AMT 110
Aircraft Instrument Systems

Chapter 10

Instruments

- People's lives depend on instruments working correctly!!!
- An A&P may not open or repair an instrument
  - An A&P may mark the outside or tighten an outside knob
- Only the manufacturer of the instrument or a certificated repair station approved for that class instrument can repair an instrument

Instruments Classifications

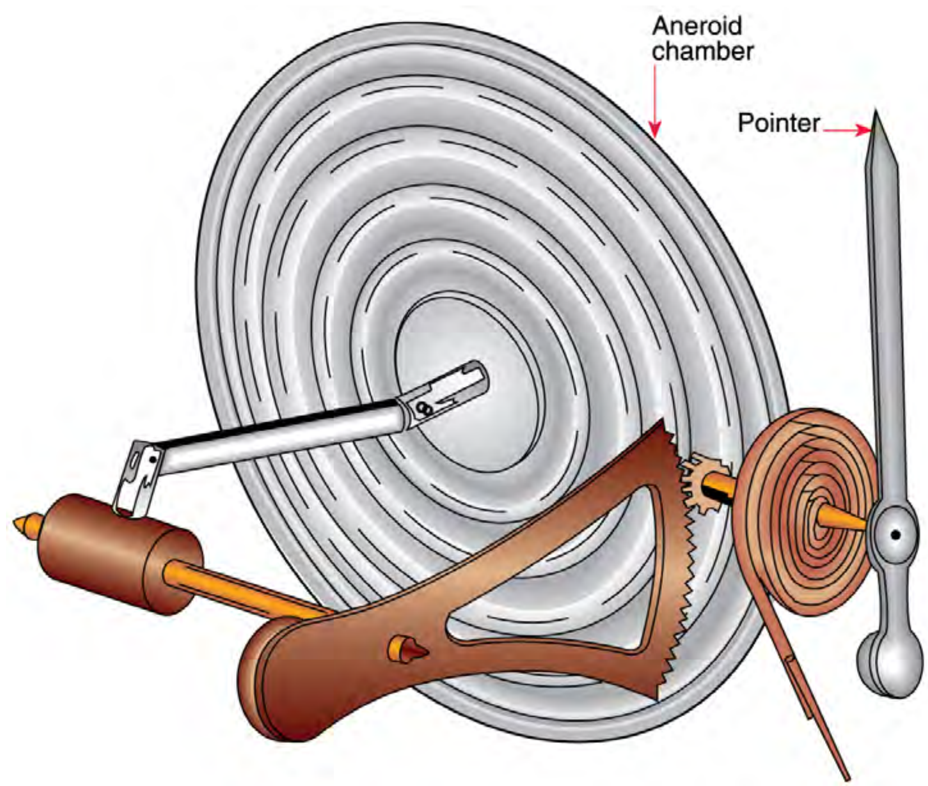
- Flight instruments
  - Used in controlling the aircraft's flight attitude
- Engine instruments
  - Used to measure operating parameters of the aircraft's engine(s)
- Navigation instruments
  - Used to guide the aircraft along a course

Pressures

- Absolute pressure - pressure that is measured from zero pressure, or from a vacuum
- Gauge pressure - pressure measured from the existing atmospheric pressure
- Differential pressure - pressure which is the difference between two opposing pressures

