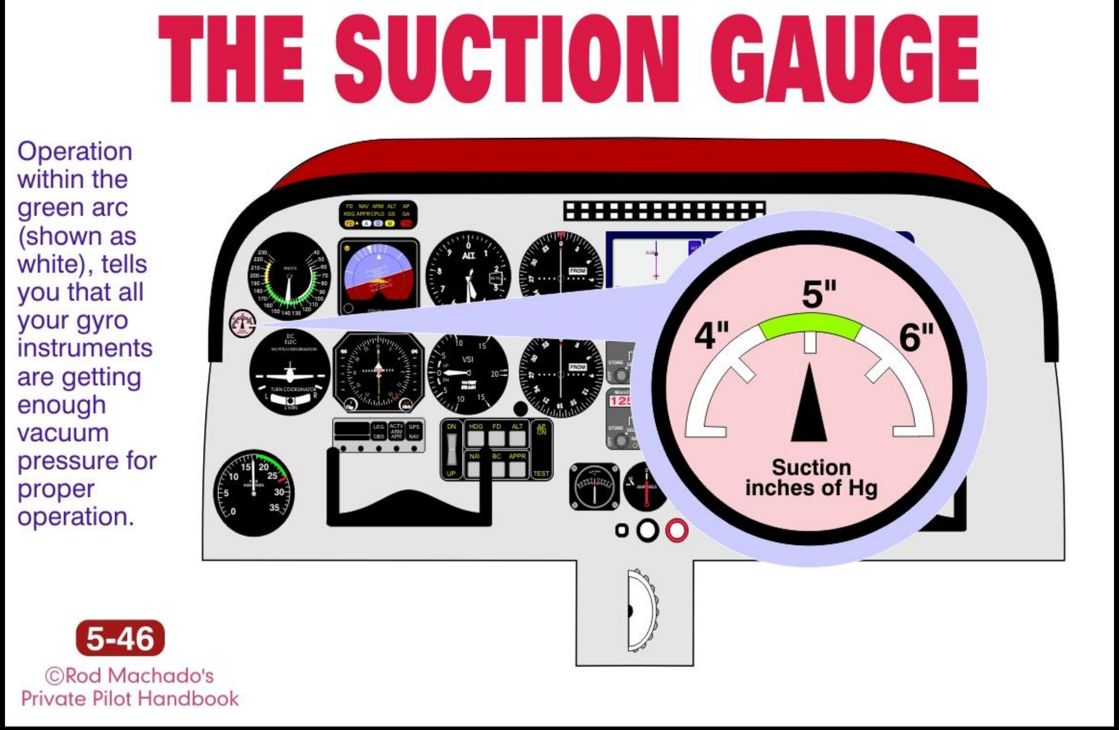


- Pneumatic gyros are driven by a jet of air impinging on buckets cut into the periphery of the wheel
- This stream of air is obtained by evacuating the instrument case with a vacuum source and allowing filtered air to flow into the case through a nozzle to spin the wheel

Vacuum Pump

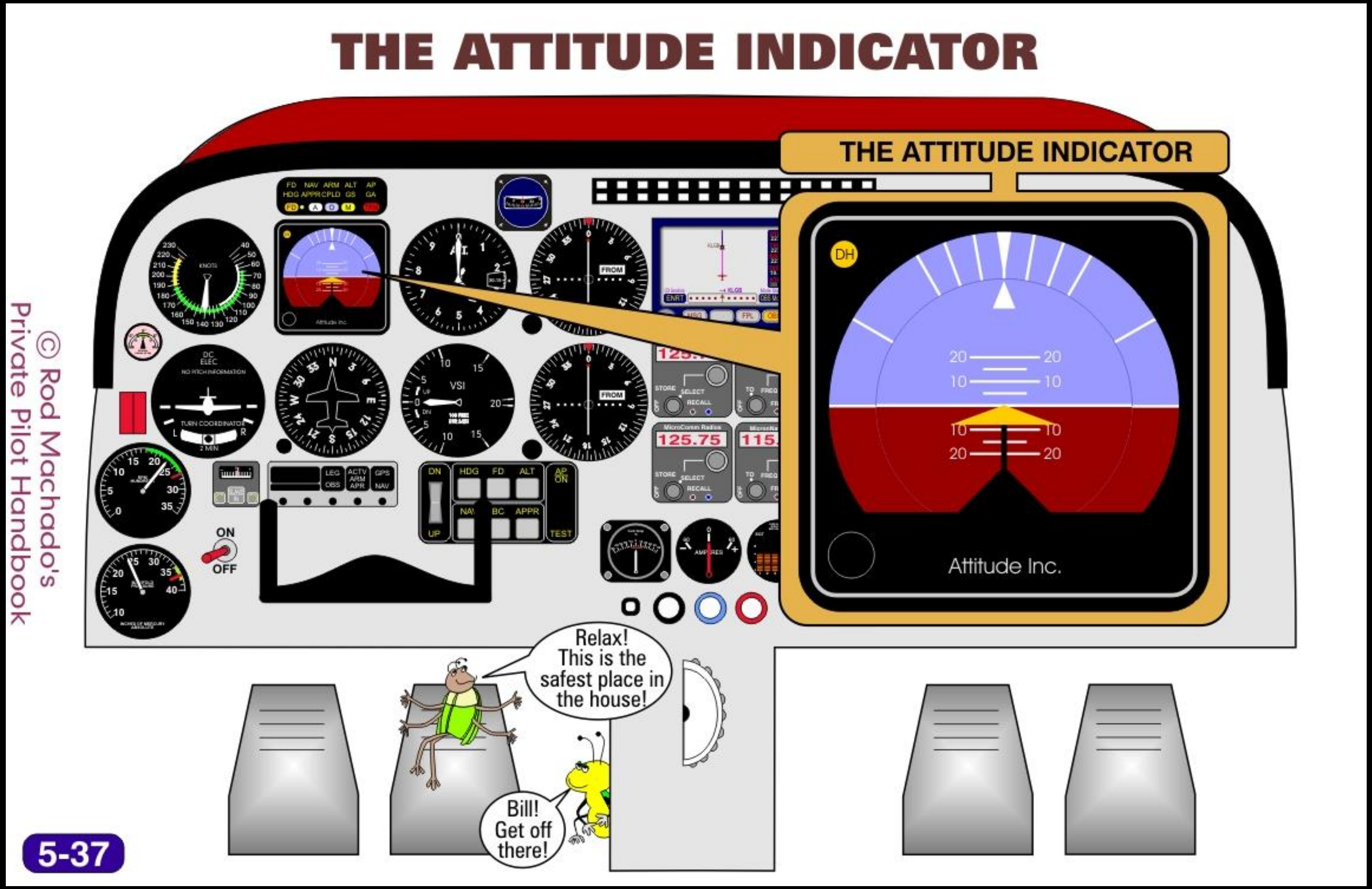
- Engine driven

Suction Gauge



- Malfunctions of the gyro instruments are usually caused by the vacuum pump not providing sufficient vacuum pressure
- Operations outside the normal range (green arc) usually result in erroneous readings on the gyro instruments
- On some airplanes, low power settings (such as a low engine idle before takeoff or long, low-power descents) produce insufficient vacuum for the instruments

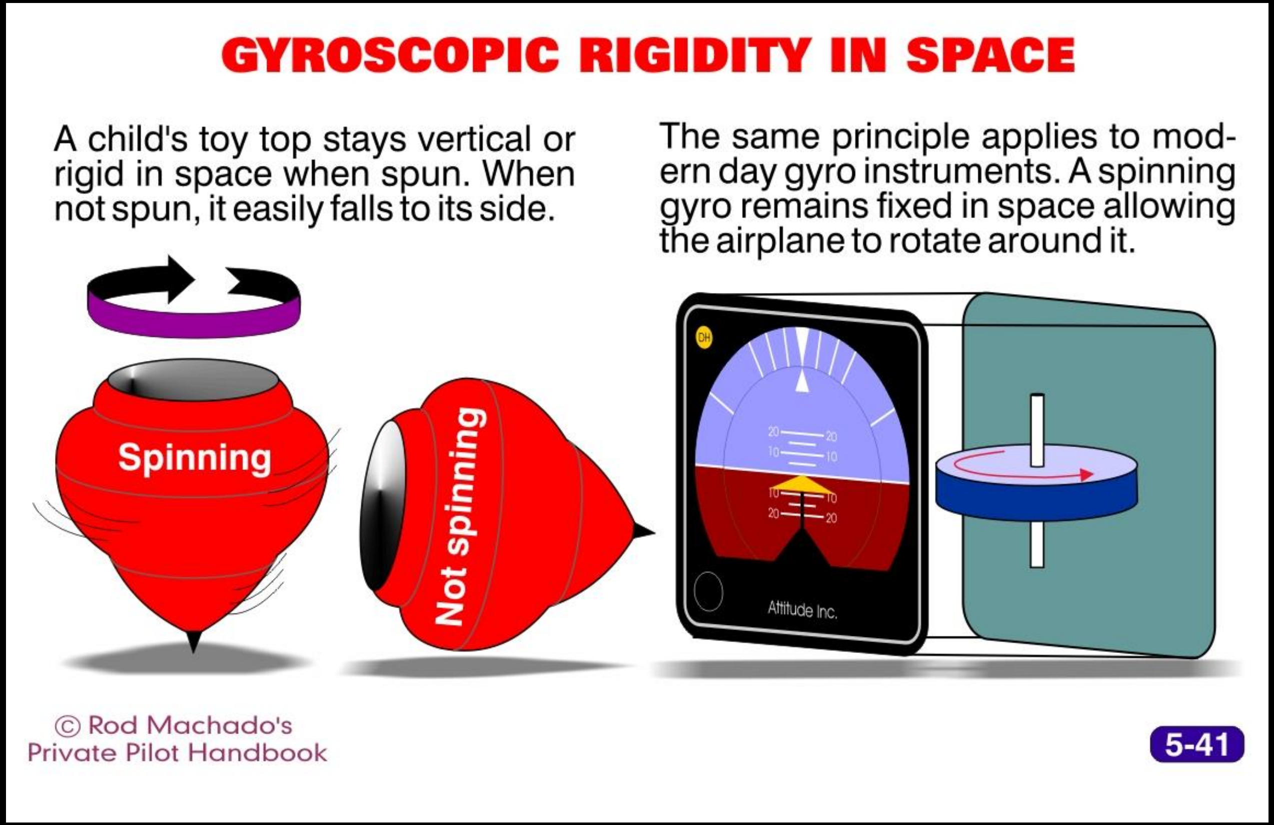
Attitude Indicator



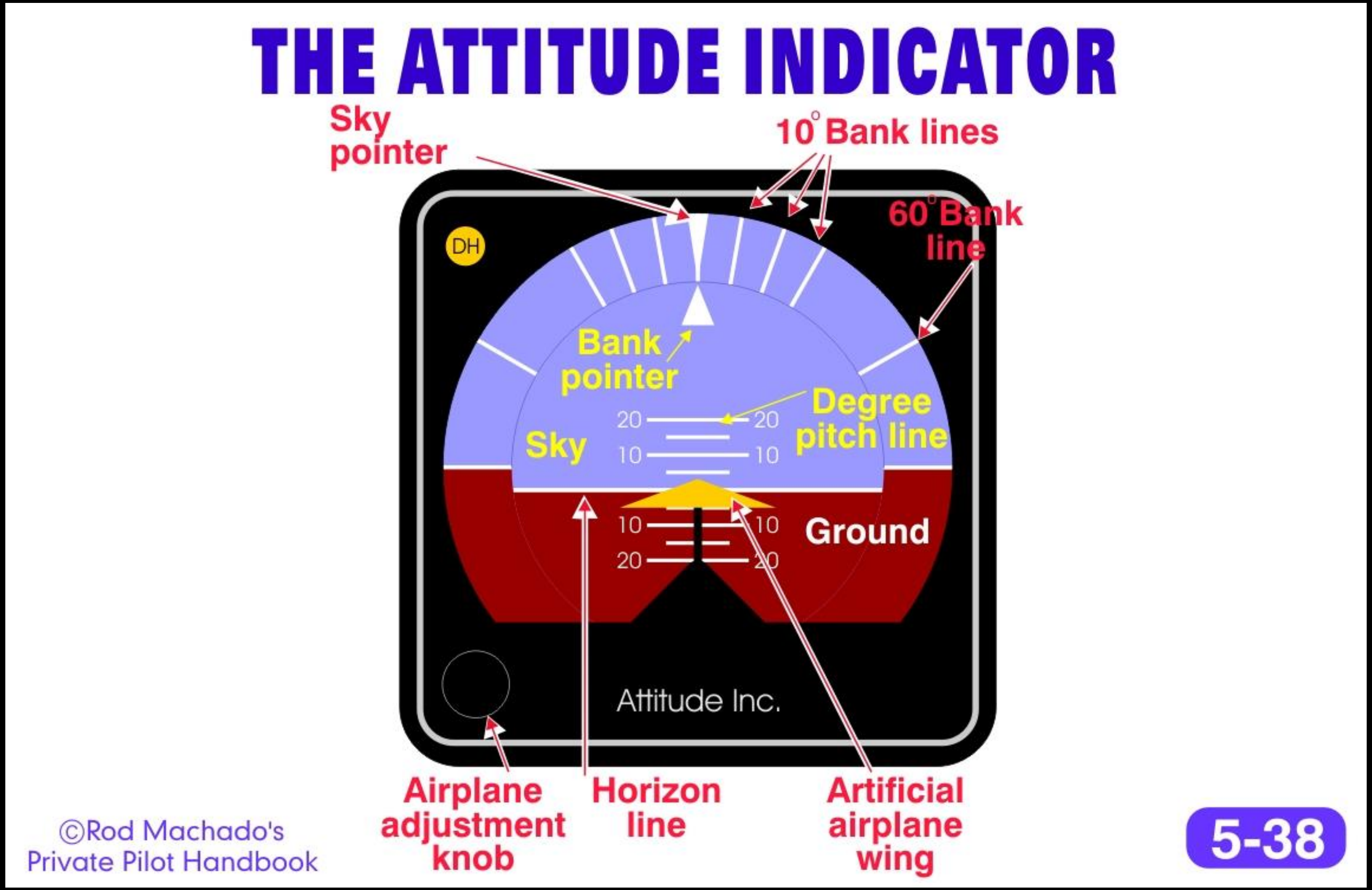
- Gyroscopic instrument operating on the principle of rigidity in space
- Shows airplane pitch and bank

Rigidity in Space

- When the attitude indicator's gyro is spun by air, it remains rigid or fixed in space
- The airplane rotates around the gyro and mechanically converts this movement into pitch and bank information on the face of the horizon card

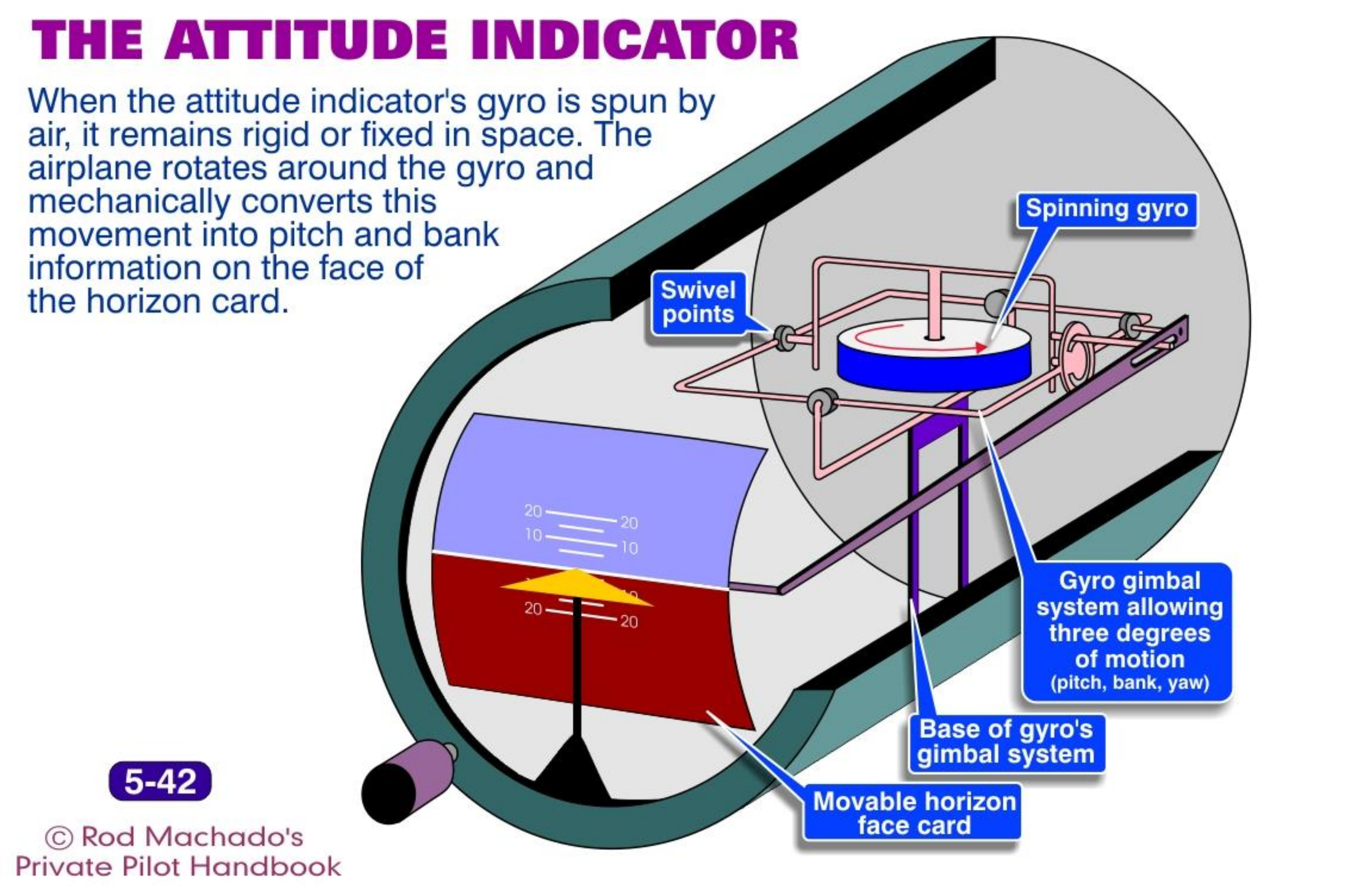


Attitude Indicator

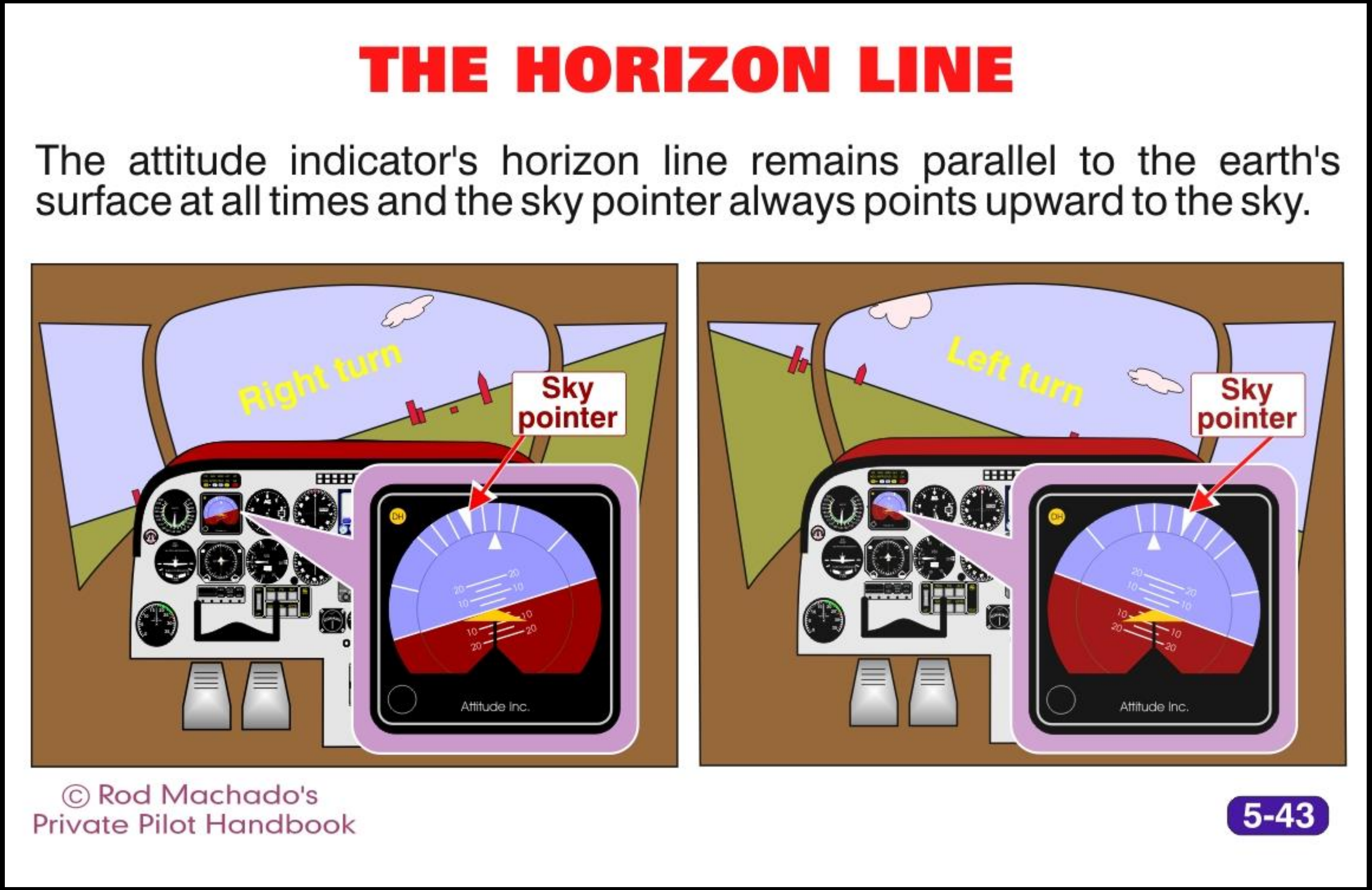


- A symbolic set of airplane wings resting over a moveable horizon card
- The card shows a white horizon line, a light colored area above the line representing the sky and a darker colored area below representing the ground
- Bank and pitch markings are also shown

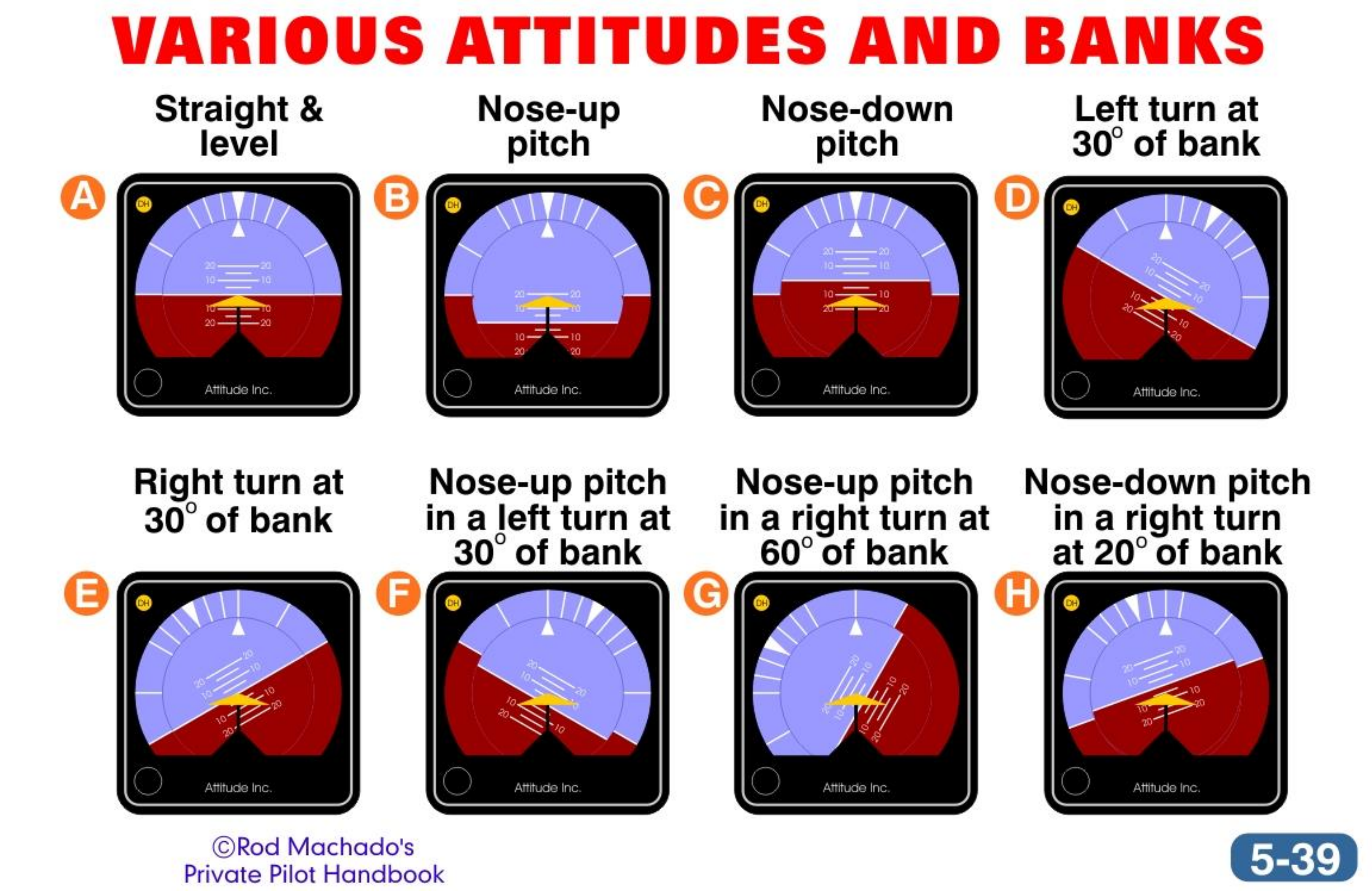
Attitude Indicator



Attitude Indicator Horizon Line

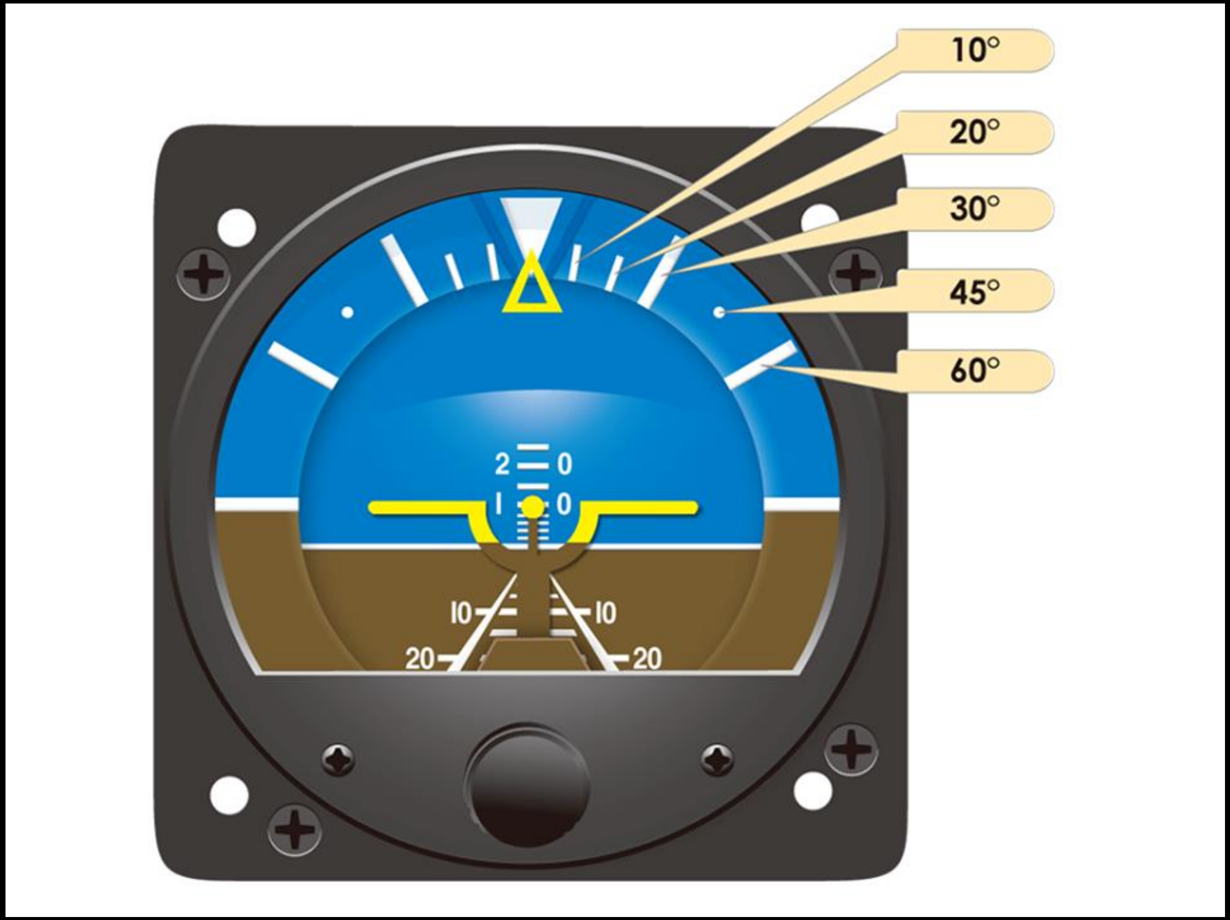


Pitch Attitude and Bank Information

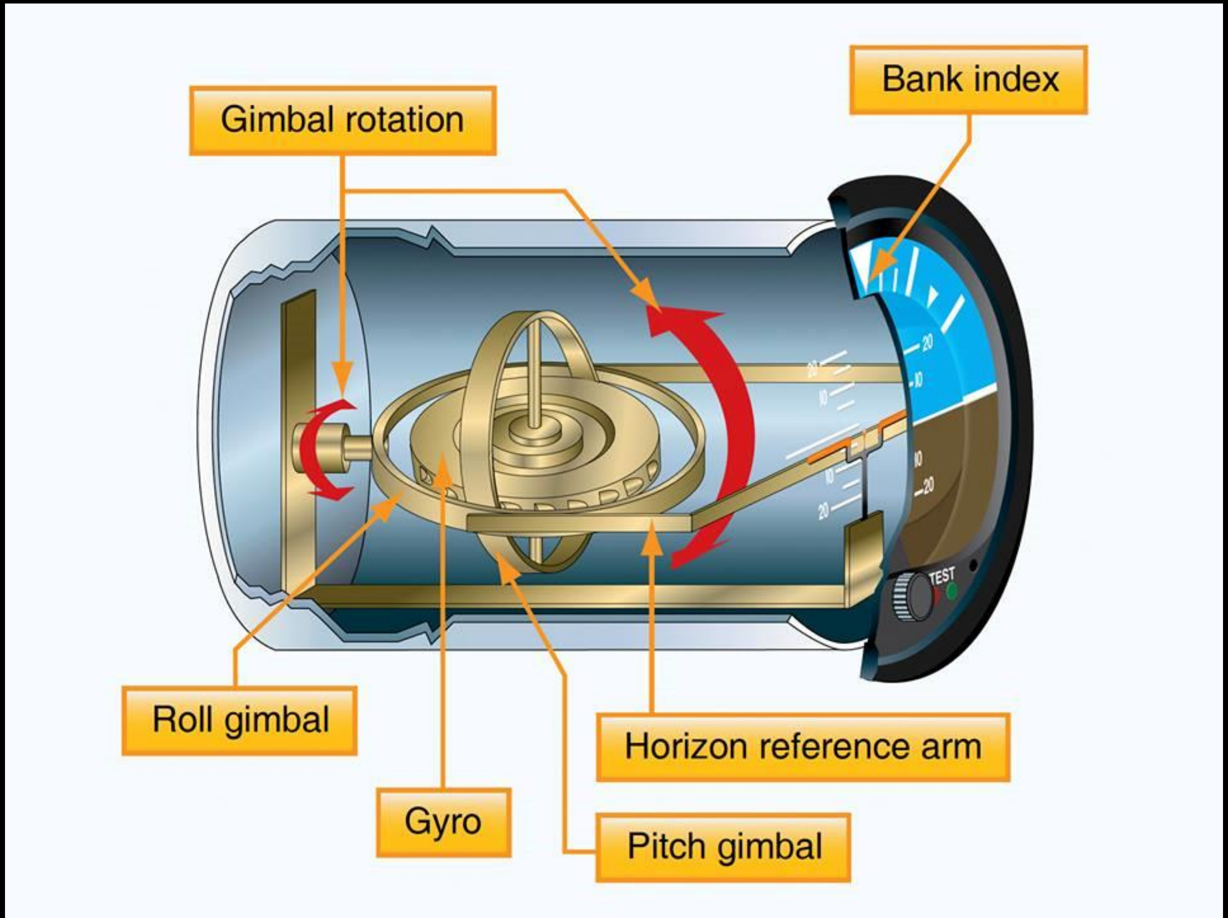


Attitude Indicator

- Provides an immediate, direct and corresponding indication of any change of aircraft pitch and bank attitude in relation to the natural horizon
- It is the pilot's primary instrument during transitions of pitch or bank attitudes



