

Flight Instruments

Flight Instruments: The Six-Pack + 1

- ▶ Pilot-Static: Airspeed and Altitude
 - ▶ Airspeed Indicator
 - ▶ Vertical Speed Indicator
 - ▶ Altimeter
- ▶ Gyroscopic: Heading, Bank, and Attitude
 - ▶ Turn Coordinator
 - ▶ Heading Indicator
 - ▶ Attitude Indicator
- ▶ Magnetic Compass: Heading

SIX BASIC FLIGHT INSTRUMENTS



Turn coordinator



Airspeed indicator



Attitude indicator

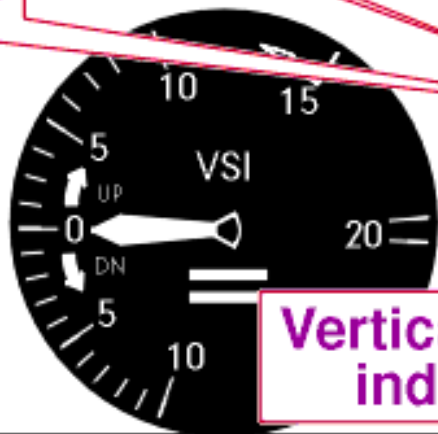


Altimeter

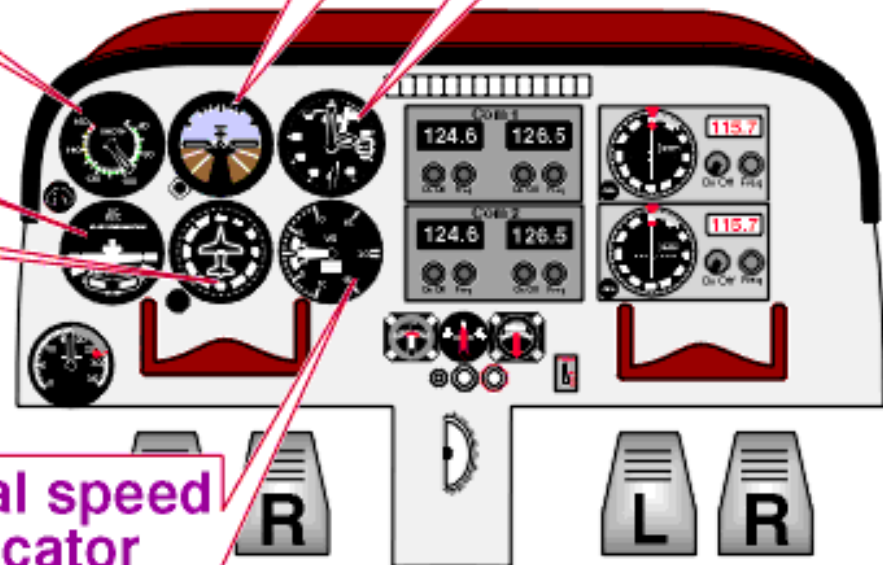
Heading indicator



5-1



Vertical speed indicator



GARMIN

NAV1 108.00
NAV2 108.00

Attitude indicator

Slip/skid indicator

TRK 360°
134.00
123.80

Altimeter

COM1
COM2

Airspeed indicator

Vertical speed indicator (VSI)

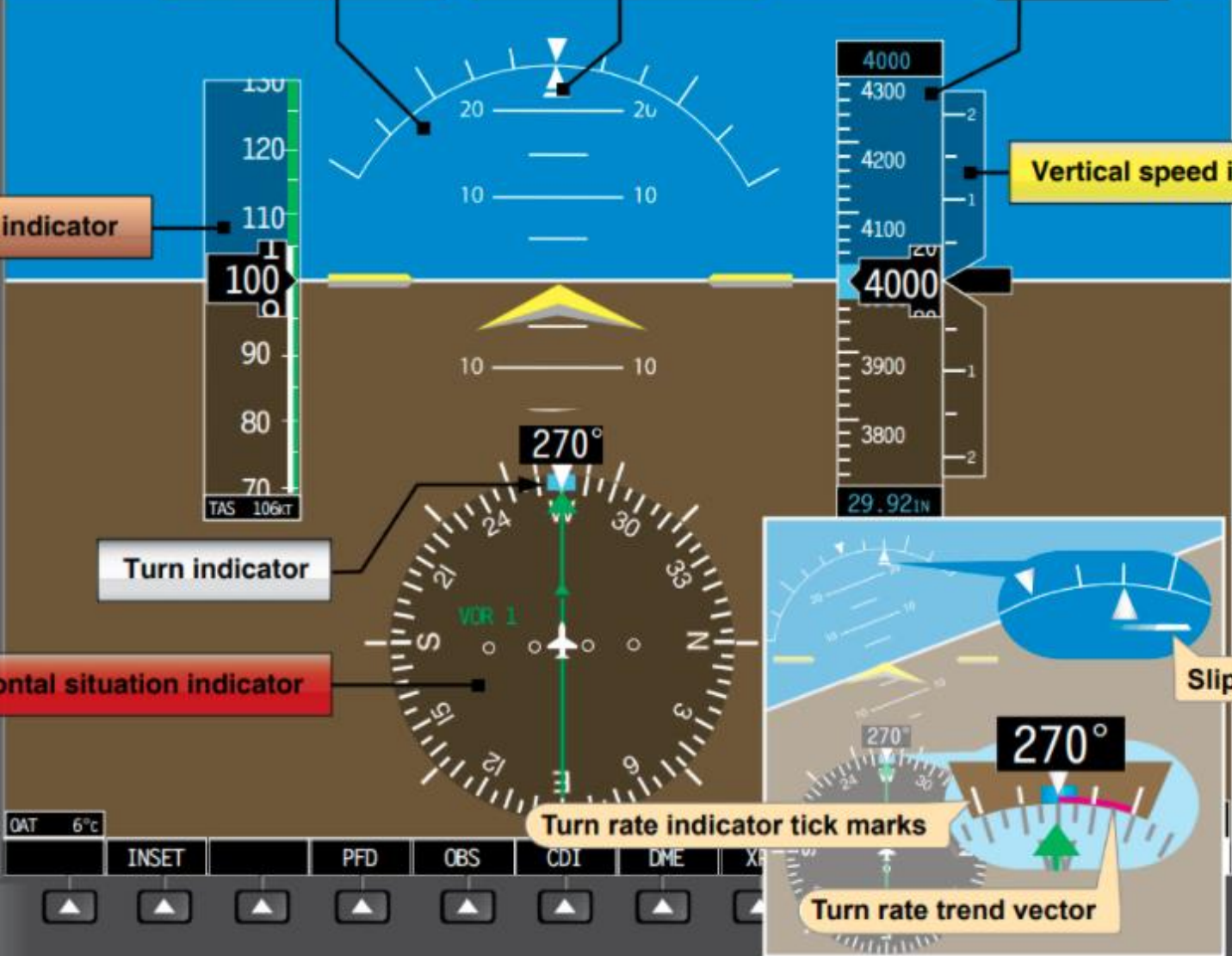
Turn indicator

Horizontal situation indicator

Slip/skid indicator

Turn rate indicator tick marks

Turn rate trend vector



NAV
PUSH VOL ID
PUSH HDG SYNC
ALT

PUSH VOL SQ
COM
EMERG
1-2
CRS BARO
PUSH CRS CTR
RANGE
PUSH PAN
MENU
D-
CLR
ENT
FMS
DFLT MAP
PUSH CRSR

Flight Instruments: Engine Monitoring

- ▶ Tachometer - RPMs
- ▶ Oil
 - ▶ Oil temperature
 - ▶ Oil pressure
- ▶ Fuel
 - ▶ Fuel quantity
 - ▶ Fuel pressure
- ▶ Engine temperature
 - ▶ Cylinder head temperature
 - ▶ Exhaust gas temperature

Pitot-Static Instruments

THE PITOT TUBE & STATIC PORT

The static port is sometimes found flush against the side of the fuselage.

A static line connects to the altimeter, vertical speed indicator and airspeed indicator.

The airspeed indicator has an additional line connecting it to the pitot tube. This allows measurement of impact air pressure.

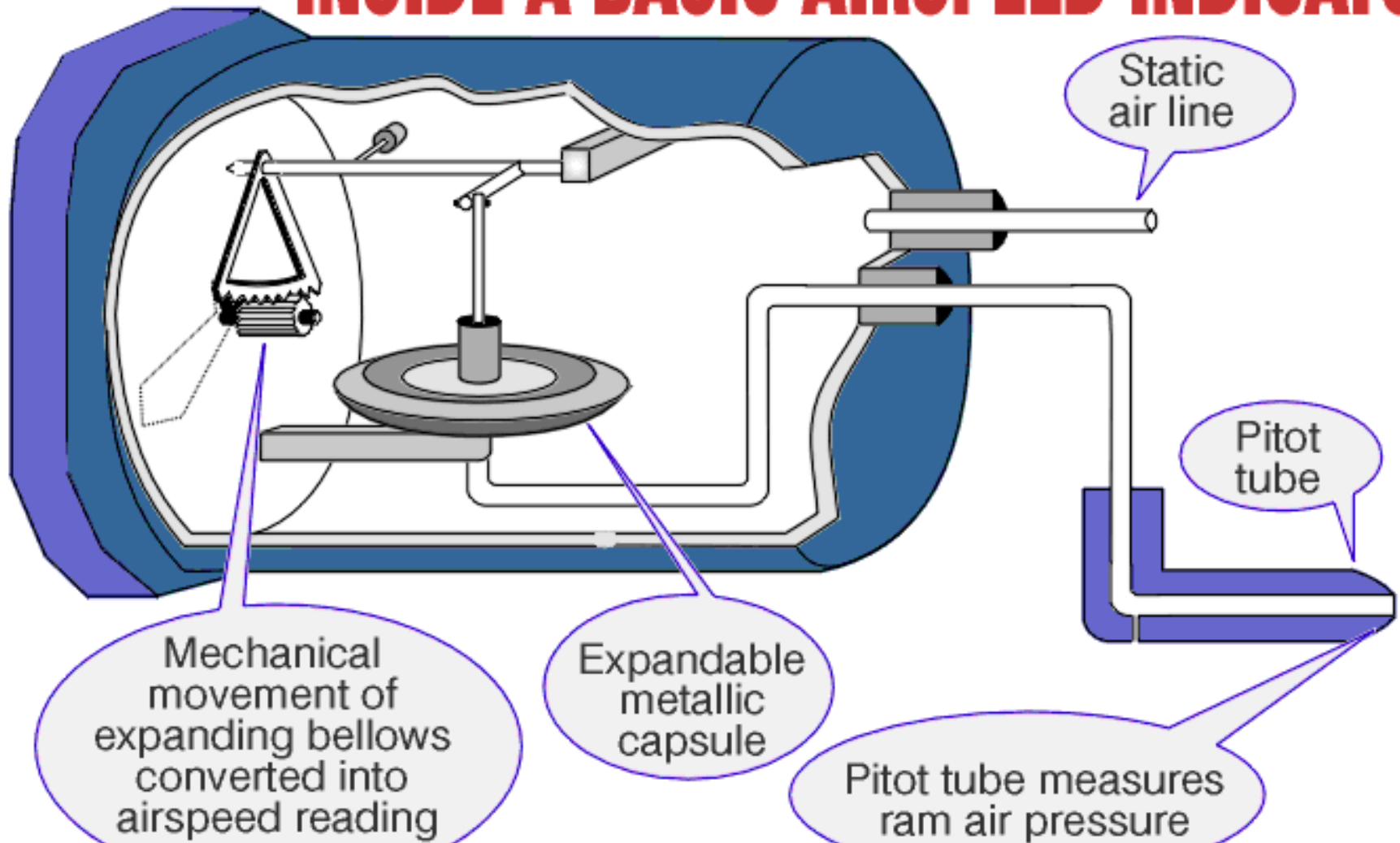
The pitot tube is normally found underneath the left wing.

Pitot-Static Instruments

- **Airspeed Indicator (ASI)**
- Altimeter
- Vertical Speed Indicator (VSI)

Airspeed Indicator

INSIDE A BASIC AIRSPEED INDICATOR



Airspeed Indicator

AIRSPEED INDICATOR MARKINGS

The red line is the never to be exceeded speed - also known as V_{ne} .

Beginning of the white arc is the power off stalling speed with gear and full flaps extended - also known as V_{so} .

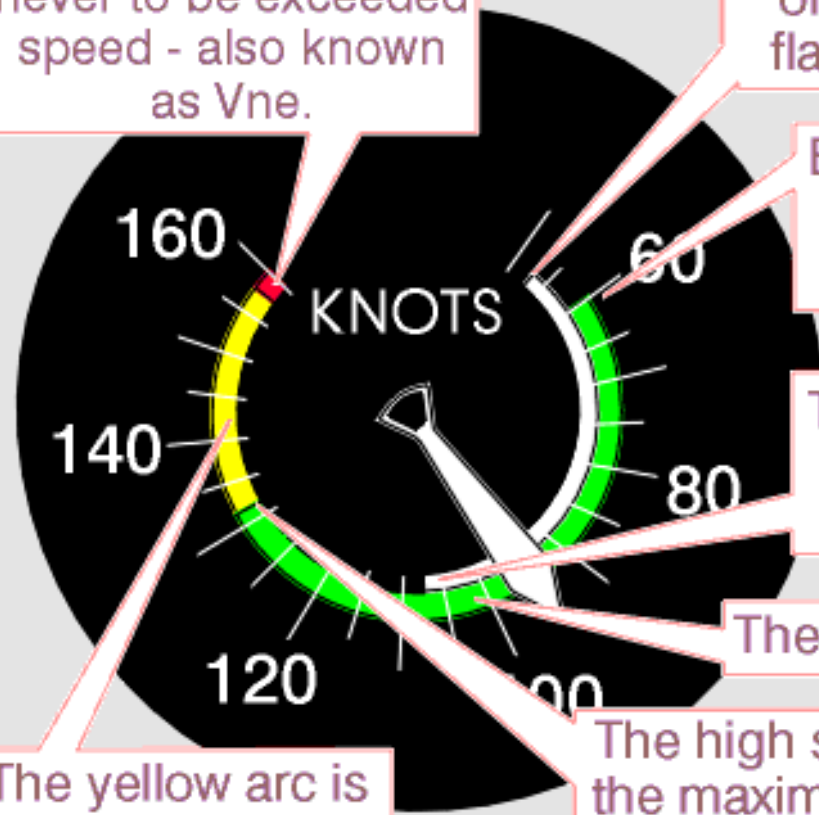
Beginning of the green arc is the power off stalling speed with the gear and flaps retracted - also known as V_{s1} .

The high speed end of the white arc is the maximum flap operating range - also known as V_{fe} .

The green arc is the normal operating range

The high speed end of the green arc is the maximum structural cruising speed - also known as V_{no} .

The yellow arc is the caution range.



GARMIN

NAV1 108.00
NAV2 108.00

Attitude indicator

Slip/skid indicator

TRK 360°
134.00
123.80

Altimeter

COM1
COM2

PUSH VOL ID

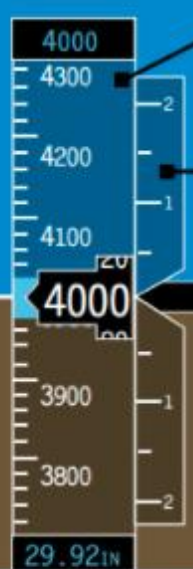
NAV

Airspeed indicator

130
120
110
100
90
80
70

TAS 106kt

PUSH HDG SYNC

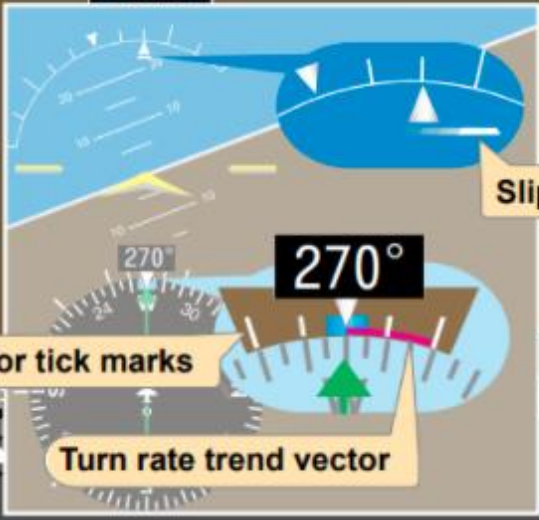


Vertical speed indicator (VSI)

Turn indicator



Horizontal situation indicator



Slip/skid indicator

Turn rate indicator tick marks

Turn rate trend vector

OAT 6°C

INSET PFD OBS CDI DME XPR

ALT

PUSH VOL SQ

EMERG COM

1-2

CRS BARO

PUSH CRS CTR RANGE

PUSH PAN

MENU

CLR ENT

DFLT MAP FMS

PUSH CRSR

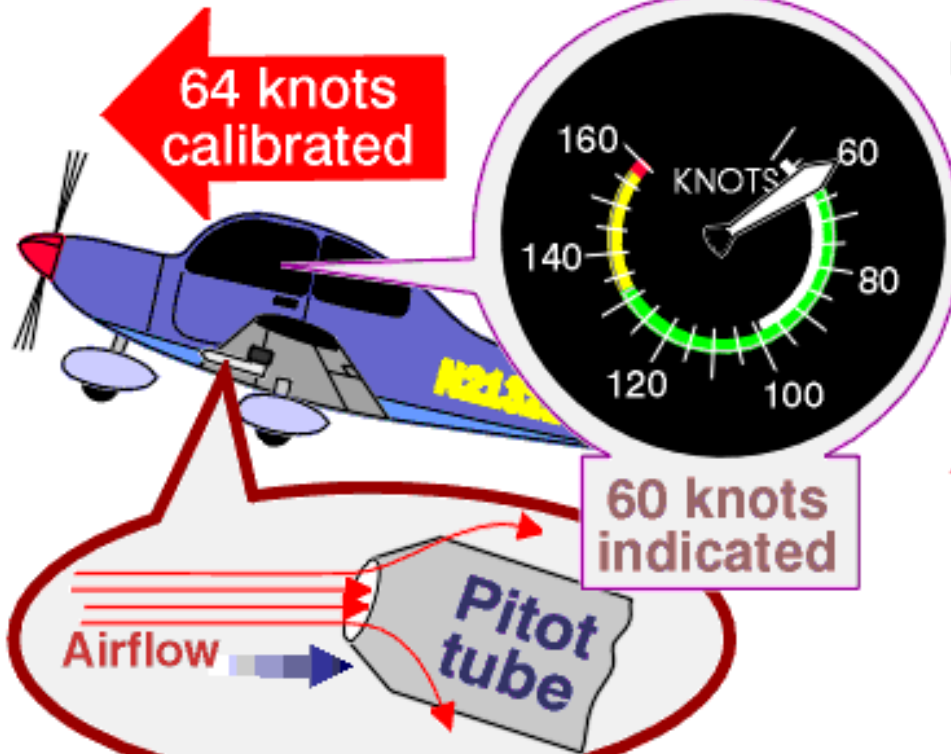
Definitions of Airspeeds

- ▶ Indicated
 - ▶ The airspeed displayed on your airspeed indicator
- ▶ Calibrated
 - ▶ Your indicated airspeed corrected for known instrument and positional errors
- ▶ True
 - ▶ Speed of the aircraft relative to the air it is flying through
- ▶ Ground Speed
 - ▶ Speed of the aircraft corrected for wind

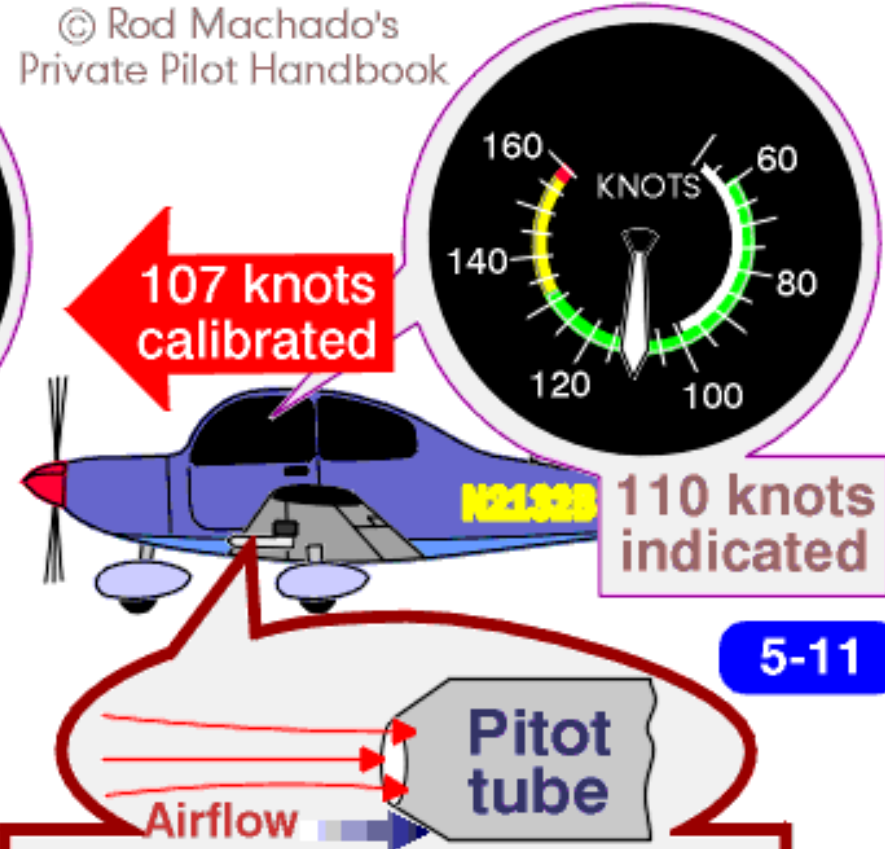
Airspeed Indicator

CALIBRATED & INDICATED AIRSPEEDS

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Sometimes the pitot tube's position or angle prevents it from capturing the moving molecules of air flowing over it. This results in the indicated airspeed being less than the calibrated airspeed.