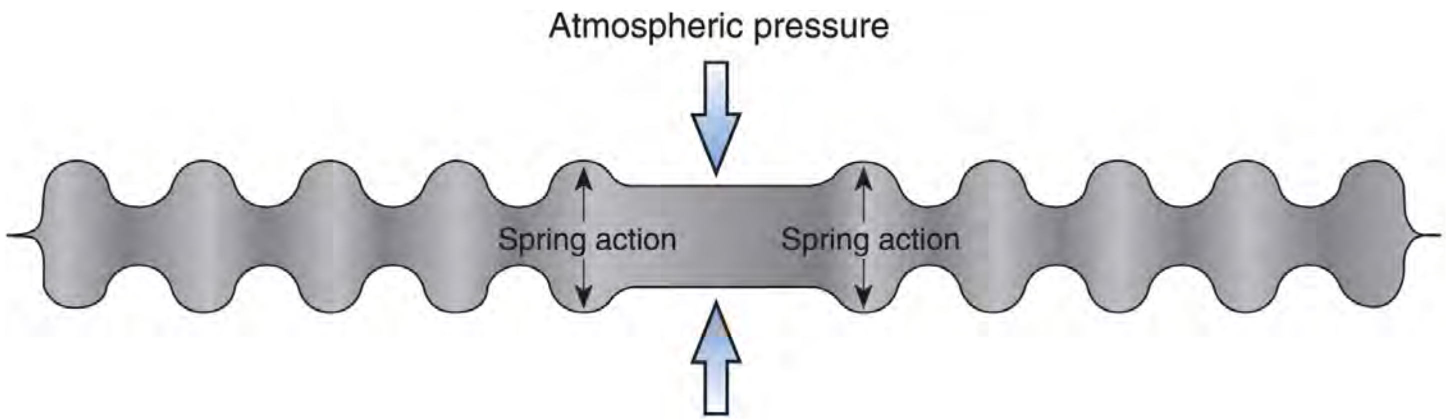
Pressure Instruments

- Aneroid - the **sensitive** component in an altimeter or barometer that measures the absolute pressure of the air.



An aneroid barometer mechanism.