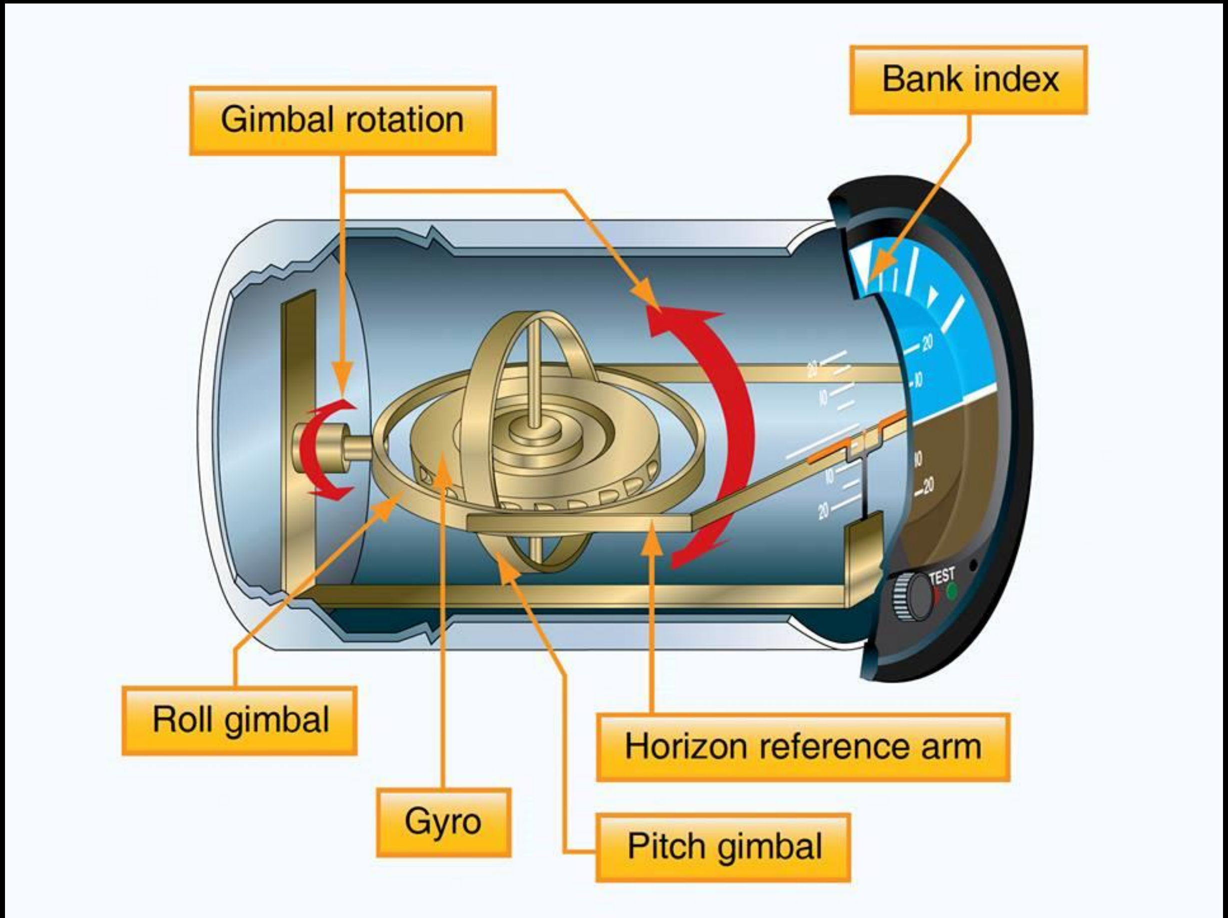
Attitude Indicator



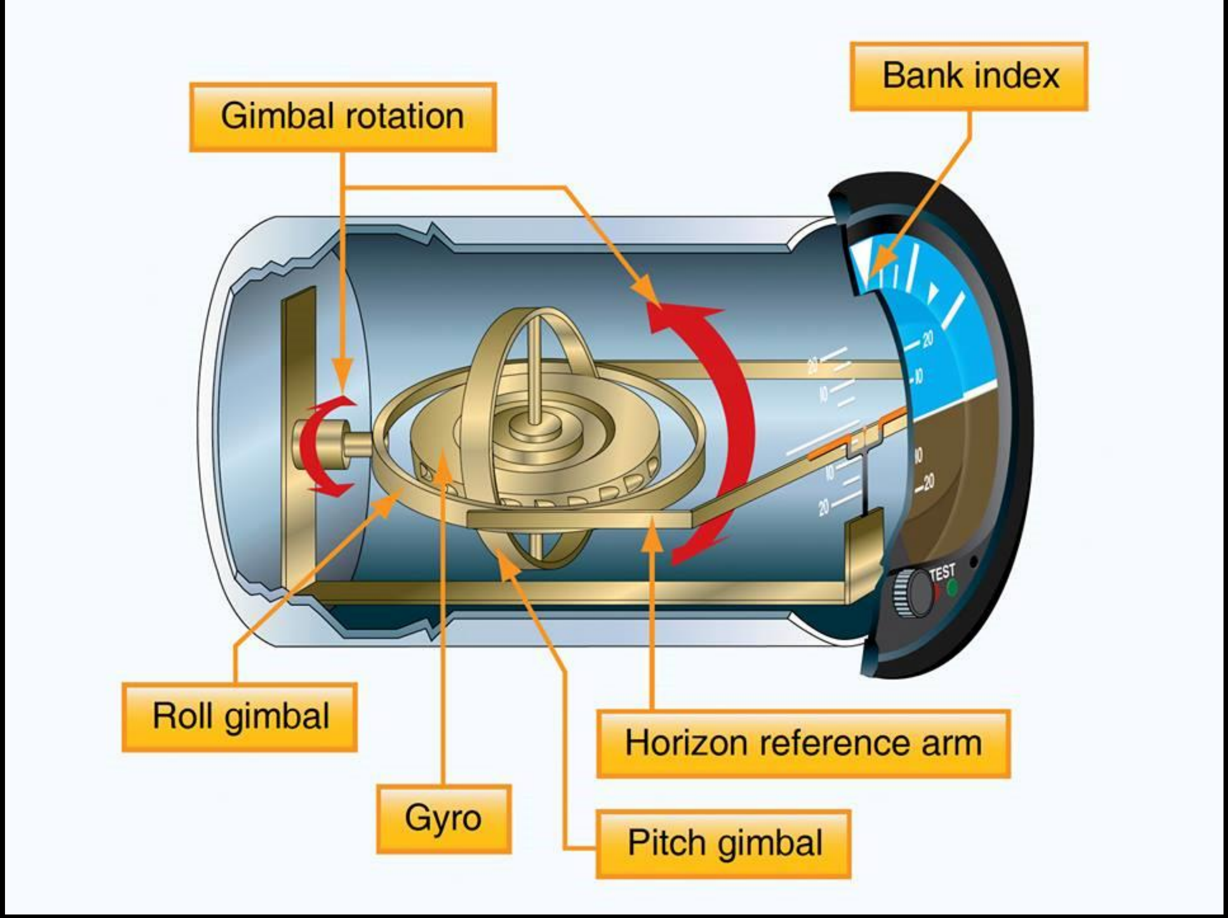
- Brass wheel with a vertical spin axis, spun at high speed by either a stream of air impinging on buckets cut into its periphery, or by an electric motor
- Gyro is mounted in a double gimbal, which allows the aircraft to pitch and roll about the gyro as it remains fixed in space
- A horizon disk is attached to the gimbals so it remains in the same plane as the gyro, and the aircraft pitches and rolls about it
- The disk has a line representing the horizon and both pitch marks and bank-angle lines

Attitude Indicator

- To function properly, the gyro must remain vertically upright while the aircraft rolls and pitches around it
- The bearings have a minimum of friction; however, even this small amount places a restraint on the gyro producing precession and causing the gyro to tilt
- To minimize this tilting, an erection mechanism inside the instrument case applies a force any time the gyro tilts from its vertical position
- This force acts in such a way to return the spinning wheel to its upright position



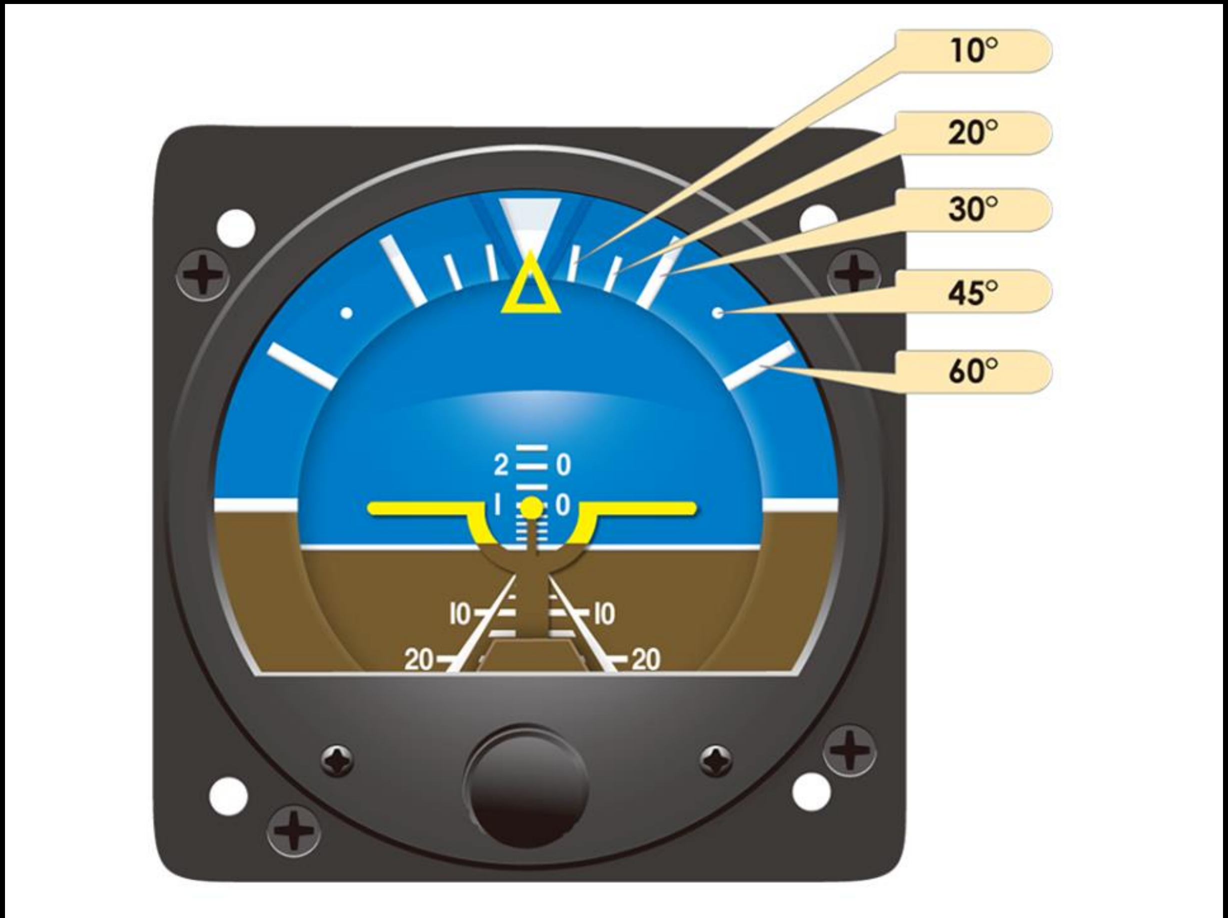
Attitude Indicator



- When an aircraft engine is first started and pneumatic or electric power is supplied to the instruments, the gyro is not erect
- A self-erecting mechanism inside the instrument actuated by the force of gravity applies a precessing force, causing the gyro to rise to its vertical position
- This erection can take as long as 5 minutes, but is normally done within 2 to 3 minutes

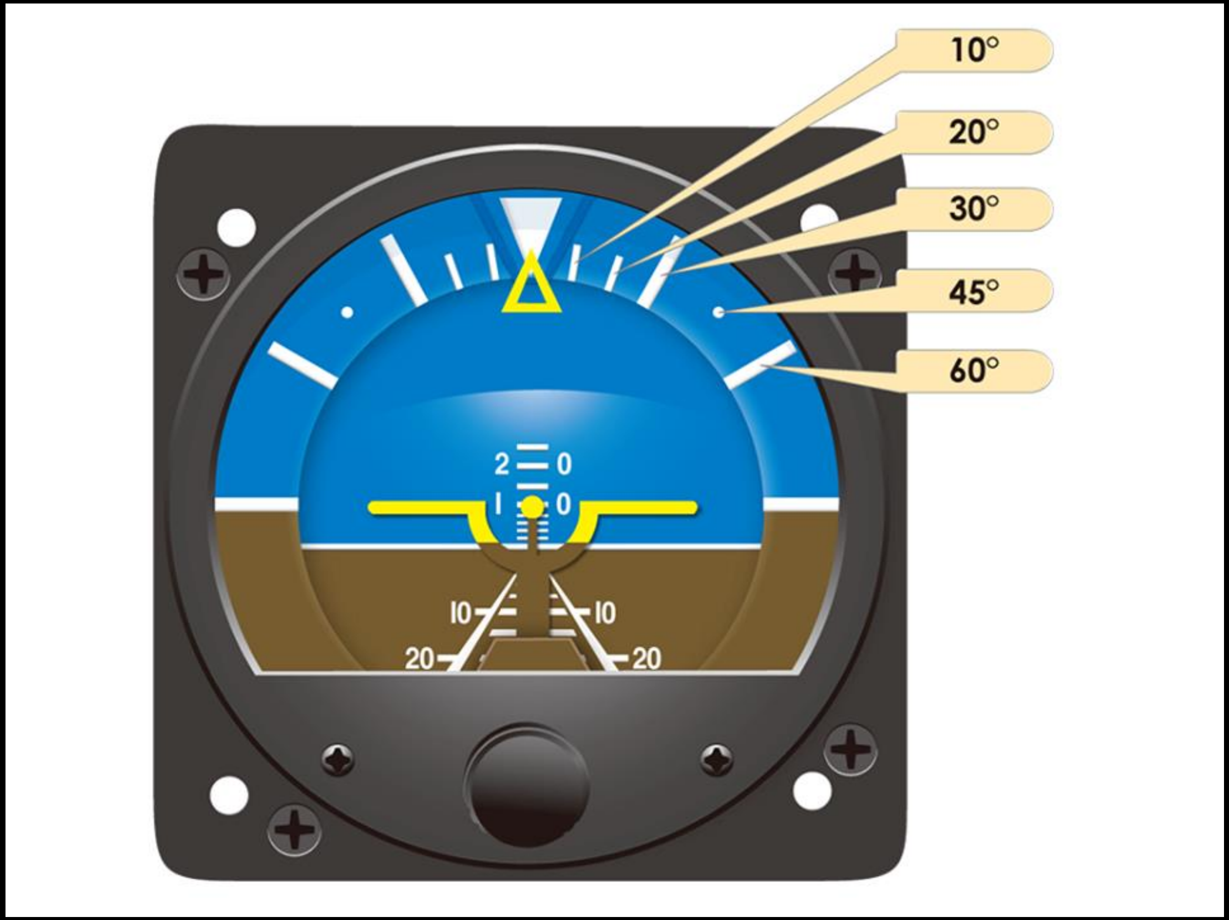
Attitude Indicator

- The top half of the horizon disc is blue, representing the sky; and the bottom half is brown, representing the ground
- A bank index at the top of the instrument shows the angle of bank
- The symbolic aircraft is mounted in the instrument case, so it appears to be flying relative to the horizon

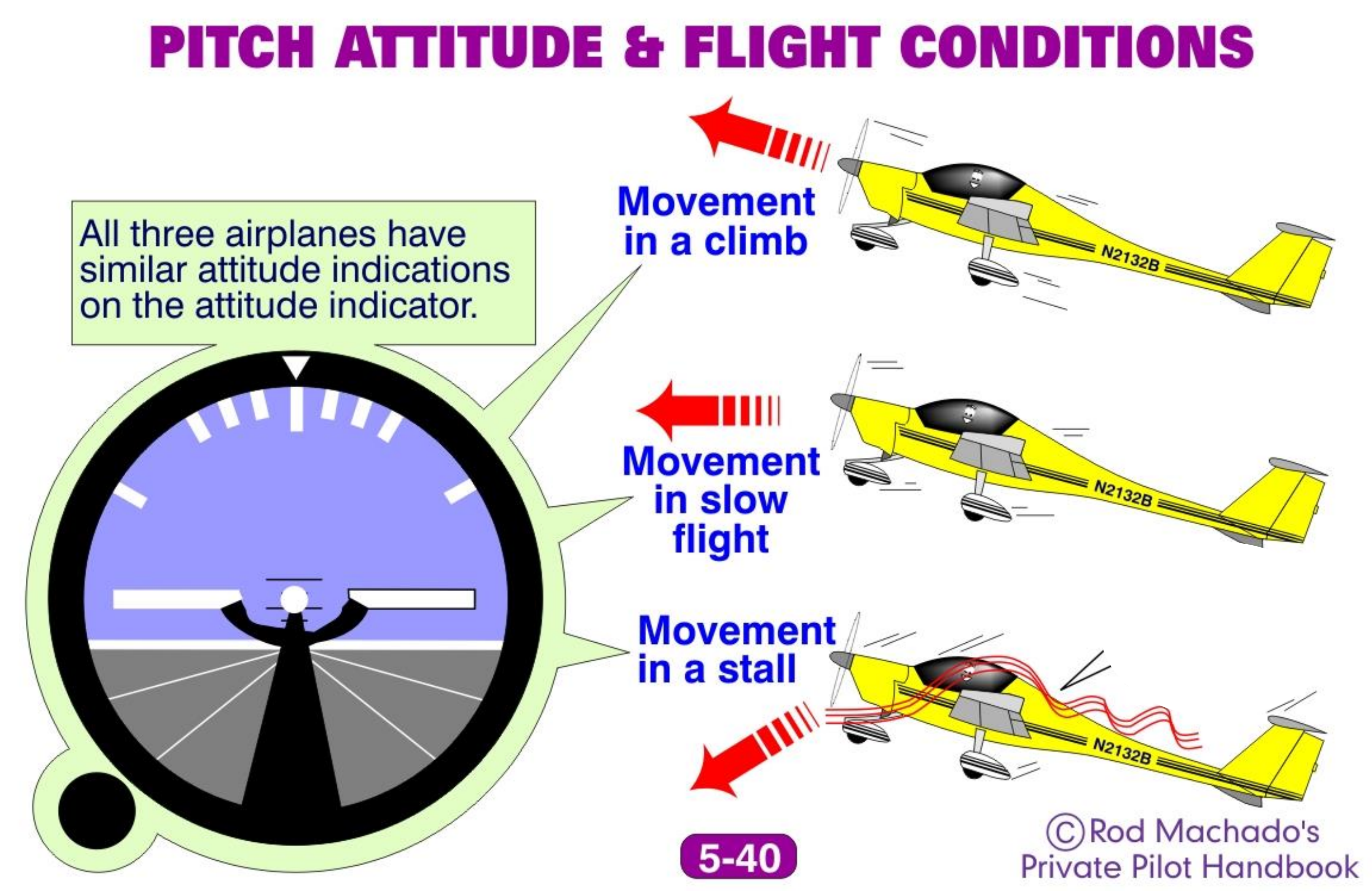


Attitude Indicator

- A knob at the bottom center of the instrument case raises or lowers the aircraft to compensate for pitch trim changes as the airspeed changes
- The width of the wings of the symbolic aircraft and the dot in the center of the wings represent a pitch change of approximately 2°
- *What airplane condition is currently shown?*



Attitude Indicator



Attitude Indicator Errors

- Following a 180° turn, it indicates a slight climb and bank in the opposite direction (turn error)
- Following a 360° turn, this error cancels itself out and is not apparent

Attitude Indicator Errors

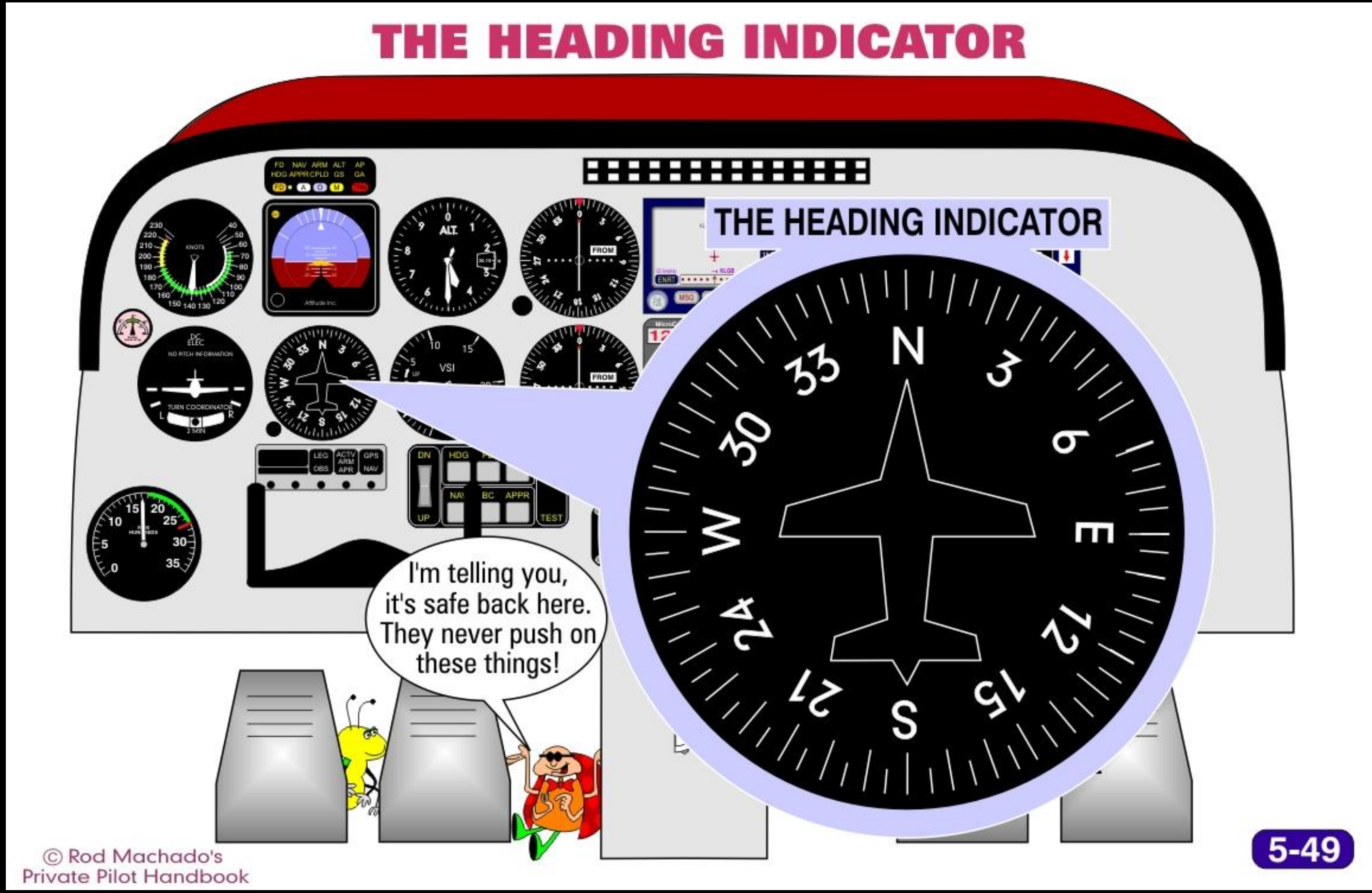
- During acceleration, the horizon bar moves down, indicating a climb (acceleration error)
- During deceleration, the horizon bar moves up, indicating a descent (deceleration error)

Attitude Indicator Errors

- These inherent errors are small and correct themselves shortly after returning to straight-and-level flight
- An attitude indicator pre-takeoff check verifies that the horizon bar stabilizes within *5 minutes*, and does not dip more than *5°* during taxiing turns

Heading Indicator

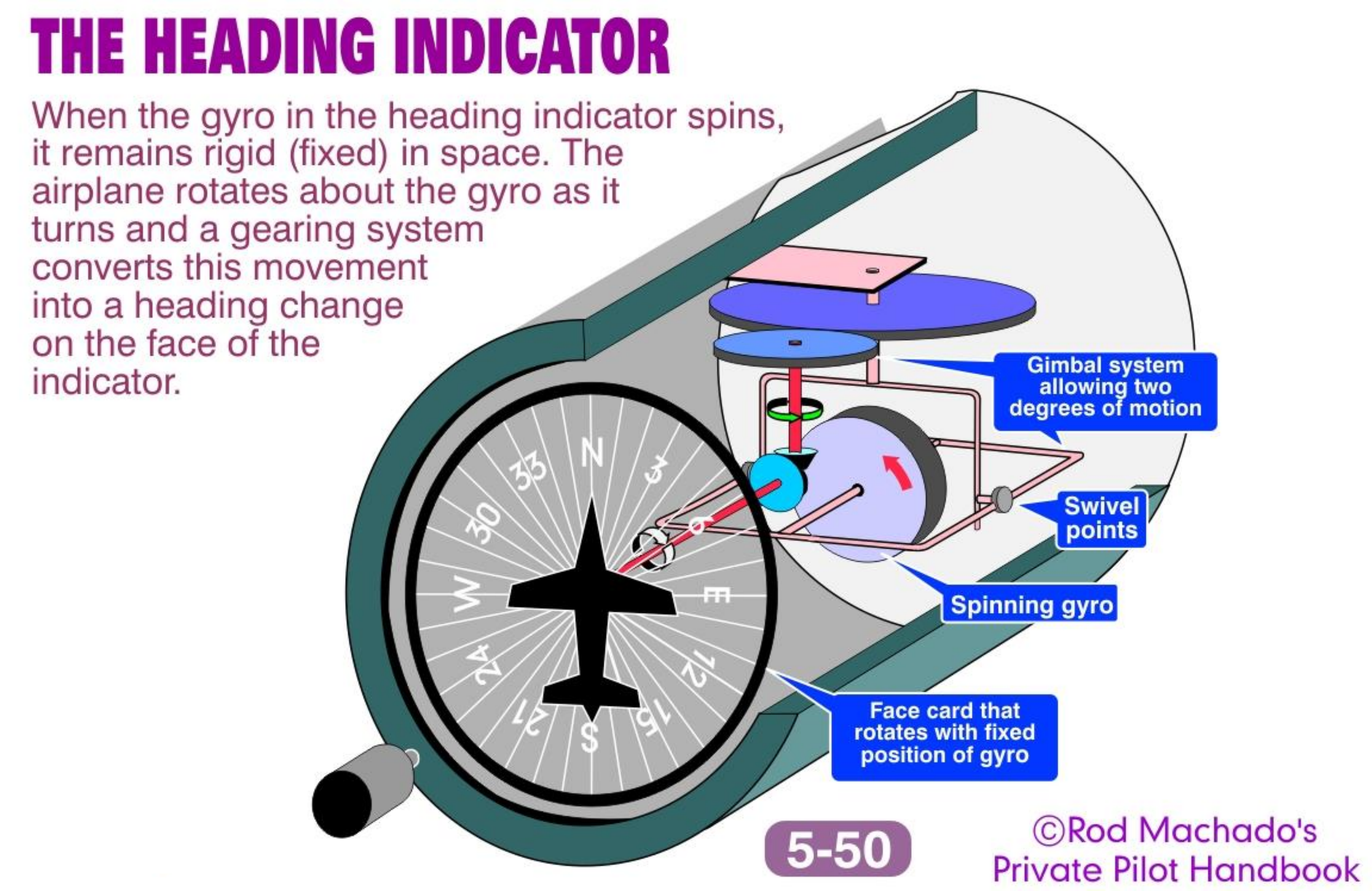
- Gyroscopic instrument operating on the principle of rigidity in space
- Sometimes called the Directional Gyro or DG



Heading Indicator

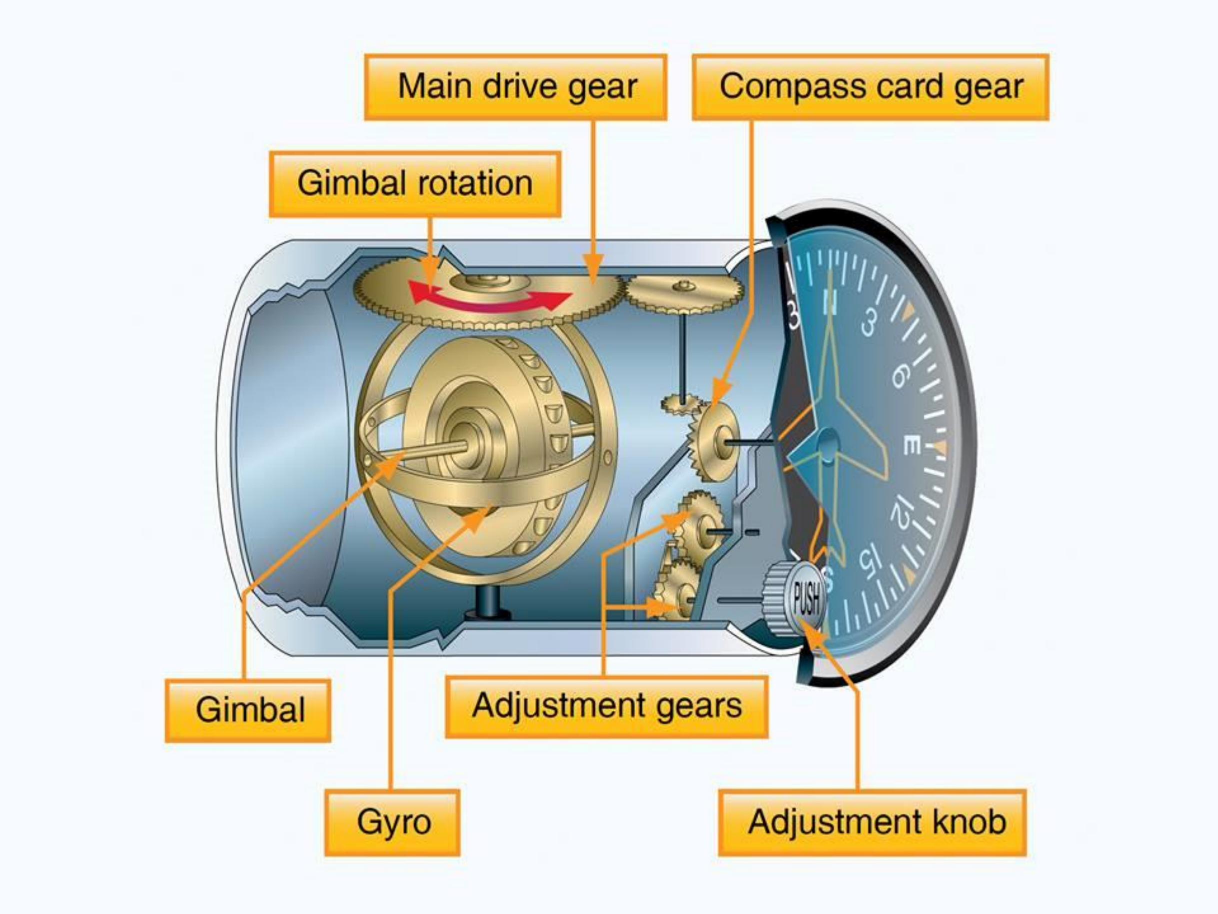
- Gyroscopic heading indicators are *not* north seeking
- Must be manually set to the appropriate heading by referring to a magnetic compass
- Rigidity causes the HI to maintain this heading indication, without the oscillation and other errors inherent in a magnetic compass