Sometimes the air striking the pitot tube is artificially accelerated which causes the indicated airspeed to read higher than the airplane's actual calibrated speed.

Airspeed Indicator

KIAS = Knots Indicated AirSpeed/KCAS = Knots Calibrated AirSpeed

AIRSPEED CALIBRATION CHART

FLAPS UP

KIAS	50	60	70	80	90	100	110	120	130	140	150
KCAS	50	64	72	81	89	98	107	116	126	135	153

FLAPS 10°

KIAS	40	50	60	70	80	90	100
KCAS	55	58	64	72	81	90	107

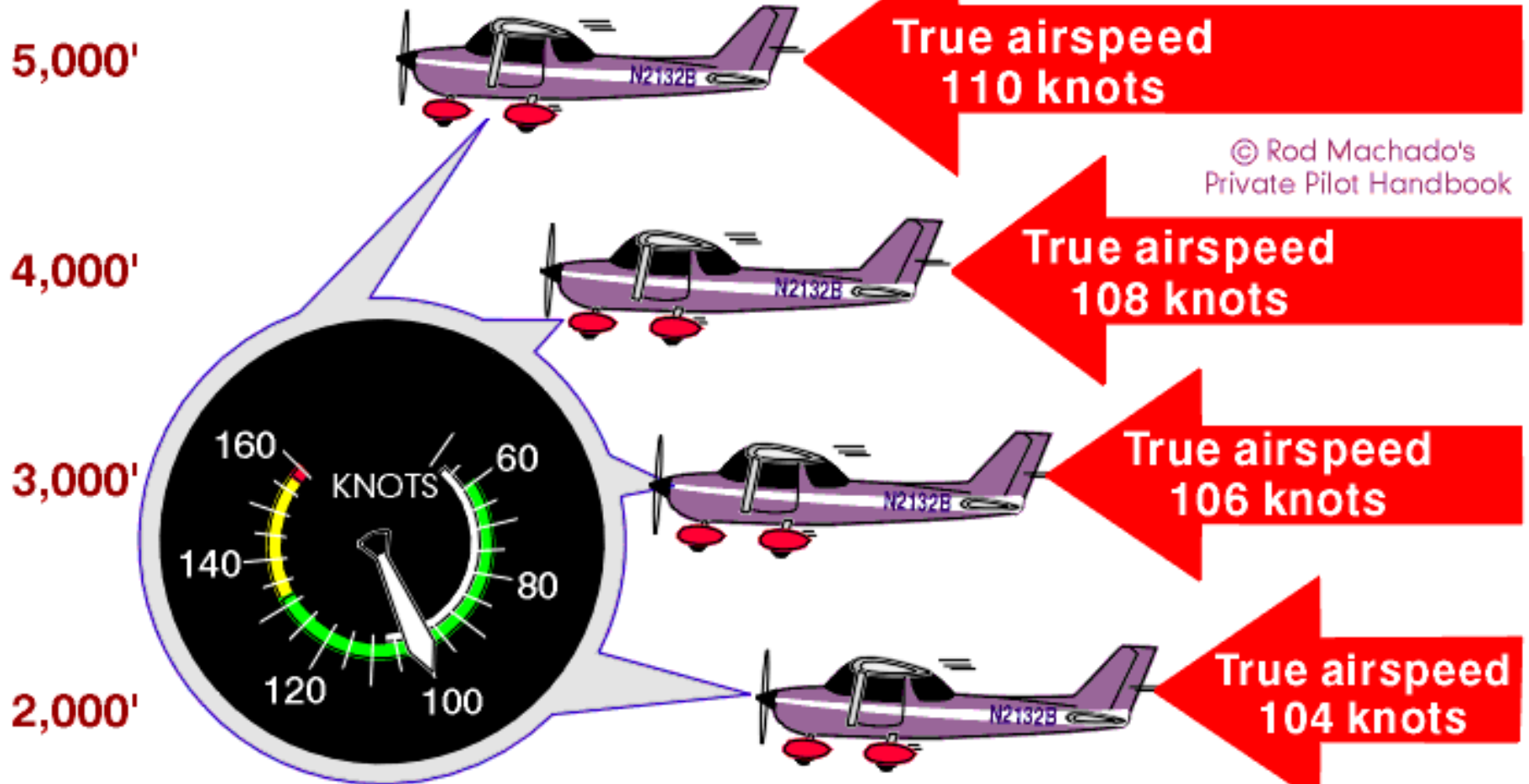
FLAPS 30°

KIAS	40	50	60	70	80	85
KCAS	54	57	62	71	80	85

Condition: Power required for level flight or maximum rated RPM dive

Airspeed Indicator

5-14 INDICATED & TRUE AIRSPEED DIFFERENCES



All airplanes have the same indicated airspeed of 100 Knots, but their true airspeed varies with altitude.

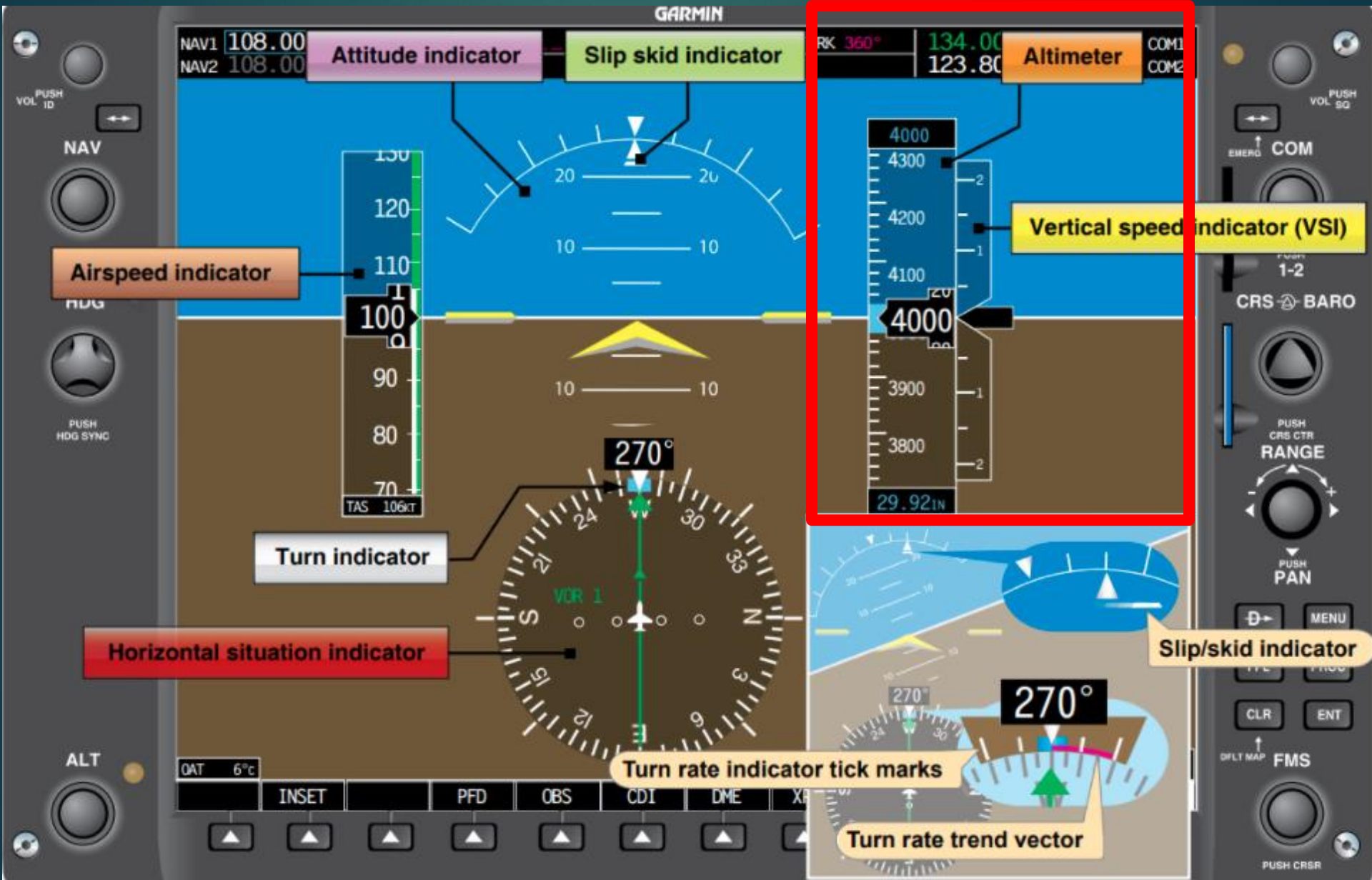
Pitot-Static Instruments

- Airspeed Indicator (ASI)
- **Altimeter**
- Vertical Speed Indicator (VSI)

Altimeter – Steam Gauge

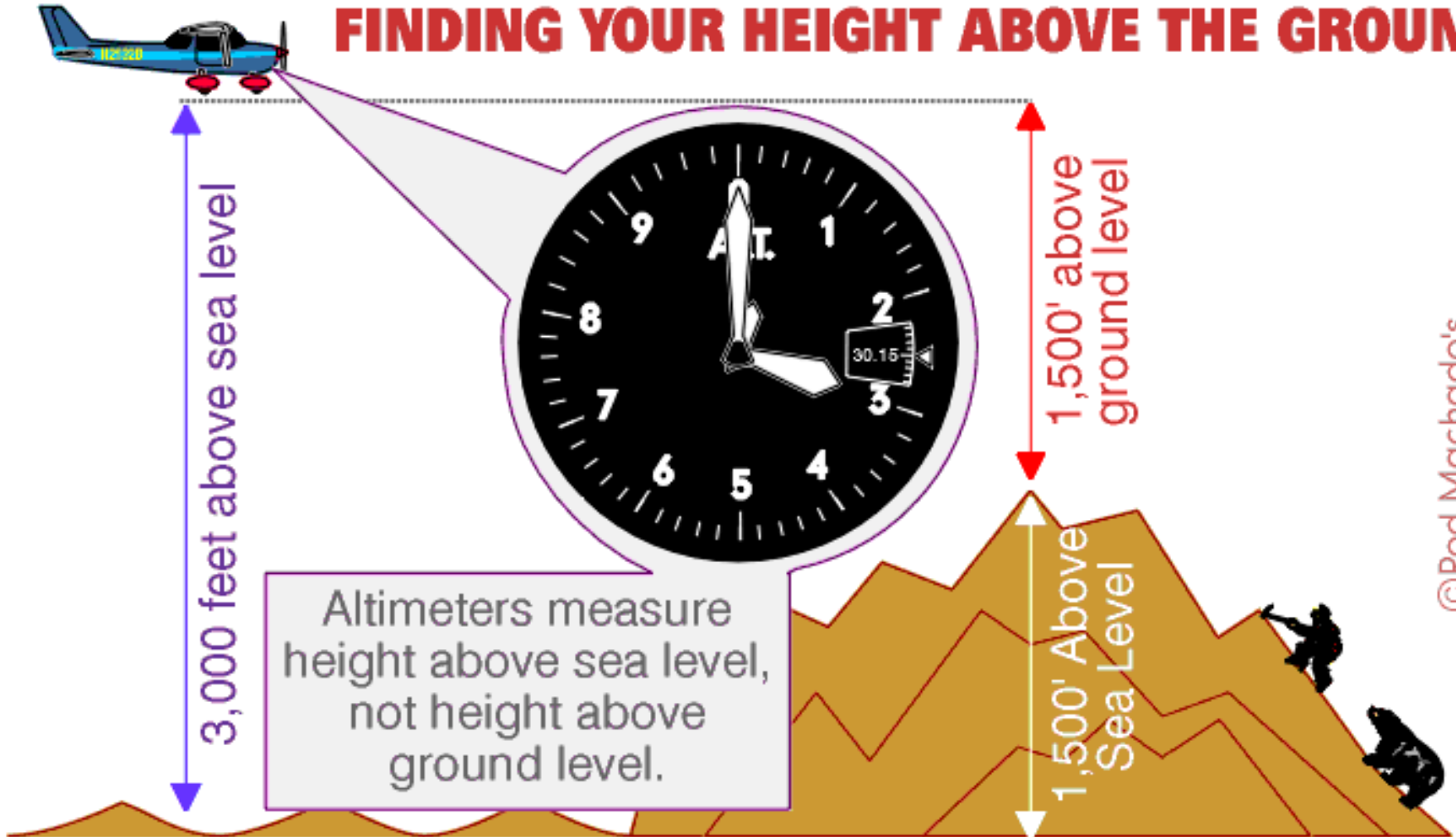


Altimeter - Glass



Altimeter

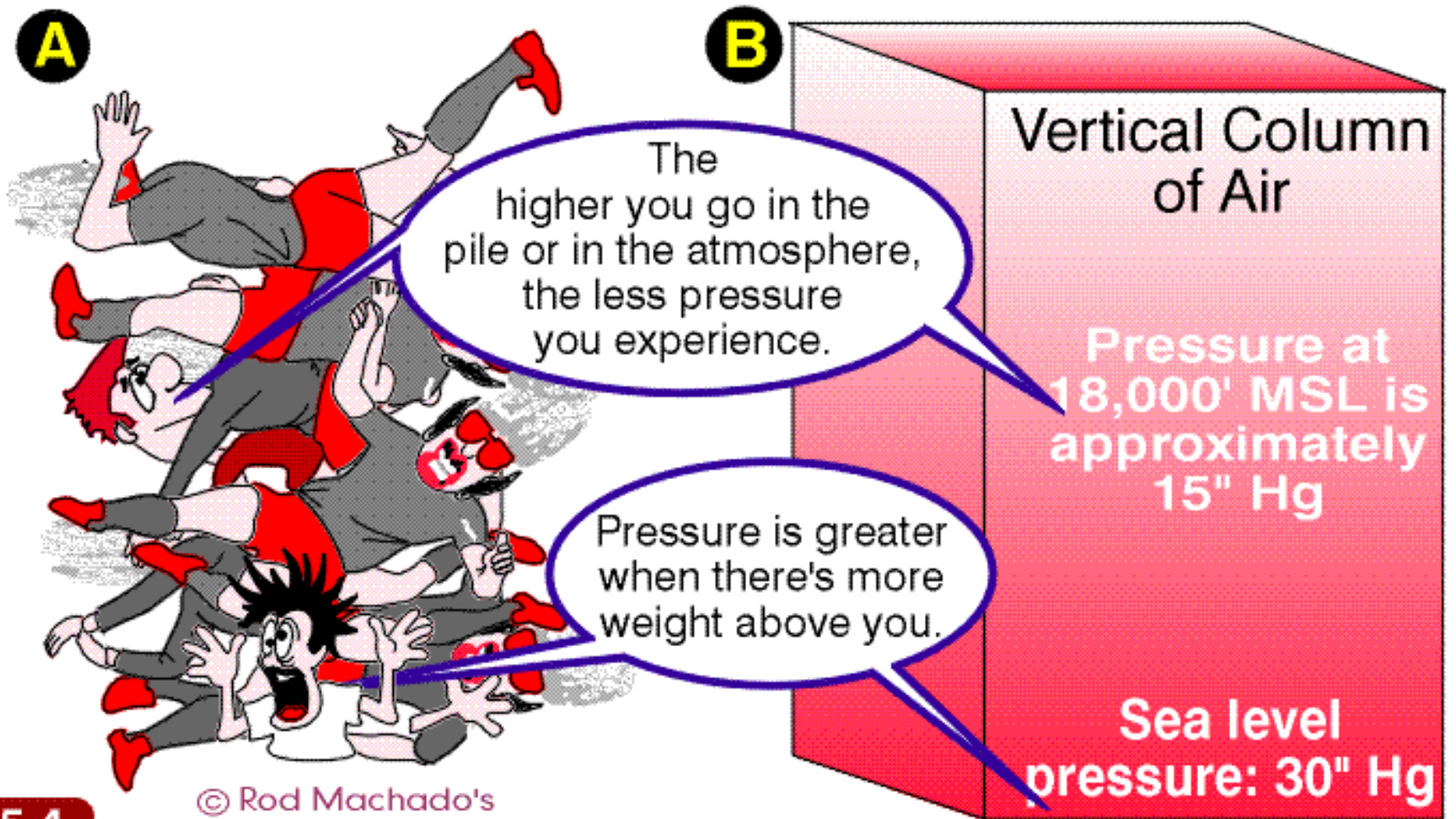
FINDING YOUR HEIGHT ABOVE THE GROUND



Finding your height above the ground requires that you subtract the ground's height (its MSL value is found on sectional charts—see Chapter 10) from your height above sea level (which is shown on your altimeter).

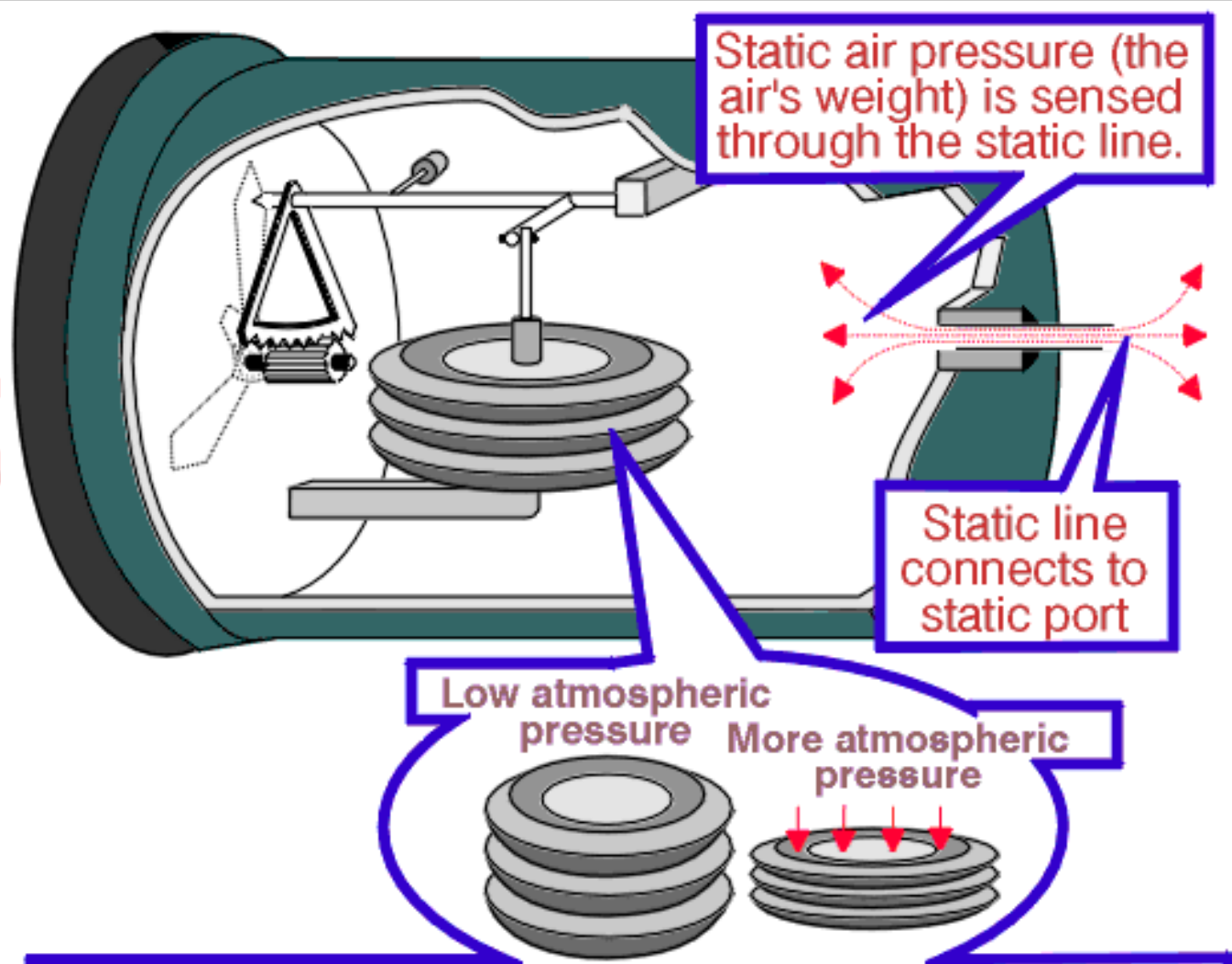
Altimeter

ATMOSPHERIC PRESSURE CHANGES WITH HEIGHT



Altimeter

INSIDE A BASIC ALTIMETER



5-18

The altimeter's capsules expand or contract based on the pressure of the atmosphere. This movement is mechanically converted into an altitude reading.