Aneroid Chamber

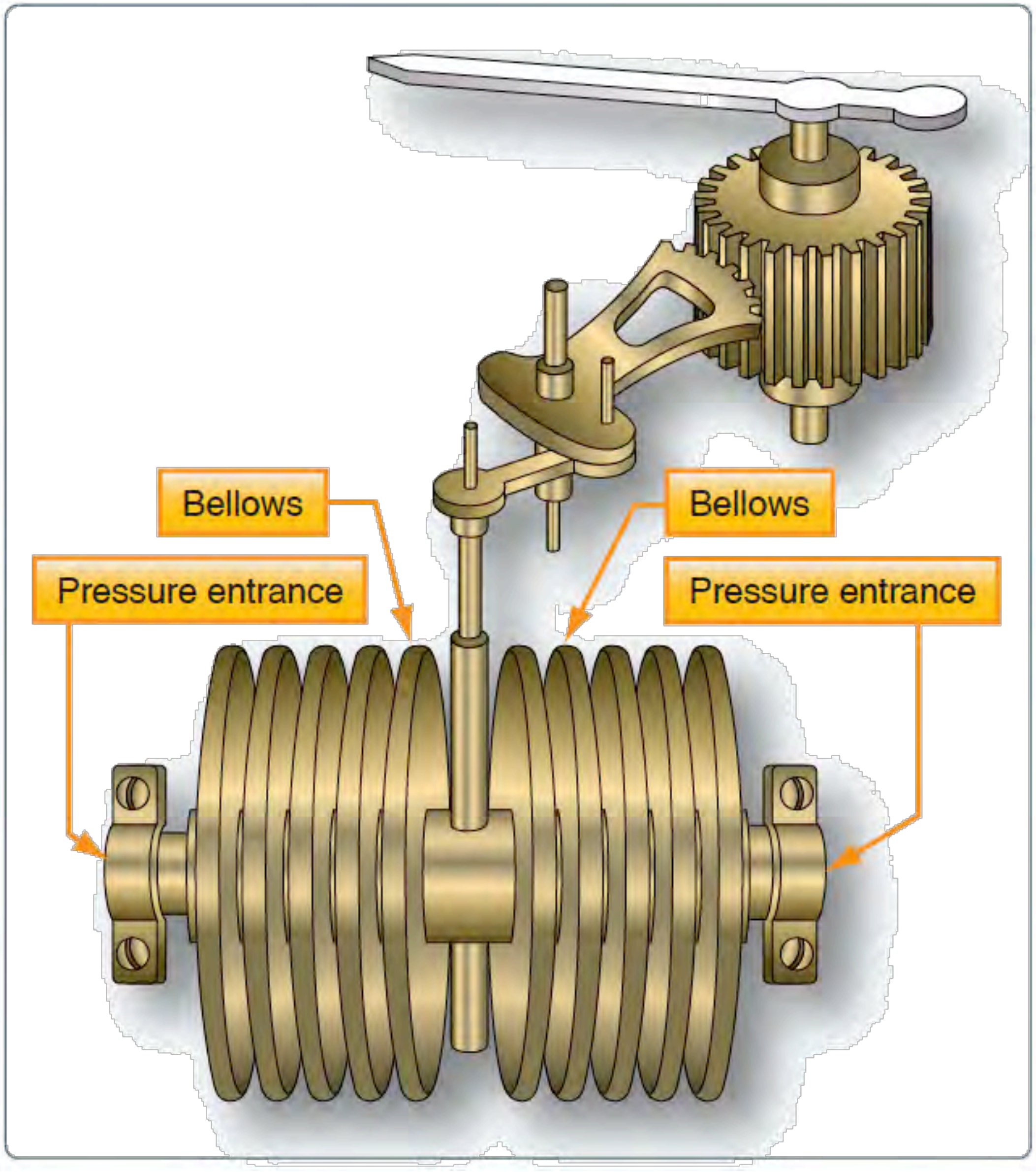


The spring action of the corrugations opposes the pressure of the air to measure any changes in the air pressure.

Pressures Instruments

- Diaphragm – a hollow disk, like an aneroid, that measures pressure other than absolute pressure.
  - The disk must have an opening to the pressure being measured.
- Bellows – stacks of diaphragms stacked together