Heading Indicator

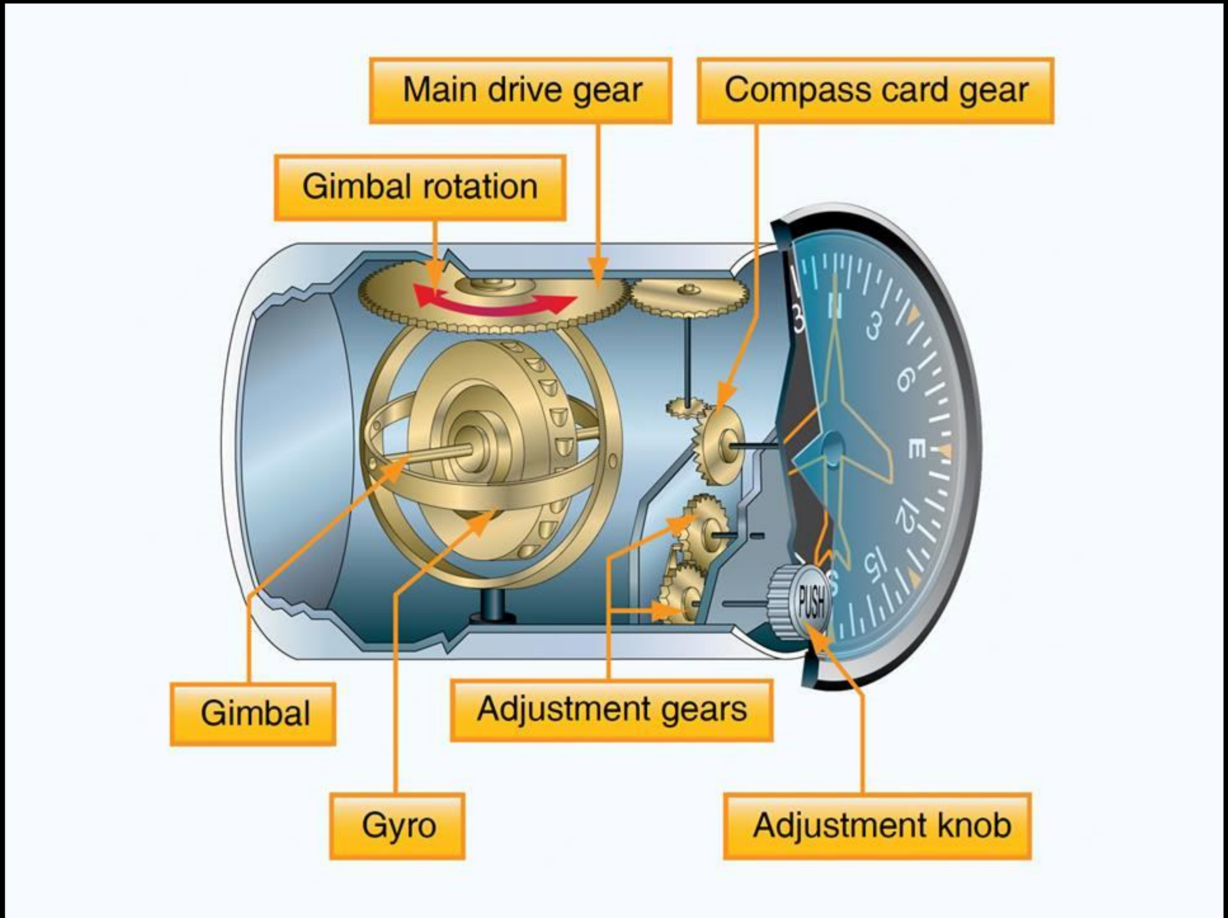


Heading Indicator

- The gyro is mounted in a double gimbal with its spin axis horizontal, permitting sensing of rotation about the vertical axis of the aircraft
- Air-driven by evacuating the case and allowing filtered air to flow into the case and out through a nozzle, blowing against buckets cut in the periphery of the wheel
- The gyro drives a vertical dial card



Heading Indicator

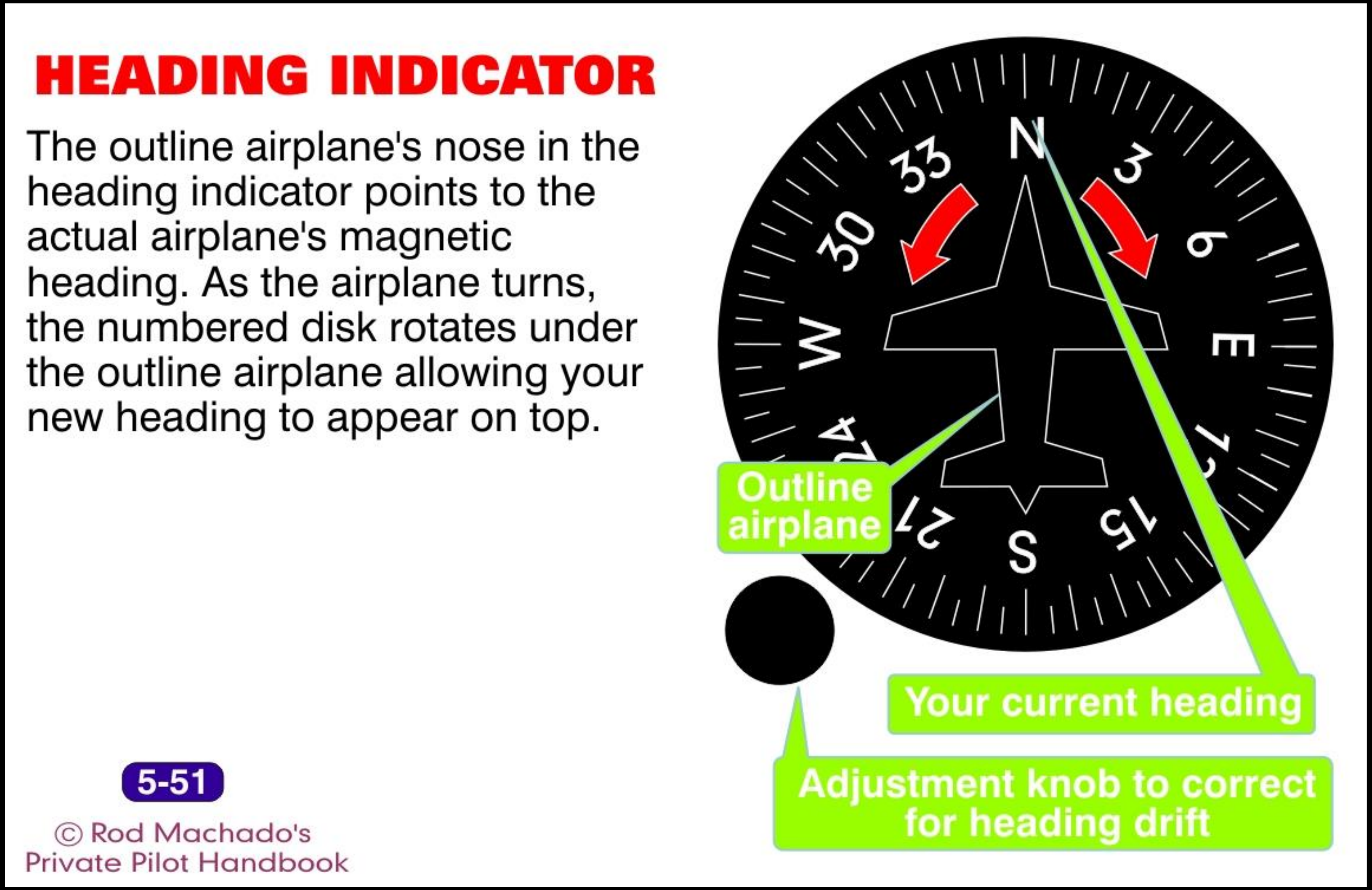


- The heading of the aircraft is shown against the nose of the symbolic aircraft which serves as the lubber line
- A knob in the front of the instrument is pushed in and turned to rotate the gyro and dial

HI Drift

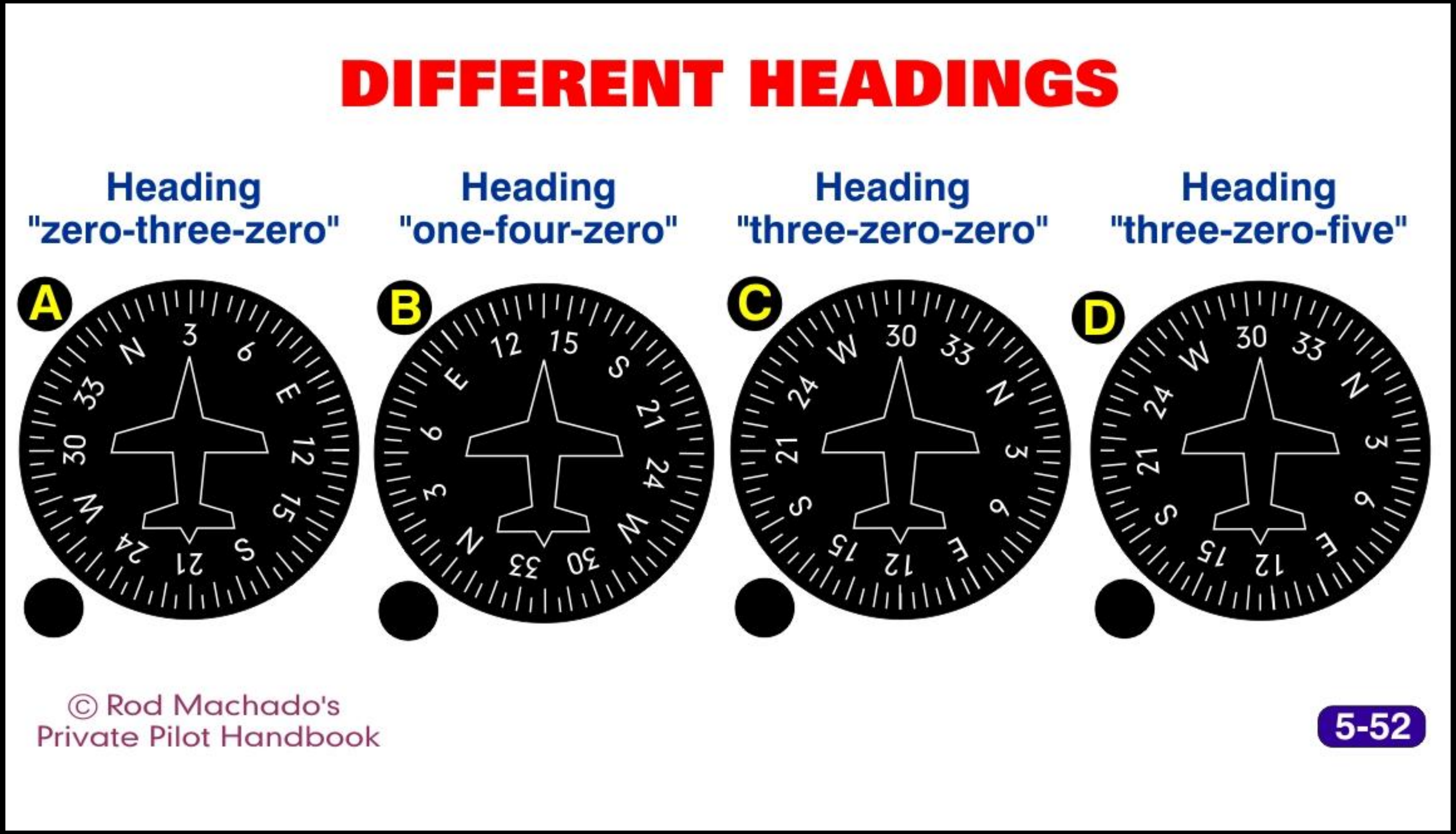
- The Earth rotates at 15° per hour while the gyro is maintaining a position relative to space
- This causes an apparent drift in the displayed heading of 15° per hour
- The HI should be checked every 15 minutes to ensure it agrees with the magnetic compass due to processional error
- The HI pre-takeoff check is made by setting it and checking for proper alignment after making taxiing turns

Heading Indicator Interpretation

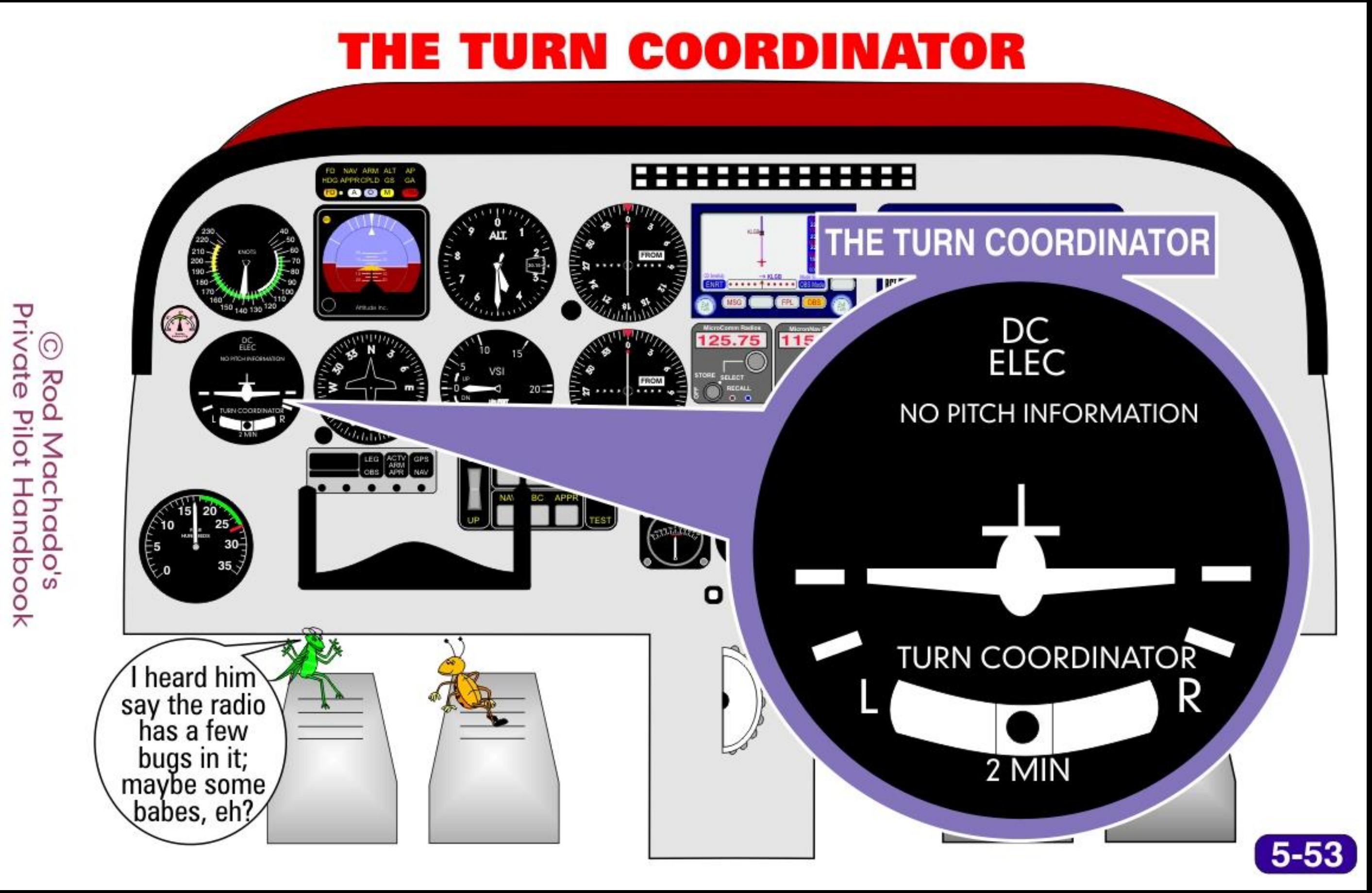


Reading Headings on HI

- All headings are 3 digits
- Add zero to indicated heading



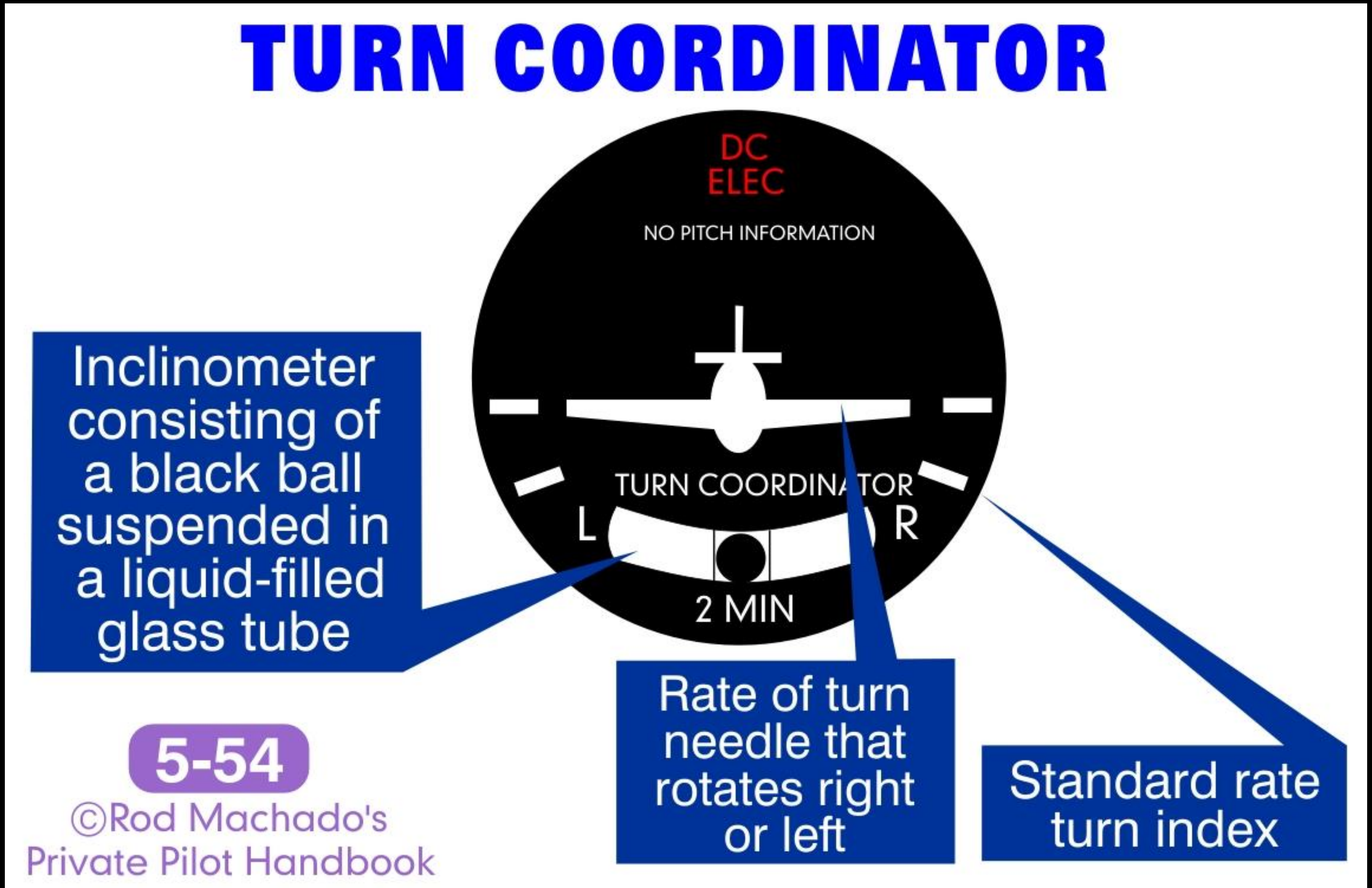
Turn Coordinator



- Electrically driven, gyroscopically-operated instrument designed to show roll rate, rate of turn, and quality of turn
- Operates on the principle of gyroscopic precession
- Does not show actual bank angle nor pitch

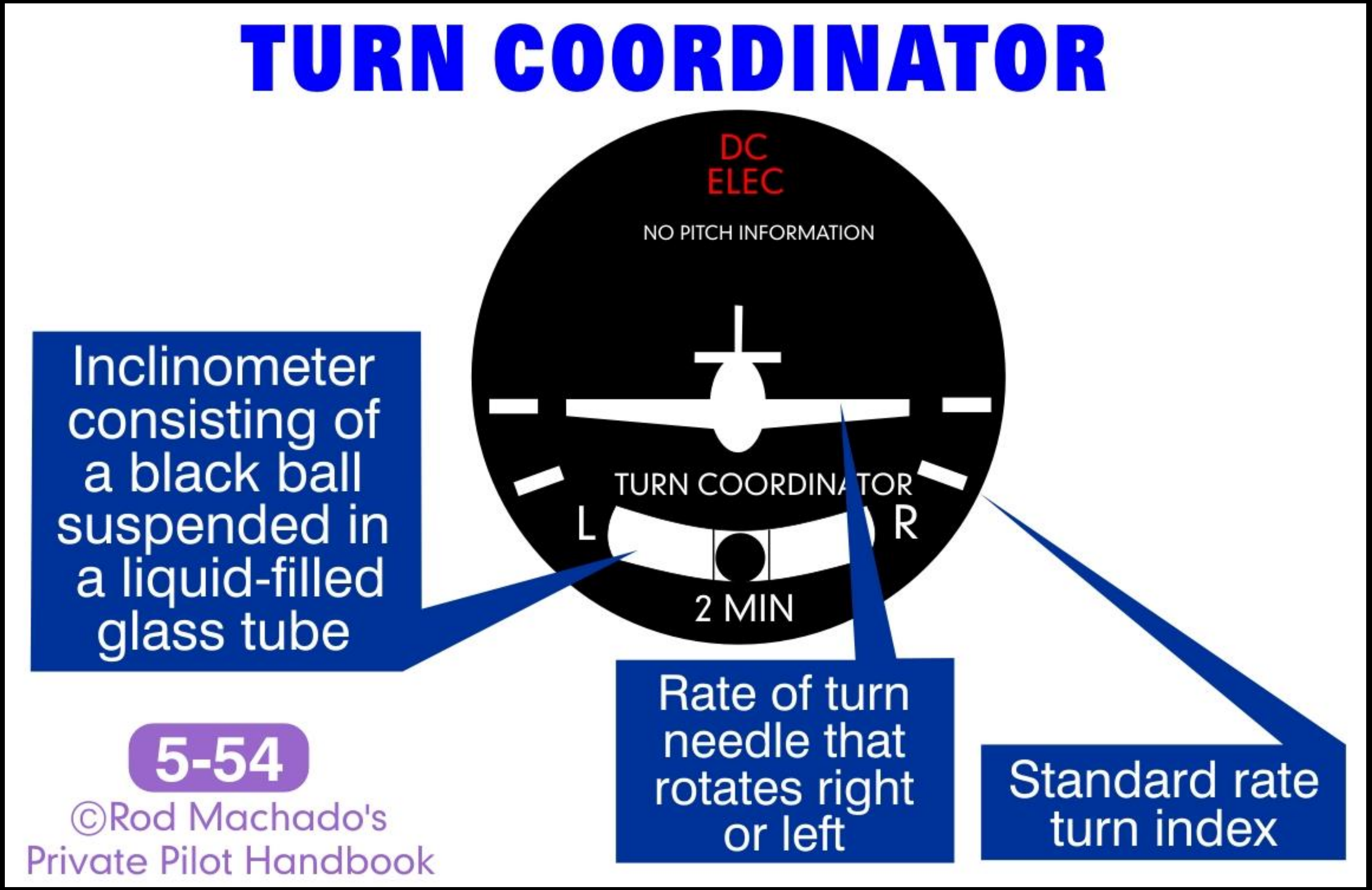
Turn Coordinator

- Consist of two instruments: a needle and an inclinometer
- Provides information on the airplane's direction of roll, rate of heading change, and whether the airplane is slipping or skidding in the turns
- (i.e., movement about its yaw and roll axes)

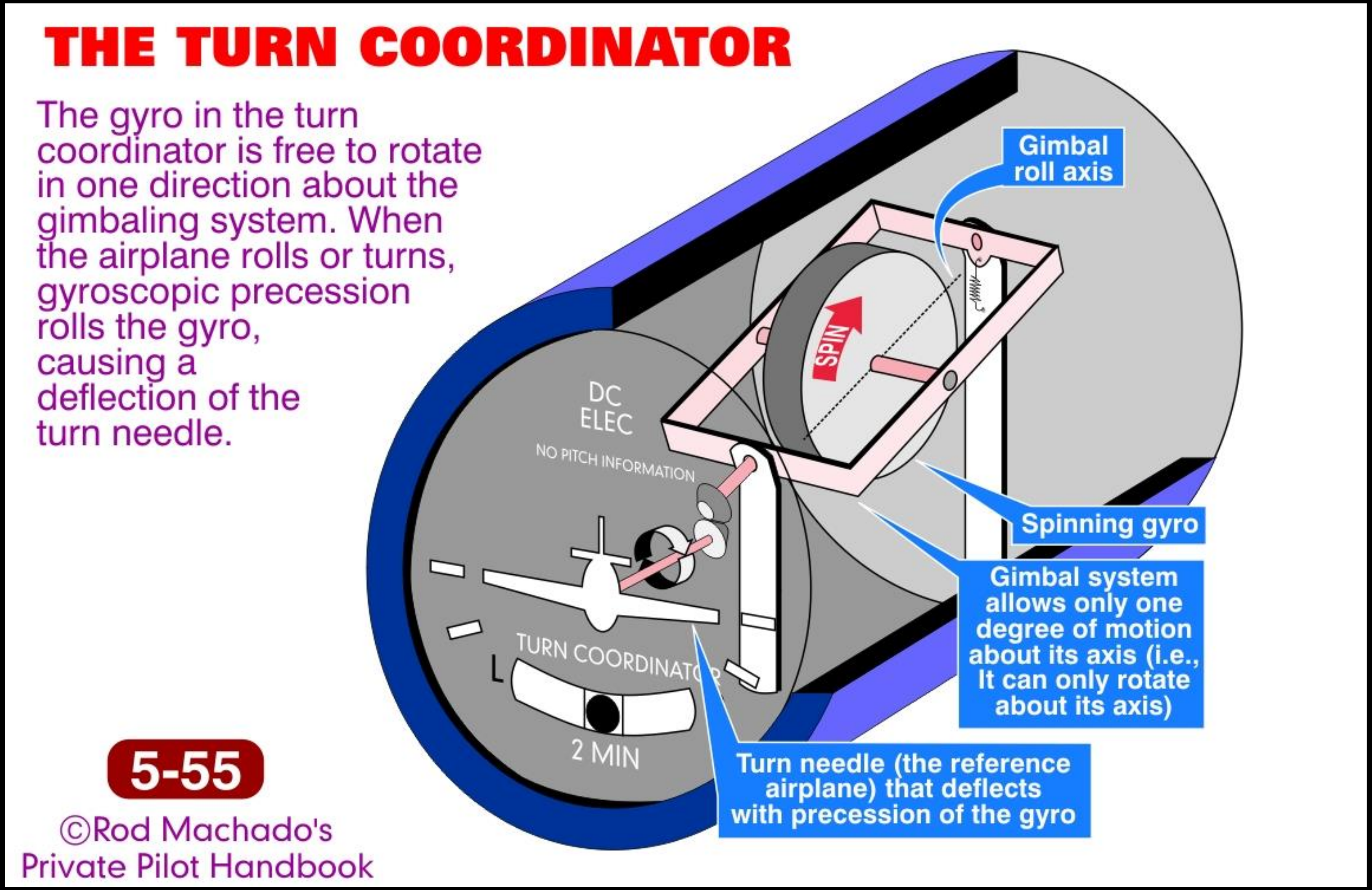


Turn Coordinator

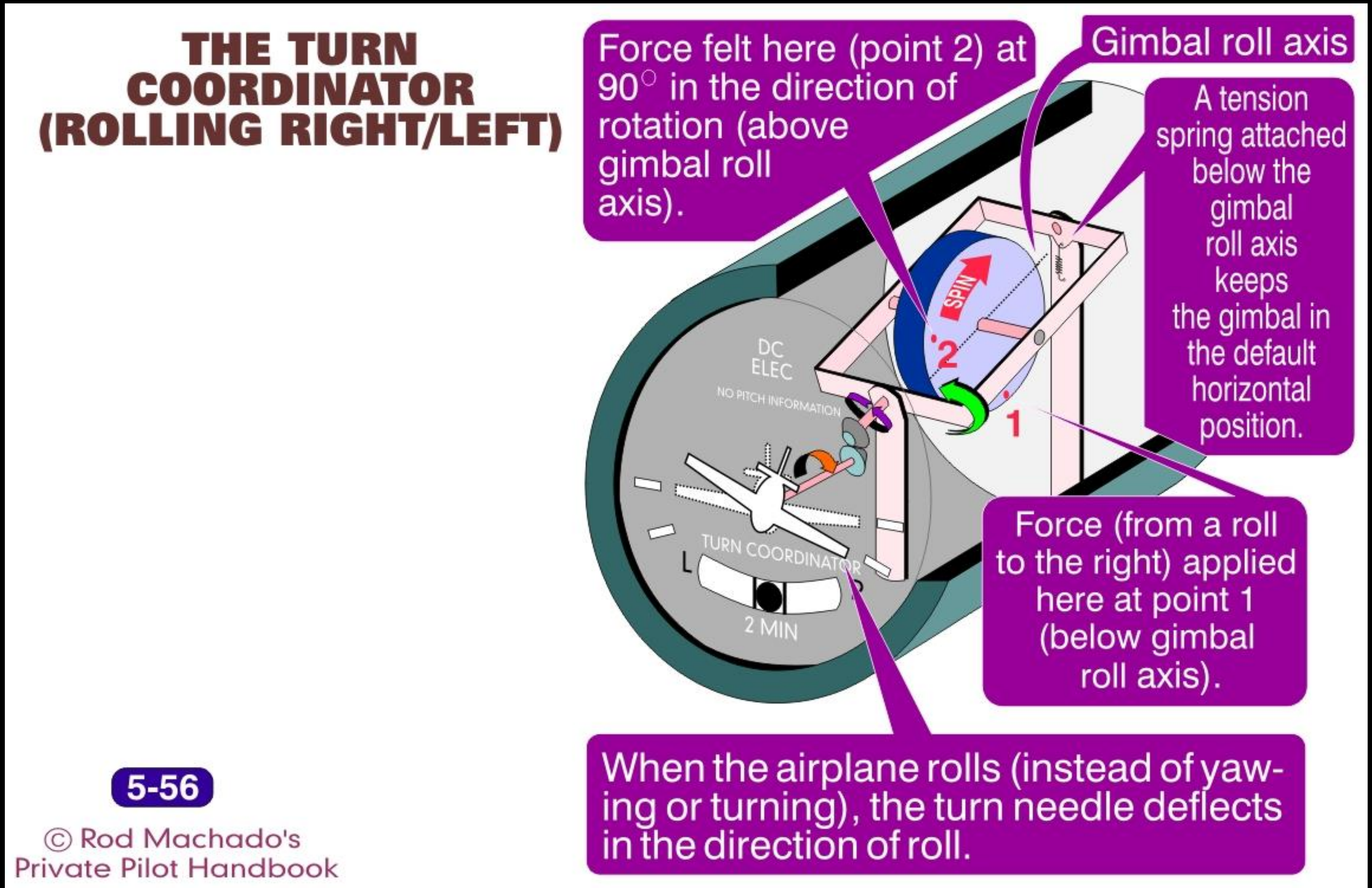
- Gyro is electrically powered, to keep at least one gyro instrument operating if the airplane's vacuum pump fails
- The airplane's lateral control (not pitch control) can be maintained with the turn coordinator alone