Altimeter

HOW THE ALTIMETER CALCULATES YOUR ALTITUDE

3000' - 27"

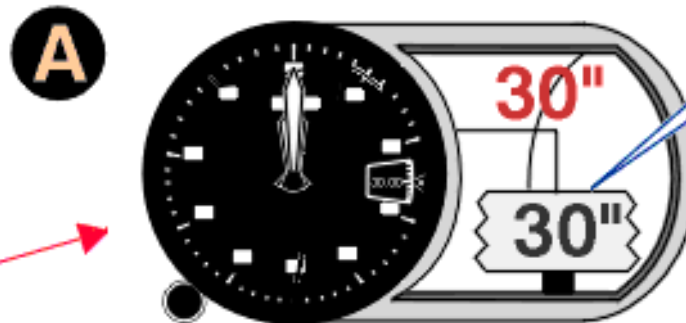


2000' - 28"

The pressure inside the capsule is 3" greater than the outside static pressure. Therefore, the capsule expands an amount equivalent to three inches of mercury. This equates to an altitude reading of 3,000 feet above sea level.

The pressure inside the capsule is the same as the outside static pressure. Therefore, the capsule doesn't expand and the hands read "zero" altitude.

1000' - 29"



Sea level
30"

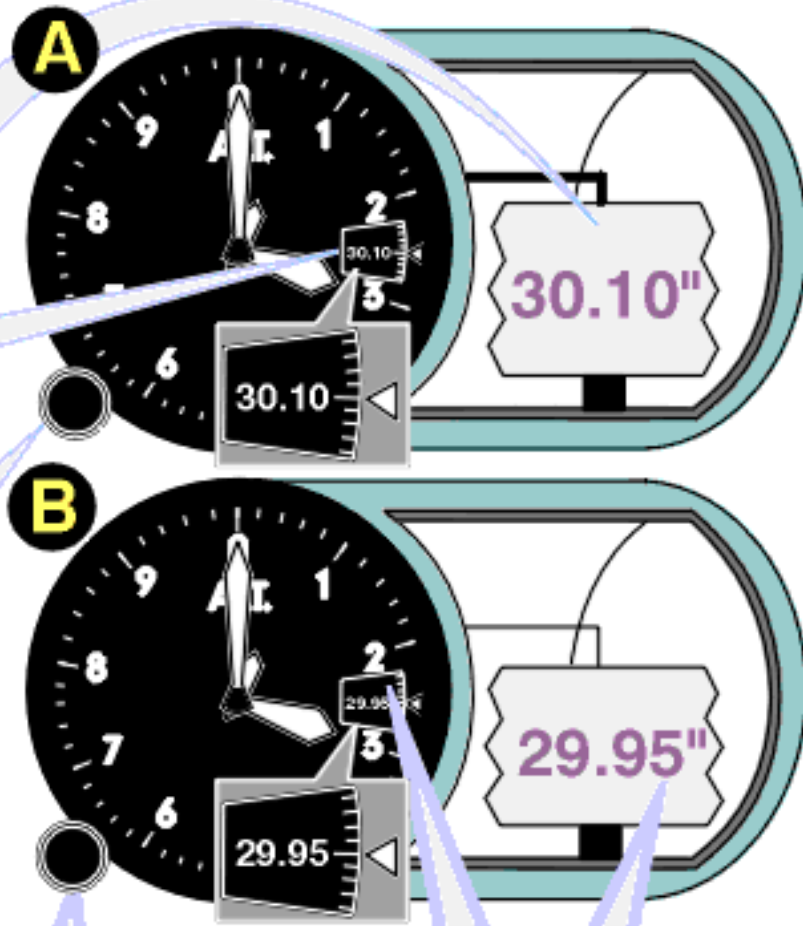
5-20

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Altimeter

WHAT HAPPENS WHEN YOU CHANGE THE ALTIMETER SETTING

Rotating the altimeter's knob, changes the numbers in the Kollsman window. This mechanically repositions an internal linkage that changes the starting point from which the altimeter begins its measurement. It is, however, much easier to think of the pressure inside the sealed capsule changing to equal the barometric pressure value set in the Kollsman window (trust me! Think about it this way and you'll never have difficulty understanding how the altimeter works).

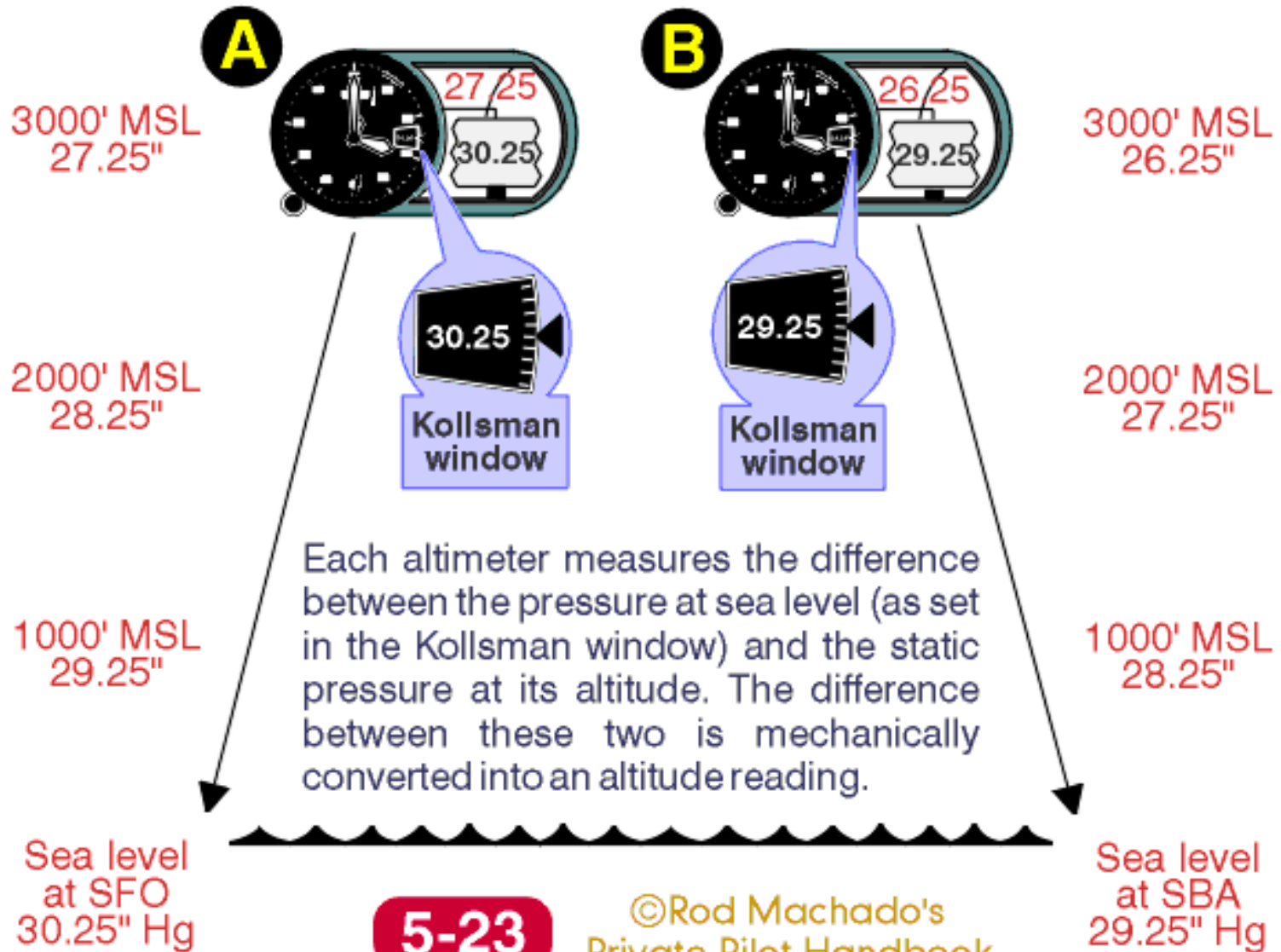


5-22

When the altimeter knob is rotated & 29.95" is set in the Kollsman window, the altimeter acts as if a pressure of 29.95" Hg has been set inside its sealed capsule.

Altimeter

HOW THE ALTIMETER CALCULATES YOUR ALTITUDE



Altimeter

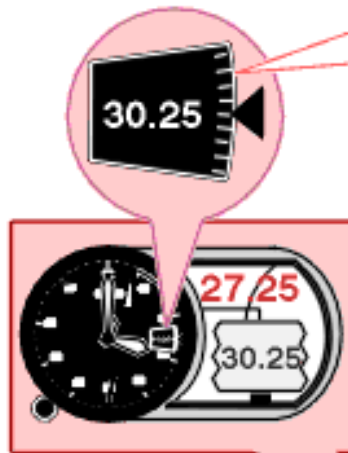
A

FAILURE TO UPDATE YOUR ALTIMETER SETTING CAN CAUSE ALTIMETER ERRORS

The pilot below starts off at 3,000' MSL over SFO with his altimeter set to the SFO station pressure of 30.25" Hg. He flies toward SBA and forgets to update his altimeter setting along the way.

With the wrong altimeter setting set in the Kollsman window, the pilot thinks he's higher than he actually is. He smacks into the mountain at the 2,000 foot level all the while thinking he's at 3,000' above sea level.

3000' MSL
27.25"



3000' MSL
26.25"

TOP 2,500' MSL

2000' MSL
28.25"

Pressure level slopes from SFO to SBA



2000' MSL
27.25"

I hate it when that happens!

1000' MSL
29.25"

1000' MSL
28.25"

30.25"
Sea level
at SFO

29.25"
Sea level
at SBA

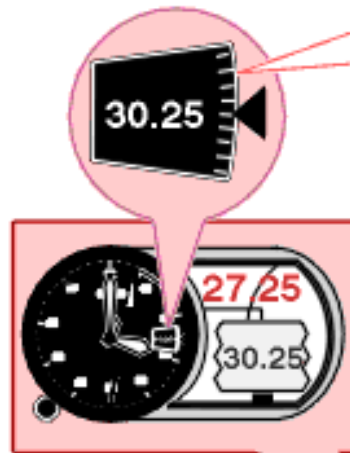
Altimeter

A

FAILURE TO UPDATE YOUR ALTIMETER SETTING CAN CAUSE ALTIMETER ERRORS

The pilot below starts off at 3,000' MSL over SFO with his altimeter set to the SFO station pressure of 30.25" Hg. He flies toward SBA and forgets to update his altimeter setting along the way.

With the wrong altimeter setting set in the Kollsman window, the pilot thinks he's higher than he actually is. He smacks into the mountain at the 2,000 foot level all the while thinking he's at 3,000' above sea level.



3000' MSL
27.25"



3000' MSL
26.25"



2000' MSL
28.25"

Pressure level slopes from S

2000' MSL
27.25"

1000' MSL
29.25"

High to Low –

LOOK OUT BELOW

30.25"
Sea level
at SFO

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29.25"
Sea level
at SBA

5-25A

Altimeter

HOW TEMPERATURE AFFECTS THE ALTIMETER

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Indicated
altitude - 4,000'



True
altitude
4,250 feet

4000' Pressure level

Warmer air
at 100°F
expands
slightly

Indicated
altitude - 4,000'



True
altitude
4,000 feet

Normal temp
air at 59°F
(standard
conditions)

Indicated
altitude - 4,000'



True
altitude
3,750 feet

Cooler
air at
32°F
shrinks
slightly

5-28

Altimeter

HOW TEMPERATURE AFFECTS THE ALTIMETER

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Indicated
altitude - 4,000'



A



True
altitude
4,250 feet

4000' Pressure level

Warmer air
at 100°F
expands
slightly

Indicated
altitude - 4,000'



B



Hot to Cold -

LOOK OUT BELOW

(standard
conditions)

Indicated
altitude - 4,000'



C



True
altitude
3,750 feet

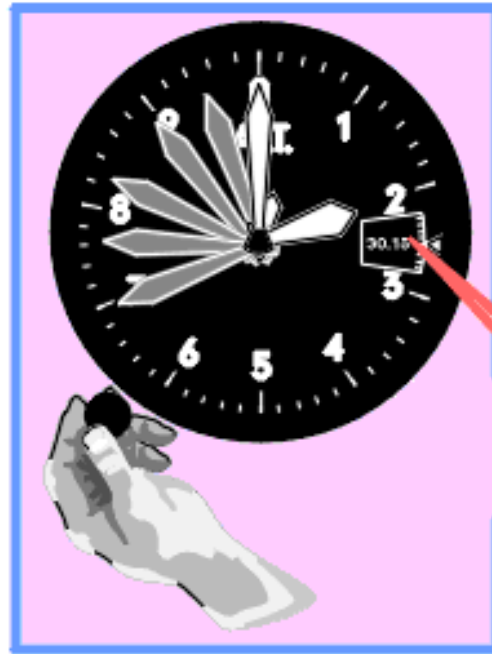
5-28

Cooler air at
32°F
shrinks
slightly

Altimeter

WHEN THE ALTIMETER SETTING ISN'T AVAILABLE

If the altimeter setting is not available while on the ground at an airport, simply rotate the knob until the altimeter hands indicate field elevation. The numbers in the Kollsman window would be your altimeter setting if it were available from attached.



Kollsman window

I think we should do a short field takeoff.



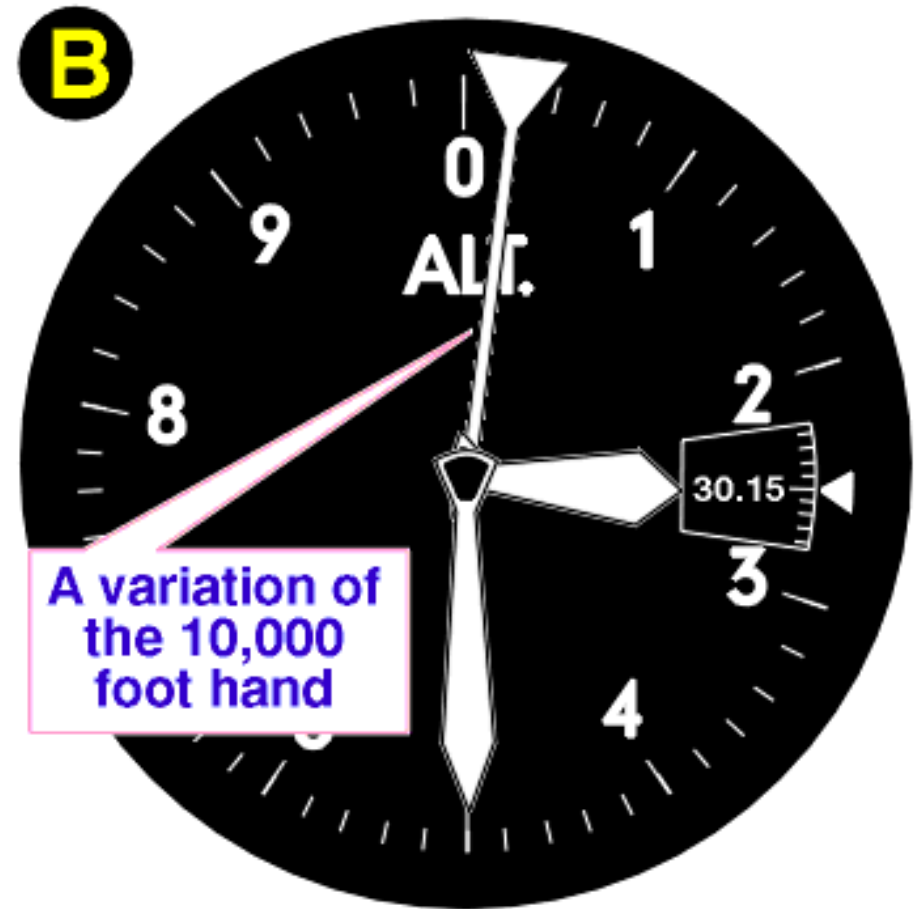
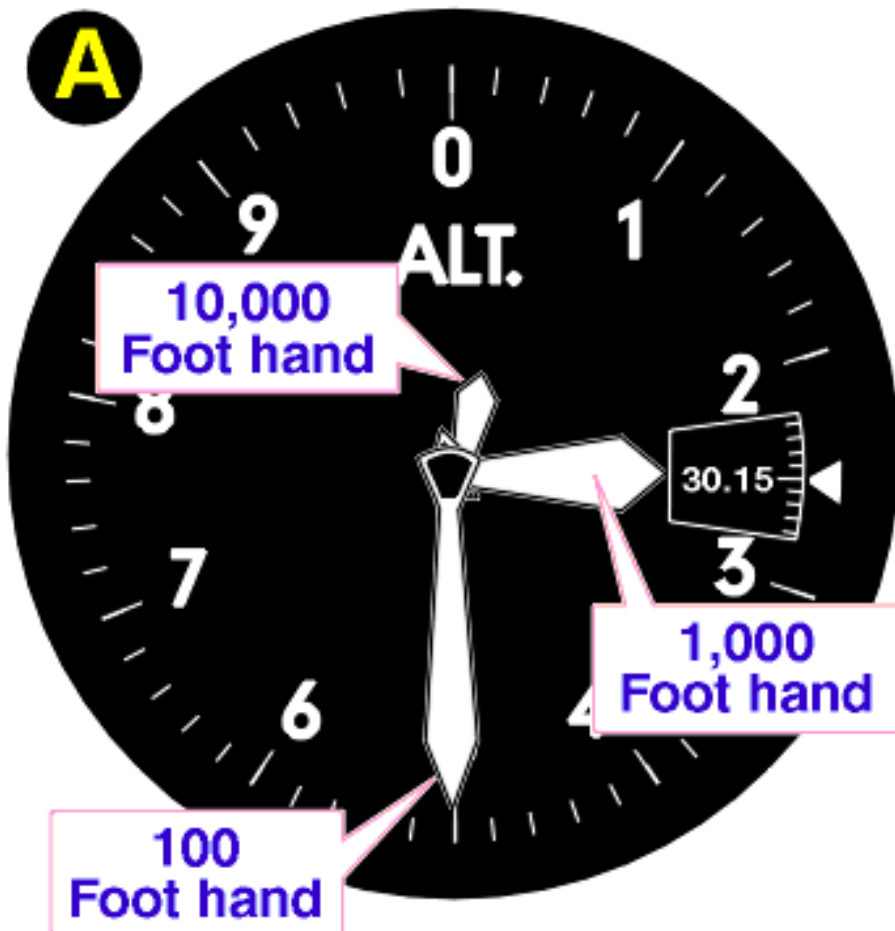
2,000' MSL