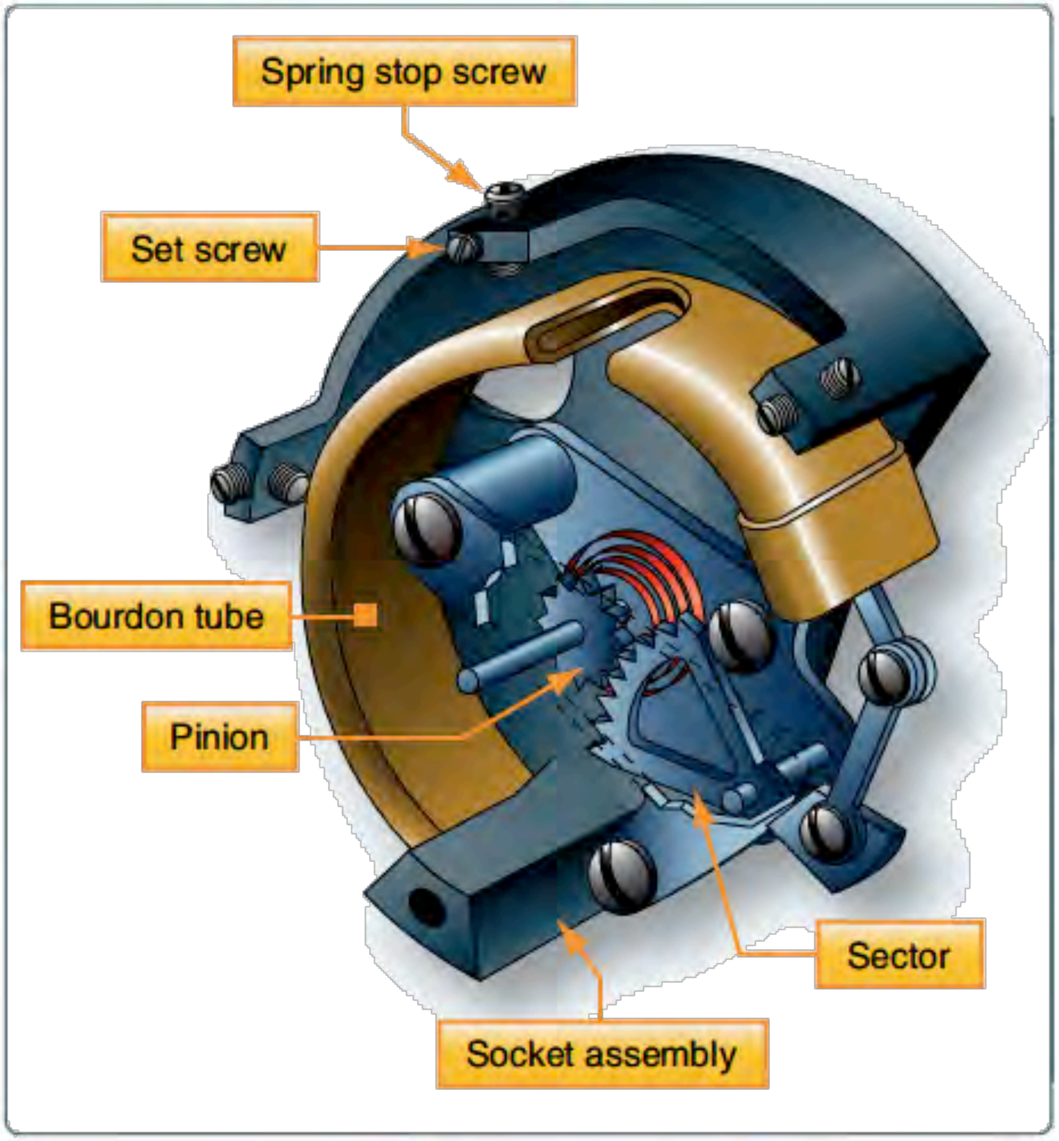
Bellows



Bourdon Tube

- Bourdon tube – pressure indicating mechanism used in most oil pressure and hydraulic pressure gauges.
  - Consists of a sealed, curved tube with an elliptical cross section
  - Pressure inside the tube tries to straighten it, and as it straightens, it moves a pointer across a calibrated dial.

Bourdon Tube



Bourdon Tube

- Can be used to measure temperature
  - Tube filled with volatile liquid
- Video 1
- Video 2