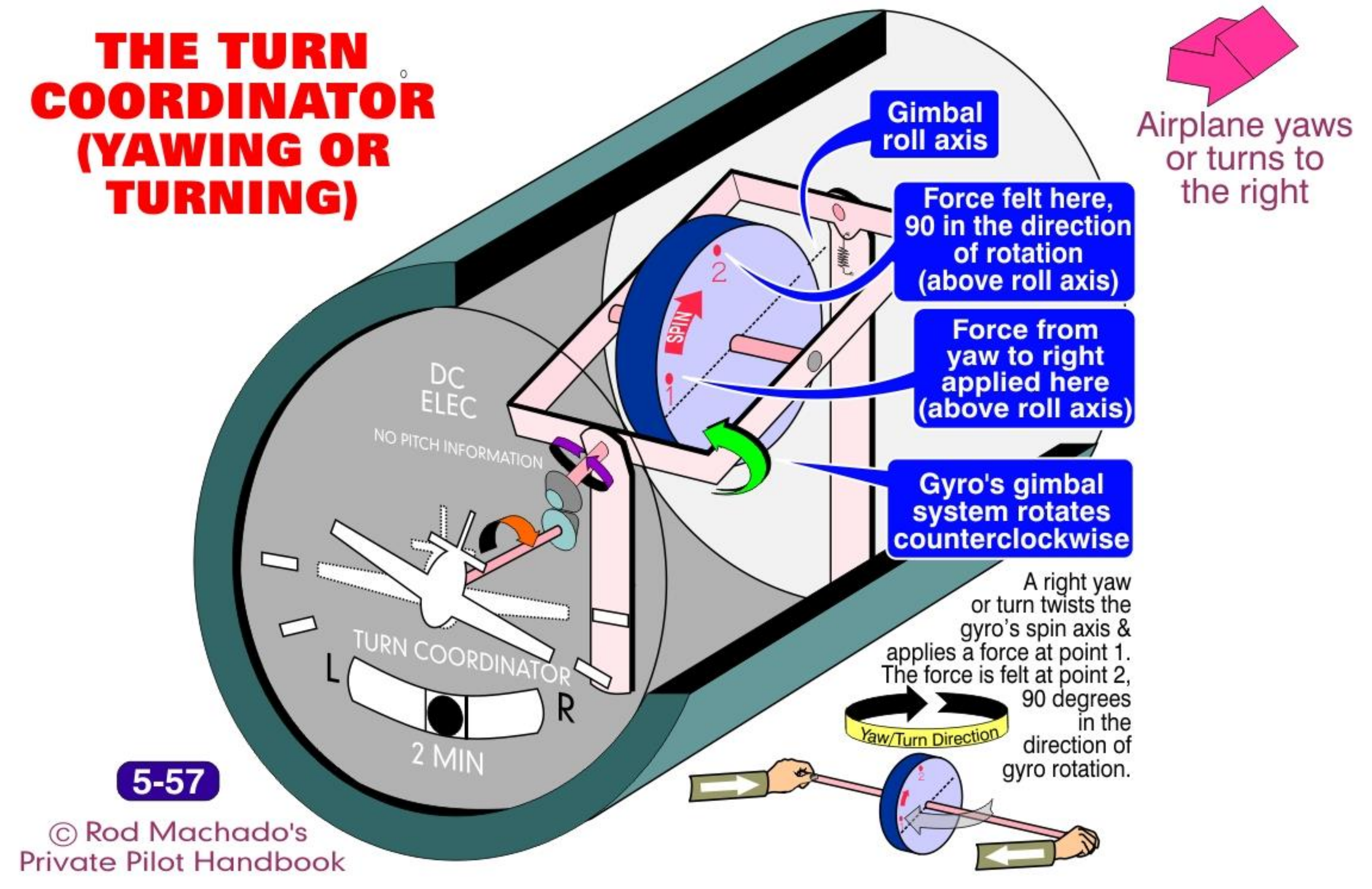
Turn Coordinator Operation



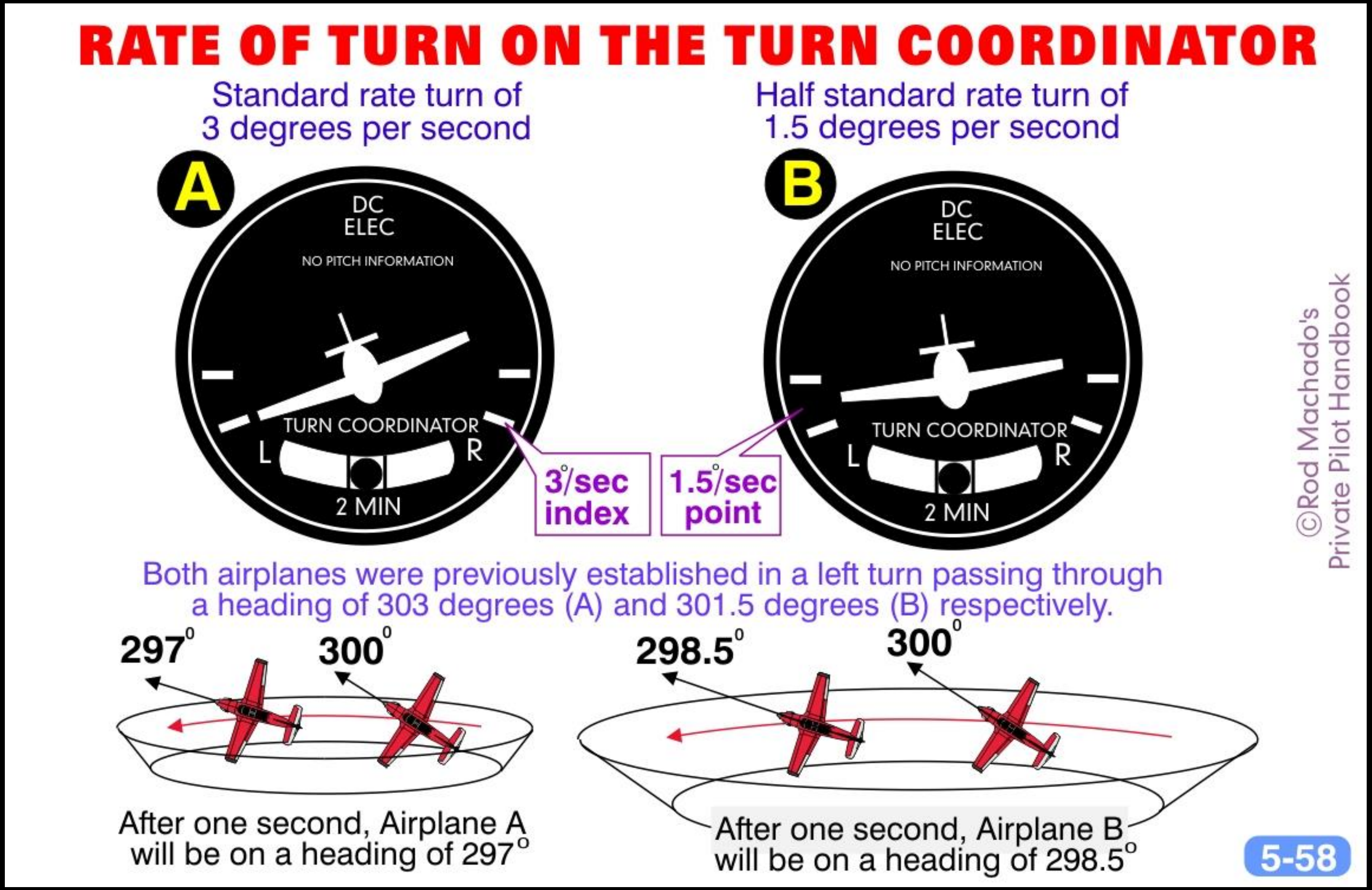
Rolling Right/Left



Yawing or Turning



Rate of Turn

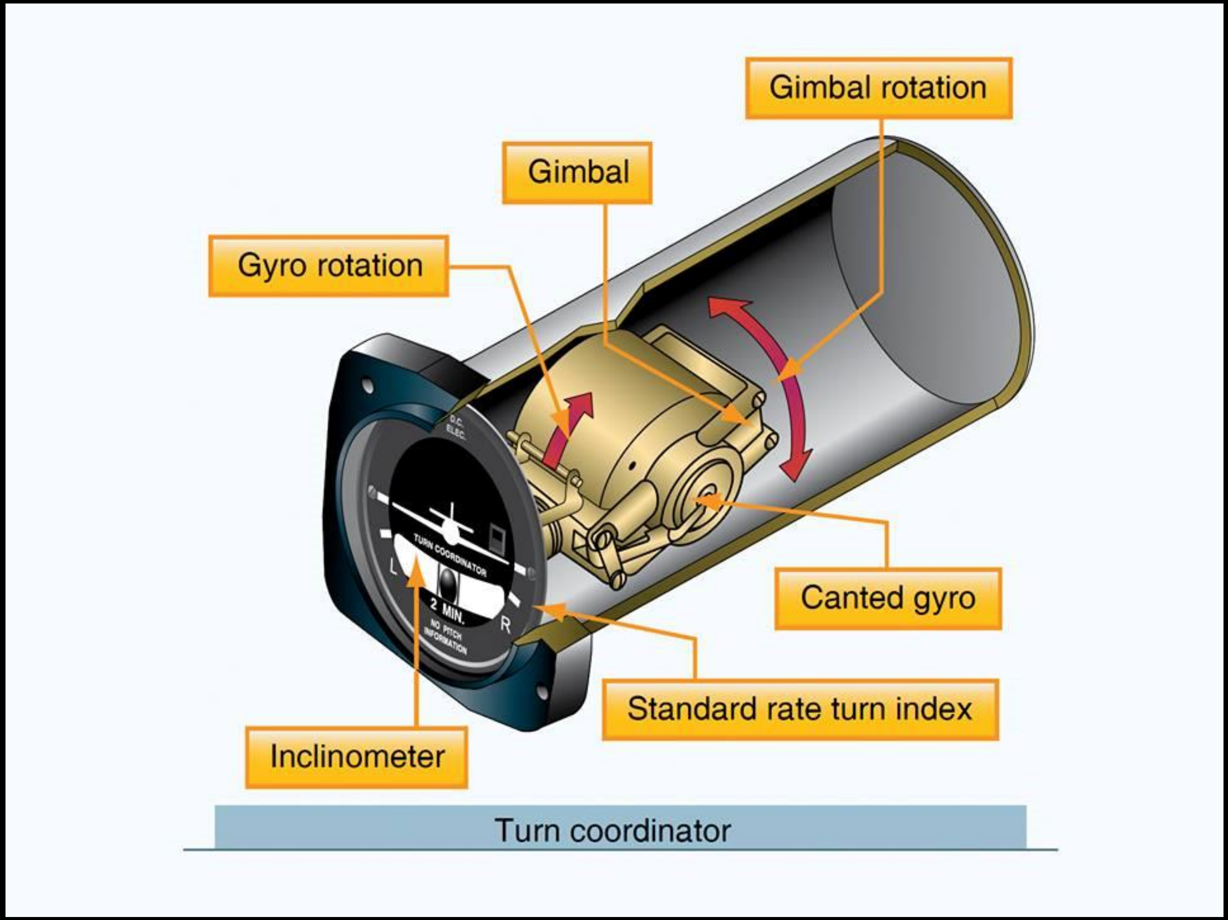

RATE OF TURN ON THE TURN COORDINATOR
Standard rate turn of
3 degrees per second
Half standard rate turn of
1.5 degrees per second
A
B
DC
ELEC
NO PITCH INFORMATION
TURN COORDINATOR
L
R
2 MIN
3°/sec
index
1.5°/sec
point
©Rod Machado's
Private Pilot Handbook
Both airplanes were previously established in a left turn passing through
a heading of 303 degrees (A) and 301.5 degrees (B) respectively.
297°
300°
298.5°
300°
After one second, Airplane A
will be on a heading of 297°
After one second, Airplane B
will be on a heading of 298.5°
5-58

Turn Coordinator

- Electrically driven, gyroscopically-operated instrument designed to show roll rate, rate of turn, and quality of turn
- A standard rate turn (3°/second) takes 2 minutes to complete a 360° turn
- A half-standard rate turn (1.5°/second) takes 4 minutes to complete a 360° turn
- It acts as a backup system in case of a failure of the vacuum powered AI

Turn Coordinator

- Operates on principle of <u>precession</u>
- Its gimbals frame is angled upward 30° from the longitudinal axis of the aircraft
- This allows it to sense both roll and yaw
- During a turn, the indicator first shows the <u>rate of banking</u> and once stabilized, the <u>turn rate</u>
- The gimbal moves a dial that is the rear view of a symbolic aircraft
- The bezel of the instrument is marked to show wings-level flight and bank for a standard rate turn



Inclinometer

- Ball is sealed inside a curved glass tube partially filled with a liquid for damping
- This ball measures the relative strength of the force of gravity and the force of inertia caused by a turn
- The inclinometer does not indicate the amount of bank - it only indicates the relationship between the angle of bank and the rate of turn

Inclinometer

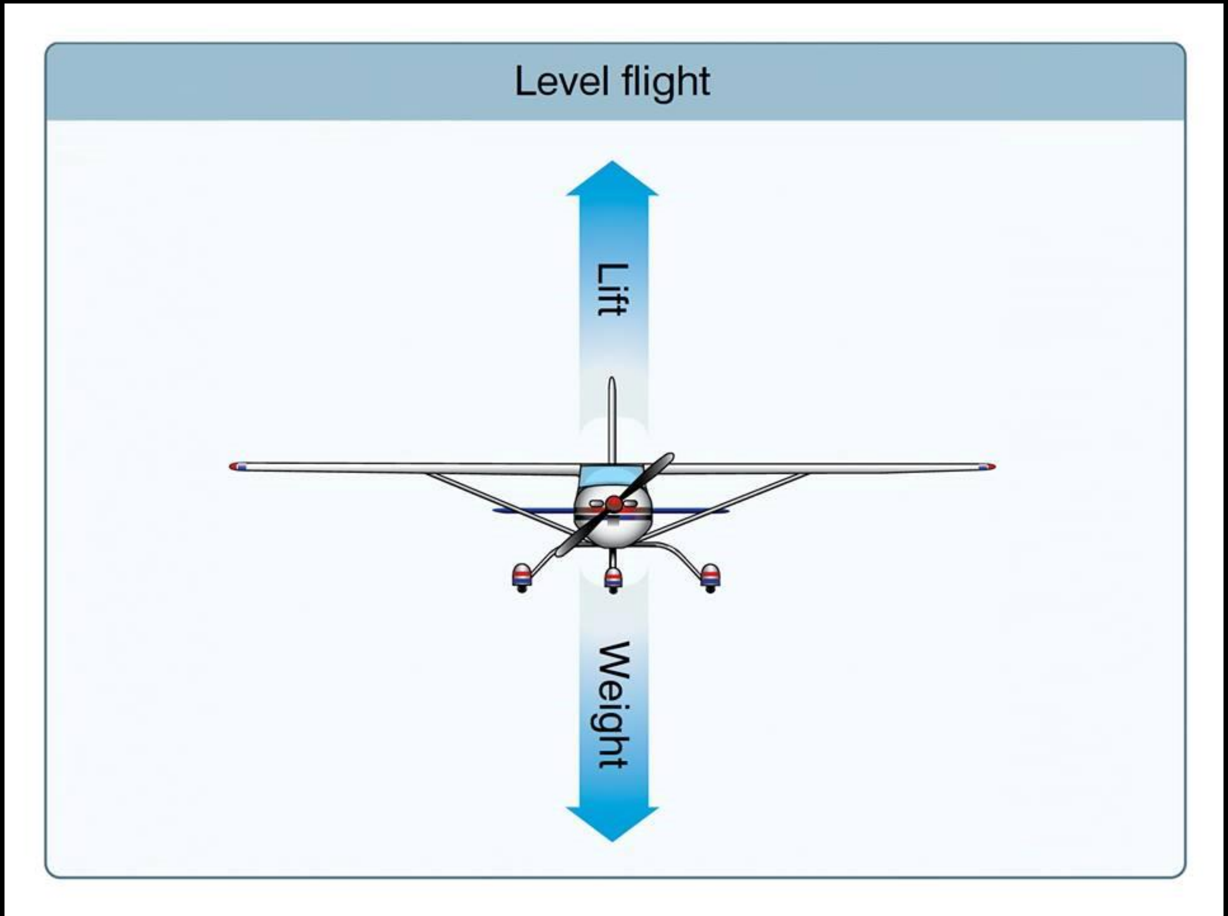
- When the aircraft is flying straight-and-level, there is no inertia acting on the ball, and it remains in the center of the tube between two wires
- In a turn made with a bank angle that is too steep, the force of gravity is greater than the inertia and the ball rolls down to the inside of the turn
- If the turn is made with too shallow a bank angle, the inertia is greater than gravity and the ball rolls upward to the outside of the turn

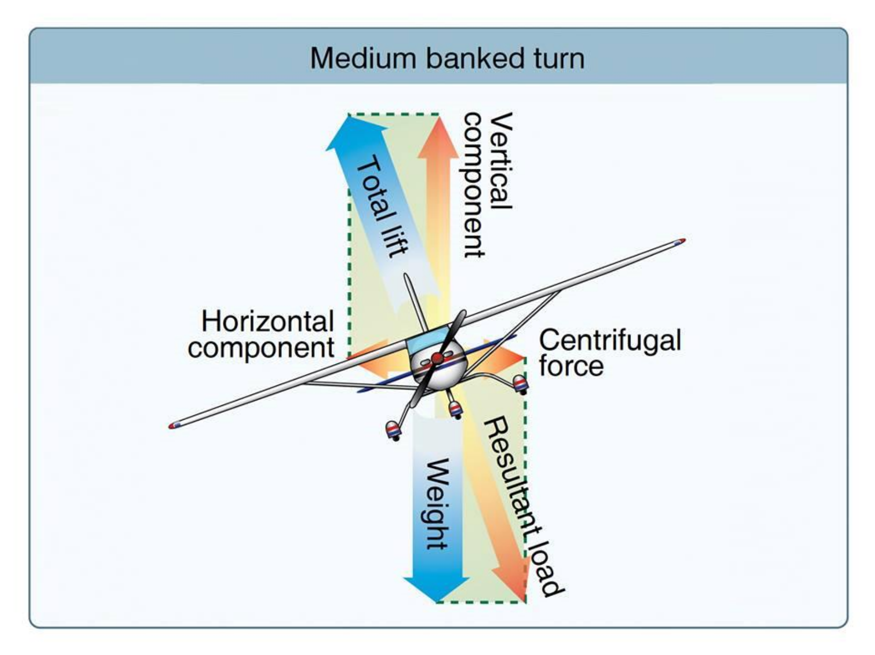
Inclinometer

Coordinated turn

- The inclinometer is called a coordination ball, which shows the relationship between the bank angle and the rate of yaw
- The turn is coordinated when the ball is in the center, between the marks
- The aircraft is skidding when the ball rolls toward the outside of the turn and is slipping when it moves toward the inside of the turn
- *The turn coordinator does not sense pitch*

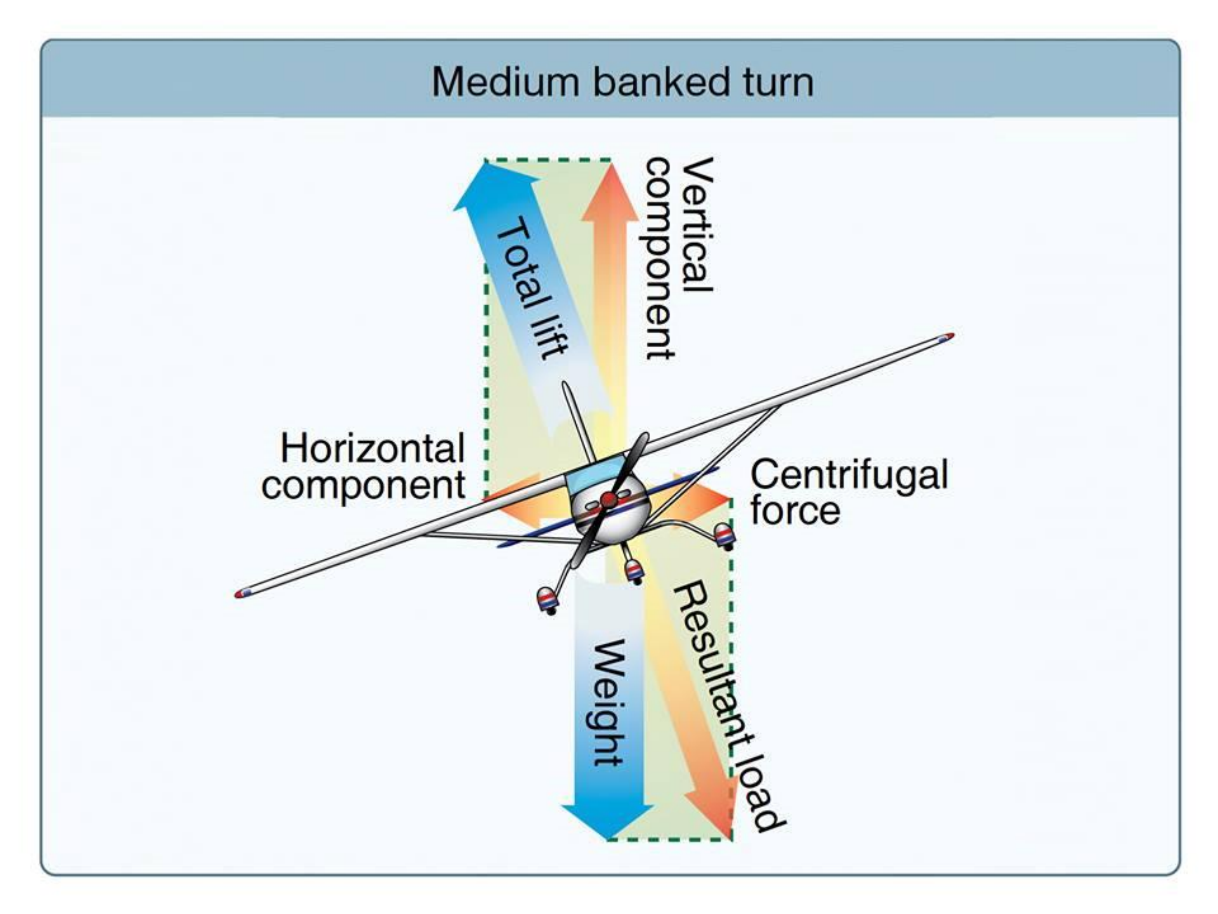
Level Flight vs. Banked Turn



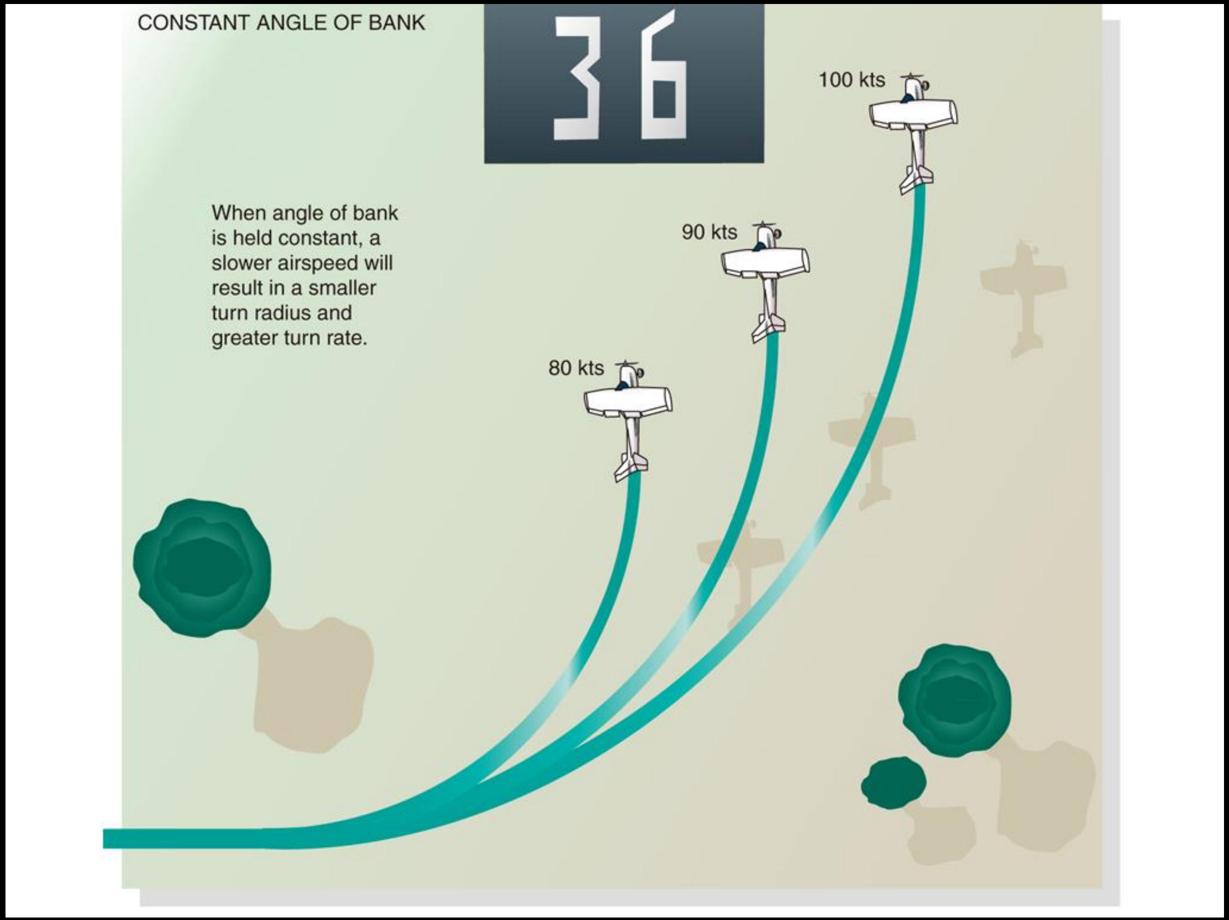


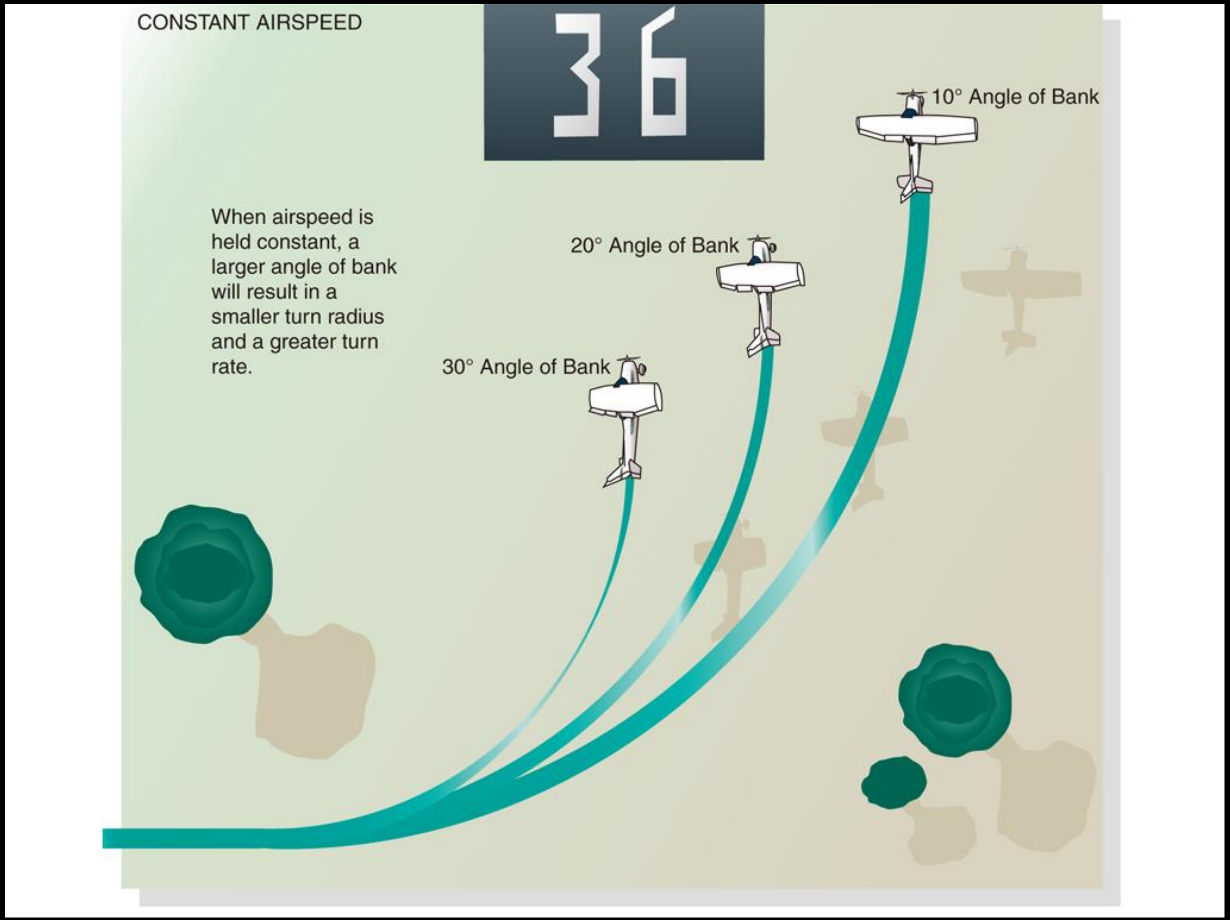
Turning Flight

- An airplane turns because of the horizontal component of lift in a banked attitude
- The greater the horizontal lift at any airspeed, the greater the rate of turn
- The angle of attack must be increased to maintain altitude during a turn because the vertical component of lift decreases