30.15" Hg
Pressure at sea level

5-29

Altimeter

READING THE ALTIMETER



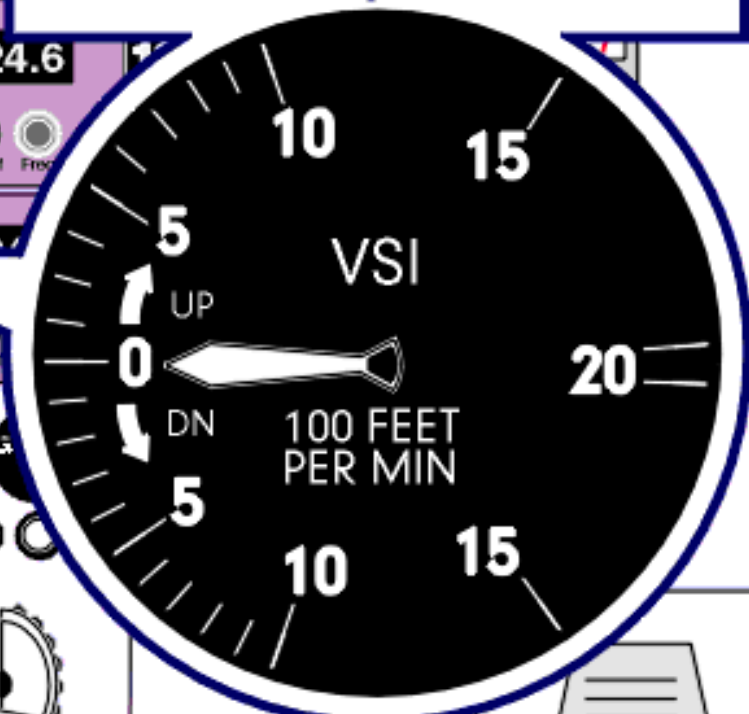
Pitot-Static Instruments

- Airspeed Indicator (ASI)
- Altimeter
- **Vertical Speed Indicator (VSI)**

VSI – Steam Gauge

THE VERTICAL SPEED INDICATOR

The vertical speed indicator



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L

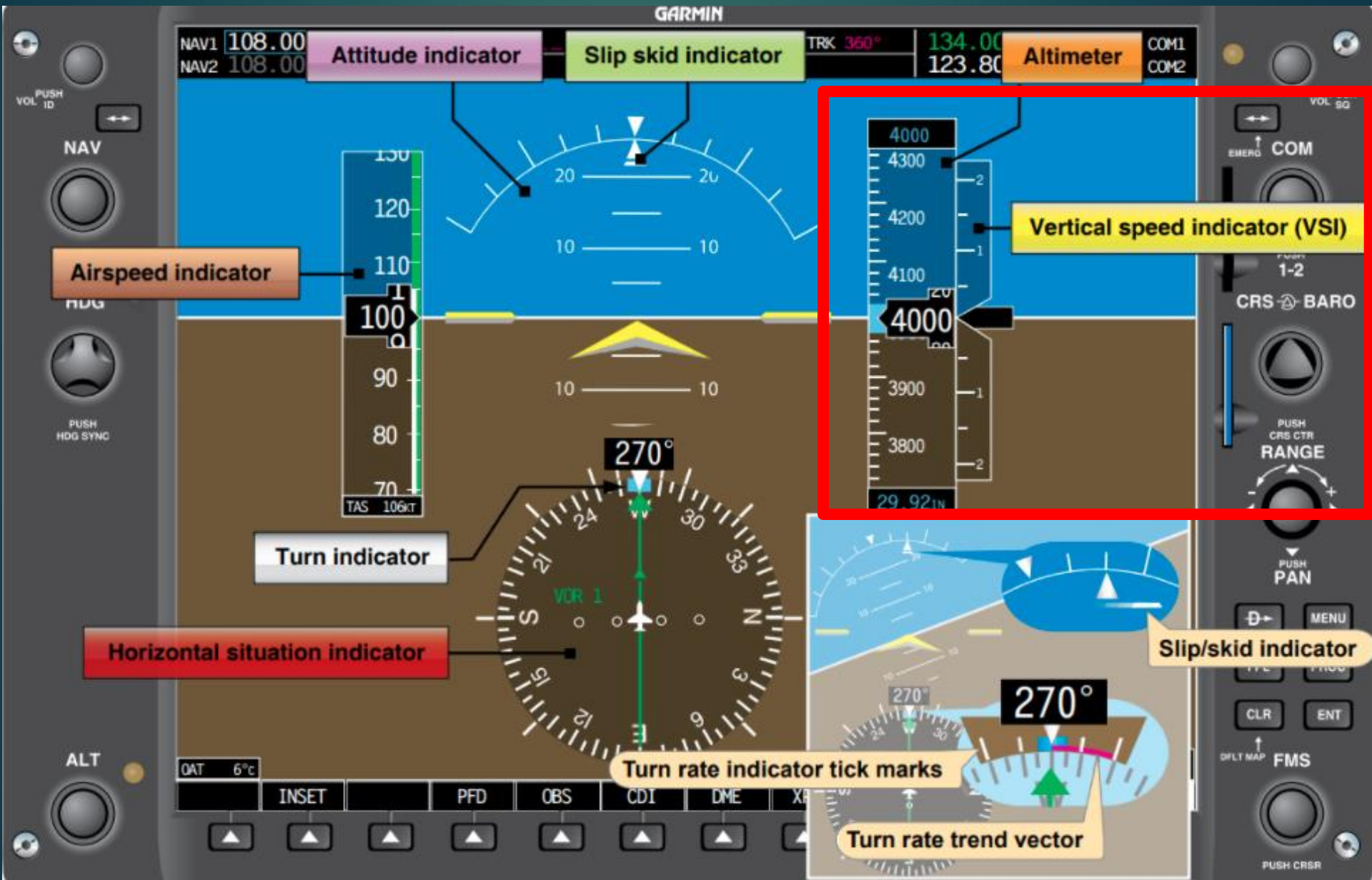
R

Murray, eat the red wire, it goes to the Hobbs meter.

L

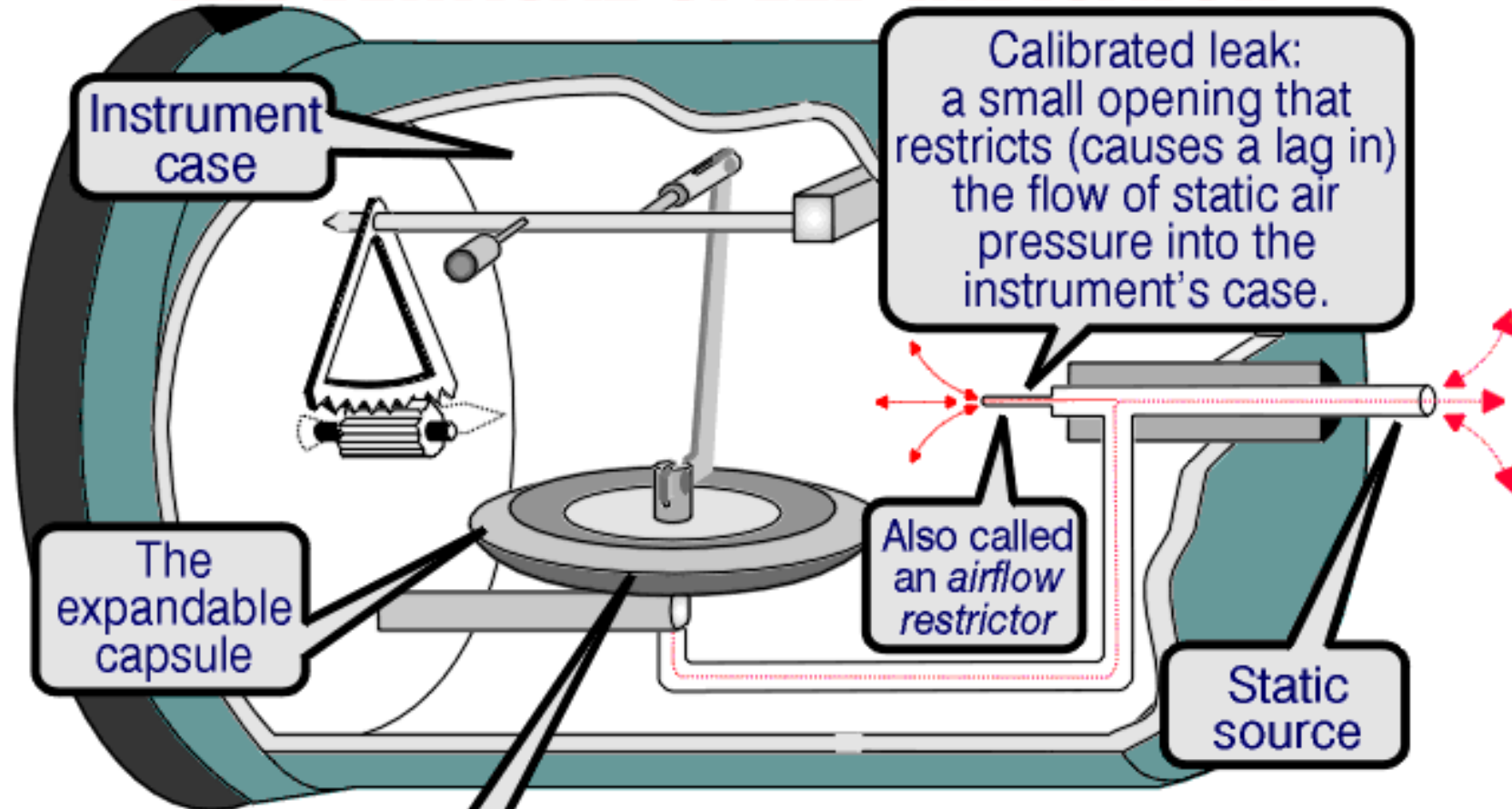
R

VSI - Glass



Vertical Speed Indicator (VSI)

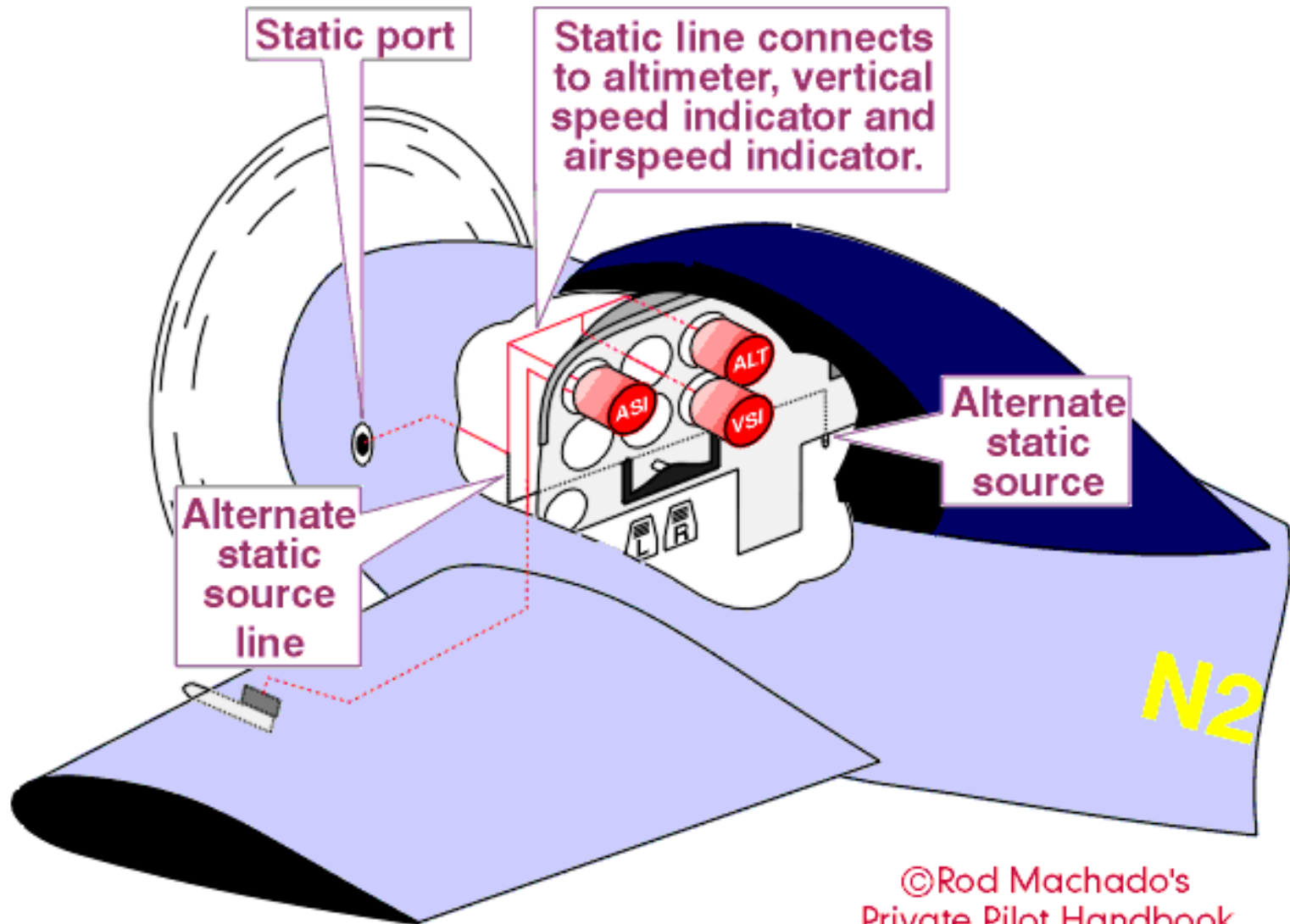
THE VERTICAL SPEED INDICATOR



The capsule expands or contracts at a rate predetermined by the calibrated leak. This expansion or contraction is mechanically converted into a rate of climb or descent.

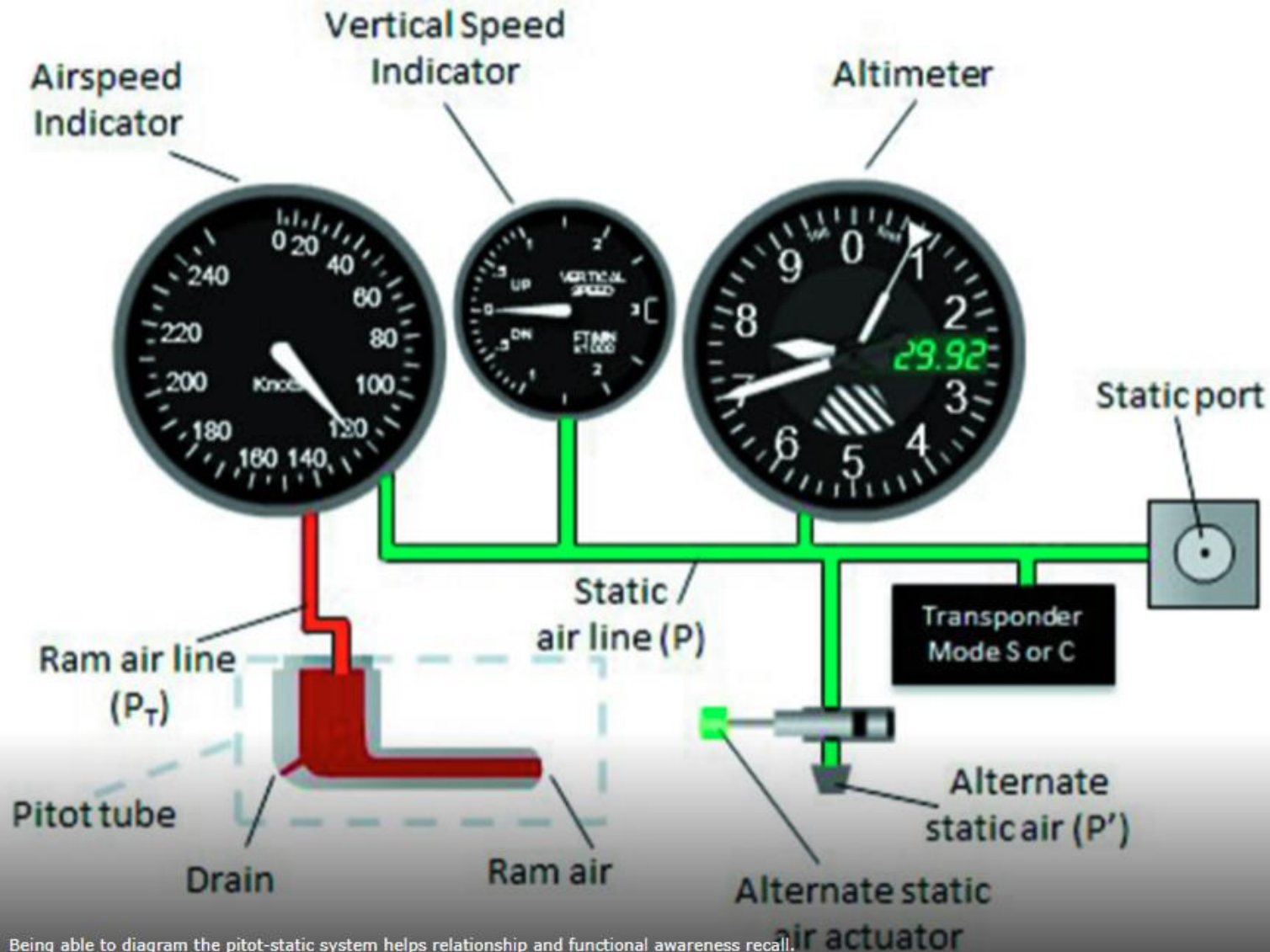
Vertical Speed Indicator (VSI)

THE ALTERNATE STATIC SYSTEM



Failure Modes of Pilot-Static Instruments

Pitot-Static System



Being able to diagram the pitot-static system helps relationship and functional awareness recall.

Gyroscopic Instruments:

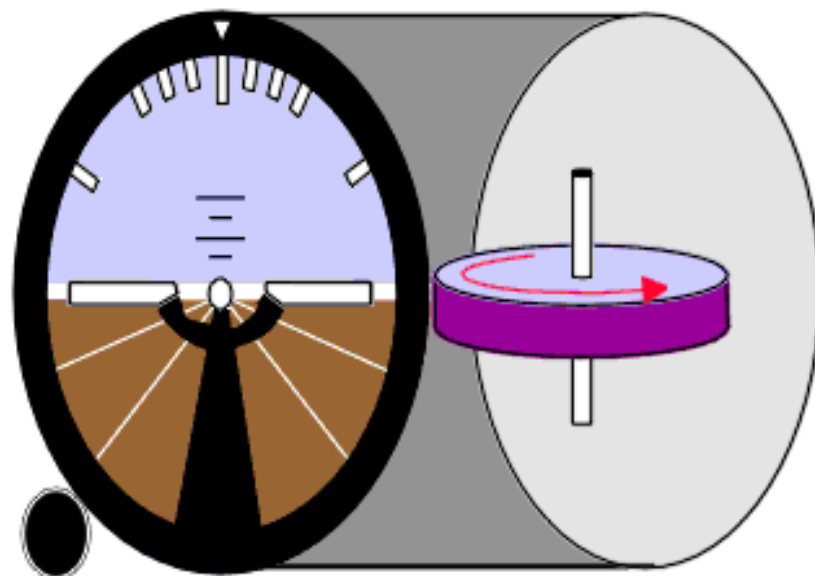
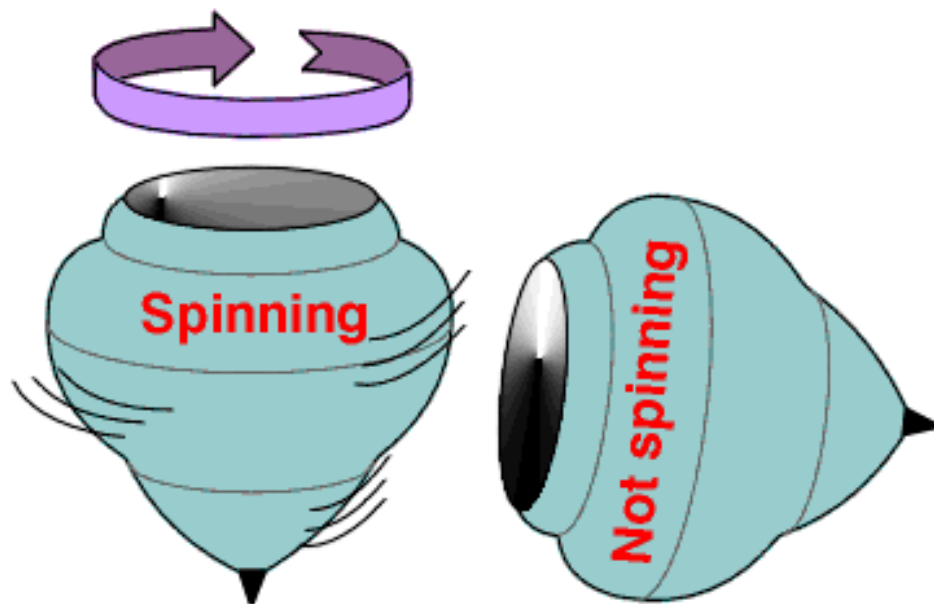
- Attitude Indicator
- Heading Indicator
- Turn Coordinator

Gyroscope Principles

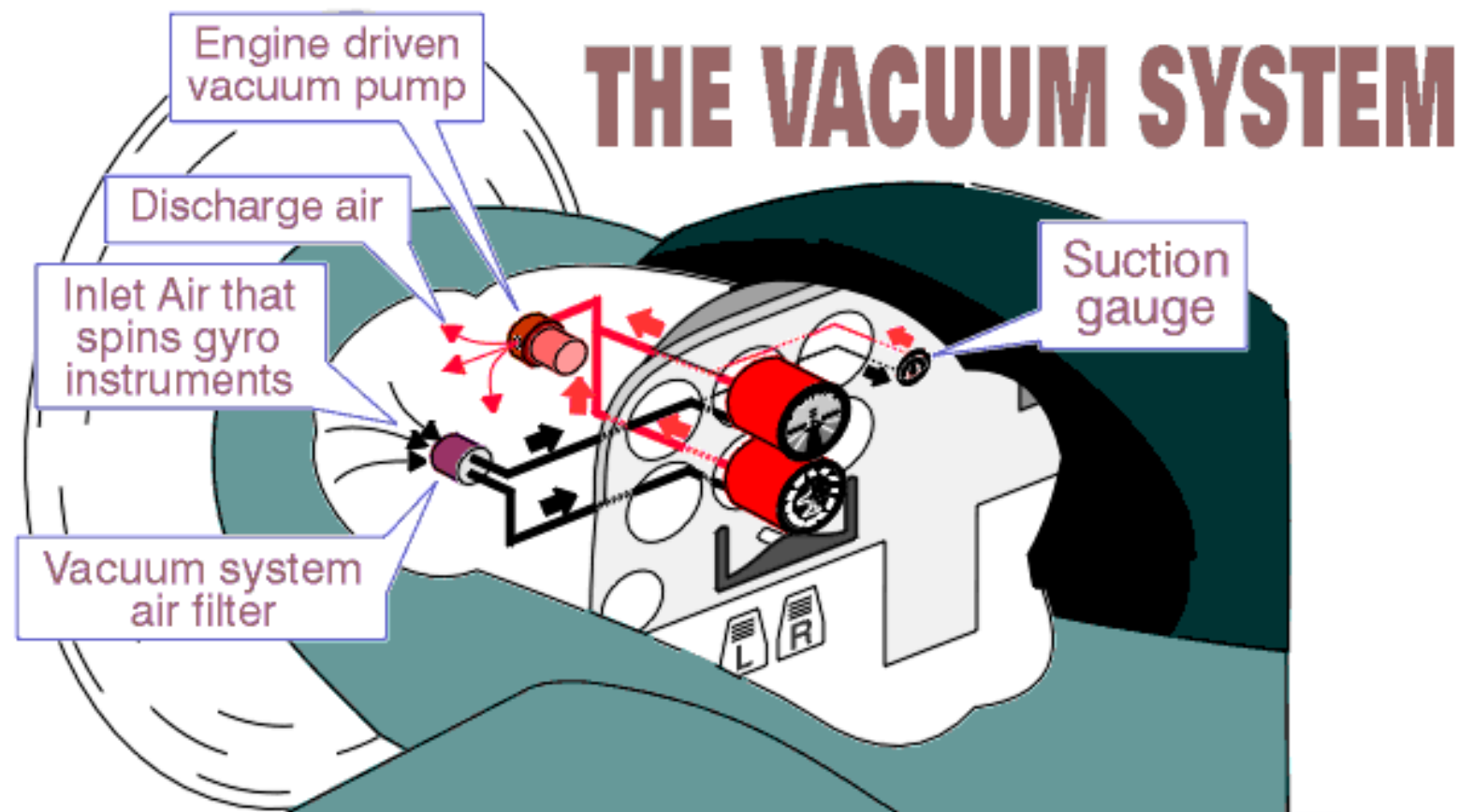
GYROSCOPIC RIGIDITY IN SPACE

A child's toy top stays vertical or rigid in space when spun. When not spun, it easily falls to its side.