Solid State Pressure Transducers

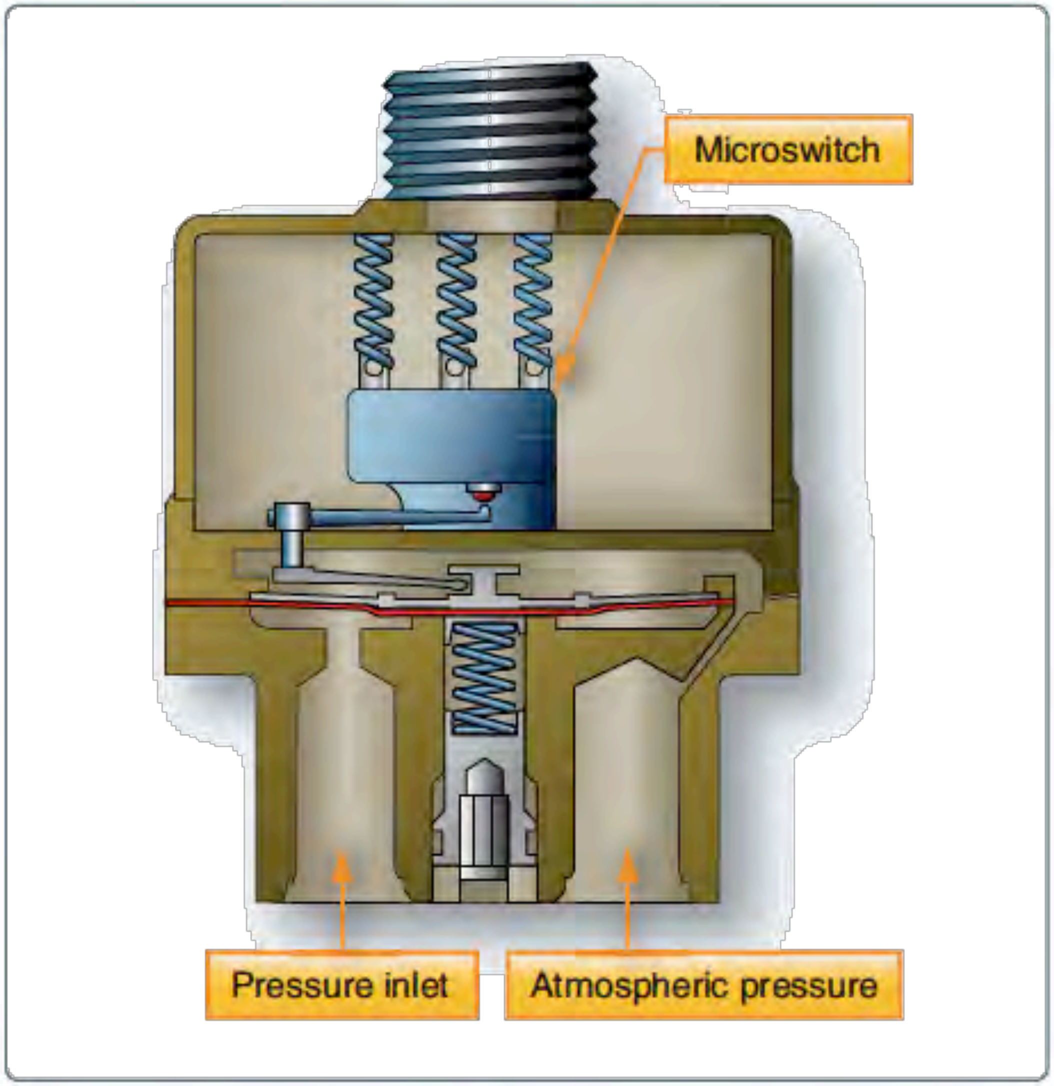
Pressure Instruments

- Oil Pressure
  - Usually gauge pressure
    - Sometime differential pressure to detect blockage
- Manifold Pressure
  - Absolute pressure
  - Measures intake manifold pressure
  - When engine is off or system is leaking, gauge will read atmospheric pressure
- Fuel Pressure
  - Gauge pressure