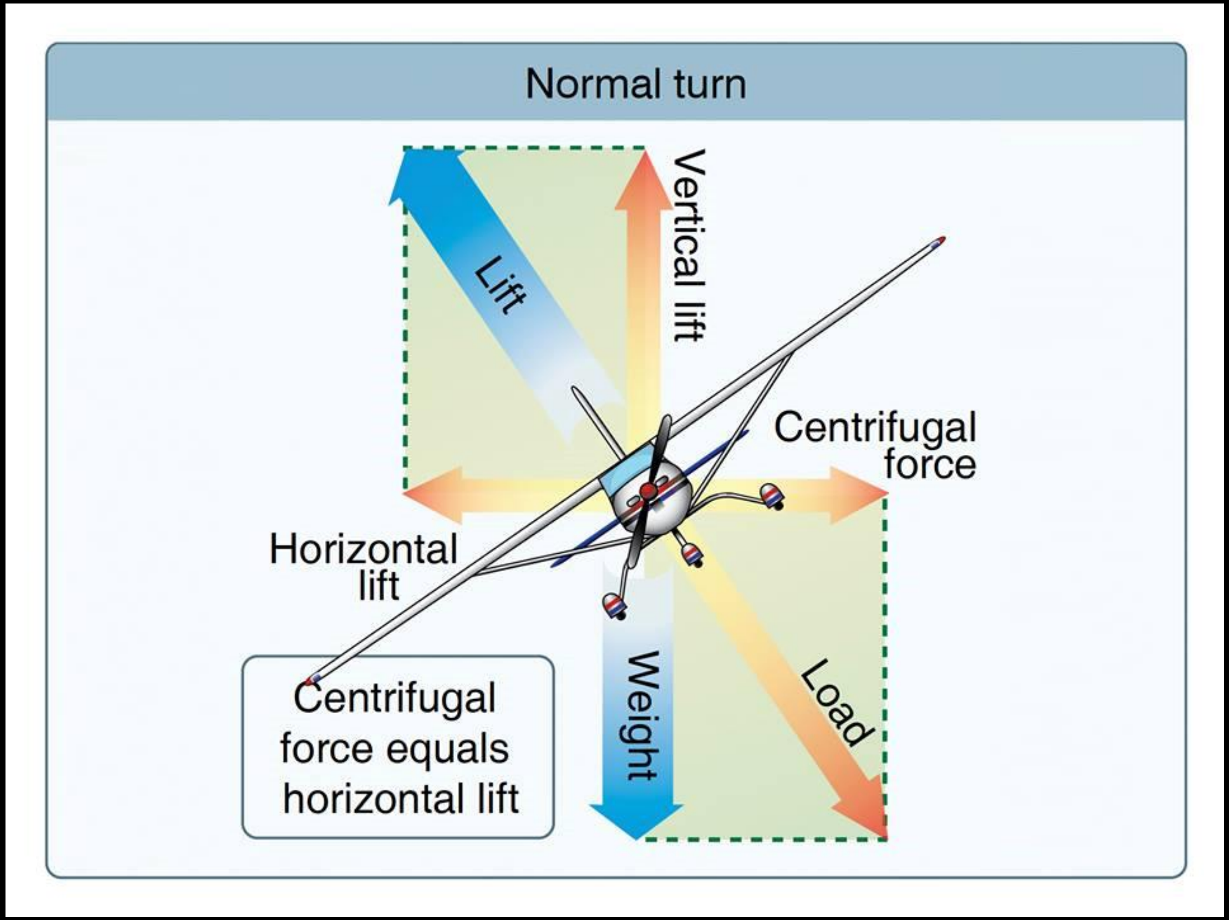


Rate vs. Radius of Turn

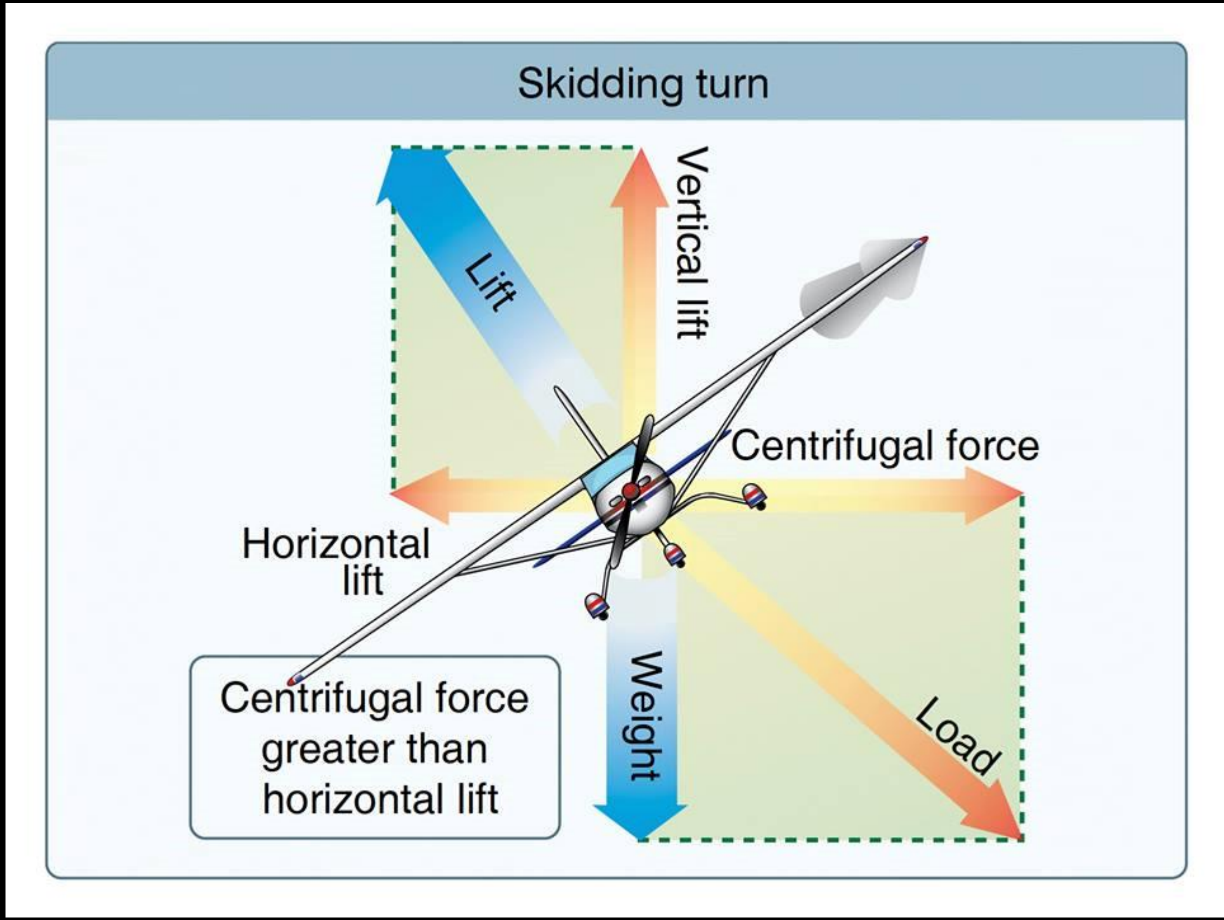




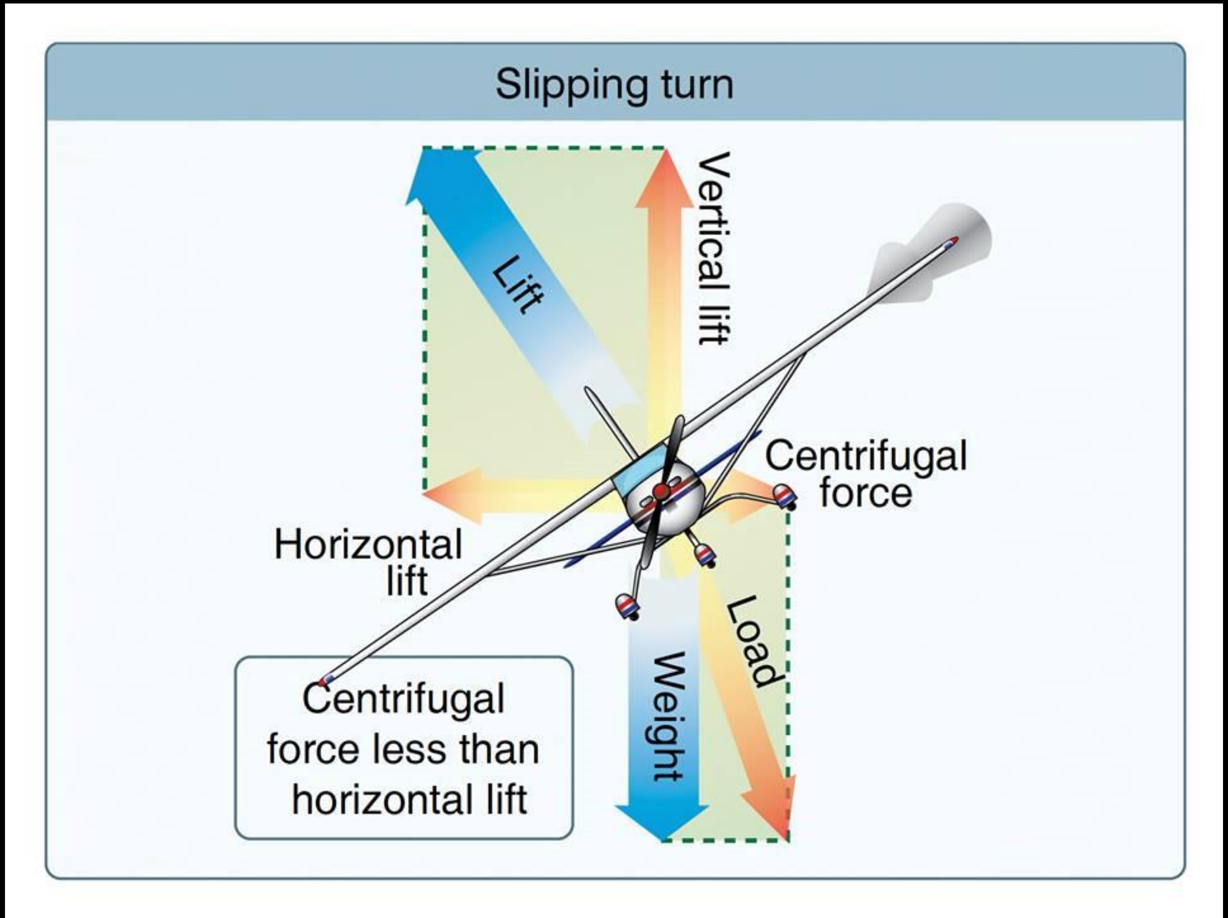
Coordinated Turn



Skidding Turn



Slipping Turn



Turn Coordinator Preflight Checks

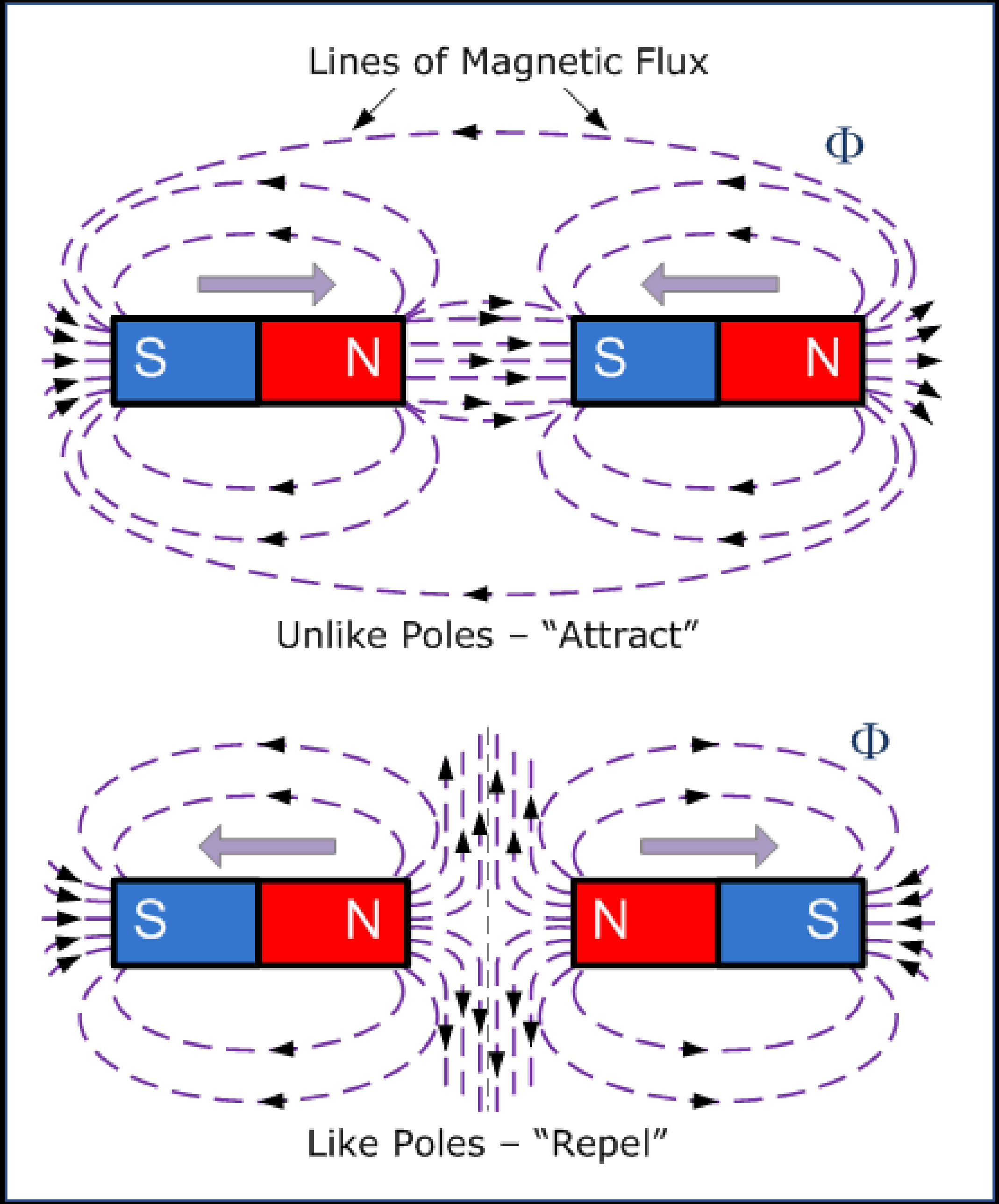
- Listen for unusual noise when Master Switch is placed ON
- Before starting the engine, the turn needle should be centered and the race full of fluid
- During a taxiing turn, the needle will indicate a turn in the proper direction and the ball will show a skid

Compass

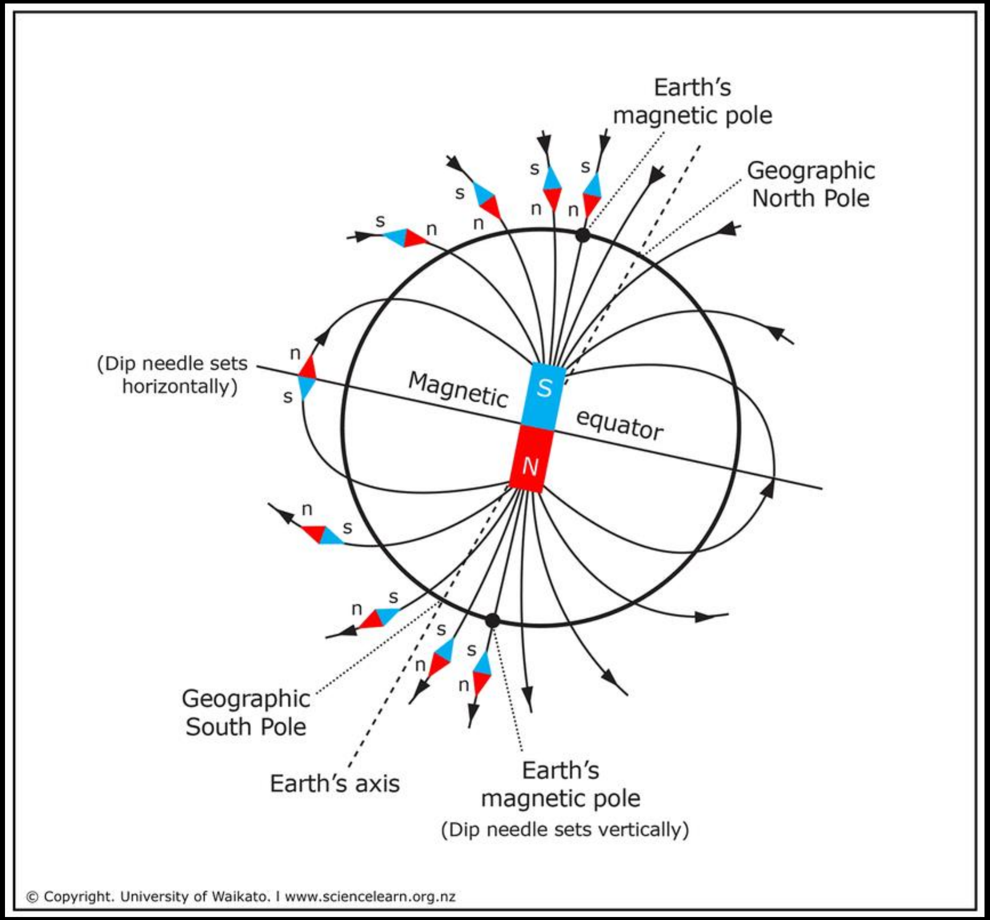
Aircraft Flight Instruments

Magnetism

- A magnet is a piece of material, usually a metal containing iron, which attracts and holds lines of magnetic flux
- Every magnet has two poles: a north pole and a south pole
- When one magnet is placed in the field of another, the unlike poles attract each other and like poles repel



Magnetism



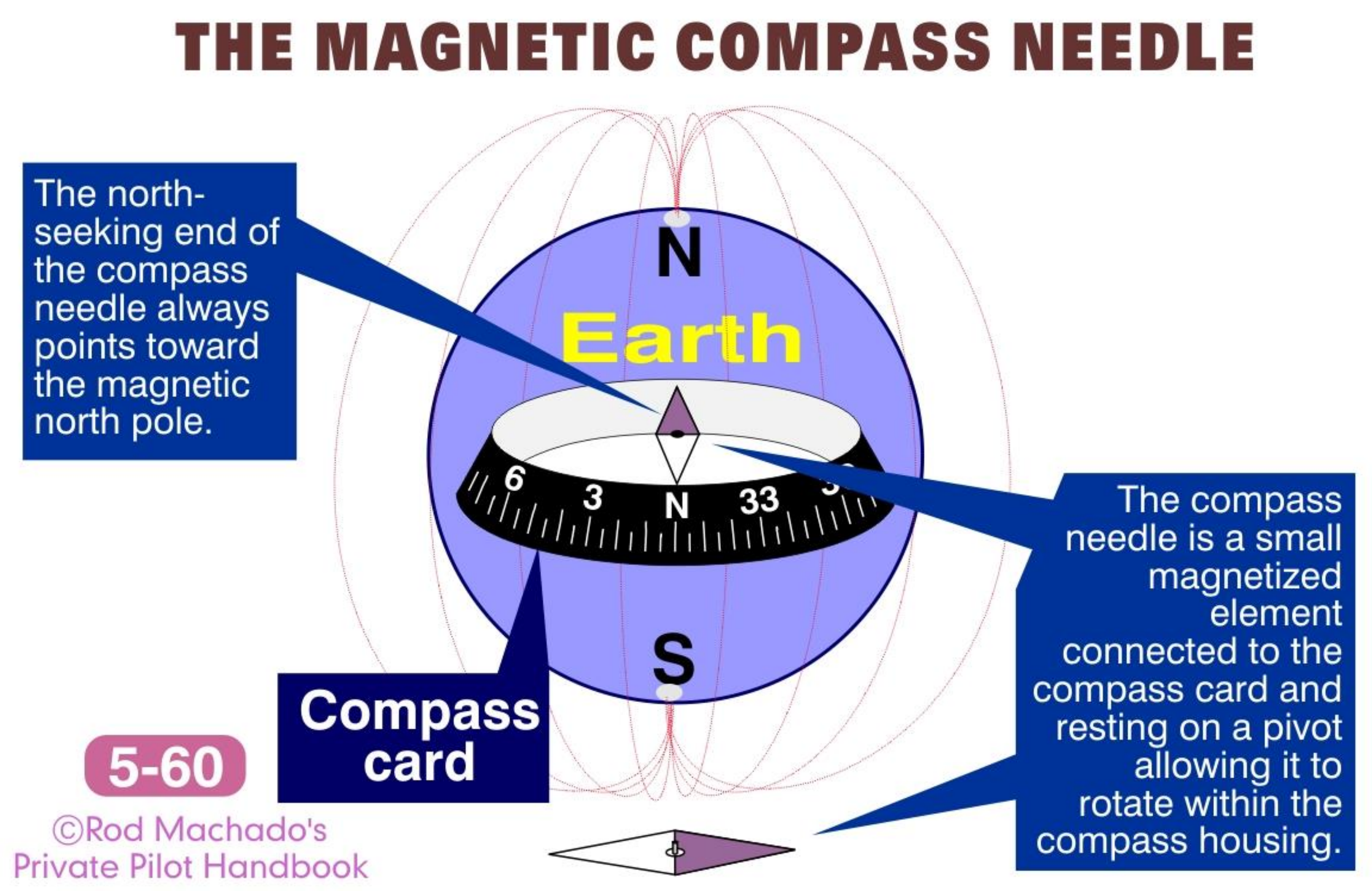
- The Earth is a huge magnet, surrounded by a magnetic field made up of invisible lines of flux
- These lines leave the surface at the magnetic North Pole and reenter at the magnetic South Pole
- Any magnet that is free to rotate aligns with the lines of magnetic flux

Magnetic Compass

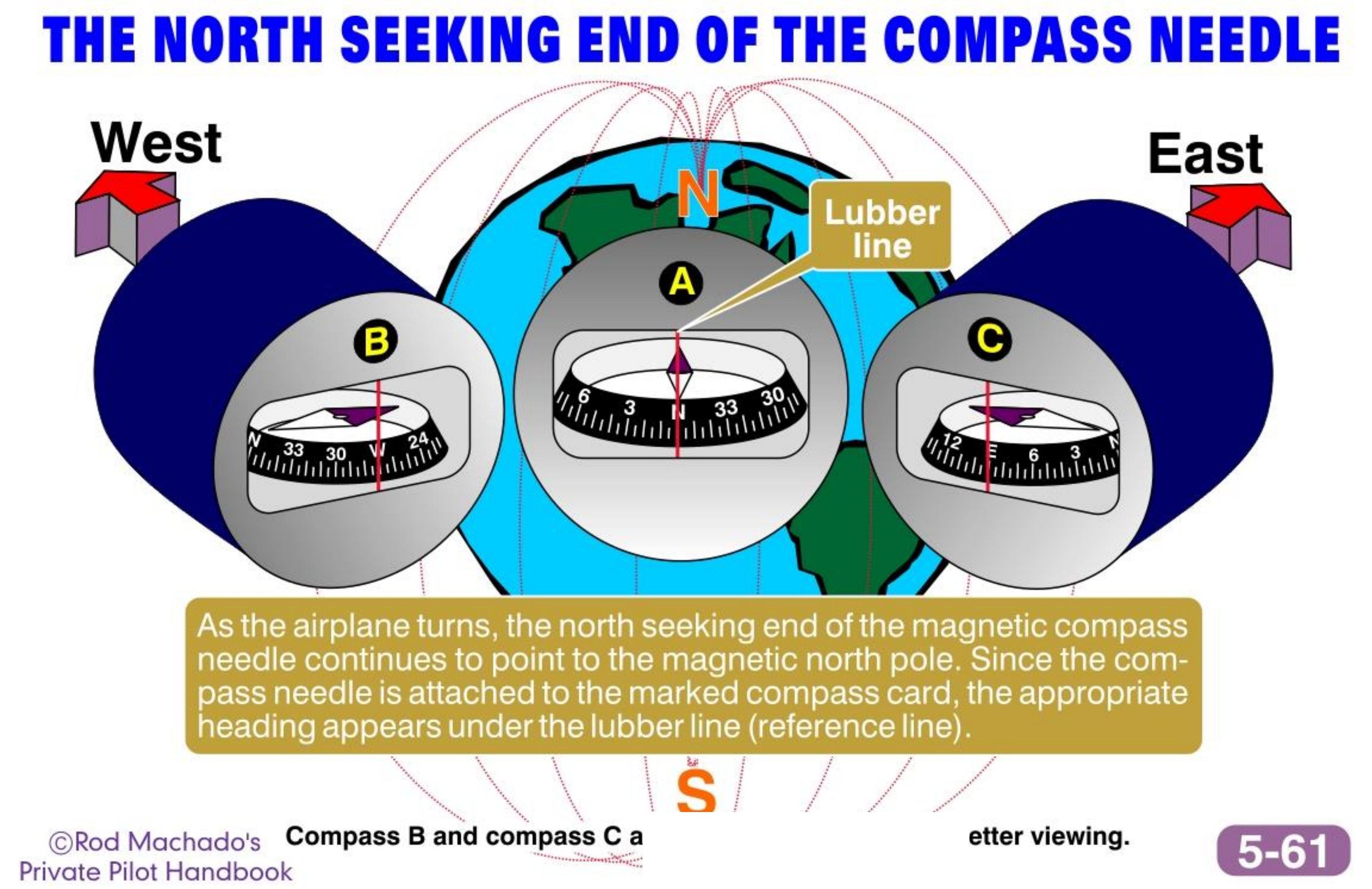
- Responds to the magnetic field between the earth's magnetic poles
- This field is constantly pulling one end of the compass needle, keeping it pointing north

Magnetic Compass Needle

- Small magnetic needle is connected to a circular compass card
- Both the card and the needle are free to rotate on a central pivot
- One end of the needle is the north-seeking end, and it always points towards the earth's magnetic north pole



Magnetic Compass



- As the airplane changes direction, it rotates around the needle and its attached card, resulting in new headings appearing in the compass' window,
- The airplane's actual heading is read under a lubber line
- To fly any heading visible on the compass card, you must turn in the opposite direction to center it under the lubber line

Magnetic Compass Overview

- Has 2 small magnets attached to a metal float sealed inside a bowl of clear compass fluid
- A graduated card is wrapped around the float and viewed through a glass window with a lubber line across it

Magnetic Compass Overview

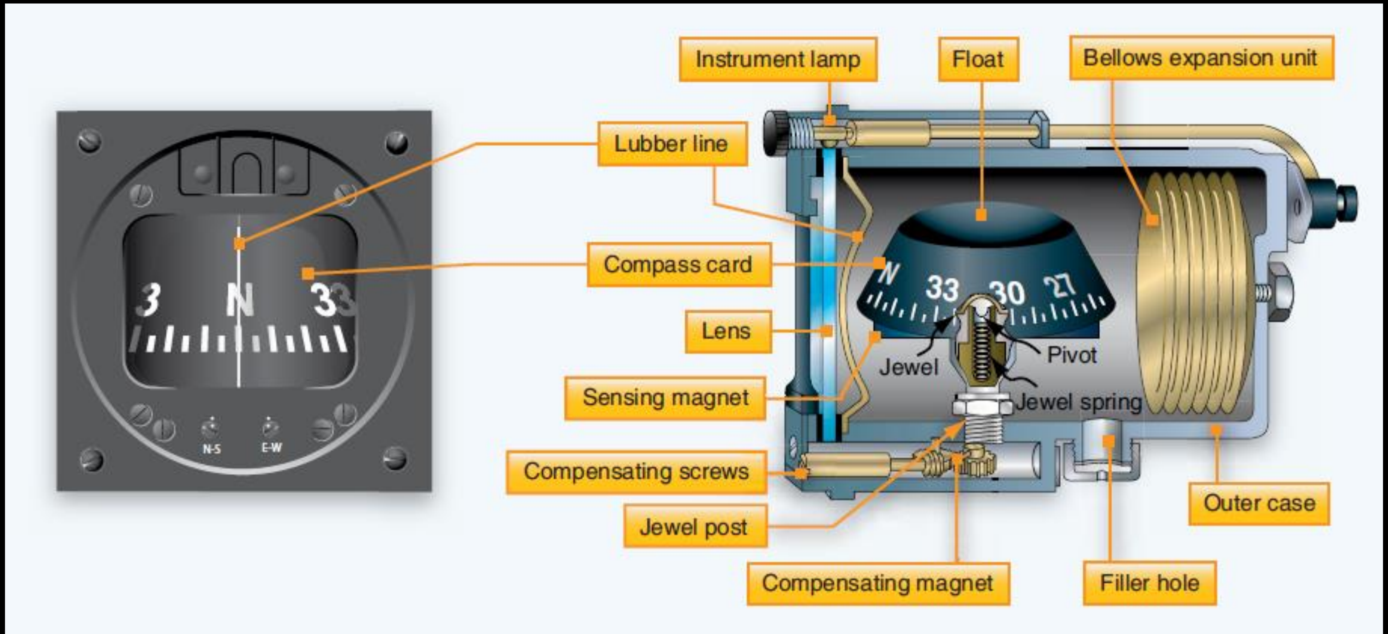
- The card is marked with letters representing the cardinal directions N,E,S, and W, and a number for each 30° between these letters (The final “0” is omitted from these directions)
- There are long and short graduation marks between the letters and numbers, with each long mark representing 10° and each short mark representing 5°

Magnetic Compass

- The magnetic compass is the <u>only</u> self-contained directional instrument in the aircraft
- It is influenced by <u>magnetic dip</u> which causes northerly turning error and acceleration/deceleration error

Magnetic Compass Construction

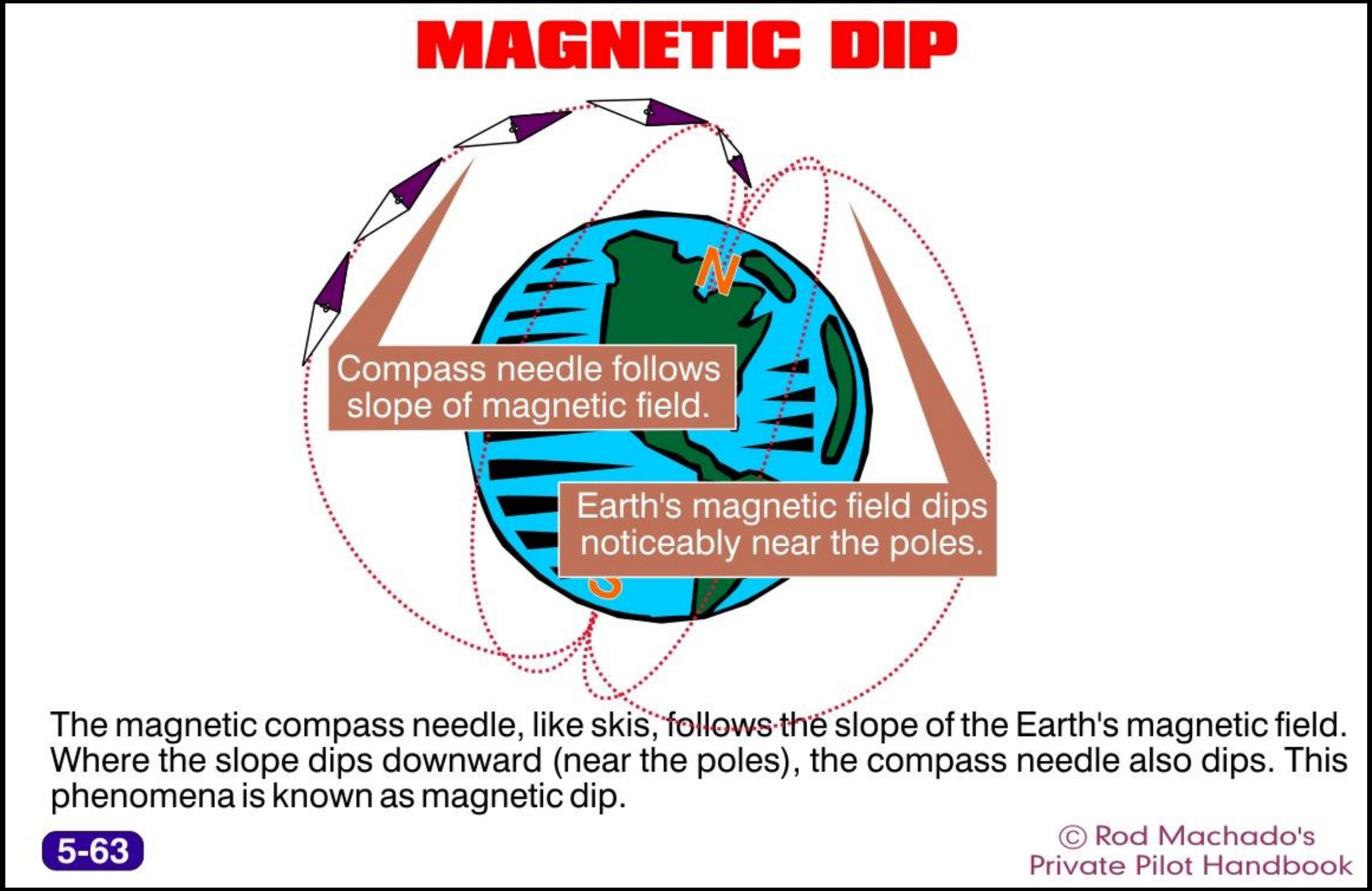
- The compass housing is entirely full of compass fluid
- The float and card assembly has a pivot in its center that rides inside a special cup
- Buoyancy of the float takes most of the weight off the pivot, and the fluid damps the oscillation of the float and card
- The pivot type mounting allows the float freedom to rotate and tilt up to approximately 18° angle of bank
- At steeper bank angles, the compass indications are erratic and unpredictable



Theory of Operation

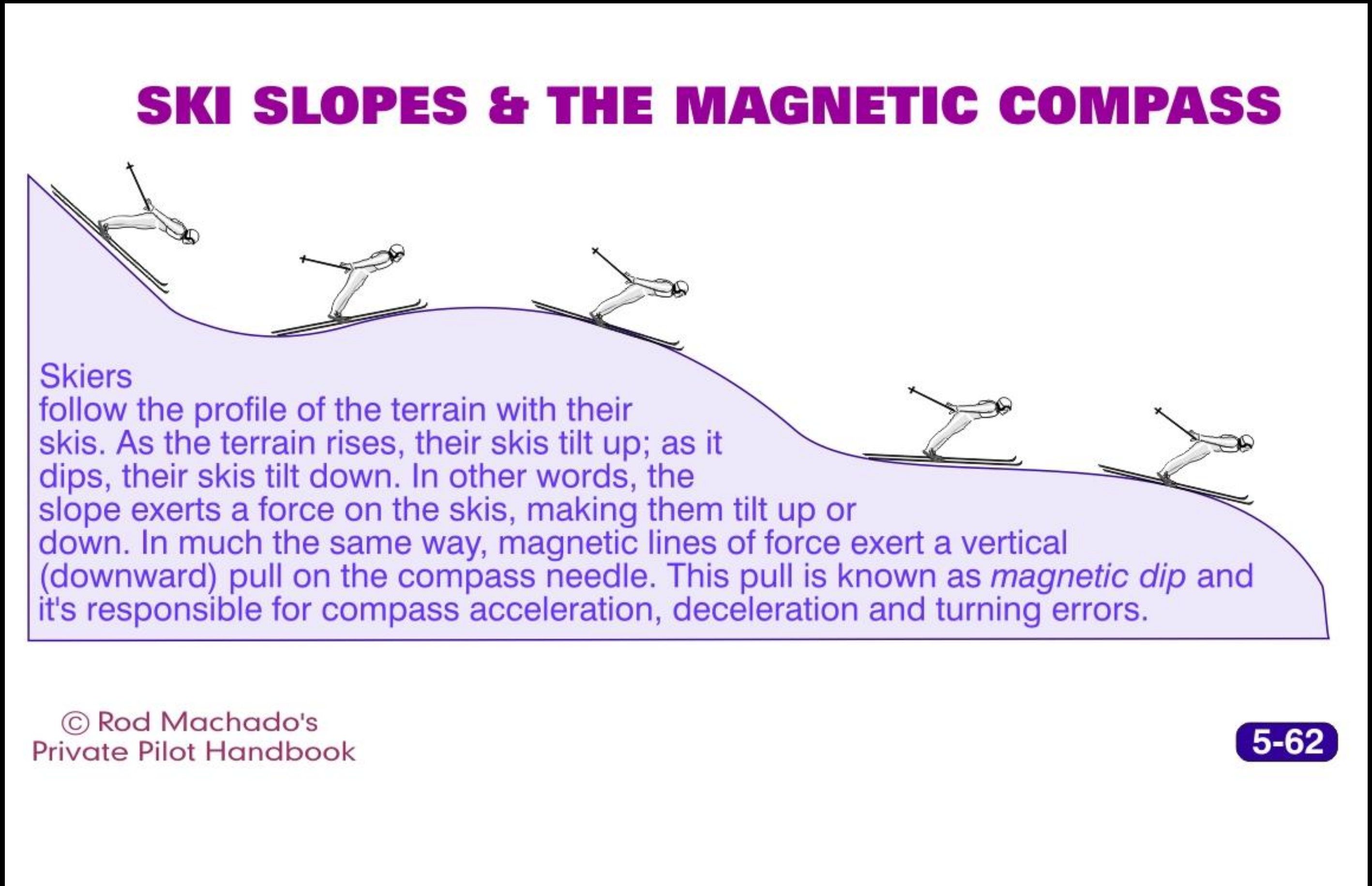
- The magnets align with the Earth's magnetic field and the pilot reads the direction on the scale opposite the lubber line
- The pilot sees the compass card from its backside
- When north as the compass shows, east is to the pilot's right, but on the card "33", which represents 330° is to the right of north
- The card remains stationary, and the compass housing and the pilot turn around it, always viewing the card from its backside