The same principle applies to modern day gyro instruments. A spinning gyro remains fixed in space allowing the airplane to rotate around it.



Gyroscope Principles



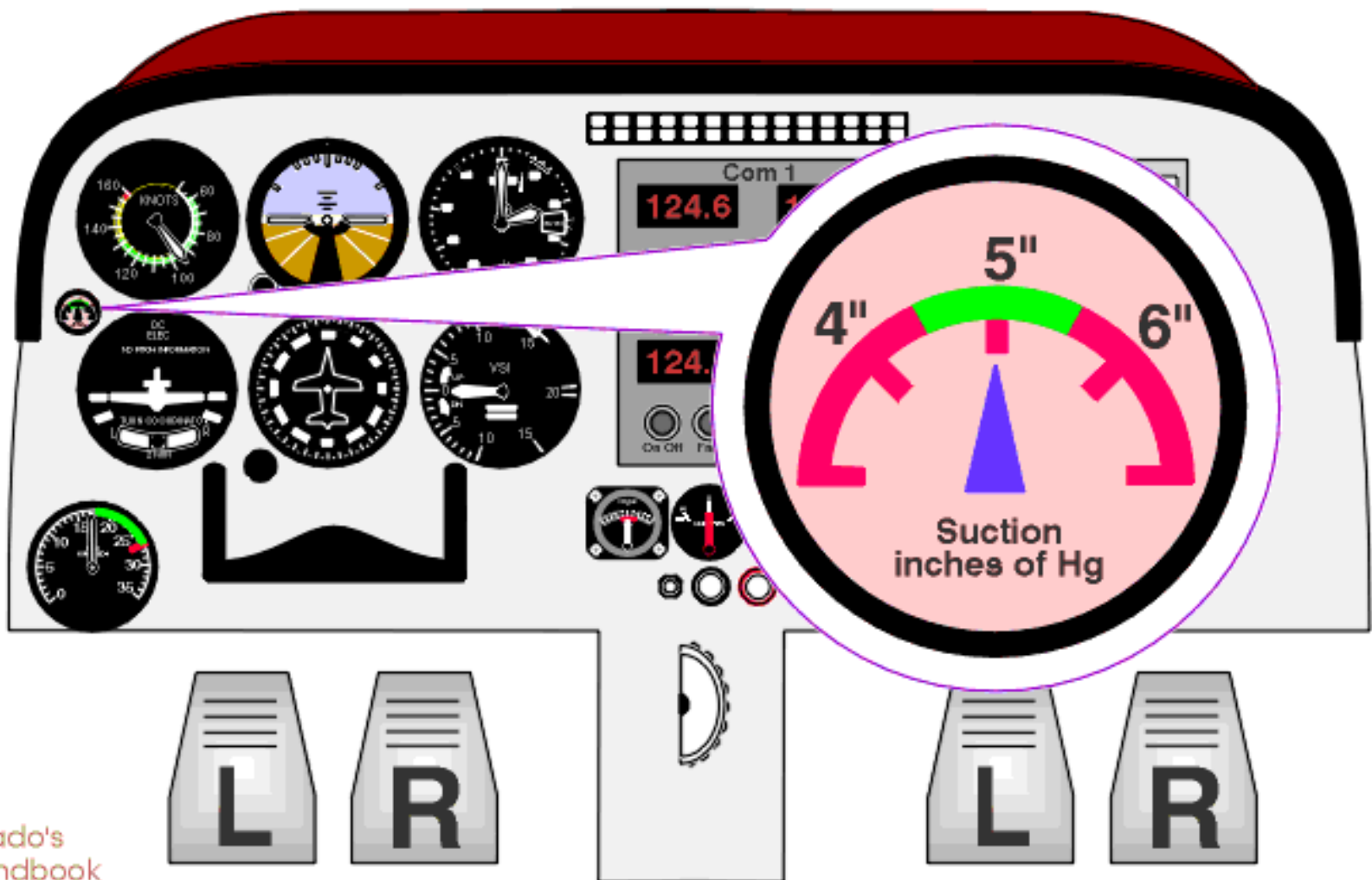
The vacuum pump sucks air over the attitude indicator and the heading indicator. Air enters these instruments from the air filter located either on the engine side of the firewall or inside the cockpit.

5-45

Gyroscope Principles

THE SUCTION GAUGE

Operation within the green arc (shown as white), tells you that all your gyro instruments are getting enough vacuum pressure for proper operation.



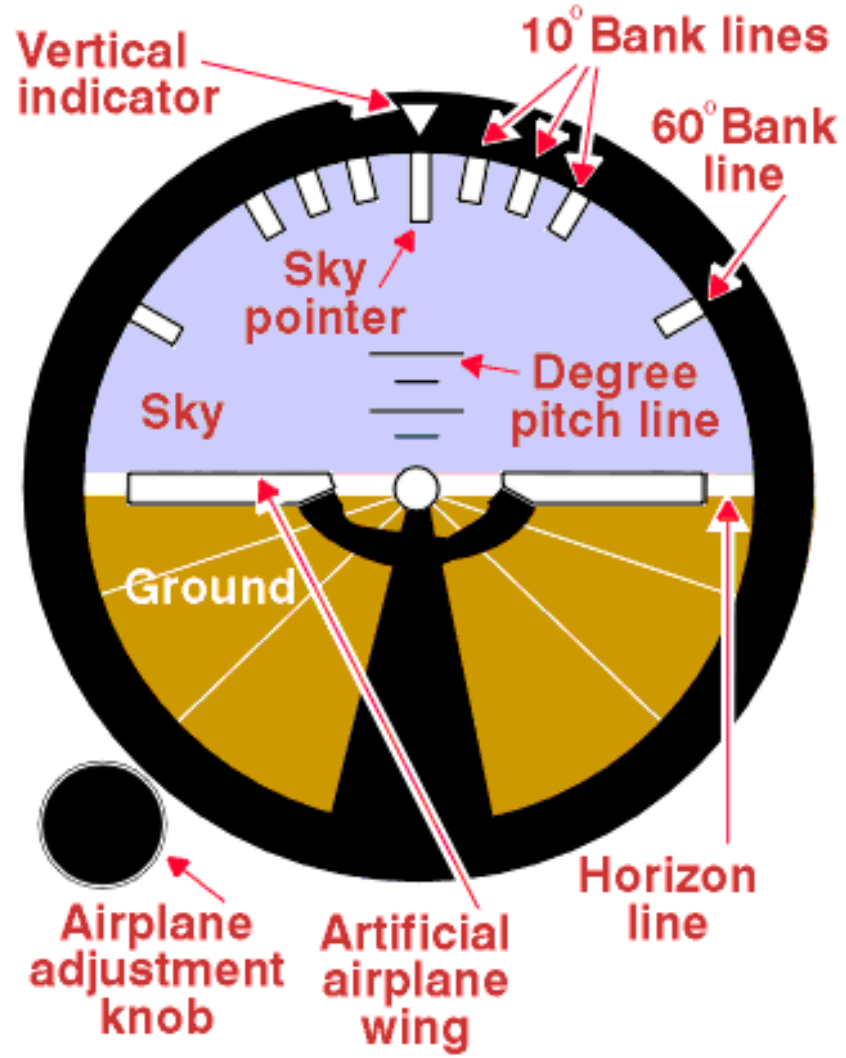
5-46

Gyroscopic Instruments:

- **Attitude Indicator**
- Heading Indicator
- Turn Coordinator

Attitude Indicator: Steam Gauge

THE ATTITUDE INDICATOR



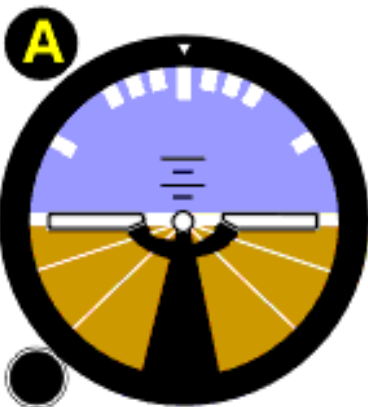
Attitude Indicator: Glass



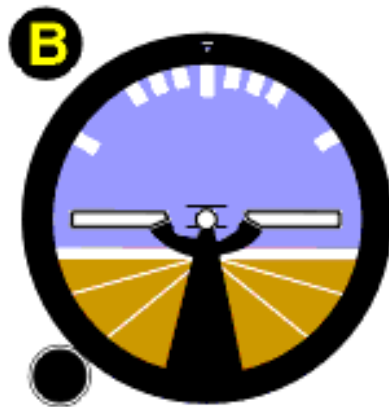
Attitude Indicator

VARIOUS ATTITUDES AND BANKS

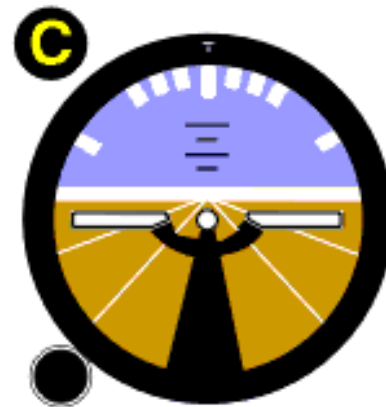
Straight & level



Straight climb



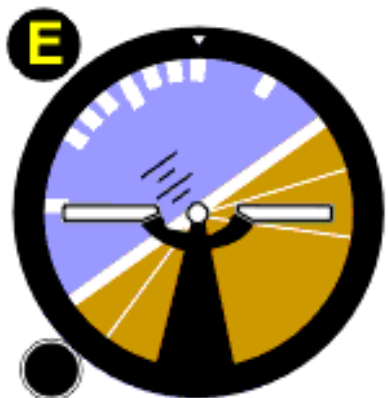
Straight descent



Left turn at 30° of bank



Right turn at 30° of bank



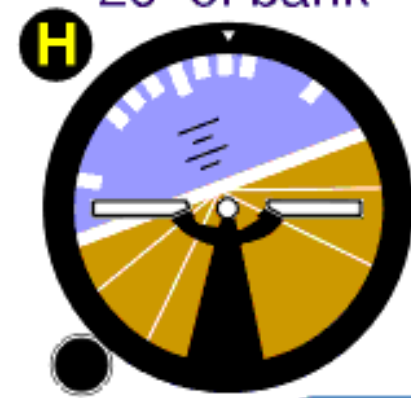
Climbing left turn at 30° of bank



Climbing right turn at 60° of bank



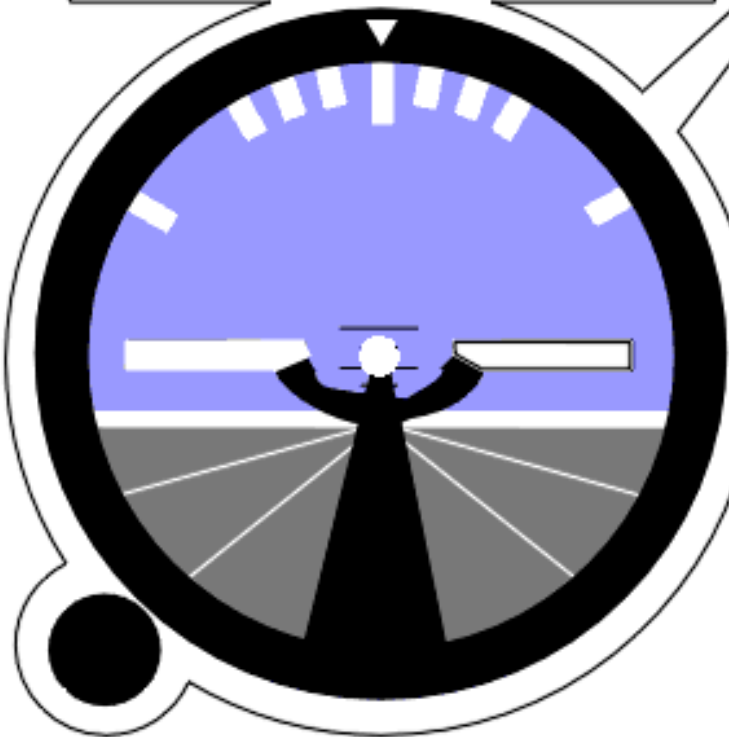
Descending right turn at 20° of bank



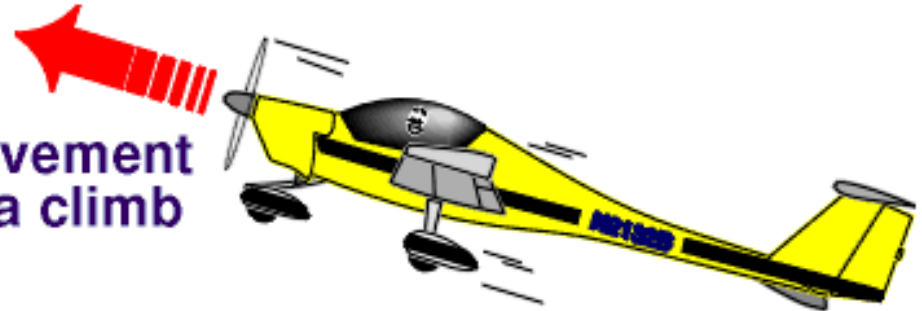
Attitude Indicator

PITCH ATTITUDE & FLIGHT CONDITIONS

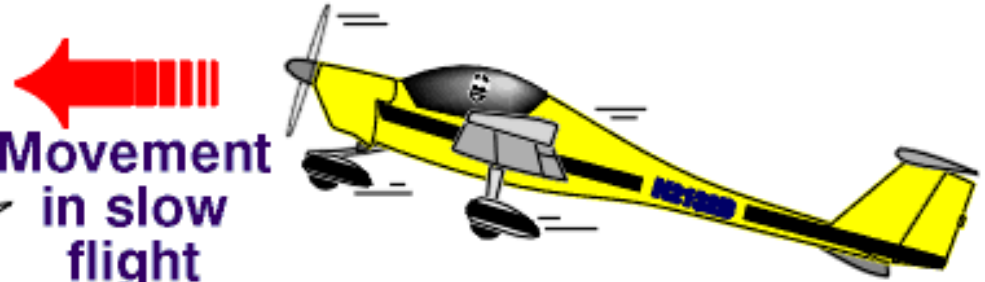
All three airplanes have similar attitude indications on the attitude indicator.



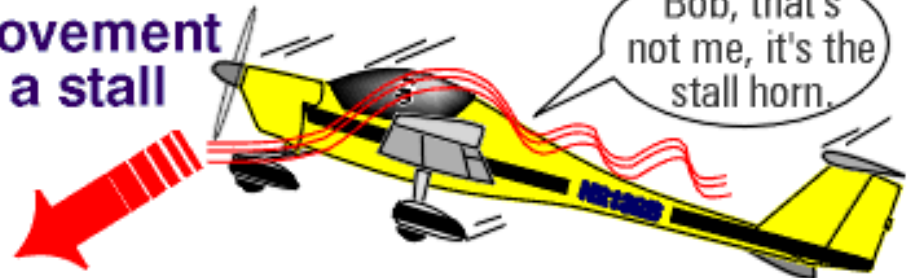
Movement
in a climb



Movement
in slow
flight



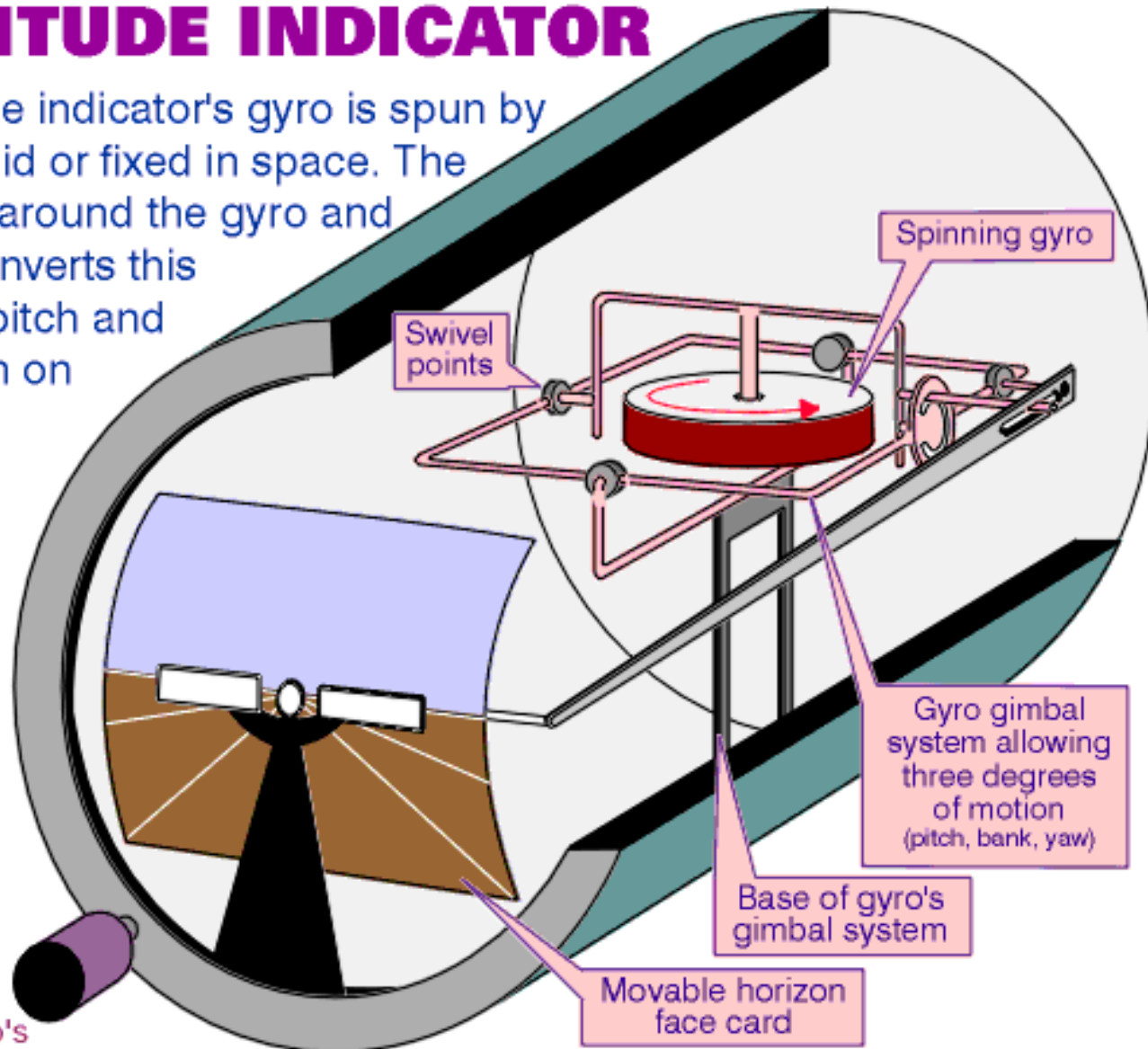
Movement
in a stall



Attitude Indicator

THE ATTITUDE INDICATOR

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.