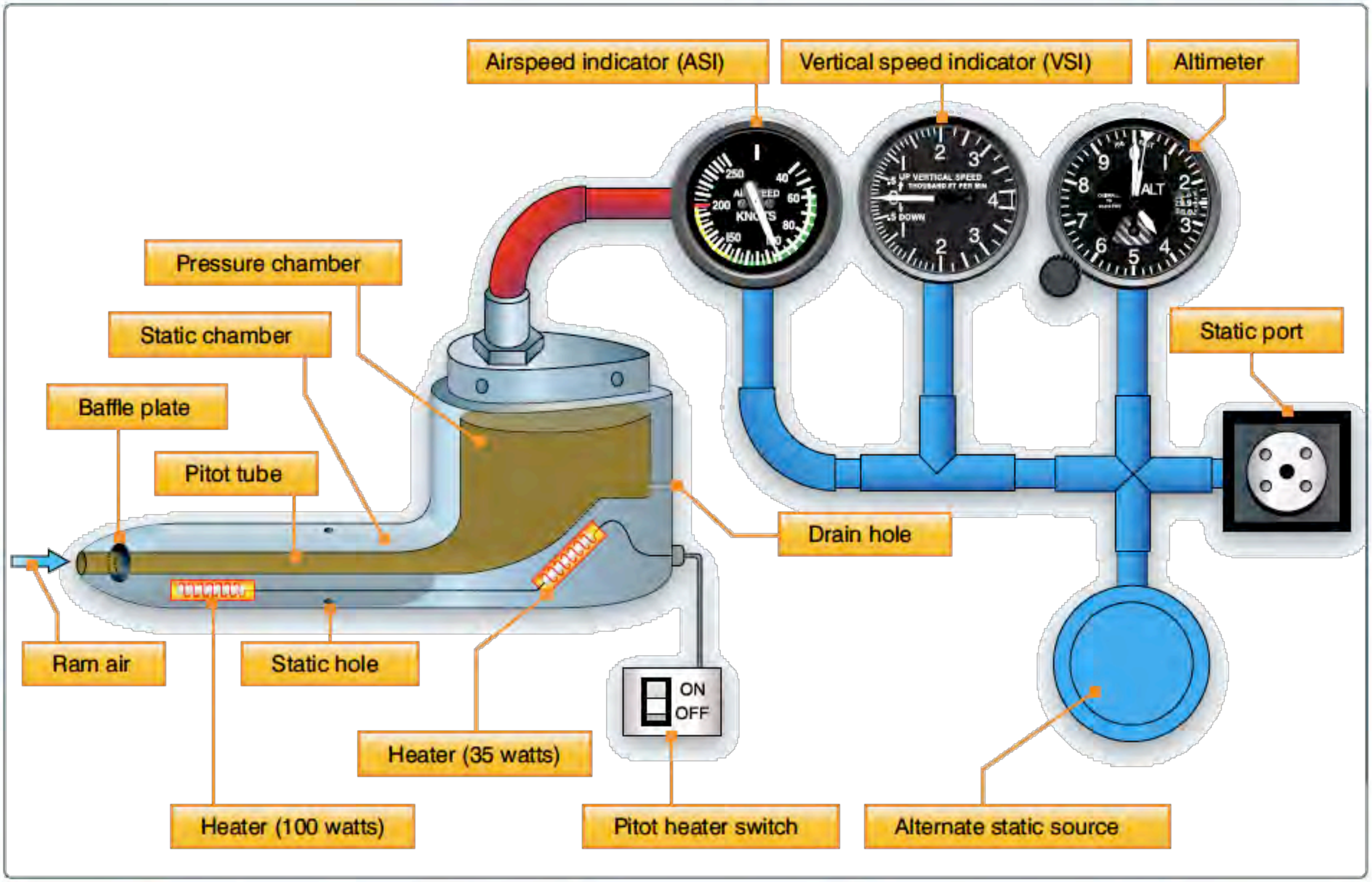
Pressure Instruments

- Fuel Flow
  - Gauge pressure and differential pressure used
- Engine Pressure Ratio (EPR)
  - Turbine power rating
  - Differential pressure
- Hydraulic Pressure
  - Gauge pressure
- Vacuum Pressure
  - Vacuum to run "steam gauges"
  - Differential pressure

Pressure Switch



Pitot-Static System



Pitot-Static System

- Video 1
- Video 2
- Video 3

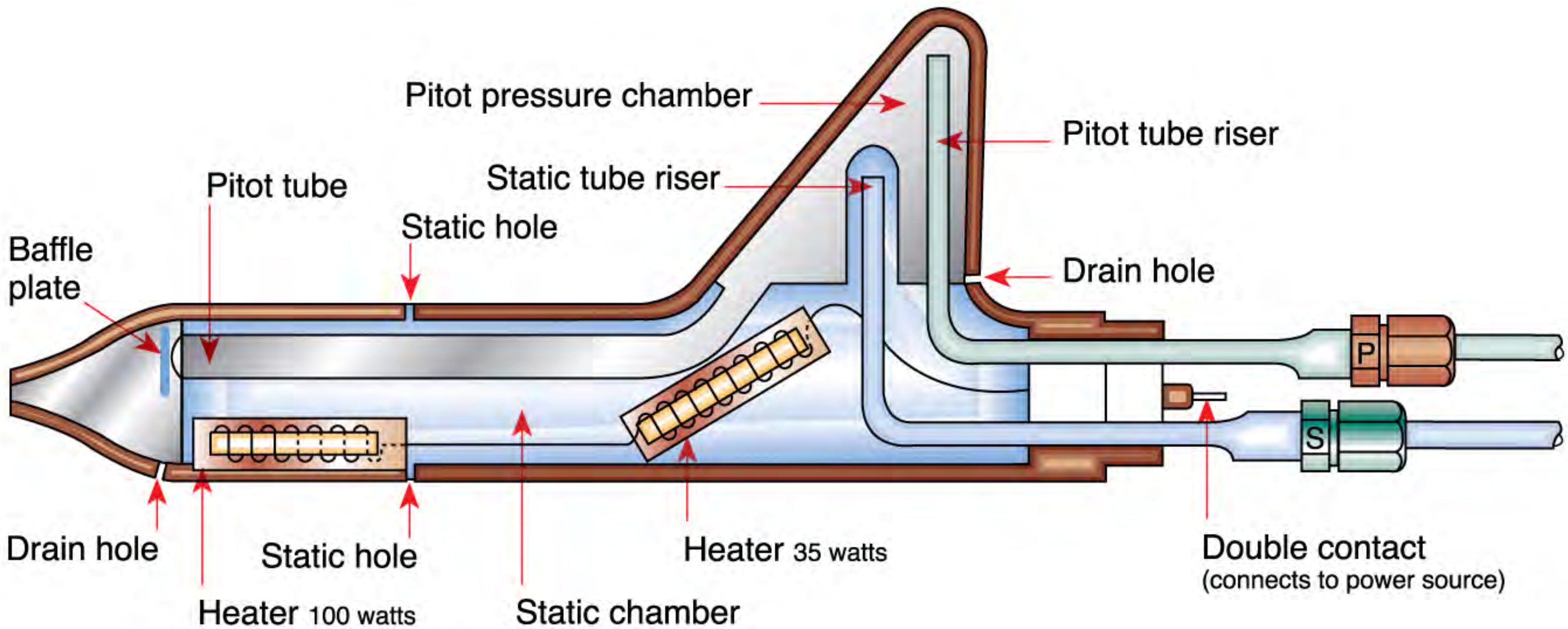
Pitot-Static System

- Pressures
  - Static pressure – the atmospheric pressure outside the aircraft
    - Comes from the static port
  - Ram pressure - pressure exerted on a body which is moving through a fluid medium
    - Comes from the pitot tube
  - The difference between ram and static pressure is used to calculate the relative airspeed