Magnetic Dip



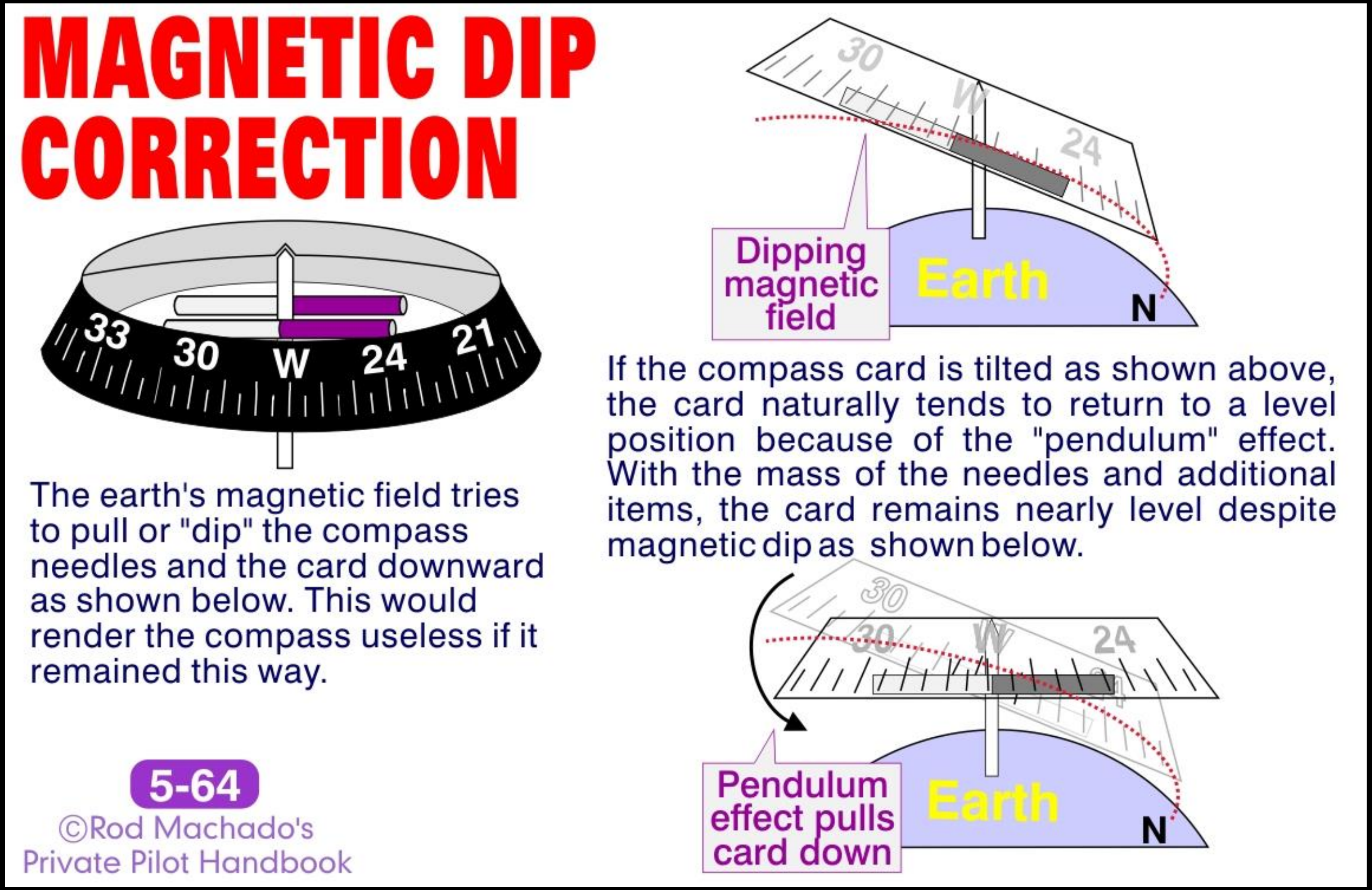
- Earth's magnetic field dips downward at nearly a 90° angle at the poles
- Very little dip in the equatorial regions

Magnetic Dip



- Just like skis following dipping terrain, the magnetic compass needle wants to tilt downward with the magnetic field

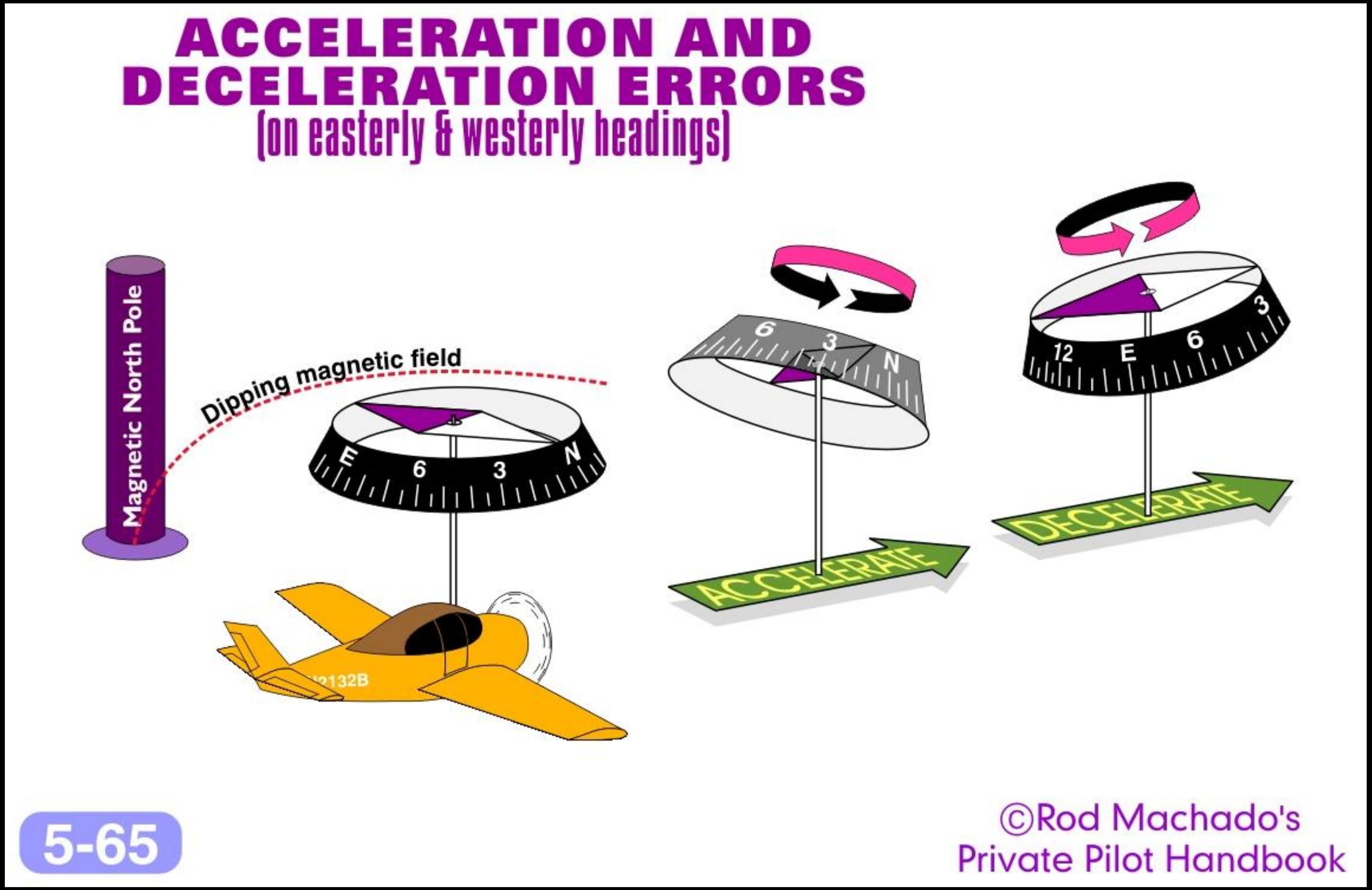
Magnetic Dip Correction



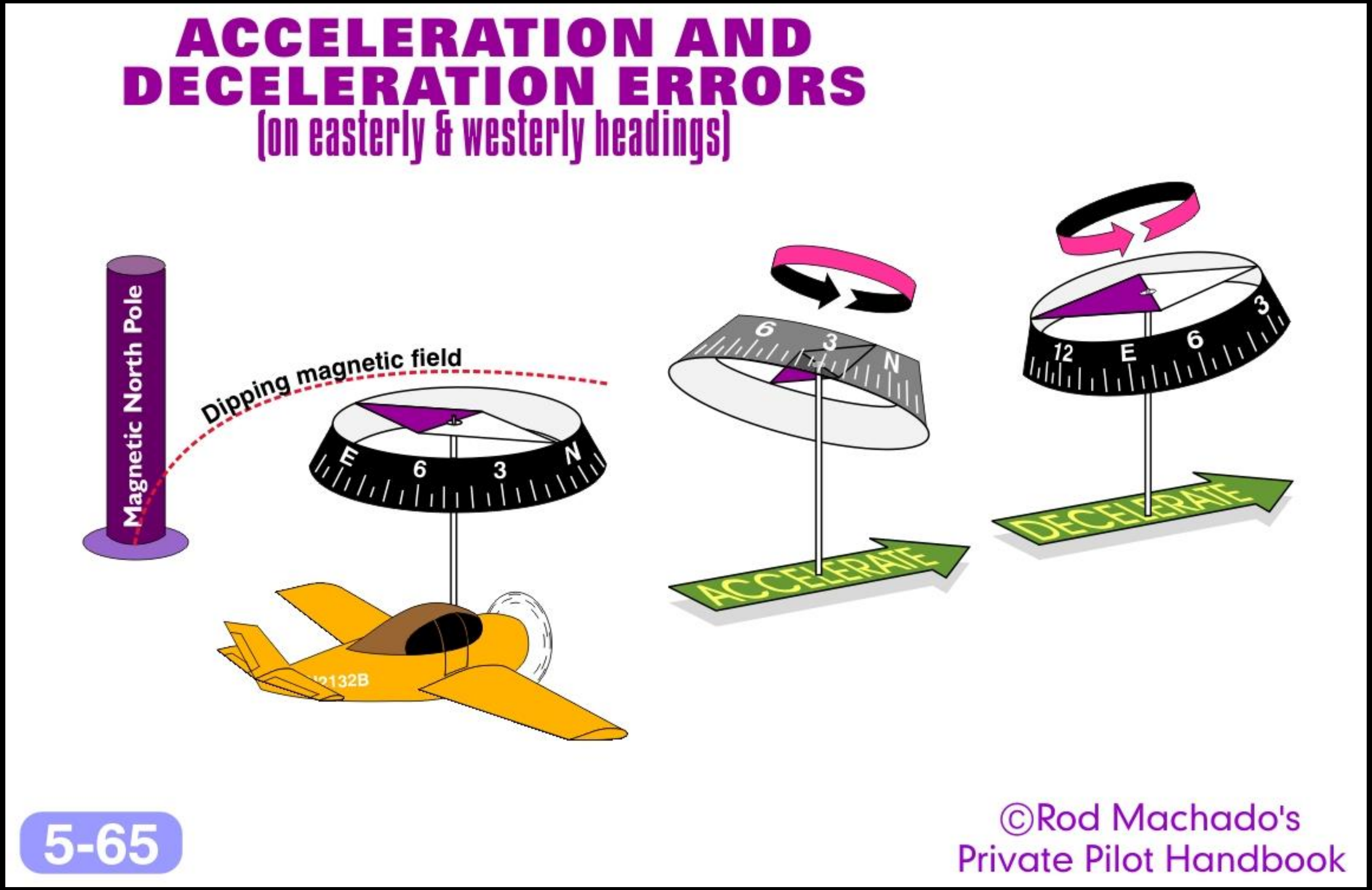
- The compass card's pendulous mounting counteracts this dip
- As long as the compass card is allowed to hang parallel to the earth, it's not restricted by the dipping magnetic field

Acceleration / Deceleration Error

- When the airplane accelerates or decelerates, the free-swinging compass card has inertia and tends to resist the speed change
- Causes the compass card to tilt within its case
- Results in acceleration-deceleration errors which are present on easterly and westerly headings only

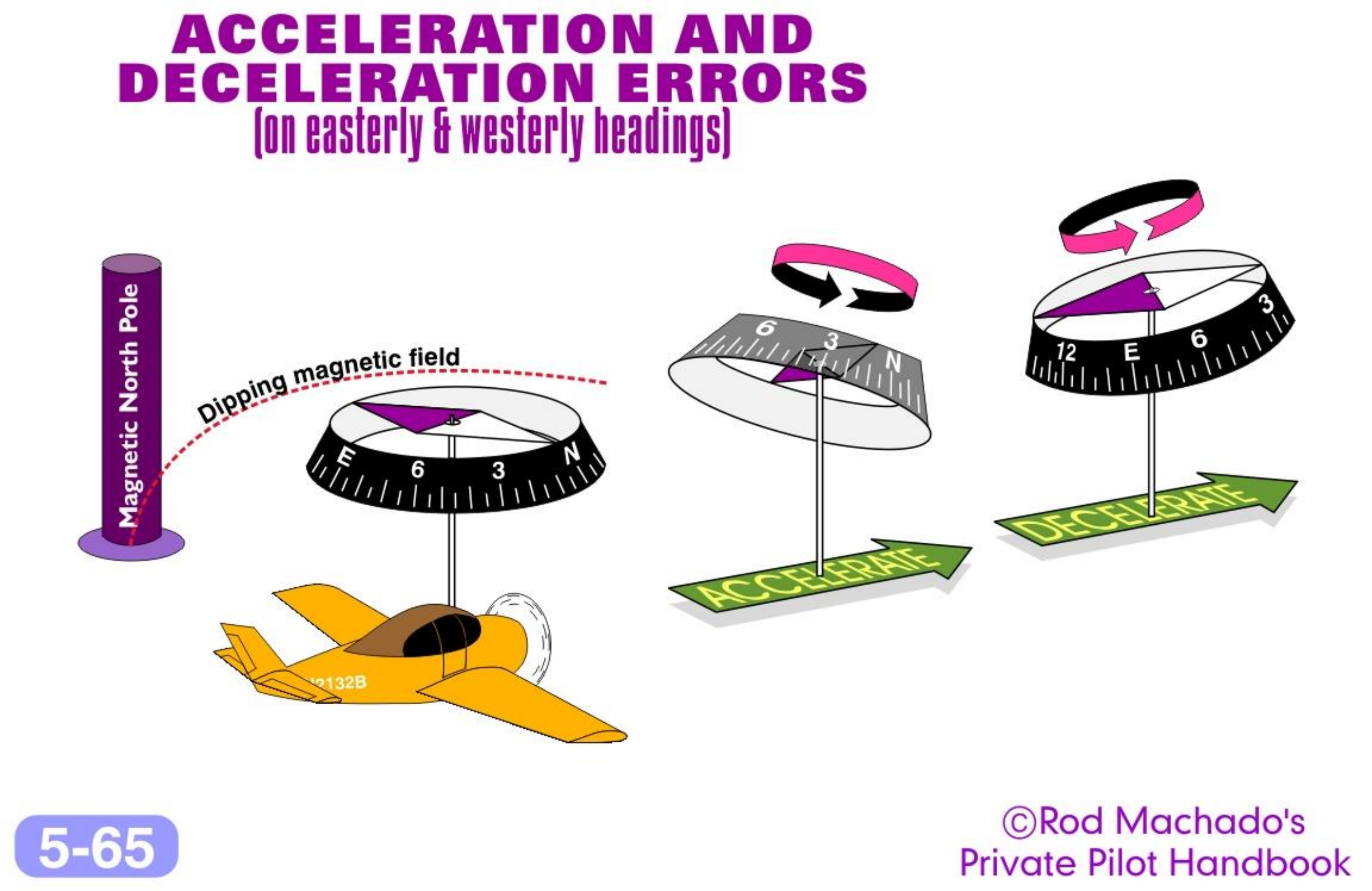


Level Unaccelerated Flight



- On an easterly (or westerly heading), the compass reads the correct heading if the airplane doesn't accelerate or decelerate
- Despite the dip in the earth's magnetic field, the compass card's pendulous mounting keeps the compass needle from trying to bend downward with the dipping magnetic field

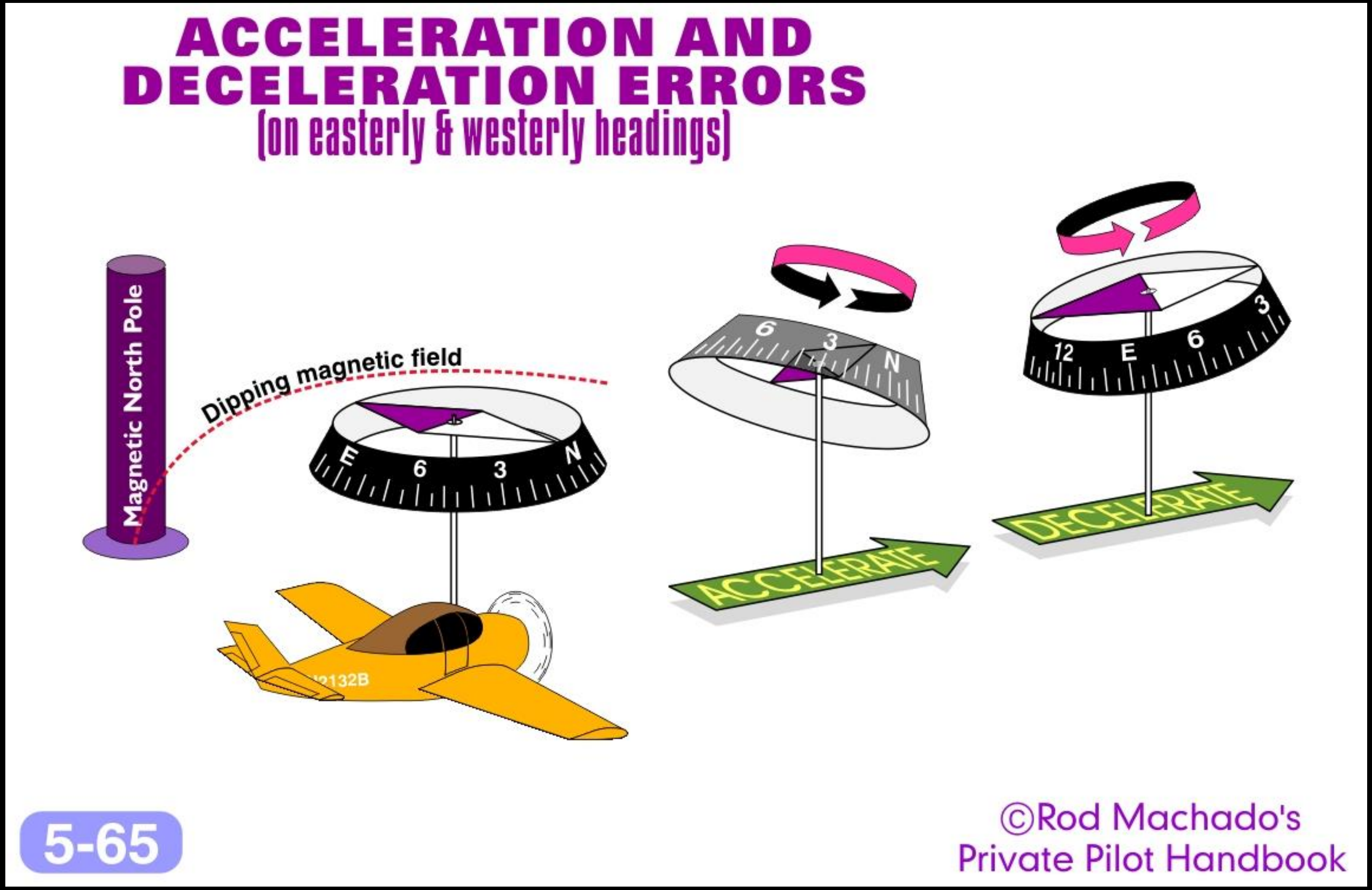
Acceleration Error



- During acceleration on an easterly (or westerly) heading, the rear of the card tilts upward as a result of the card's inertia
- Allows the north-seeking end of the compass needle to dip downward as it tries to align itself with the earth's dipping magnetic field
- This twists the compass card clockwise resulting in the temporary appearance of a more northerly heading

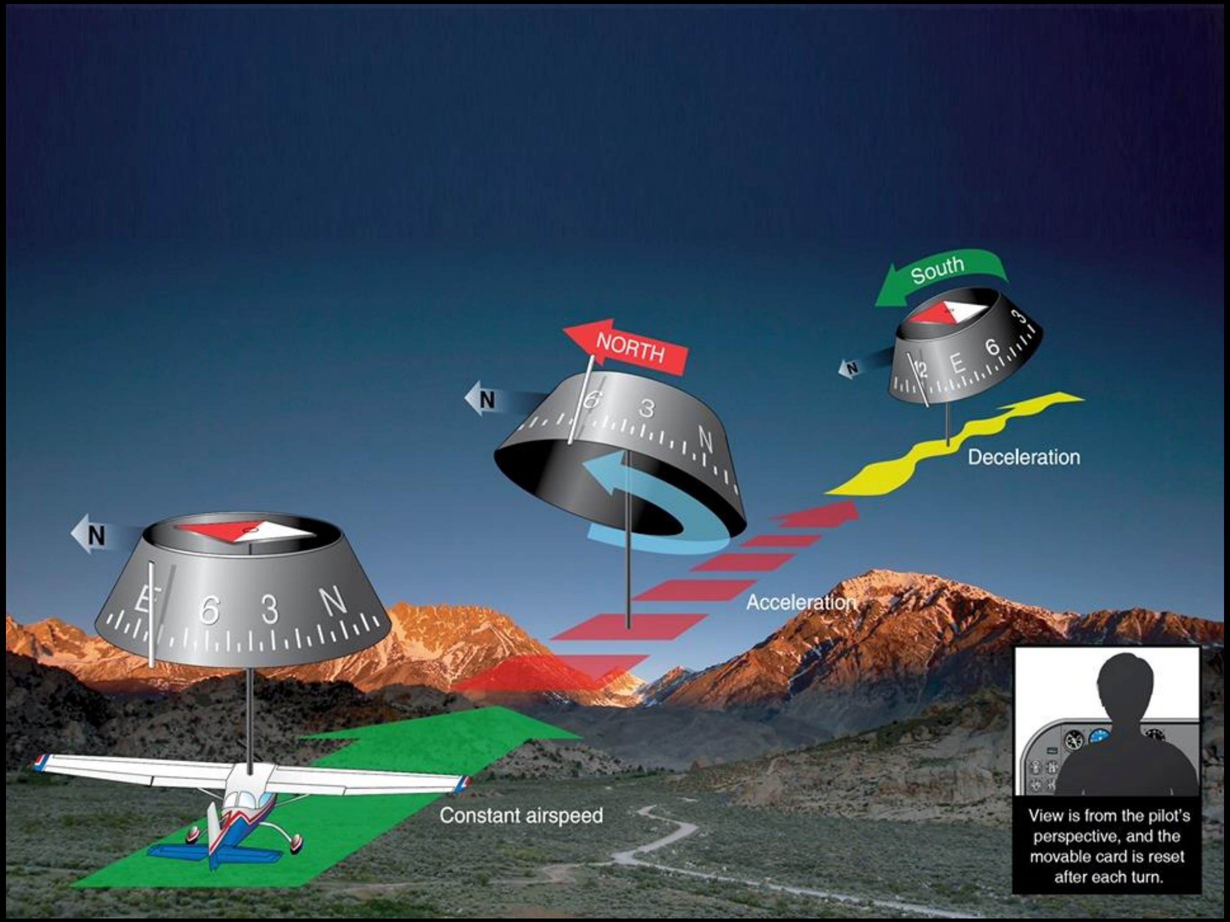
Deceleration Error

- Deceleration on an easterly (or westerly) heading causes the rear of the compass card to swing downward
- The north seeking end of the compass needle dips downward, causing the compass card to twist counterclockwise
- This temporarily results in the compass indicating a more southerly heading



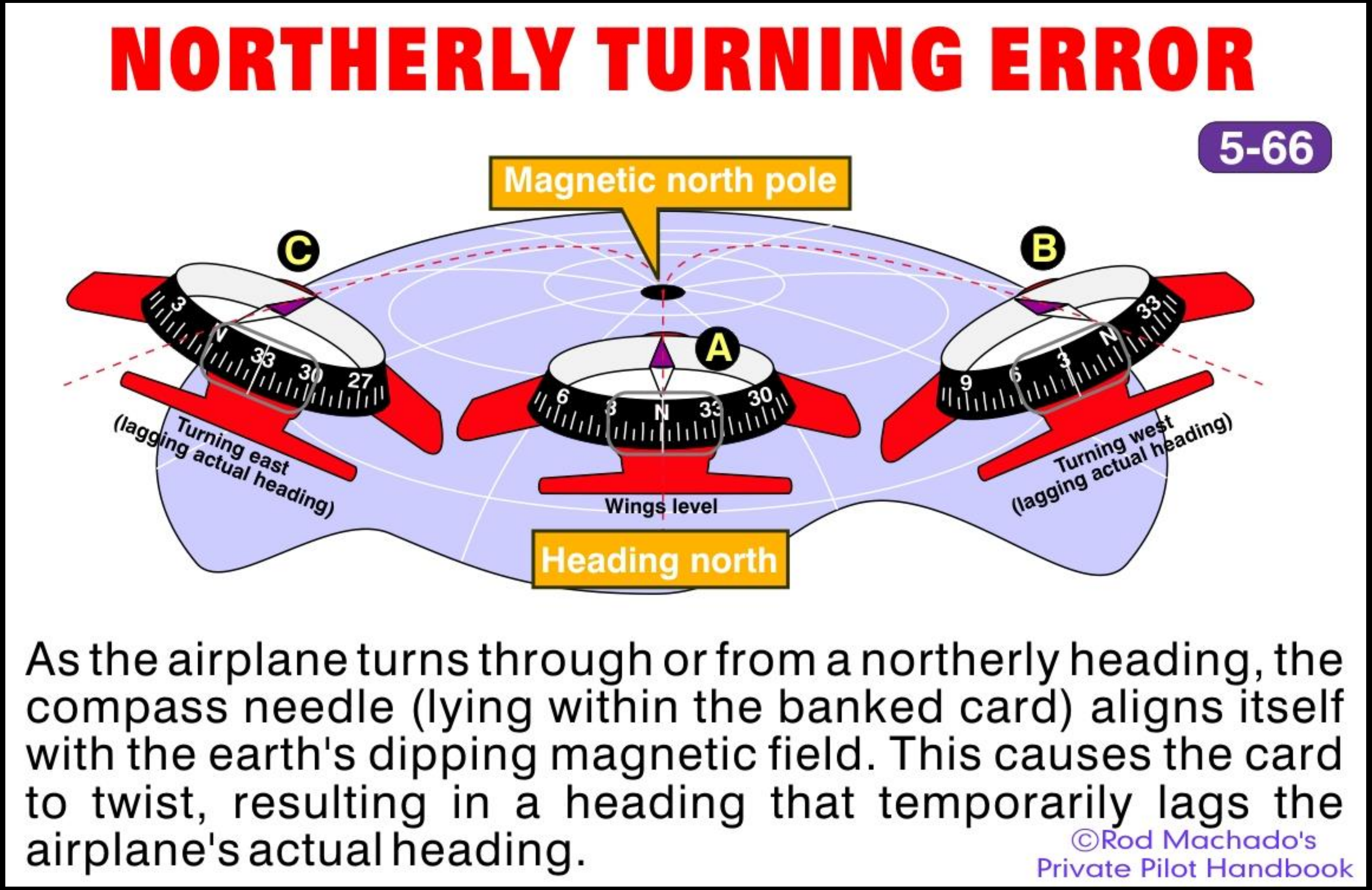
Acceleration/ Deceleration Error

- Most pronounced on headings of *east* and *west*
- When accelerating, the compass indicates a turn toward the north
- When decelerating it indicates a turn toward the south
- ANDS
  Accelerate North Decelerate South



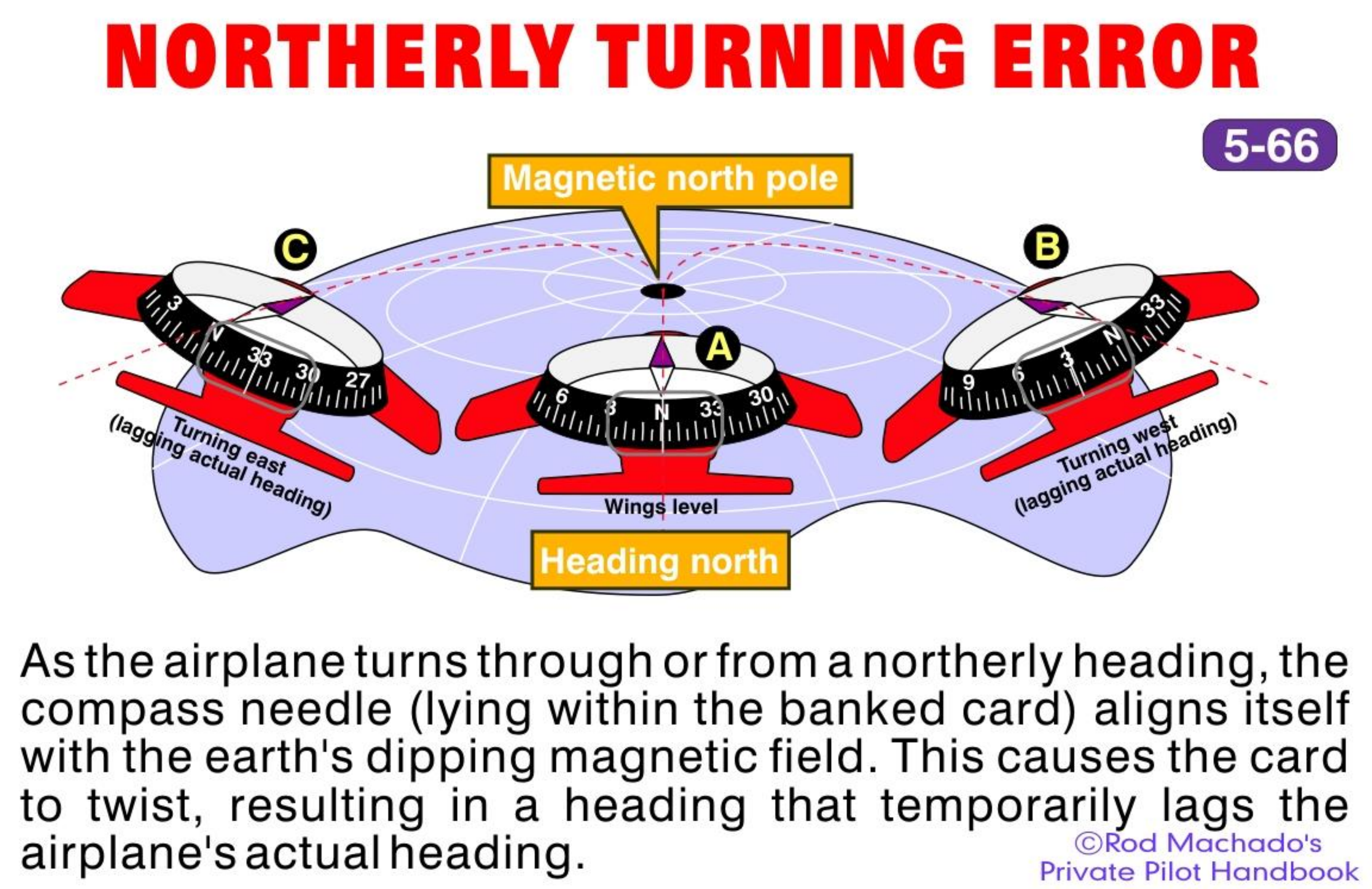
Northerly Turning Error

- Only experienced on northerly or southerly headings
- Caused by the compass card being forced to tilt when the airplane is in a bank
- The pendulous properties of the card can't prevent the compass needle's north-seeking end from pointing downward in the direction of the dipped magnetic field

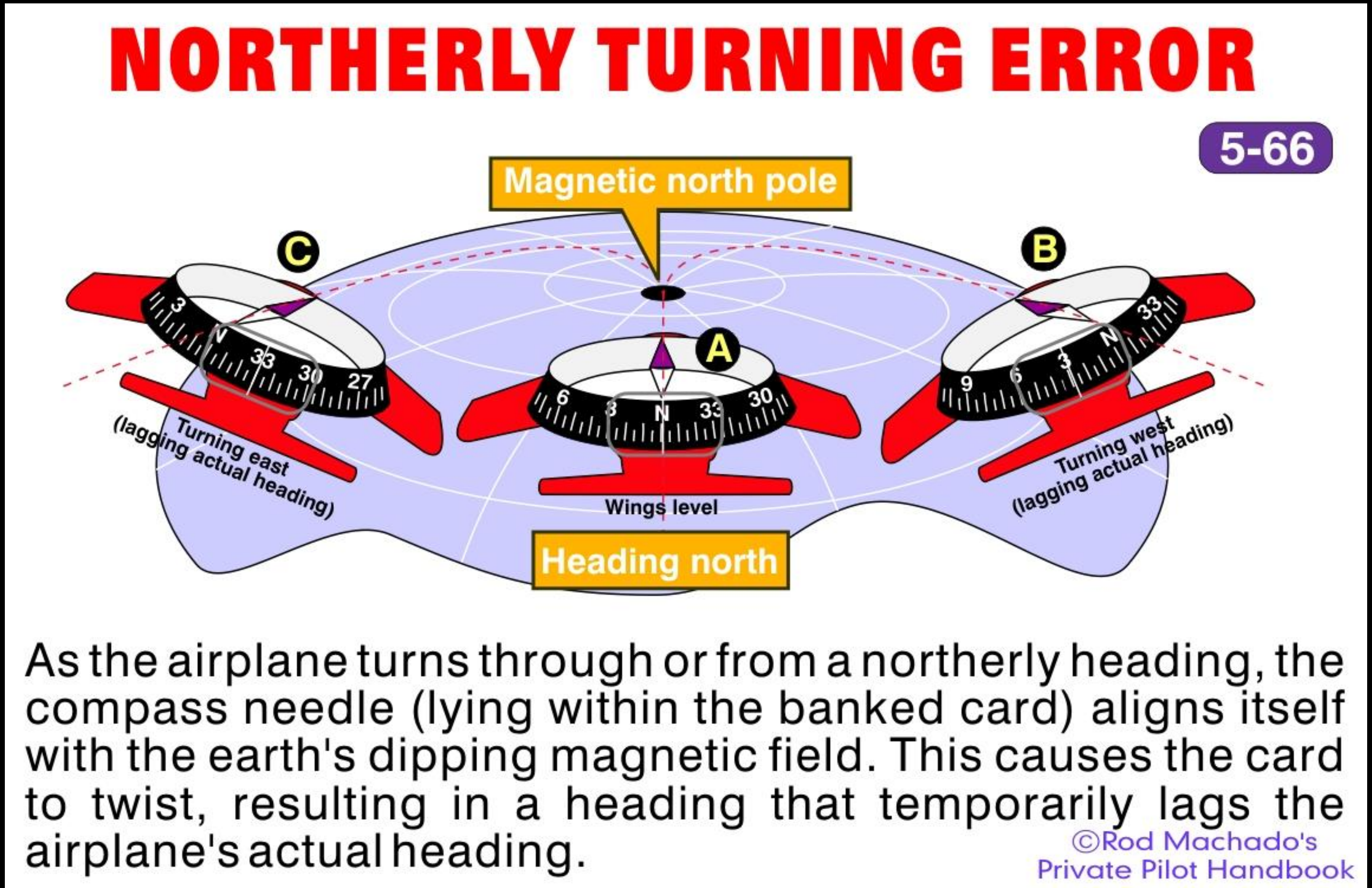


Northerly Turning Error

- As the airplane turns from or through a northerly heading, the compass reading lags the airplane's heading
- Airplane B is in a left turn and its heading is approximately 360°
- Yet its compass shows a heading of 030°- lagging behind its actual direction