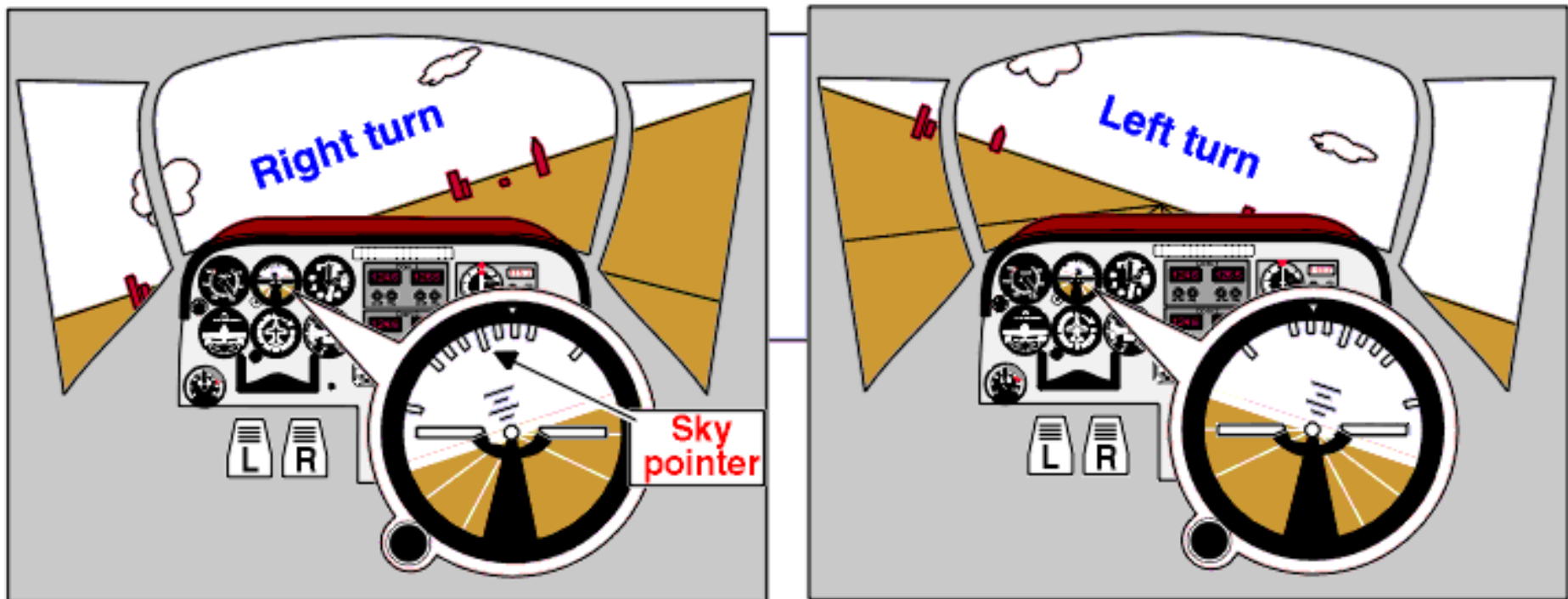


5-42

Attitude Indicator

THE HORIZON LINE

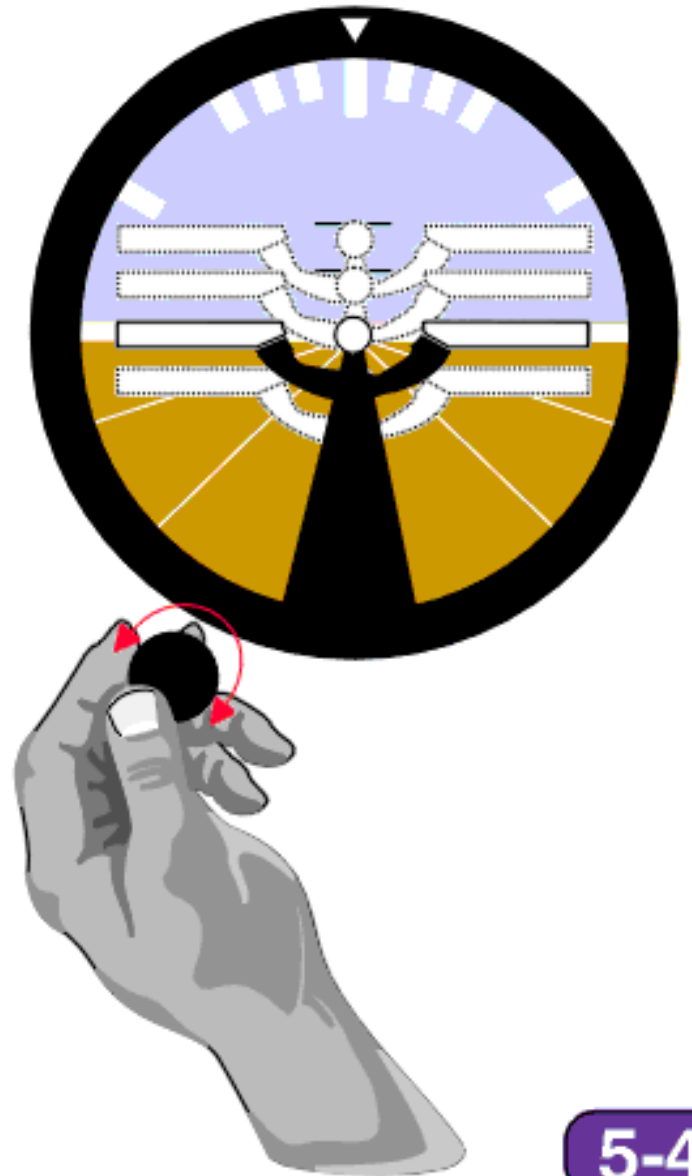
The attitude indicator's horizon line remains parallel to the earth's surface at all times and the sky pointer always points upward to the sky.



Attitude Indicator

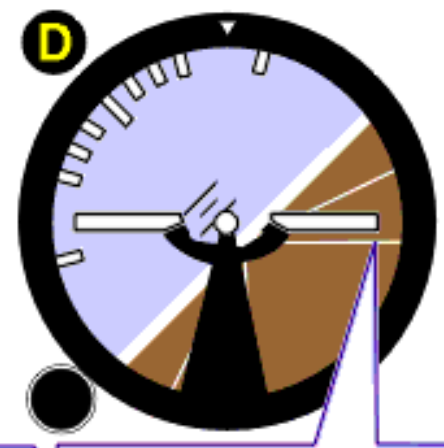
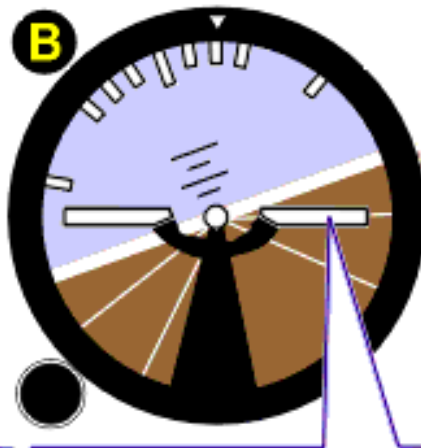
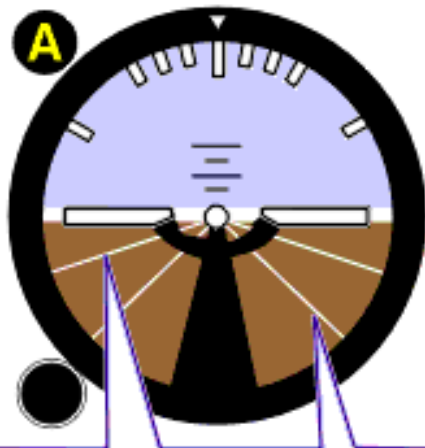
ATTITUDE INDICATOR ADJUSTMENT KNOB

Turning the adjustment knob allows you to reset the small airplane's position. You may need to do this to show the straight & level position when flying at variable weights & speeds since this changes your angle of attack.



Attitude Indicator

THE ATTITUDE INDICATOR'S DIAGONAL BANK LINES



These are the attitude indicator's 20° & 45° bank lines (sometimes it's a 15° bank line vs. a 20° bank line).

The airplane's wings are parallel to the first white line which produces a 20° bank.

The airplane's wings are parallel to the second white line which produces a 45° degree bank.

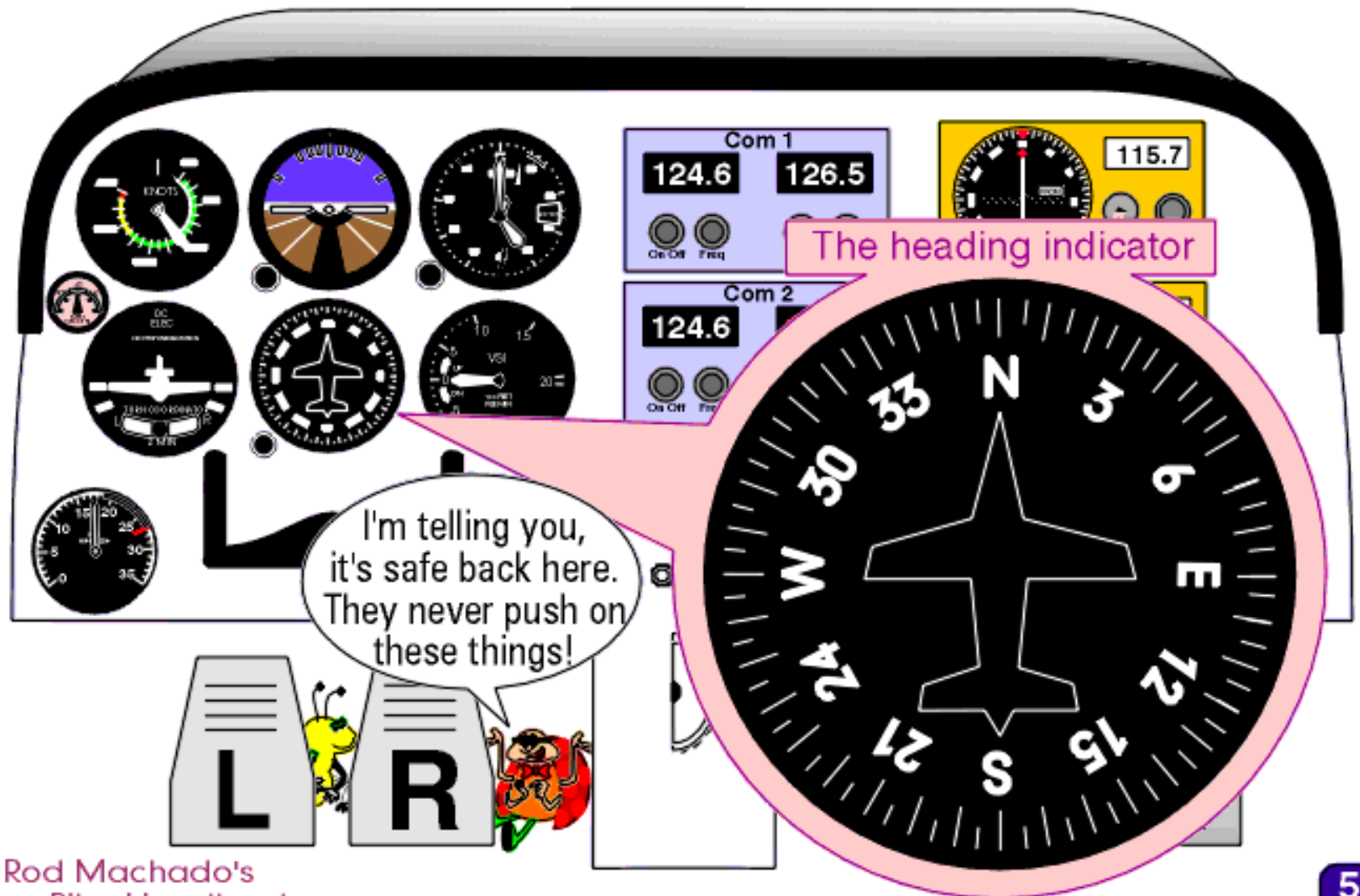
The wings are above & parallel to the 45° bank line. The airplane is in a nose-up attitude at a 45° bank.

Gyroscopic Instruments:

- Attitude Indicator
- **Heading Indicator**
- Turn Coordinator

Heading Indicator – Steam Gauge

THE HEADING INDICATOR



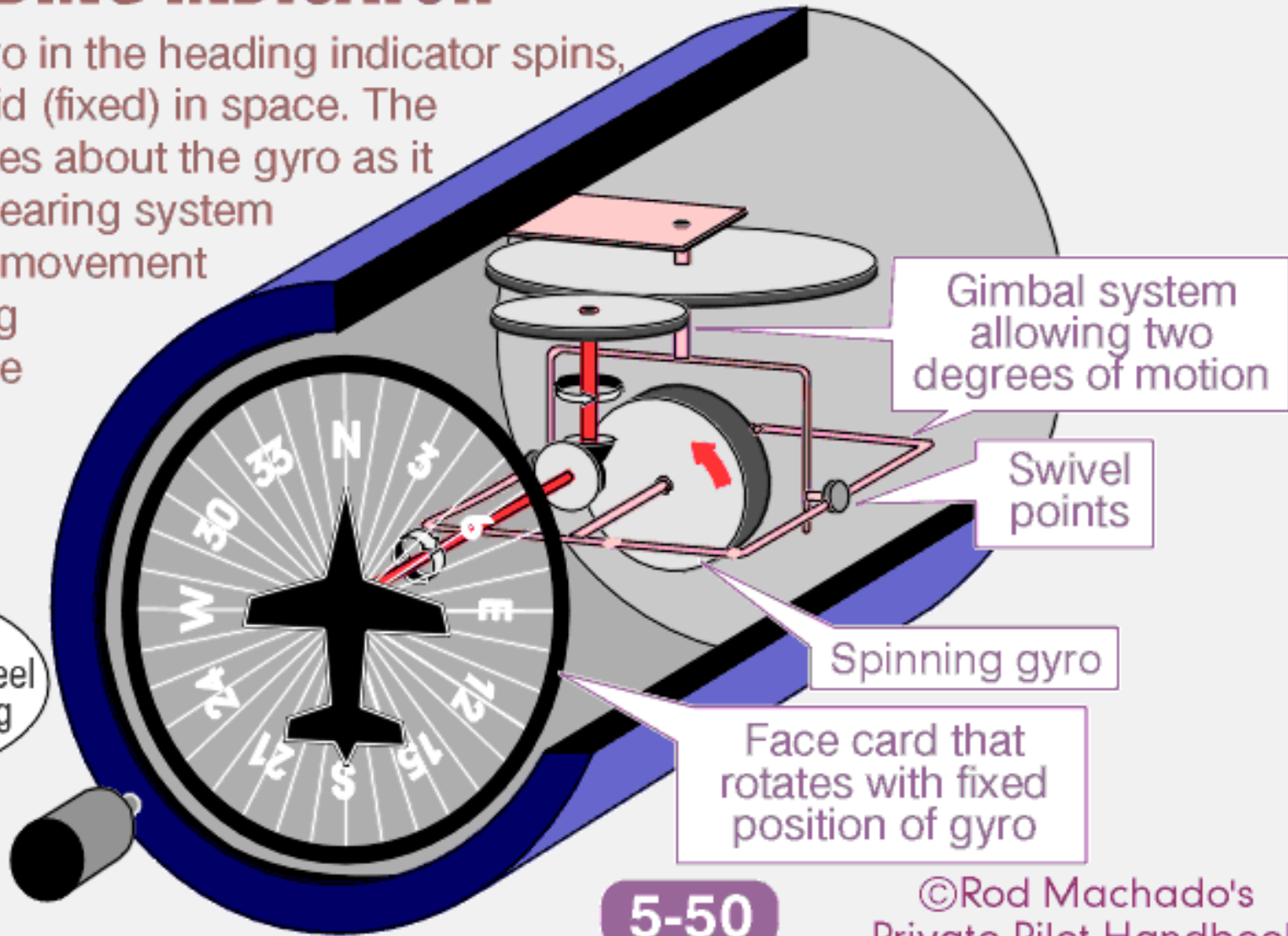
Heading Indicator – Glass



Heading Indicator

THE HEADING INDICATOR

When the gyro in the heading indicator spins, it remains rigid (fixed) in space. The airplane rotates about the gyro as it turns and a gearing system converts this movement into a heading change on the face of the indicator.



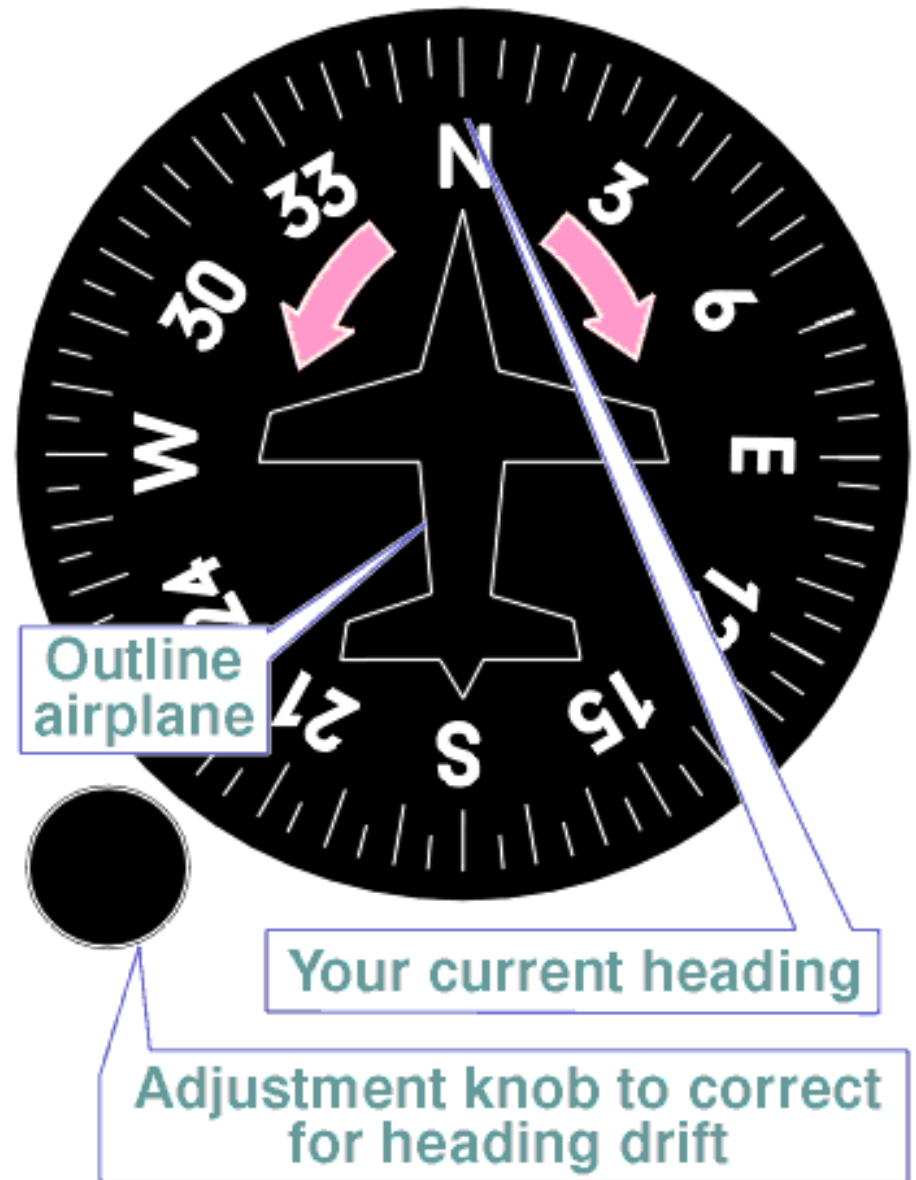
I'm tellin' ya, the spinning wheel does something for me!



Heading Indicator

HEADING INDICATOR

The outline airplane's nose in the heading indicator points to the actual airplane's magnetic heading. As the airplane turns, the numbered disk rotates under the outline airplane allowing your new heading to appear on top.

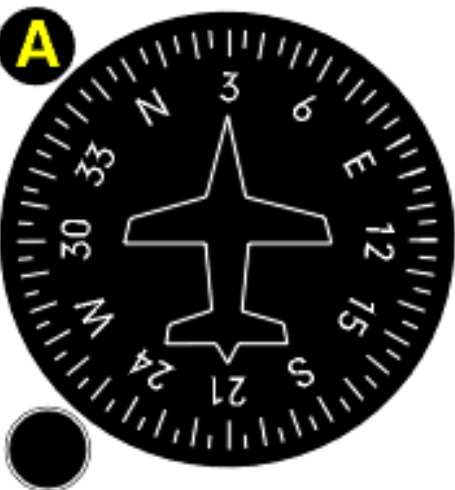


5-51

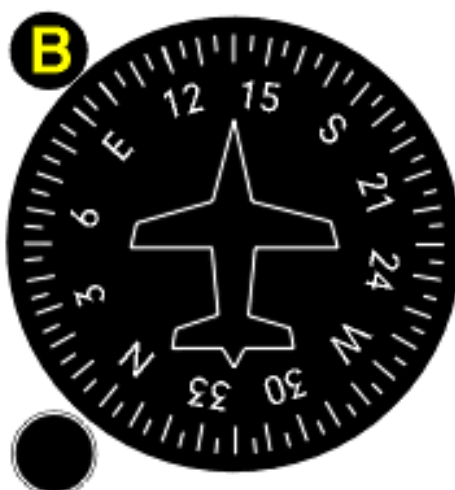
Heading Indicator

DIFFERENT HEADINGS

Heading
"zero-three-zero"



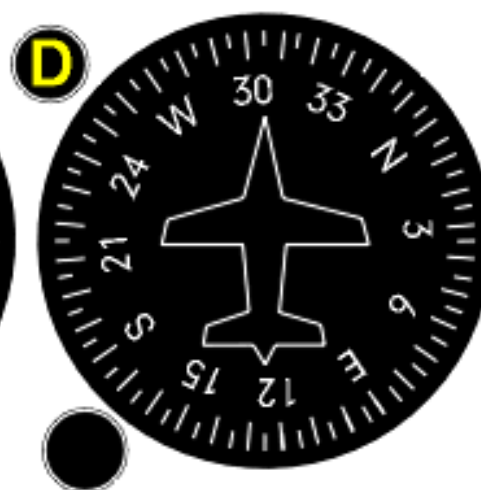
Heading
"one-four-zero"



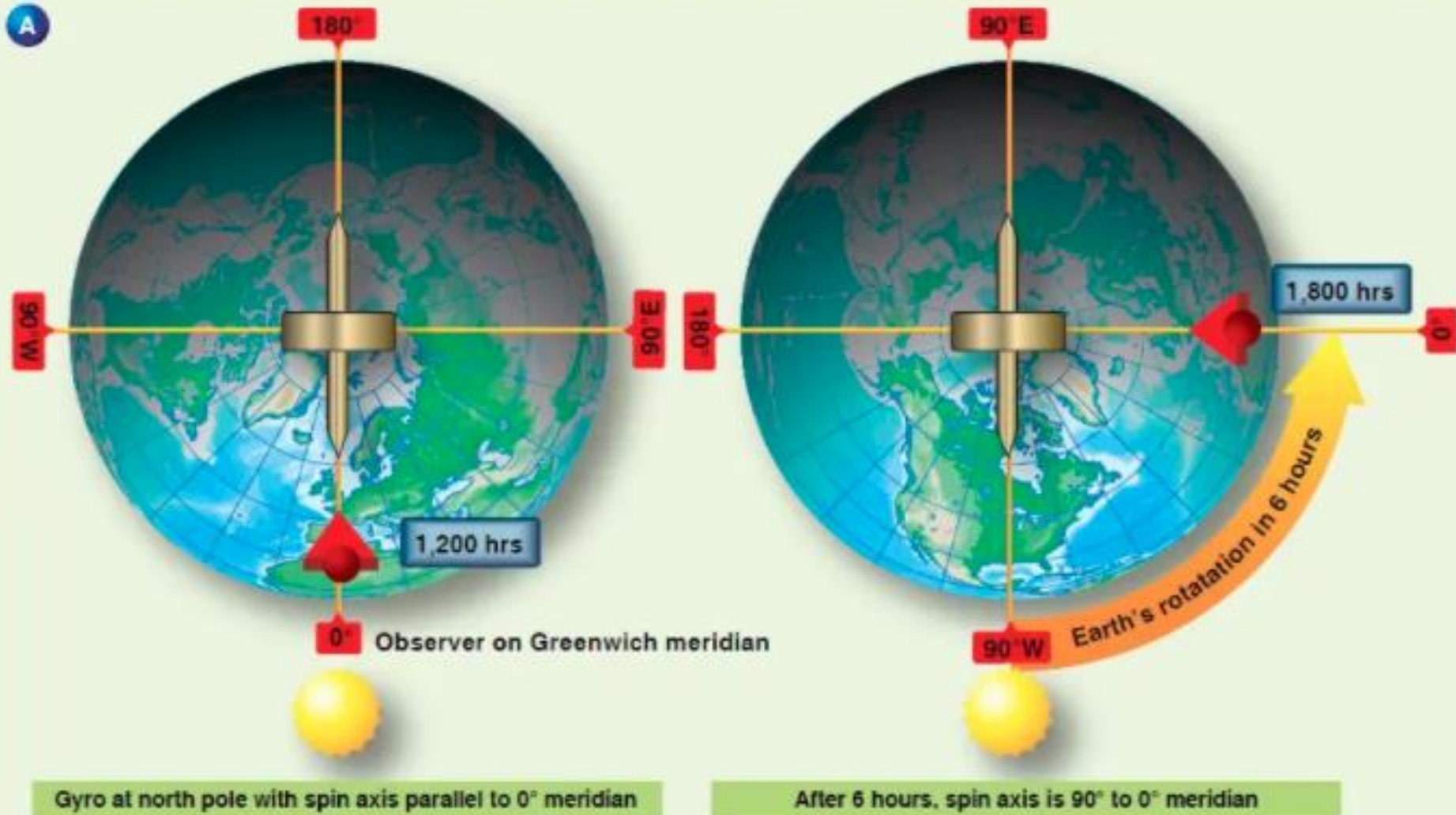
Heading
"three-zero-zero"



Heading
"three-zero-five"



Gyroscopic Precession of HI



Gyroscopic Instruments:

- Attitude Indicator
- Heading Indicator
- **Turn Coordinator**

Turn Coordinator: Steam Gauge

THE TURN COORDINATOR

The turn coordinator



© Rod Machado's
Private Pilot Handbook

I heard him say the radio has a few bugs in it; maybe some babes, eh?

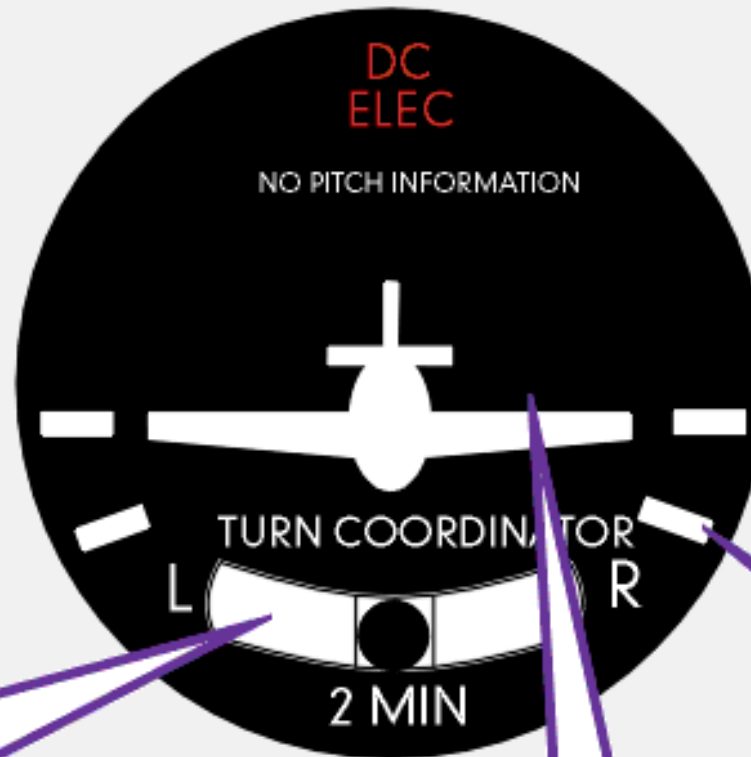


Turn Coordinator: Glass



Turn Coordinator

TURN COORDINATOR



Inclinometer consisting of a black ball suspended in a liquid-filled glass tube

Rate of turn needle that rotates right or left

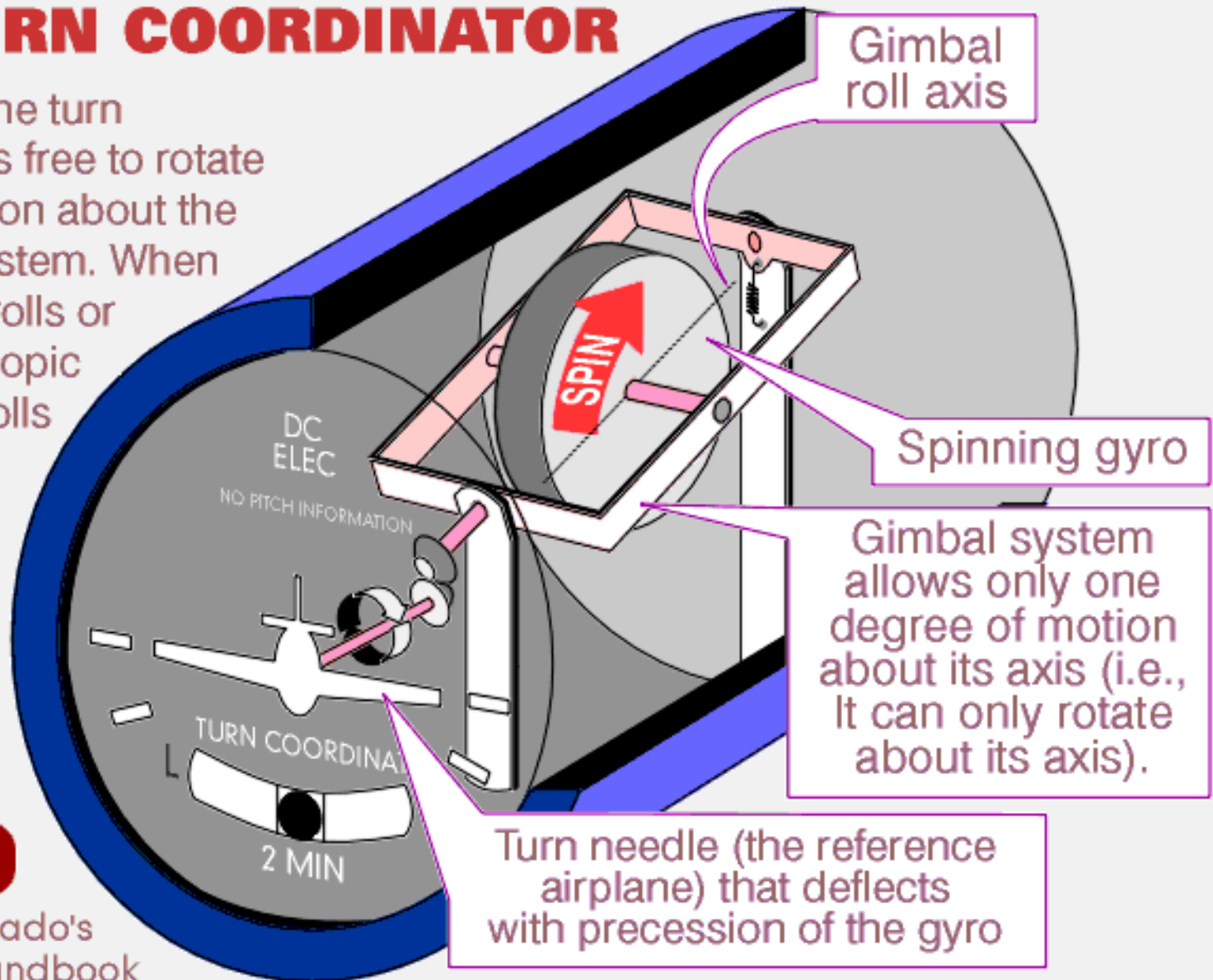
Standard rate turn index

5-54

Turn Coordinator

THE TURN COORDINATOR

The gyro in the turn coordinator is free to rotate in one direction about the gimbaling system. When the airplane rolls or turns, gyroscopic precession rolls the gyro, causing a deflection of the turn needle.

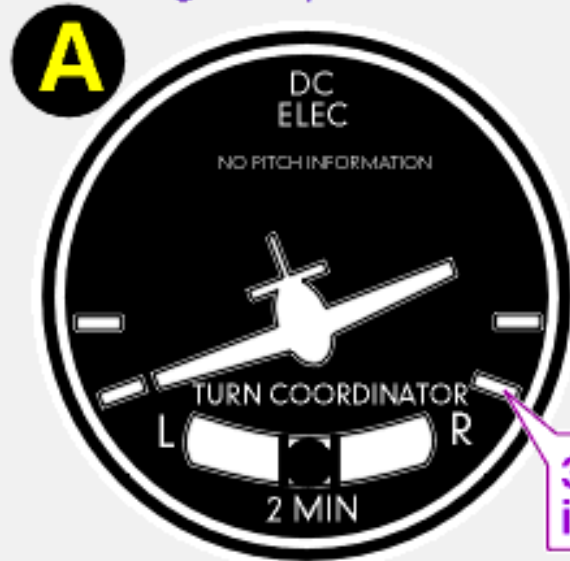


5-55

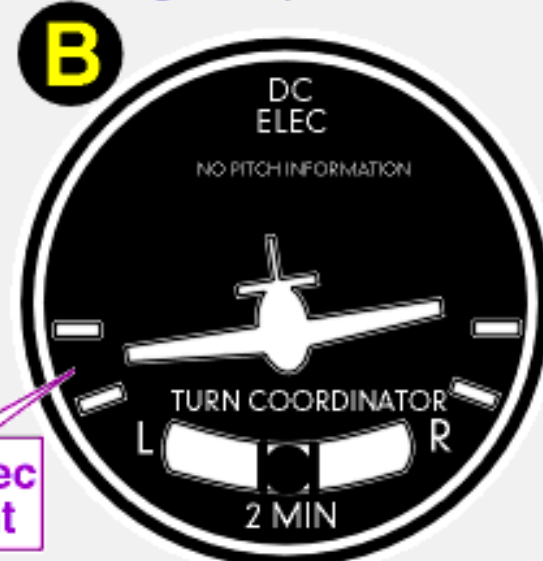
Turn Coordinator

RATE OF TURN ON THE TURN COORDINATOR

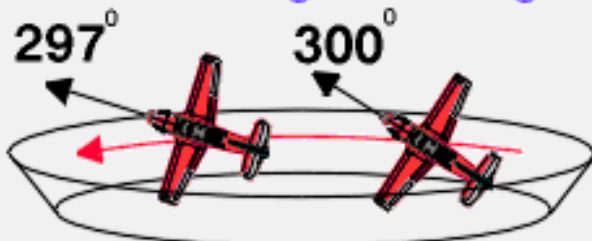
Standard rate turn of 3 degrees per second



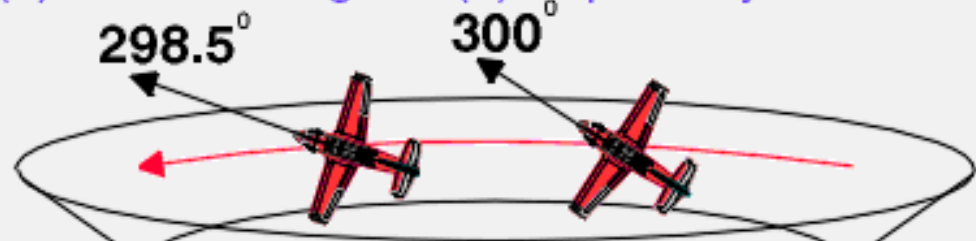
Half standard rate turn of 1.5 degrees per second



Both airplanes were previously established in a left turn passing through a heading of 303 degrees (A) and 301.5 degrees (B) respectively.



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°

Magnetic Compass

Magnetic Compass

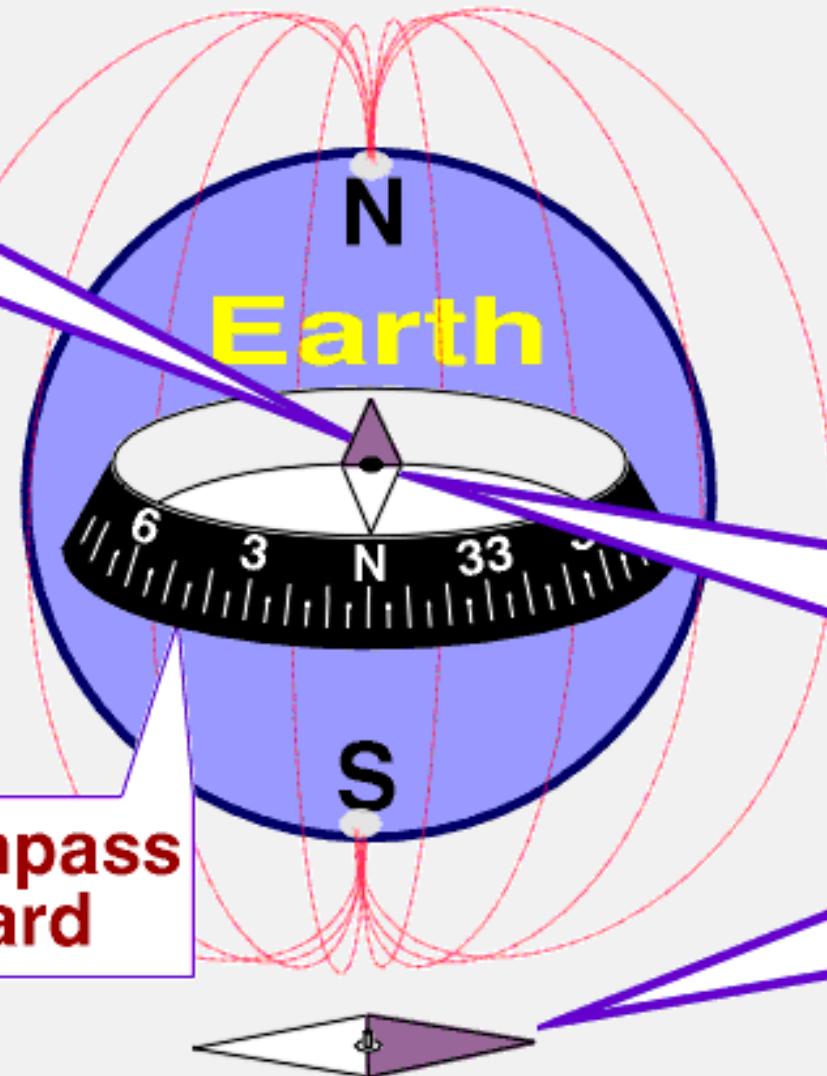
THE MAGNETIC COMPASS NEEDLE

The north-seeking end of the compass needle always points toward the magnetic north pole.

Compass card

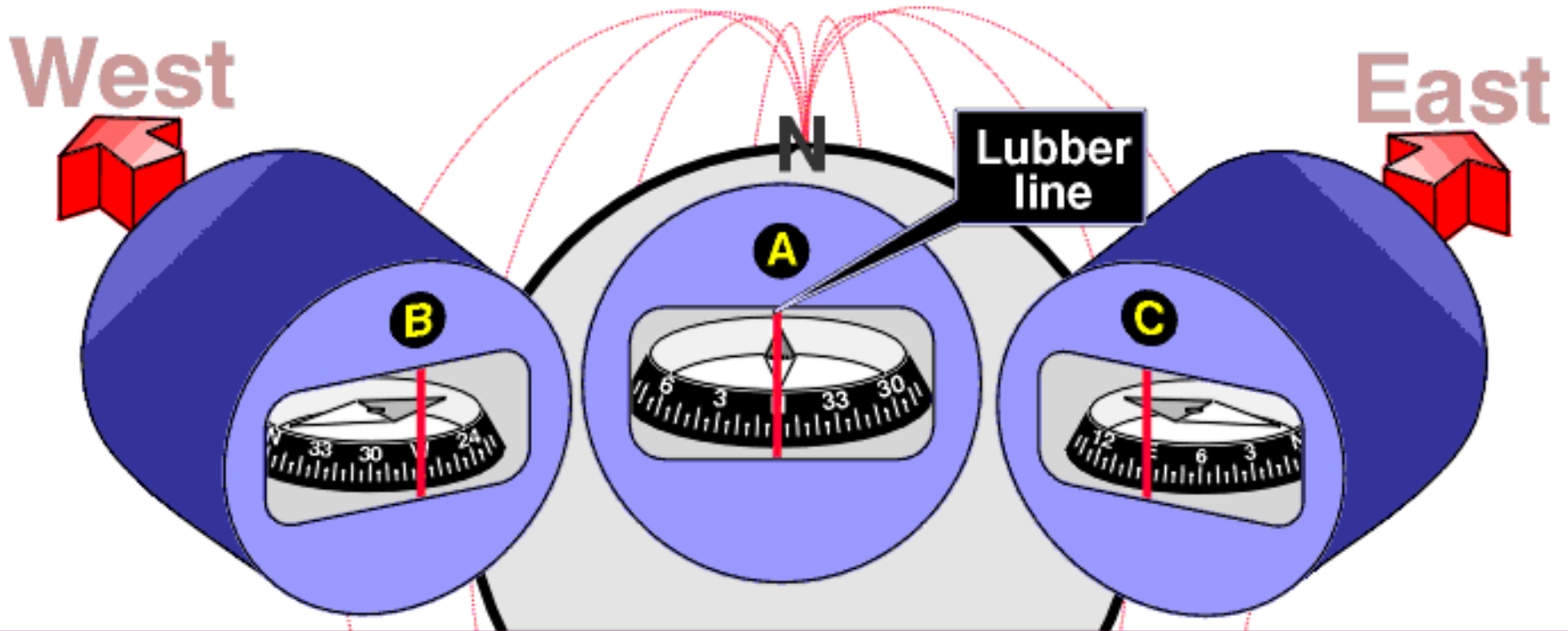
5-60

The compass needle is a small magnetized element connected to the compass card and resting on a pivot allowing it to rotate within the compass housing.