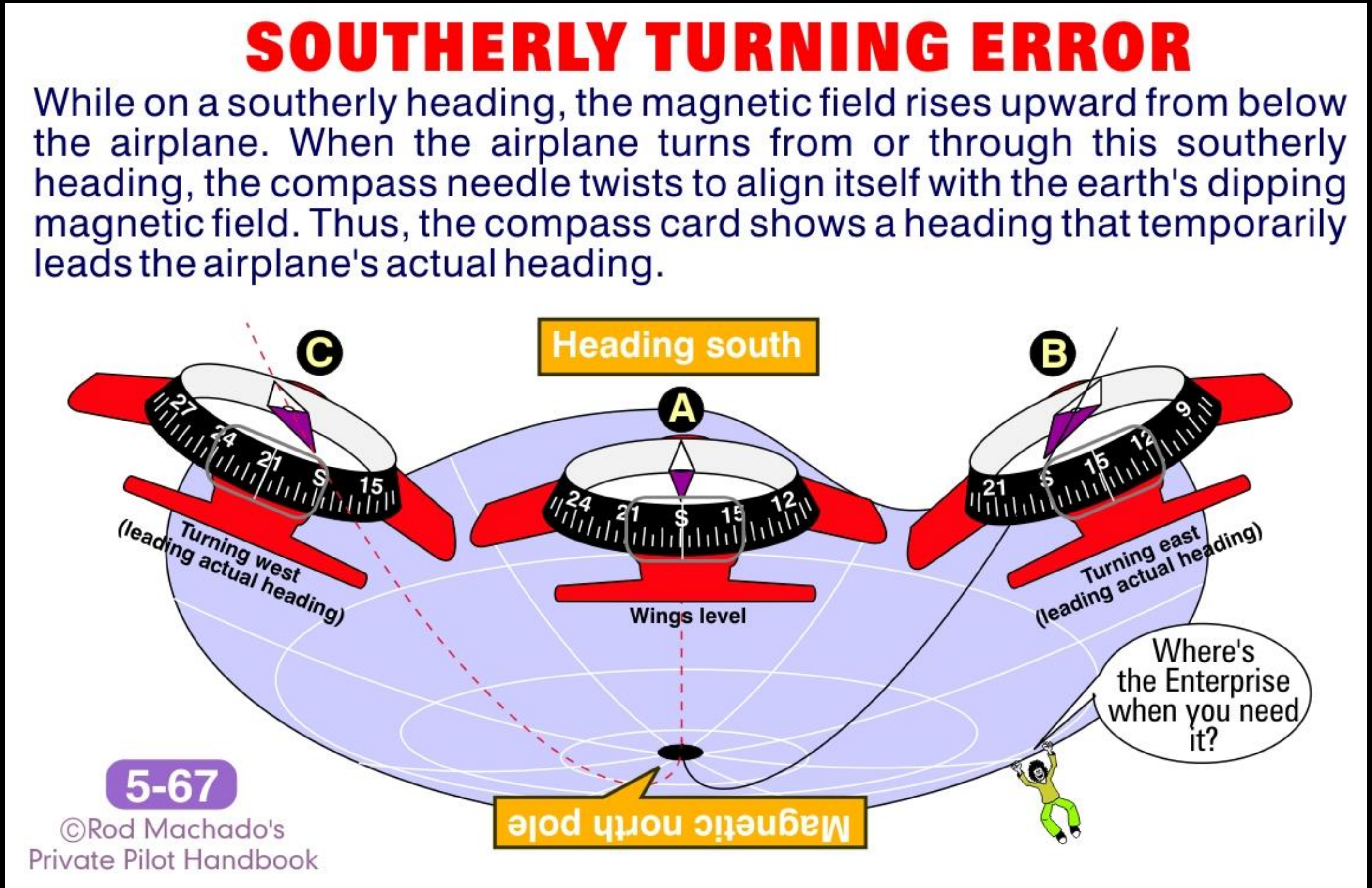
Northerly Turning Error



- Airplane C is in a right turn and its heading is nearly 360°
- Its compass shows a heading of 330°, which is lagging behind its actual direction
- As the airplane turns away from a northerly heading, these turning errors disappear and the airplane's correct heading appears under the lubber line
- Airplane A has no turning error because it's not in a turn

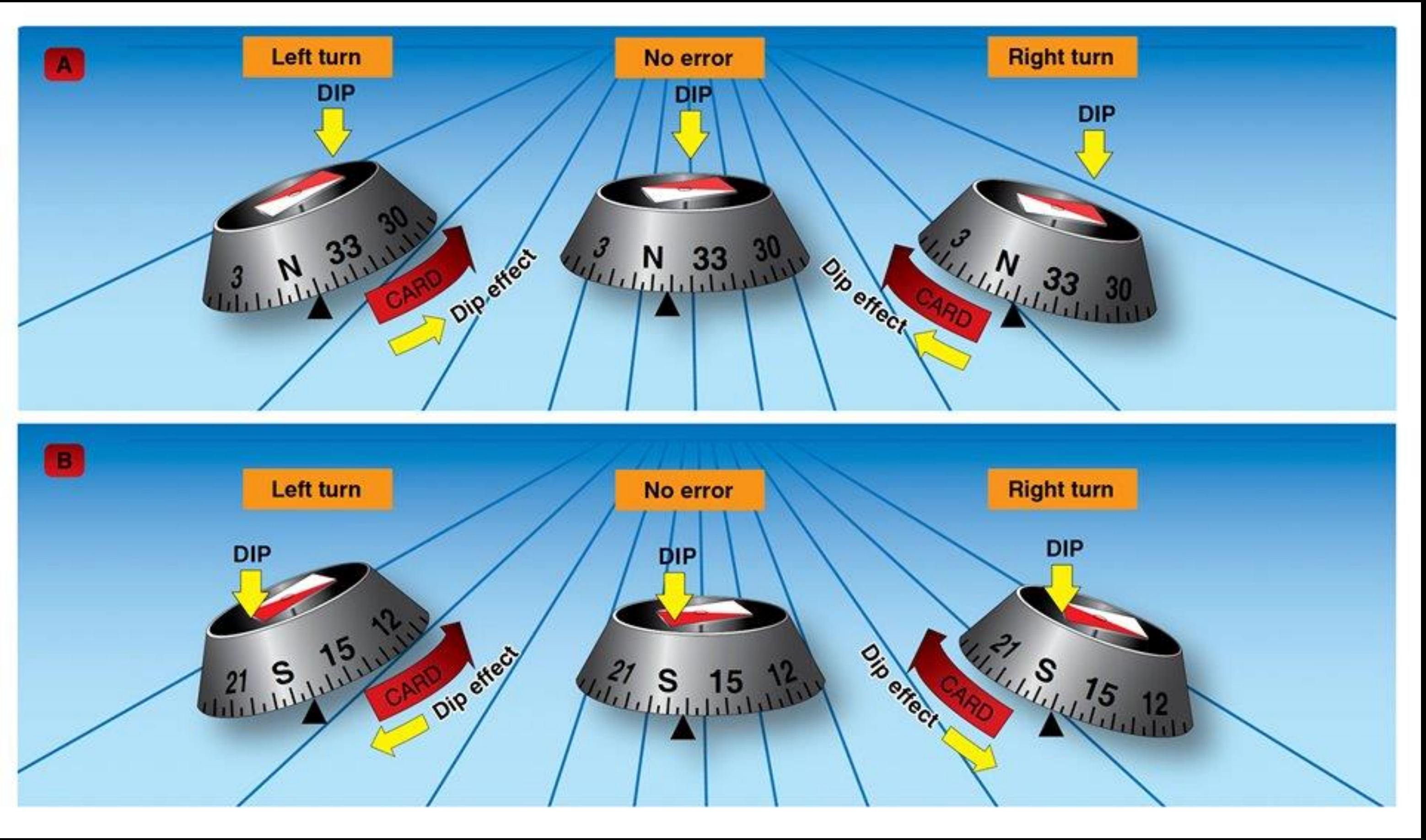
Turning Error Turning South

- Heading directly south with the wings level produces the correct compass reading
- As the airplane turns from or through a southerly heading, the compass reading leads the airplane's actual heading
- As a heading of east or west is approached, the turning errors disappear

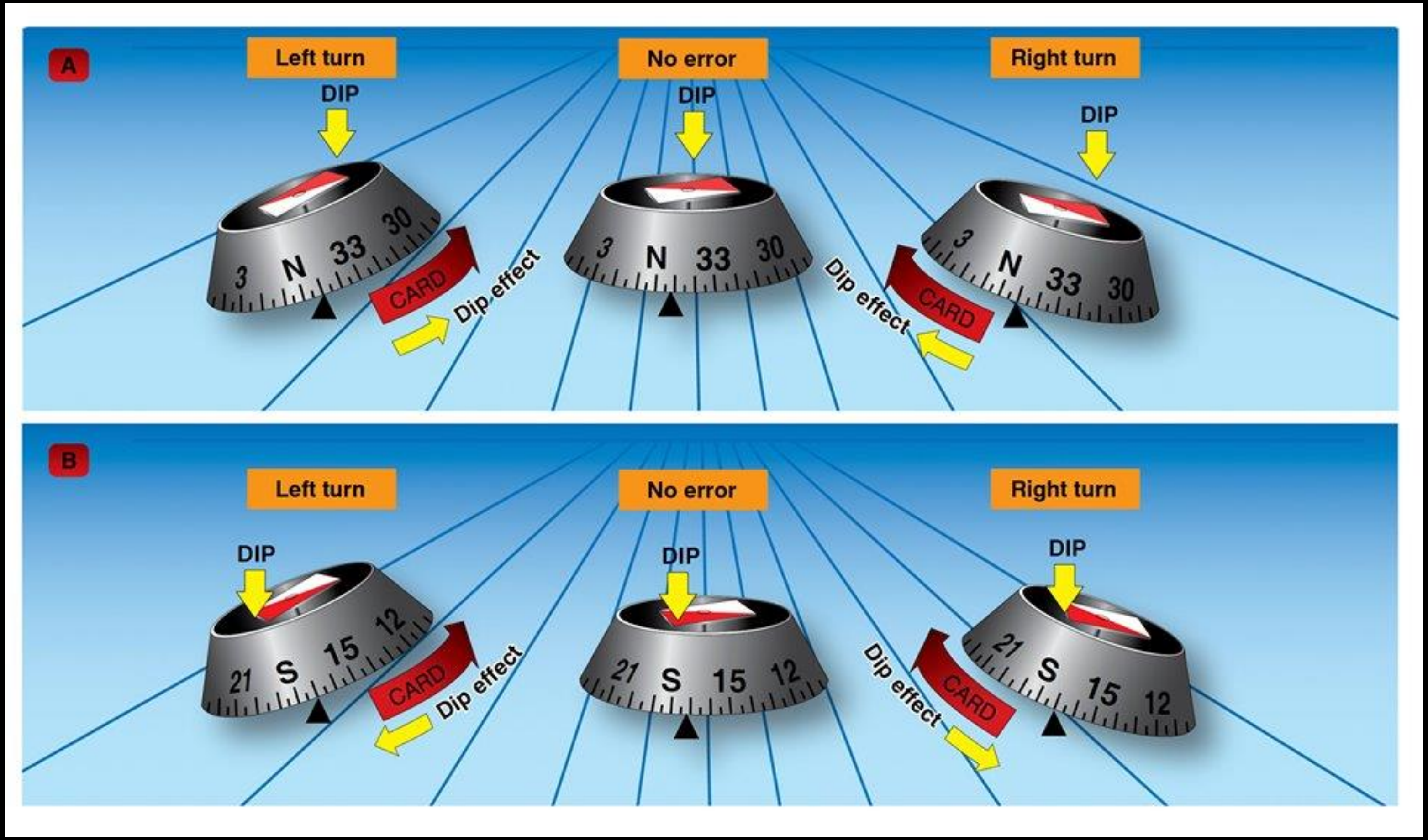


Northerly Turning Error

- Compass will lag behind (or indicate opposite) the actual aircraft heading while turning through headings in the northern half of the compass rose
- Compass will lead (or overshoot) the aircraft's actual heading in the southern half



Northerly Turning Error



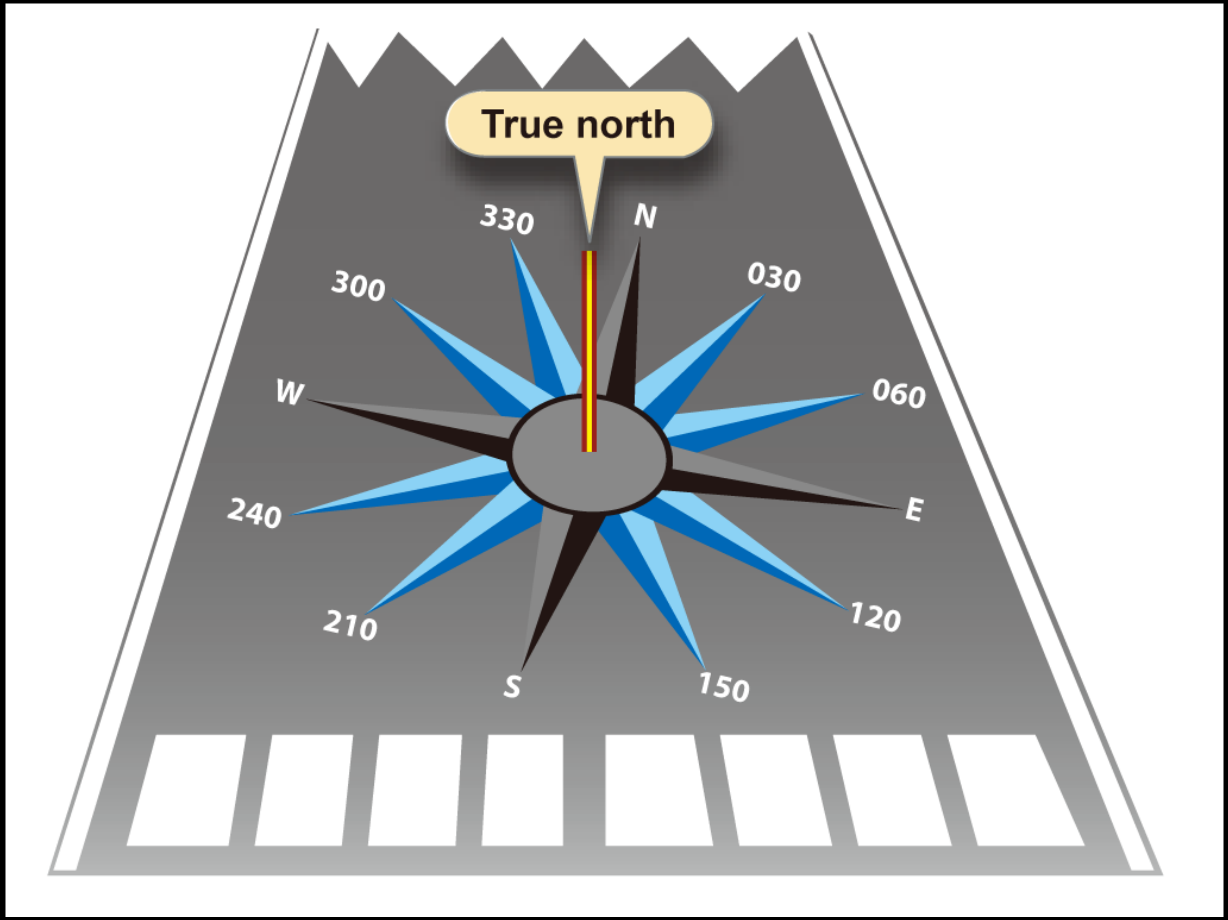
- Error is most pronounced when turning through north or south, and is approximately equal in degrees to the latitude
- When rolling into a turn on an easterly or westerly heading the compass will indicate the approximate correct magnetic heading if the roll into the turn is smooth
- Pilot action: OSUN Overshoot South, Undershoot North

Magnetic Deviation

- The magnets in a compass align with any magnetic field
- Local magnetic fields in an aircraft caused by electrical current flowing in the structure or any magnetized part of the structure, conflict with the Earth’s magnetic field and cause a compass error called deviation
- Deviation is different on each heading, but it is not affected by the geographic location
- Deviation error can be minimized when a pilot or AMT Swings the compass

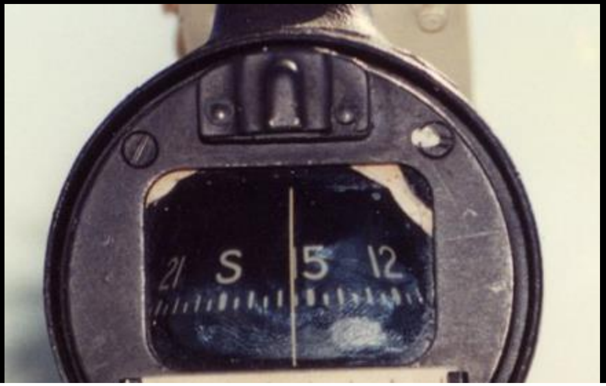
Compass Rose

- Some airports have a compass rose, which is a series of lines marked out on a taxiway or ramp at some location where there is no magnetic interference
- Lines, oriented to magnetic north are painted every 30°
- The pilot or AMT aligns the aircraft on each magnetic heading and adjusts compensating magnets to minimize the difference between the compass indication and the actual magnetic heading of the aircraft



Compass Correction Card

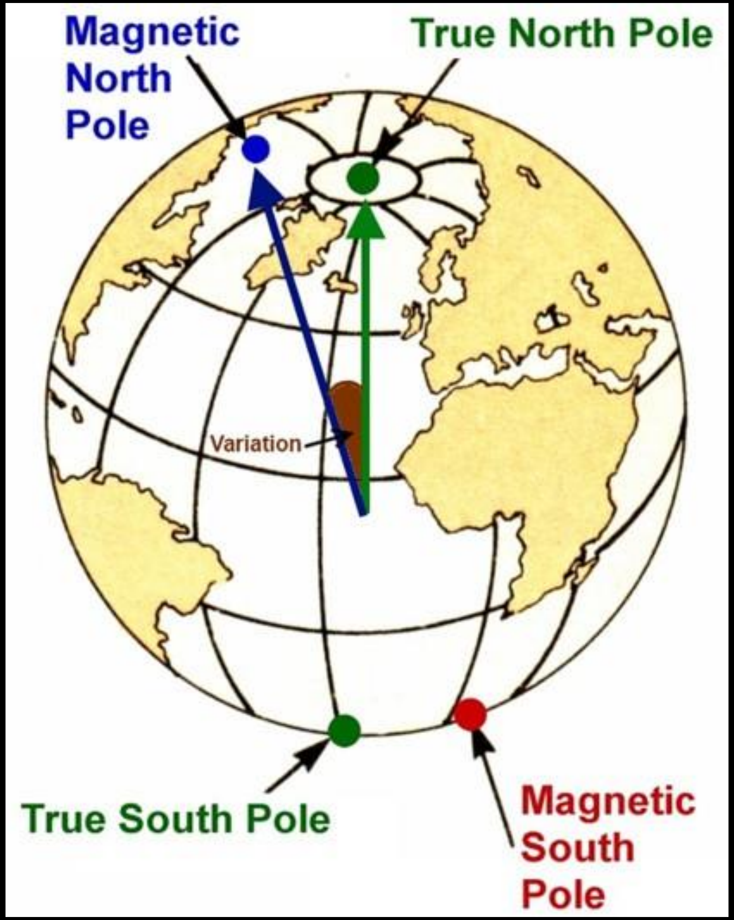
- Any error that cannot be removed is recorded on a compass correction card placed near the compass
- If the pilot wants to fly a magnetic heading of 120° (radios on) the pilot should fly a compass heading of 123°



FOR	000	030	060	090	120	150
STEER						
RDO. ON	001	032	062	095	123	155
RDO. OFF	002	031	064	094	125	157

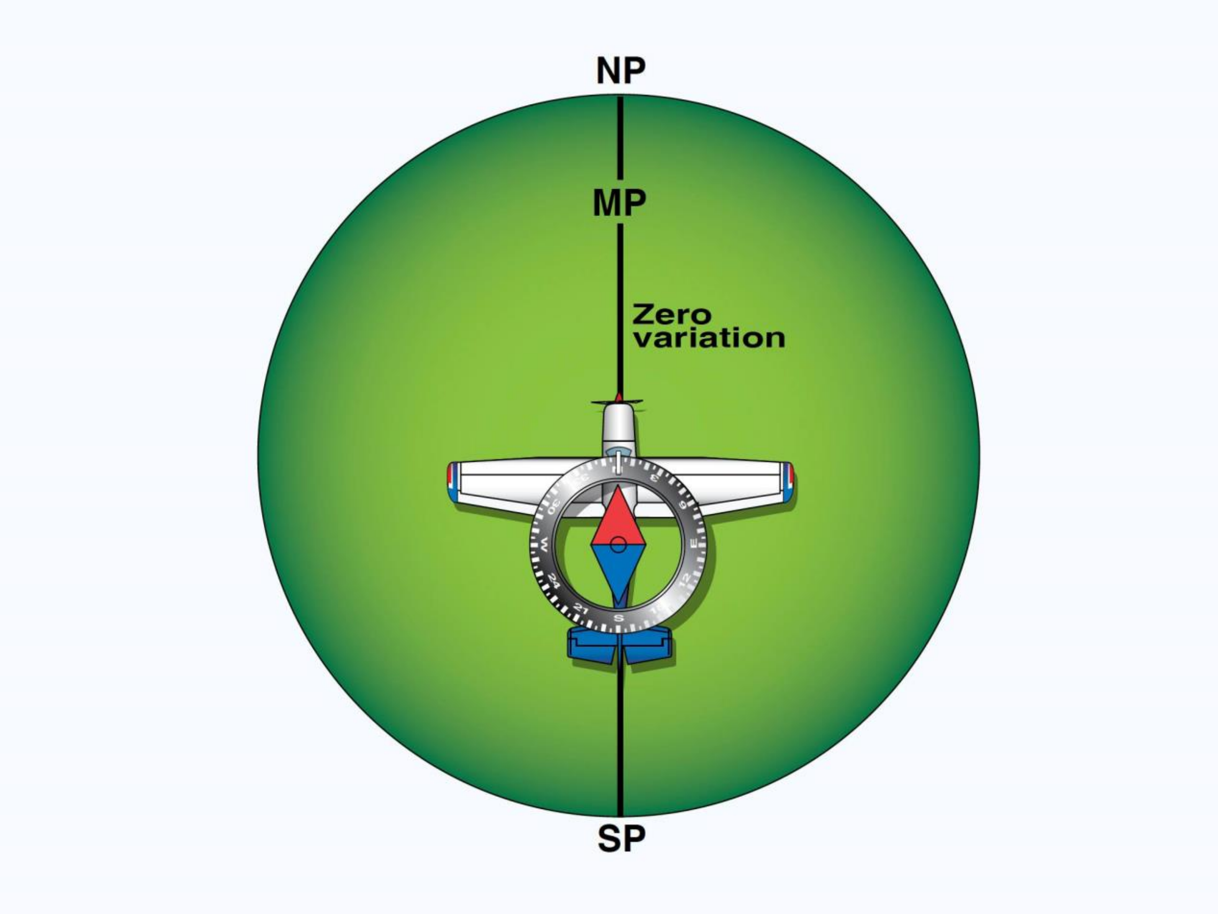
FOR	180	210	240	270	300	330
STEER						
RDO. ON	176	210	243	271	296	325
RDO. OFF	174	210	240	273	298	327

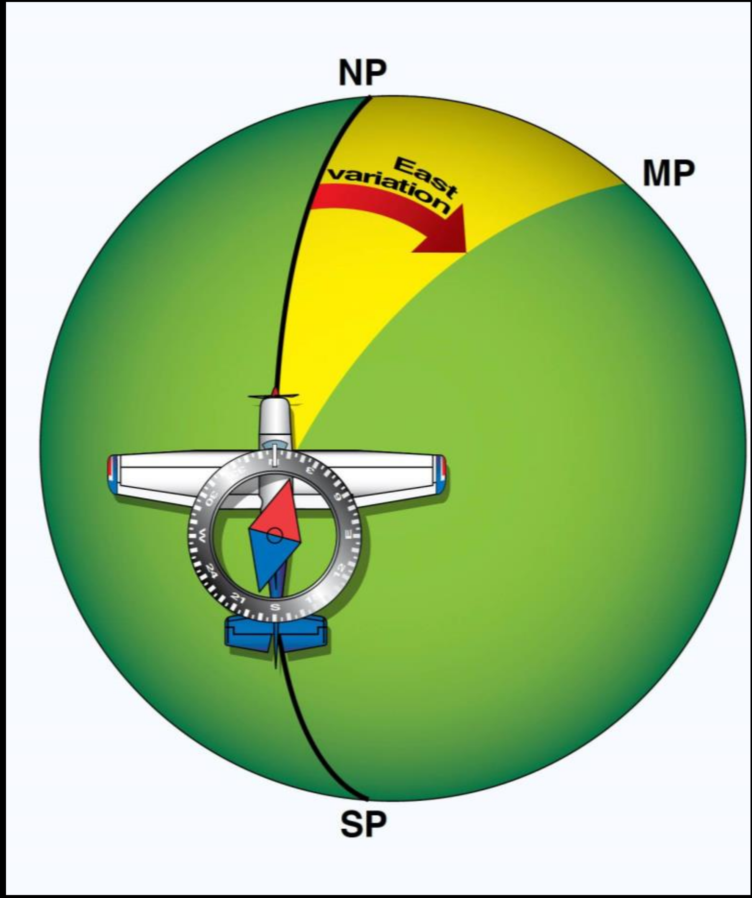
Magnetic Variation



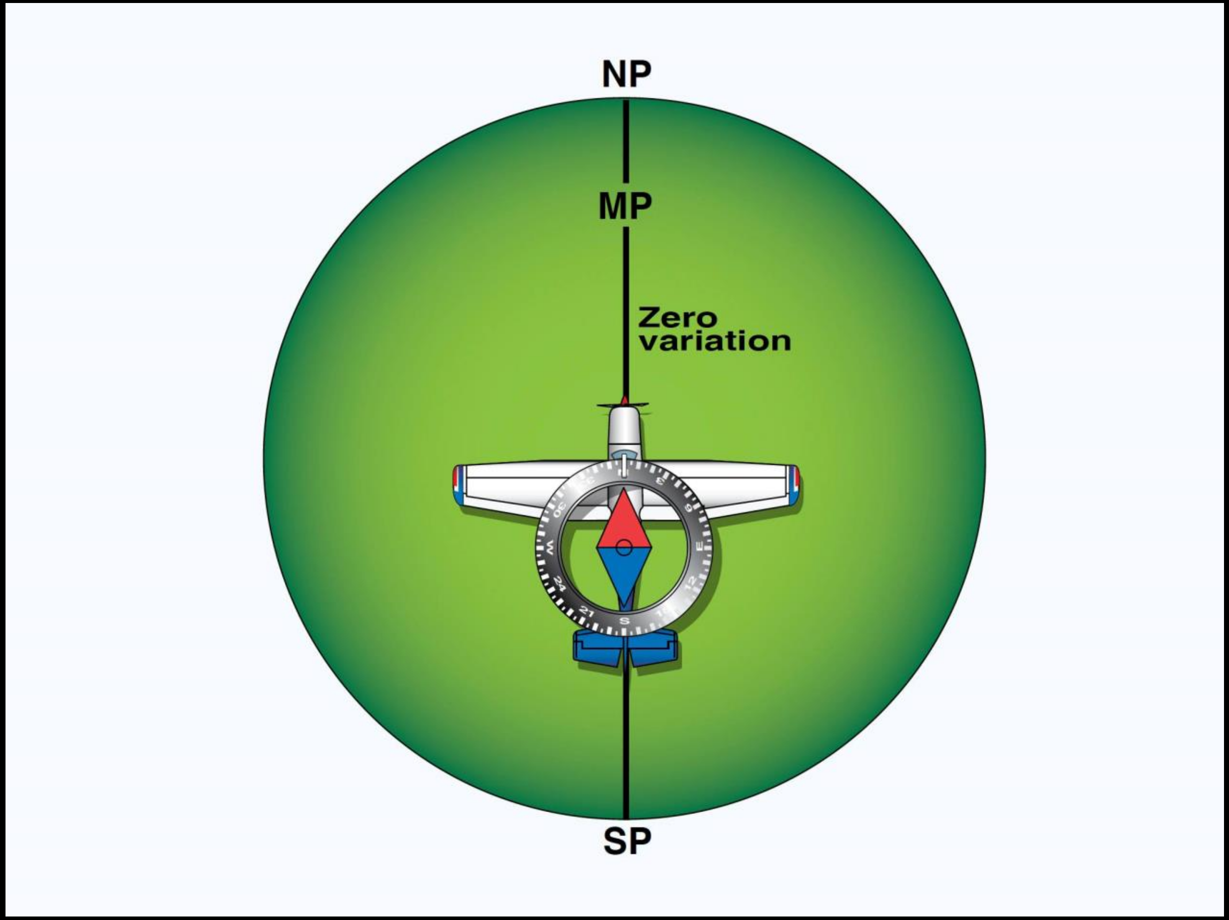
- Earth rotates about its geographic axis
- Charts are drawn using meridians of longitude that pass through the geographic poles called true directions
- The north magnetic pole to which the magnetic compass points is not collocated with the geographic north pole, but is some 1,300 miles away
- Directions measured from the magnetic poles are called magnetic directions
- The difference between true and magnetic directions is called *variation*

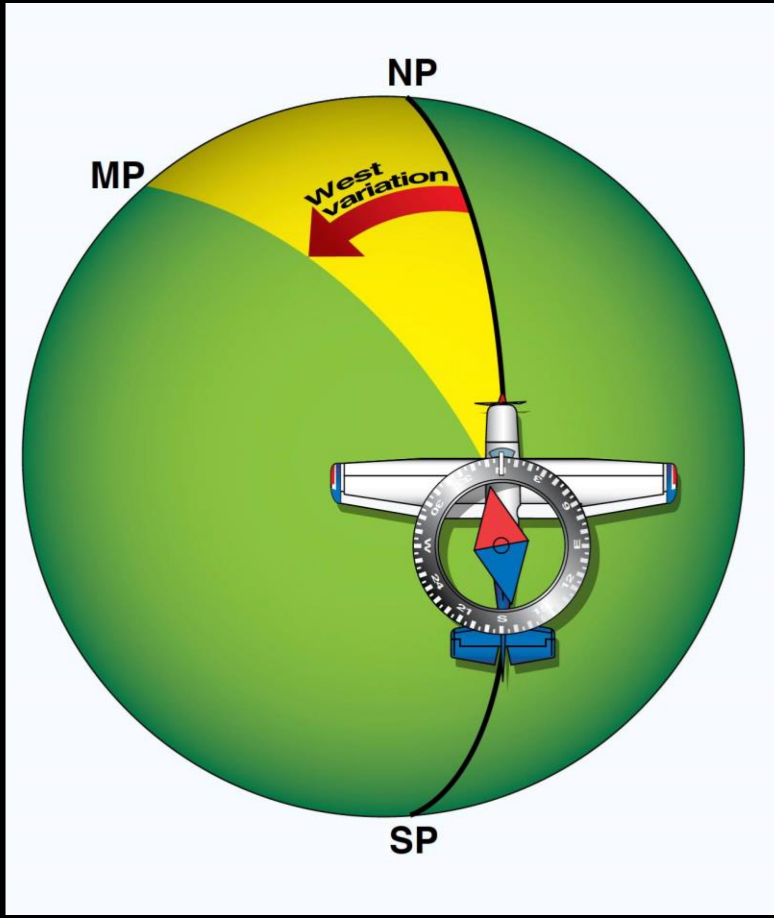
Easterly Magnetic Variation



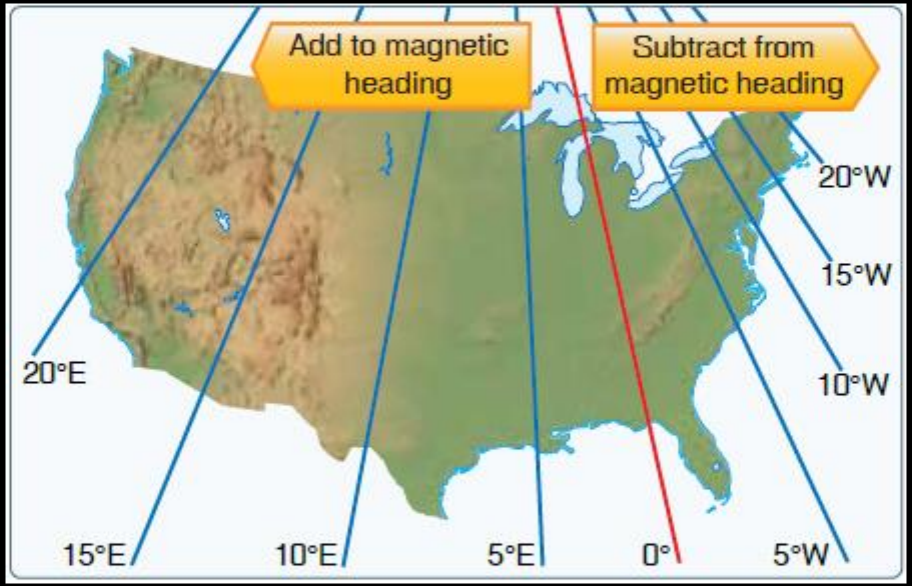


Westerly Magnetic Variation





Isogonic Lines



- Identifies the number of degrees of variation in that area
- The line of zero variation is called the ***agonic*** line
- East or West of this line a correction must be applied to a compass indication to get a true direction
- Variation error does not change with the heading of the aircraft
- True Course +/- Variation = Magnetic Course
- *East is Least (subtract) ...*
  West is Best (add)

Oscillation Error

- A combination of all the other errors
- Results in the compass card swinging back and forth around the heading being flown
- When setting the gyroscopic heading indicator to agree with the magnetic compass, use the average indication between the swings

Magnetic Compass Pre-Takeoff Check

- A magnetic compass pre-takeoff check verifies that:
  - 1. The liquid chamber is full of fluid
  - 2. The compass is free turning
  - 3. No bubbles appear in the fluid
  - 4. The compass agrees with a known heading with radios and electrical systems ON

Setting Heading Indicator Using Magnetic Compass

- The HI is not subjected to turning errors or acceleration/deceleration errors
- Is gyro-stabilized and its accuracy isn't affected by turning or a change in speed
- When initially setting the HI to the value in the magnetic compass, make sure the airplane is in wings-level, unaccelerated flight
- This is the only time you can be sure the compass value is most accurate

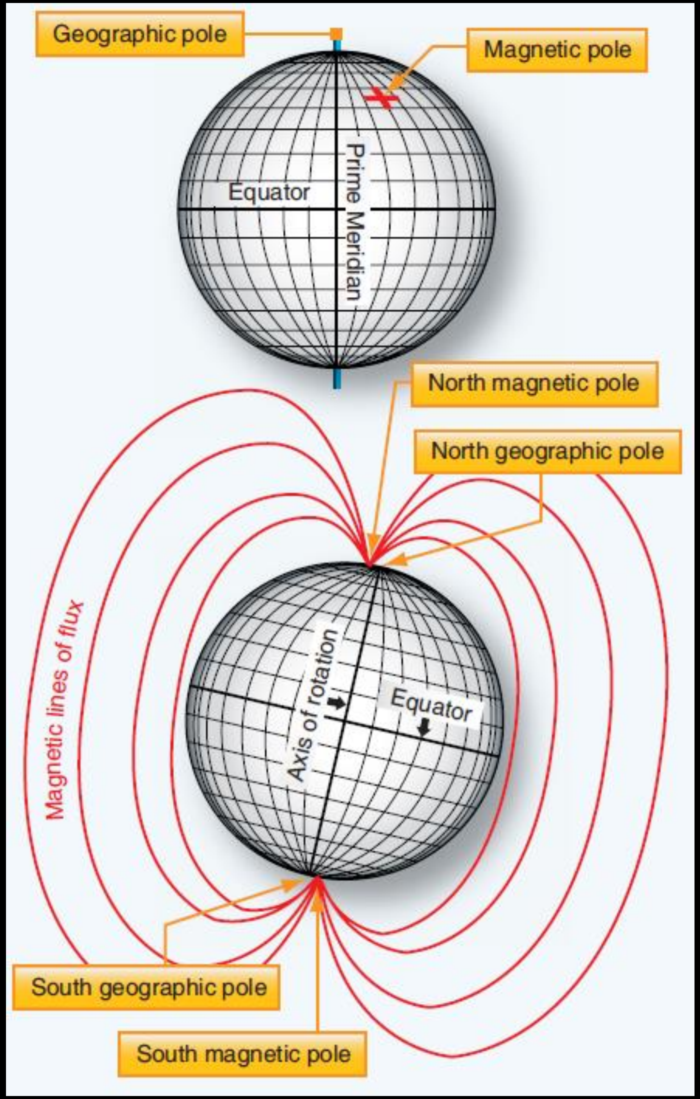
Vertical Card Magnetic Compass

- The floating magnet type of compass not only has all the errors just described, but also lends itself to confused reading
- The vertical card magnetic compass eliminates some of the errors and confusion
- The dial is rotated by a set of gears from a shaft-mounted magnet, and the nose of the symbolic airplane on the instrument glass represents the lubber line for reading the heading

Typical Heading and VOR Indicators

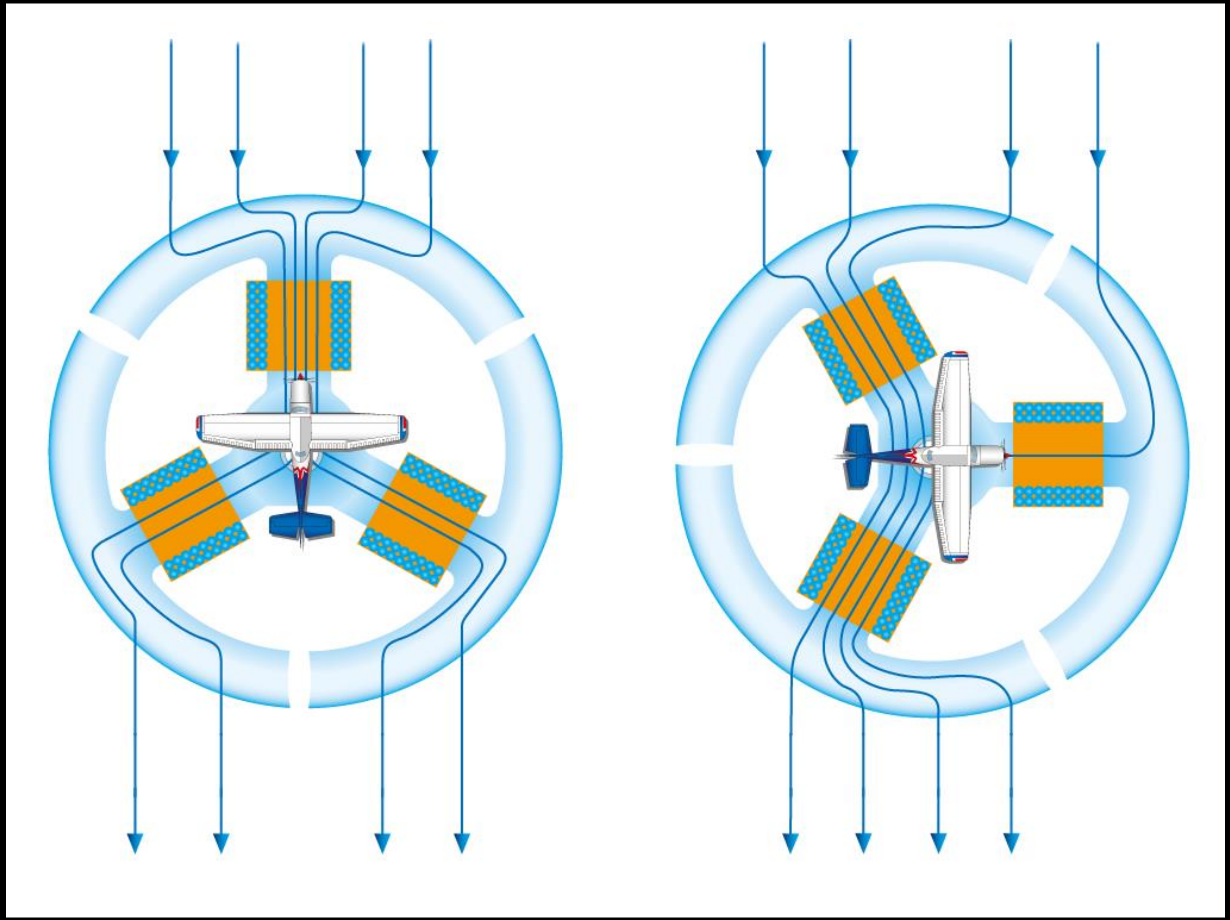
Flux Gate Compass System

- The lines of flux in the Earth's magnetic field have two basic characteristics:
- A magnet aligns with these lines
- An electrical current is induced in any wire crossed by them

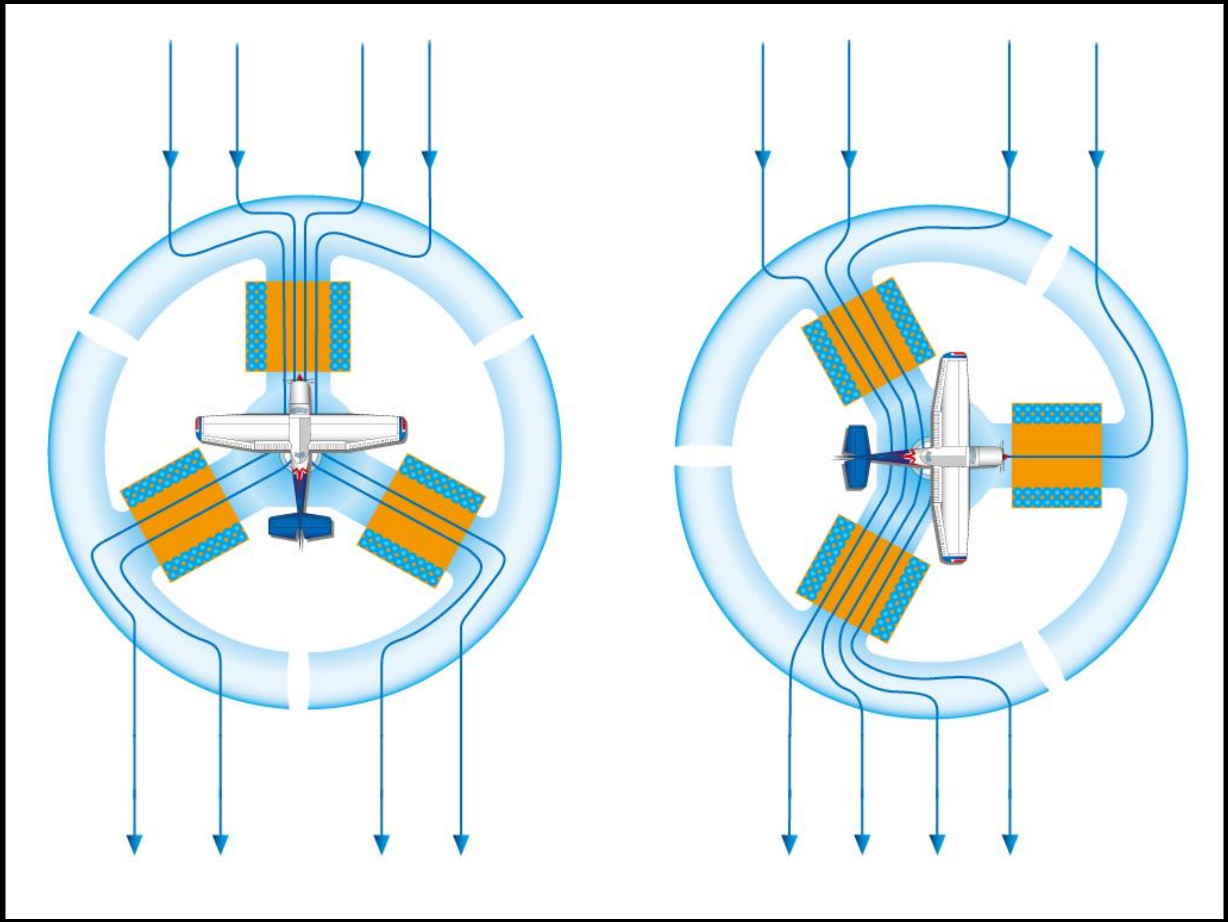


Flux Valve

- Small segmented ring made of soft iron that accepts lines of magnetic flux
- Electrical coil is wound around each of the three legs to accept the current induced in this ring by the Earth's magnetic field
- As this flux cuts across the windings in the three coils, it causes current to flow in them



Flux Valve



- These three coils are connected so the current flowing in them changes as the heading of the aircraft changes
- The three coils are connected to three similar but smaller coils in a synchro inside the instrument case
- The synchro rotates the dial of an RMI or HSI

Remote Indicating HSI

- Magnetic slaving transmitter is mounted remotely; usually in a wingtip to eliminate the possibility of magnetic interference
- Contains the flux valve, which is the direction-sensing device of the system
- Signal is relayed to the HSI

Remote Magnetic Indicator (RMI)

Temperature Gauge

- Temperature used for aircraft performance calculations
- Determine airframe and carburetor icing potential

Electronic Flight Instruments

Aircraft Flight Instruments

Garmin G1000 HSI/RMI

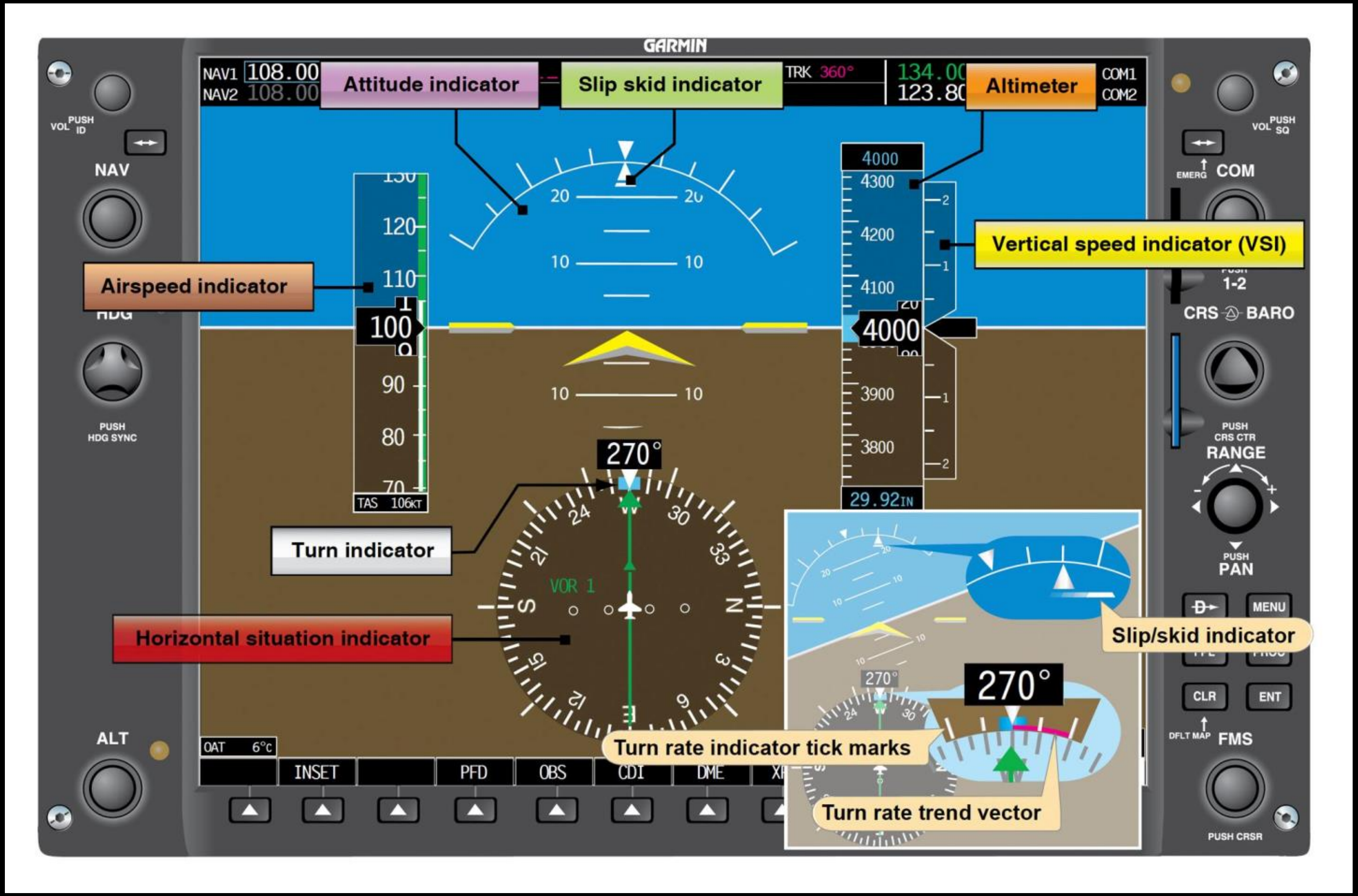
Electronic Flight Instruments

- Integrate many individual instruments into a single presentation called a primary flight display (PFD)
- AI on the PFD is larger than conventional round-dial presentations of an AI
- Airspeed and altitude indications are presented on vertical tape displays

Electronic Flight Instruments

- The vertical speed indicator is depicted using conventional analog presentation
- Turn coordination is shown using a segmented triangle near the top of the attitude indicator
- The rate-of-turn indicator appears as a curved line display at the top of the HI in the lower half of the PFD

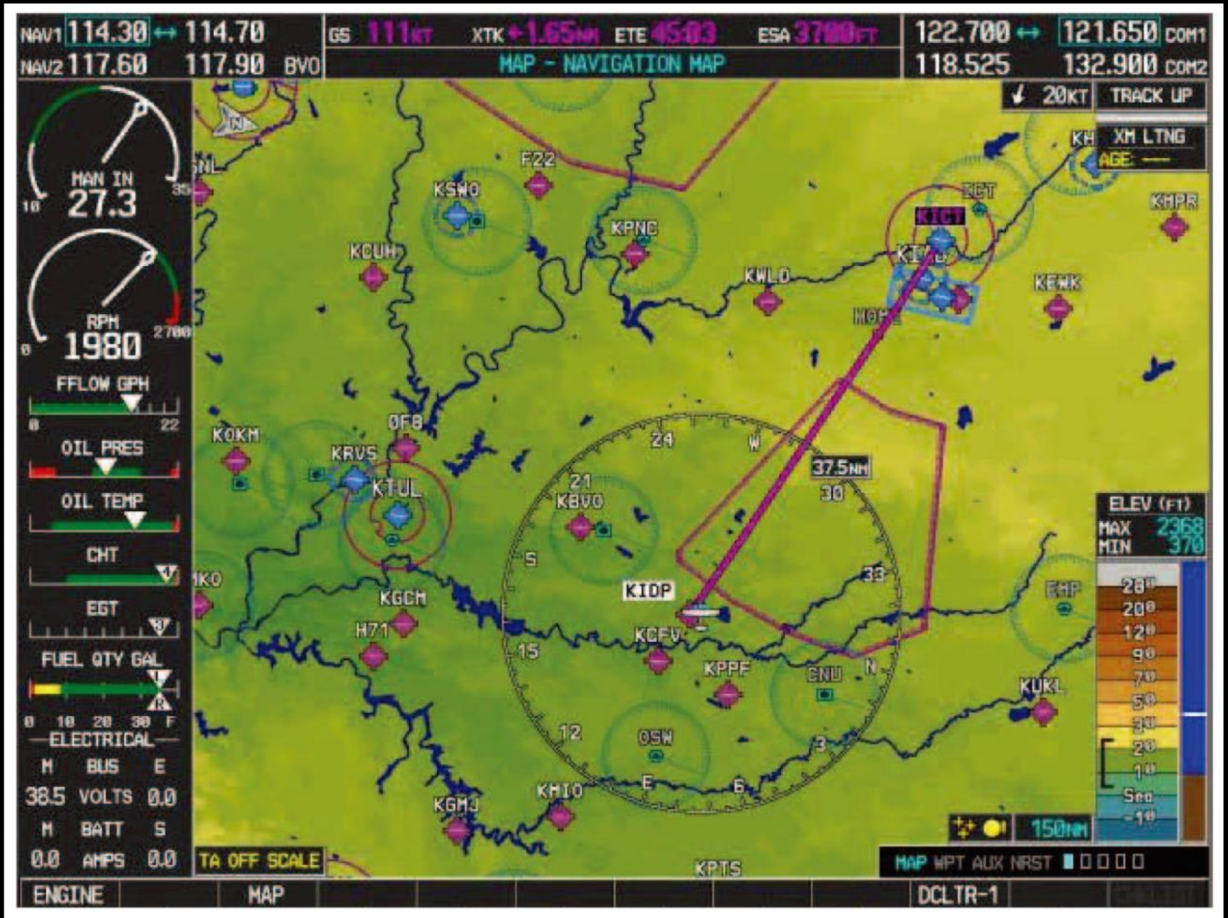
Electronic Flight Instruments



•

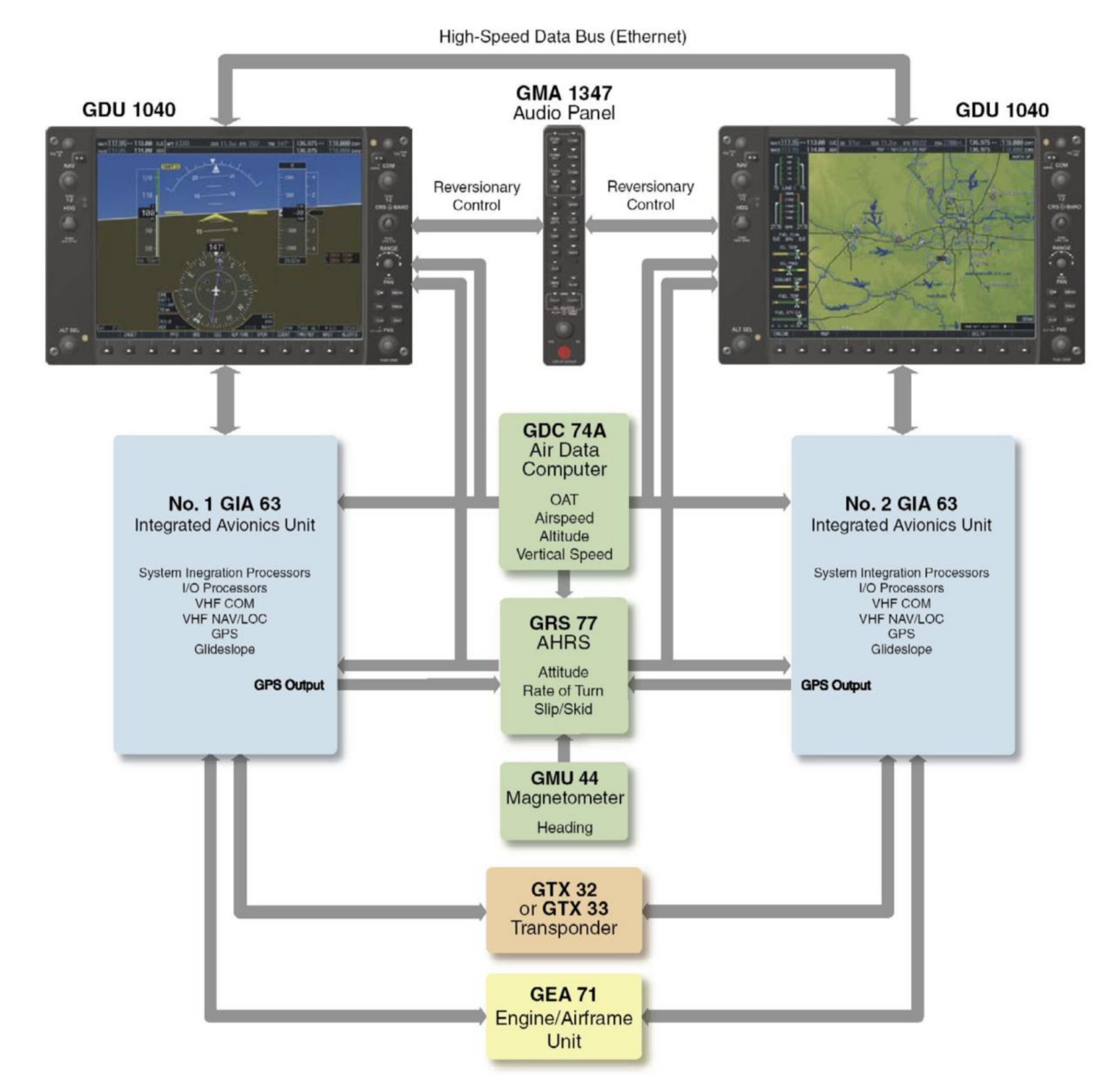
Multi Function Display

•



G1000 System

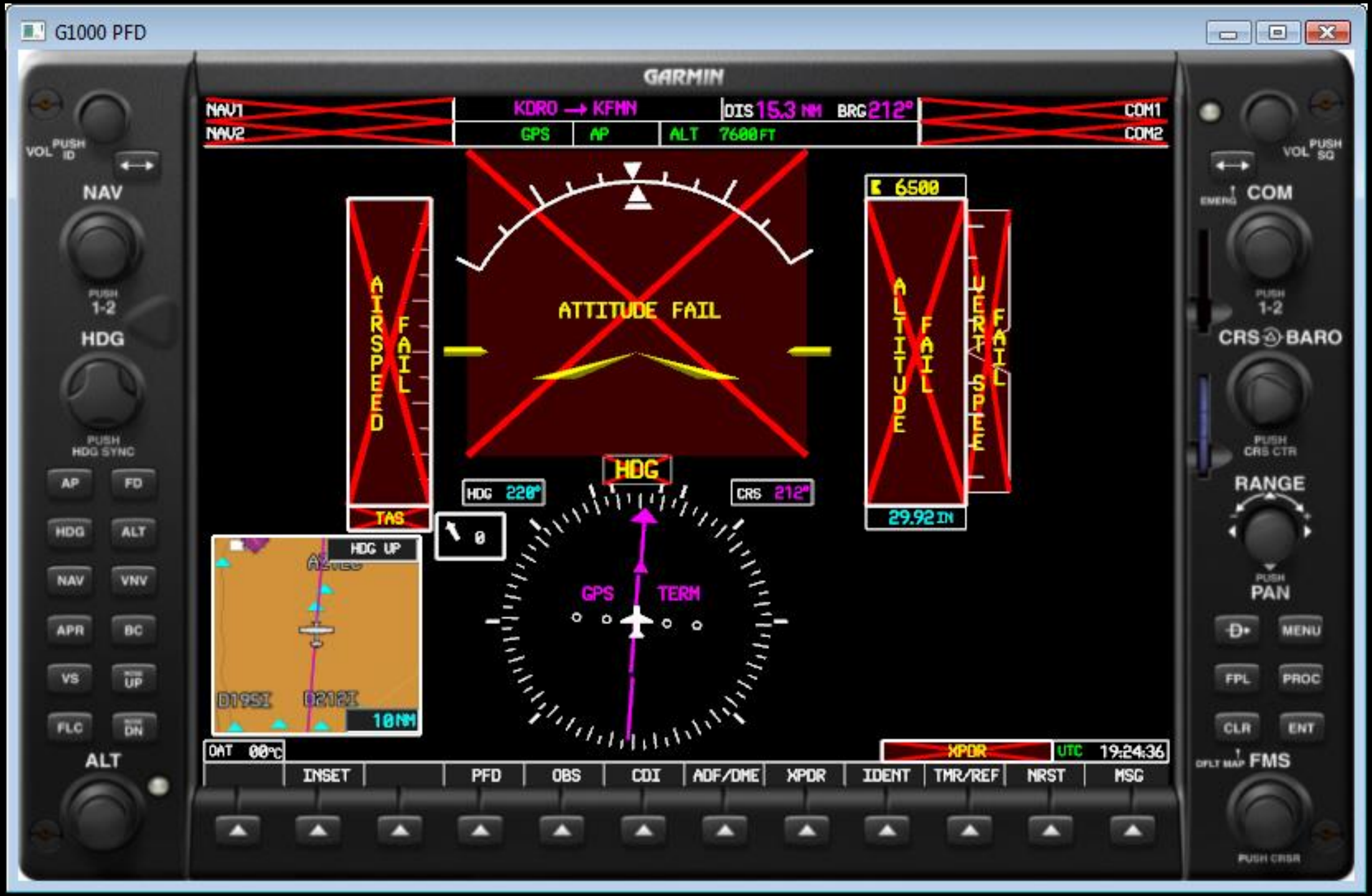
- DU – Display Unit (PFD/ND)
- ADC – Air Data Computer
- AHRS – Attitude Heading Reference System
- Magnetometer
- Integrated Avionics Unit
- Transponder
- Engine/Airframe Unit
- Audio Panel



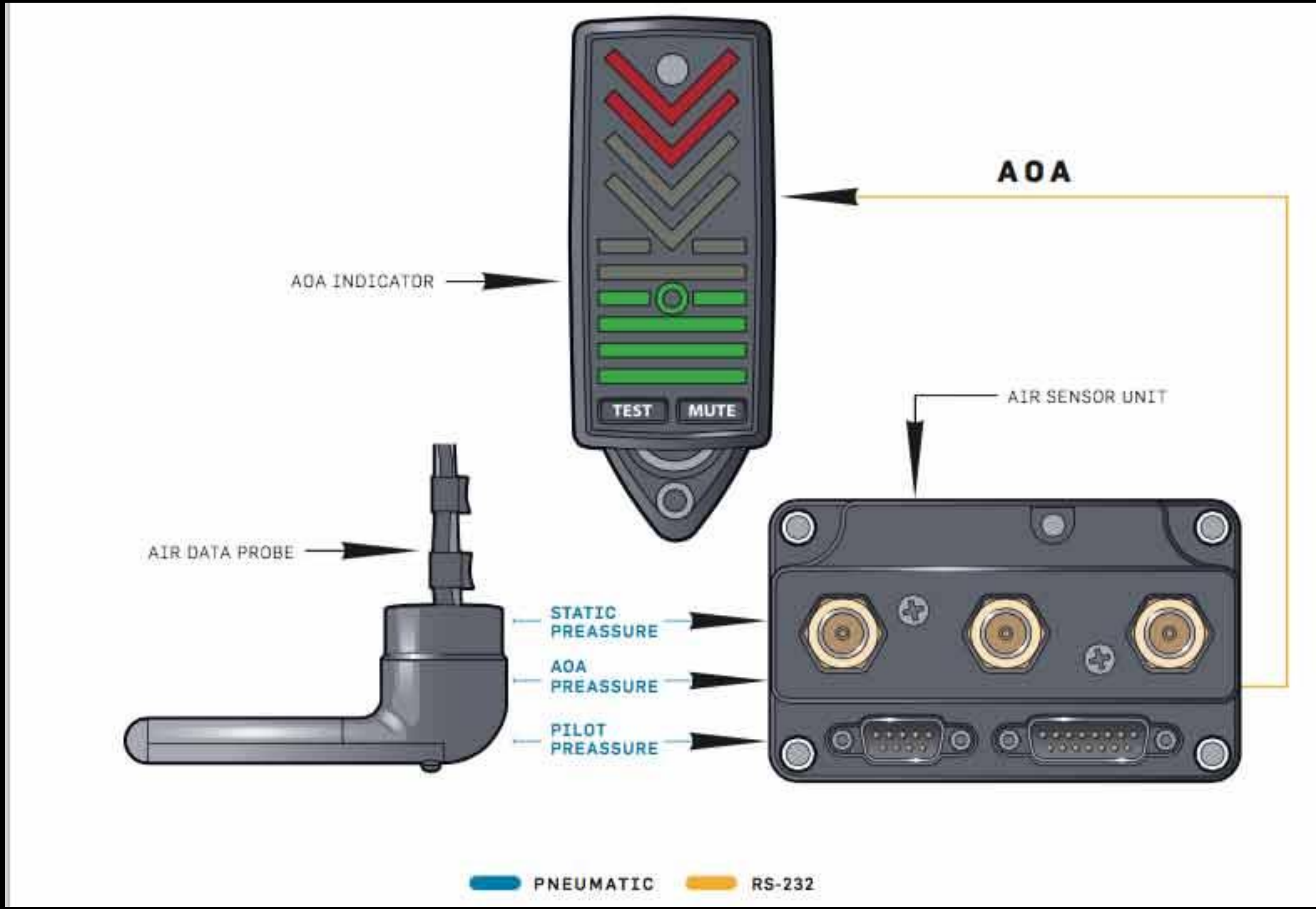
System Malfunctions

Red Indication + Tone

-



G1000 System



Knowledge Check

When an airplane is on an easterly heading and accelerates, what is the initial movement by the compass?

A. Initially indicates a turn to the south
B. Initially indicates a turn to the north
C. Indicates no turn
D. Oscillates from north to south

Knowledge Check

When an airplane is on an easterly heading and accelerates, what is the initial movement by the compass?

A. ~~Initially indicates a turn to the south~~
B. Initially indicates a turn to the north
C. ~~Indicates no turn~~
D. ~~Oscillates from north to south~~