Magnetic Compass

THE NORTH SEEKING END OF THE COMPASS NEEDLE

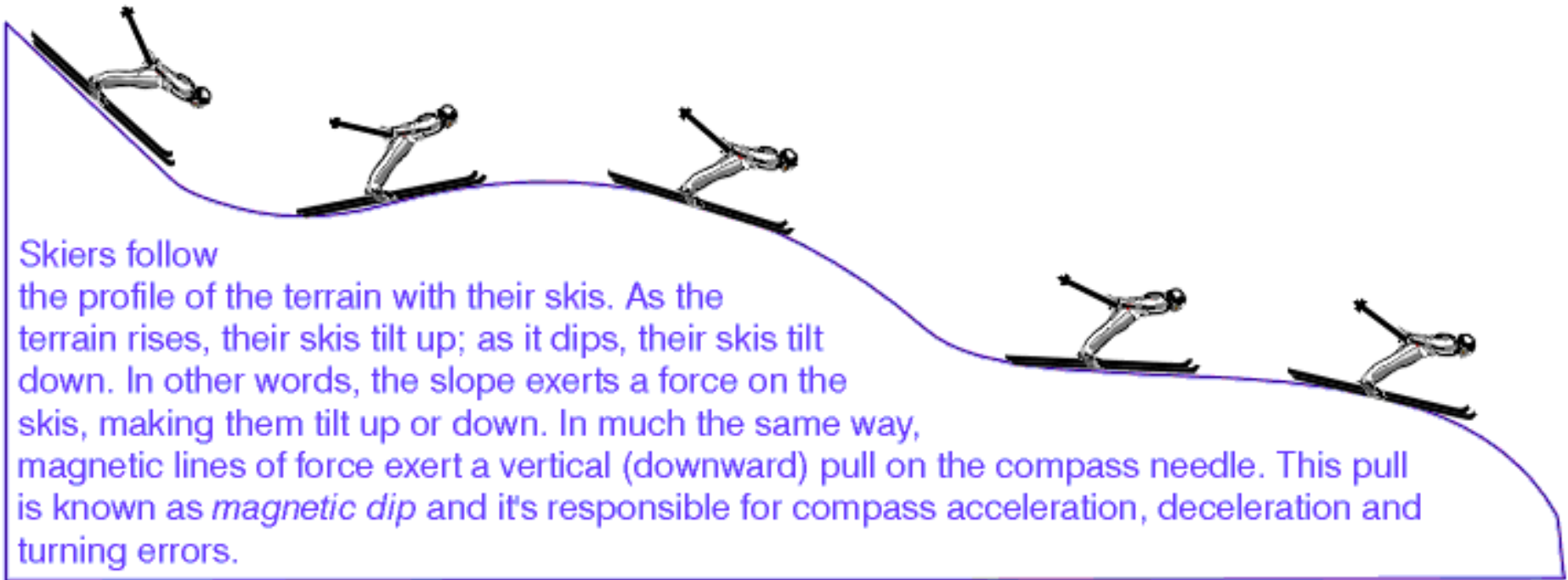


As the airplane turns, the north seeking end of the magnetic compass needle continues to point to the magnetic north pole. Since the compass needle is attached to the marked compass card, the appropriate heading appears under the lubber line (reference line).

Compass B & compass C are rotated toward you for better viewing.

Magnetic Compass

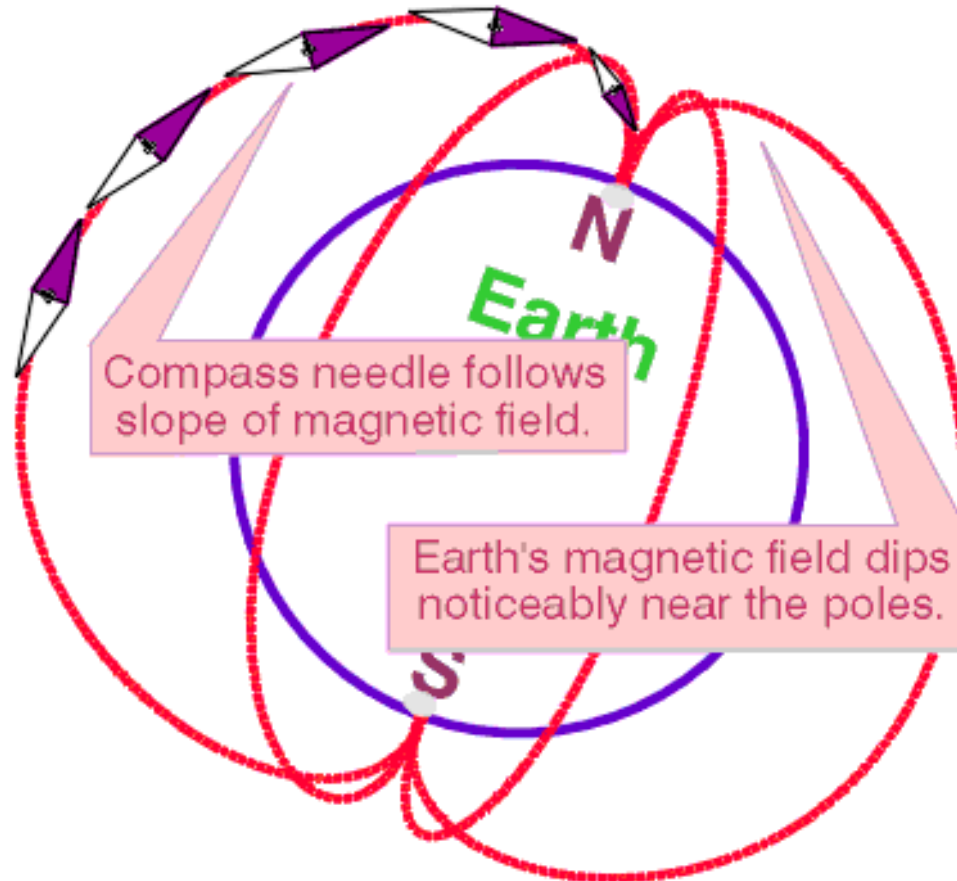
SKI SLOPES & THE MAGNETIC COMPASS



Skiers follow the profile of the terrain with their skis. As the terrain rises, their skis tilt up; as it dips, their skis tilt down. In other words, the slope exerts a force on the skis, making them tilt up or down. In much the same way, magnetic lines of force exert a vertical (downward) pull on the compass needle. This pull is known as *magnetic dip* and it's responsible for compass acceleration, deceleration and turning errors.

Magnetic Compass

MAGNETIC DIP



The magnetic compass needle, like skis, follows the slope of the Earth's magnetic field. Where the slope dips downward (near the poles), the compass needle also dips. This phenomena is known as magnetic dip.

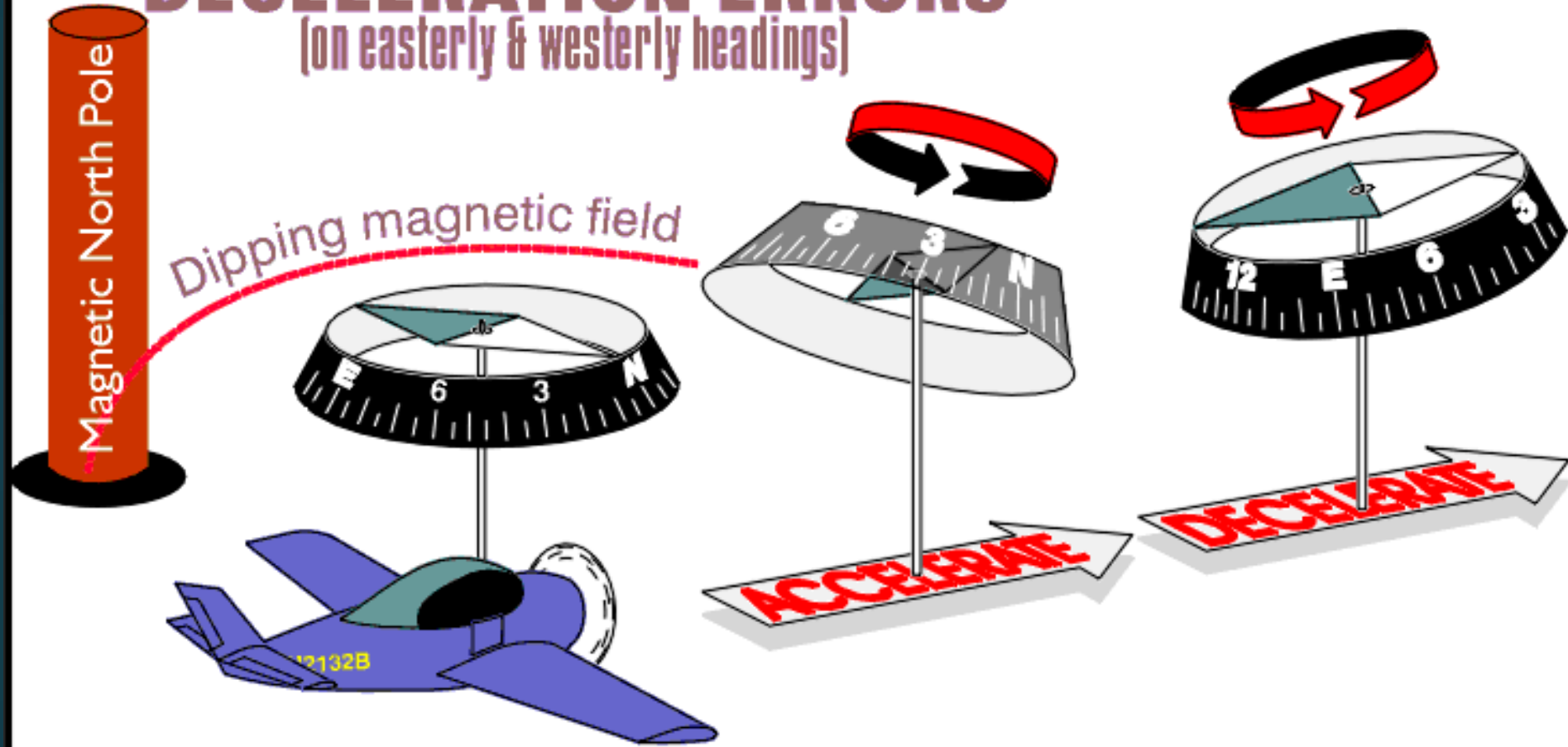
Magnetic Compass

ACCELERATION AND DECELERATION ERRORS (on easterly & westerly headings)



Magnetic Compass

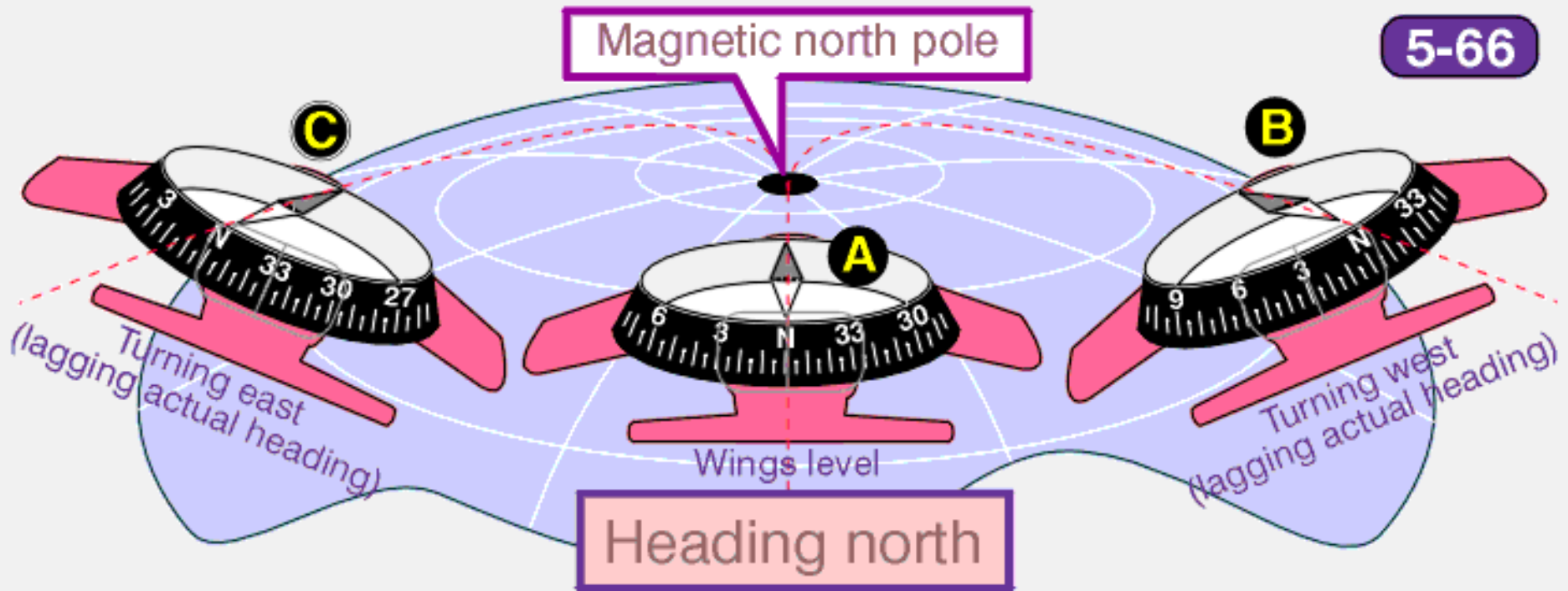
ACCELERATION AND DECELERATION ERRORS (on easterly & westerly headings)



Accelerate North, Decelerate South = ANDS

Magnetic Compass

NORTHERLY TURNING ERROR

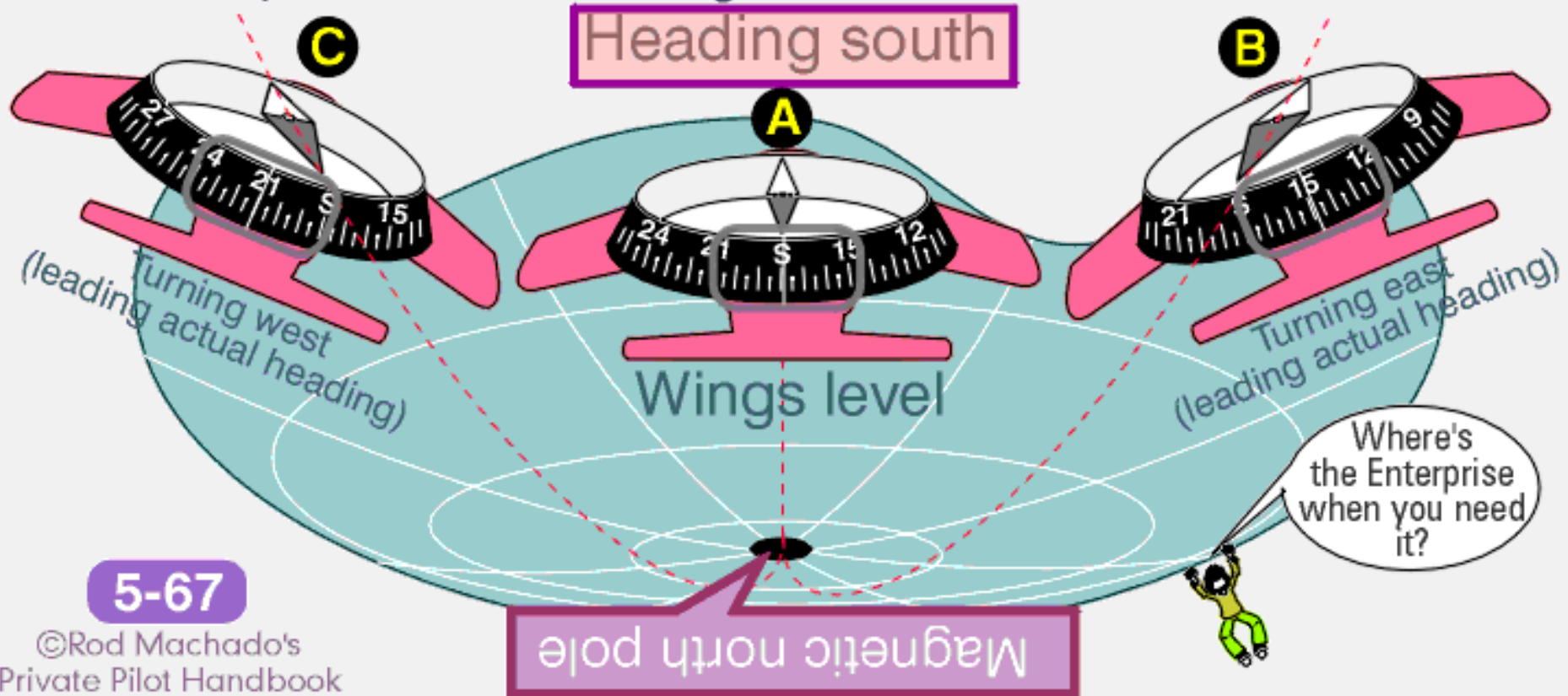


As the airplane turns through or from a northerly heading, the compass needle (lying within the banked card) aligns itself with the earth's dipping magnetic field. This causes the card to twist, resulting in a heading that temporarily lags the airplane's actual heading.

Magnetic Compass

SOUTHERLY TURNING ERROR

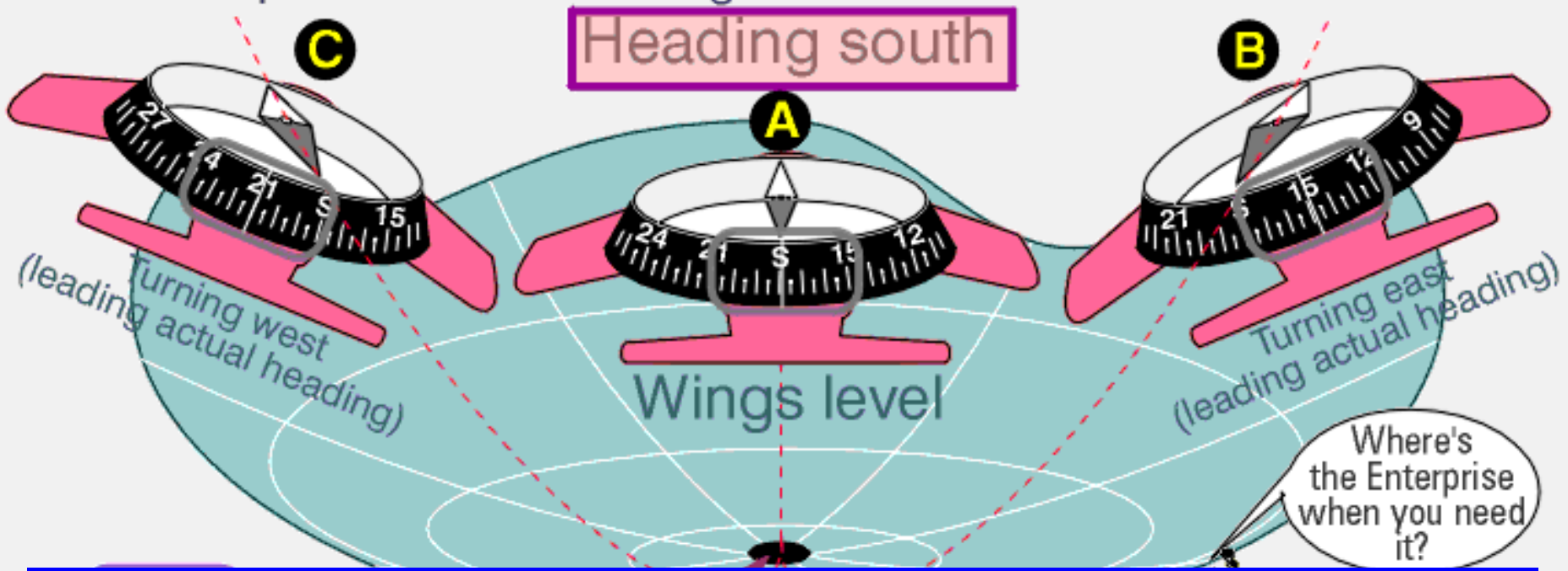
While on a southerly heading, the magnetic field rises upward from below the airplane. When the airplane turns from or through this southerly heading, the compass needle twists to align itself with the earth's dipping magnetic field. Thus, the compass card shows a heading that temporarily leads the airplane's actual heading.



Magnetic Compass

SOUTHERLY TURNING ERROR

While on a southerly heading, the magnetic field rises upward from below the airplane. When the airplane turns from or through this southerly heading, the compass needle twists to align itself with the earth's dipping magnetic field. Thus, the compass card shows a heading that temporarily leads the airplane's actual heading.



North Opposes, South Exceeds = NOSE



ANDS: Accelerate North, Decelerate South
UNOS: Undershoot North, Overshoot South
NOSE: North Opposes, South Exceeds

Next Session: Feb 12

- ▶ Quiz: Aerodynamics of Thrust & Drag
- ▶ Presentation: Airspace
- ▶ Reading:
 - ▶ Machado Chapter 9
 - ▶ Pilot's Handbook Chapter 15