Pitot-Static System

- Airspeed indicator inputs
  - Ram pressure (pitot tube)
  - Static pressure
- Vertical speed indicator
  - Static pressure
- Altimeter
  - Static pressure

Pitot-Static Head

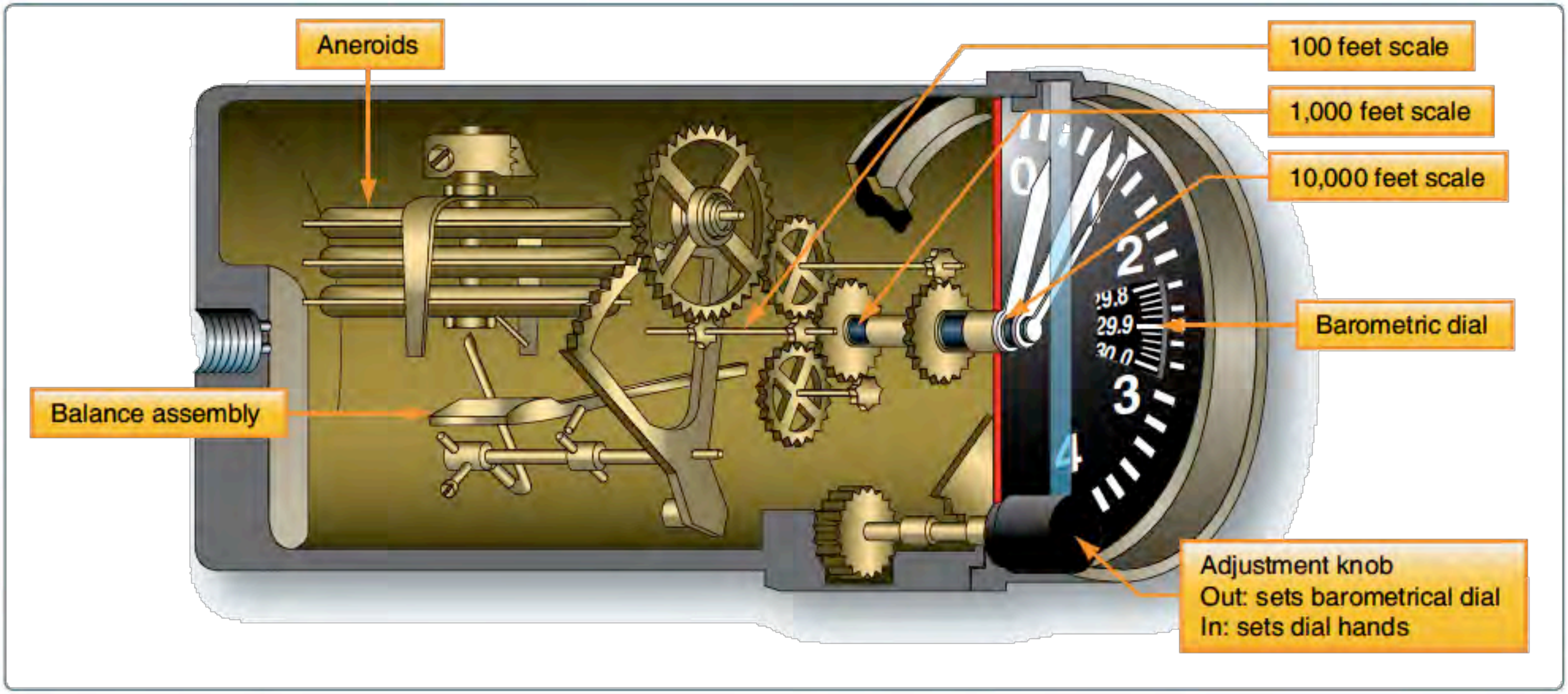


An electrically heated pitot-static head.

Pitot Tube

Static Port

Altimeters



Aneroids
100 feet scale
1,000 feet scale
10,000 feet scale
Barometric dial
Balance assembly
Adjustment knob
Out: sets barometrical dial
In: sets dial hands

Altimeters

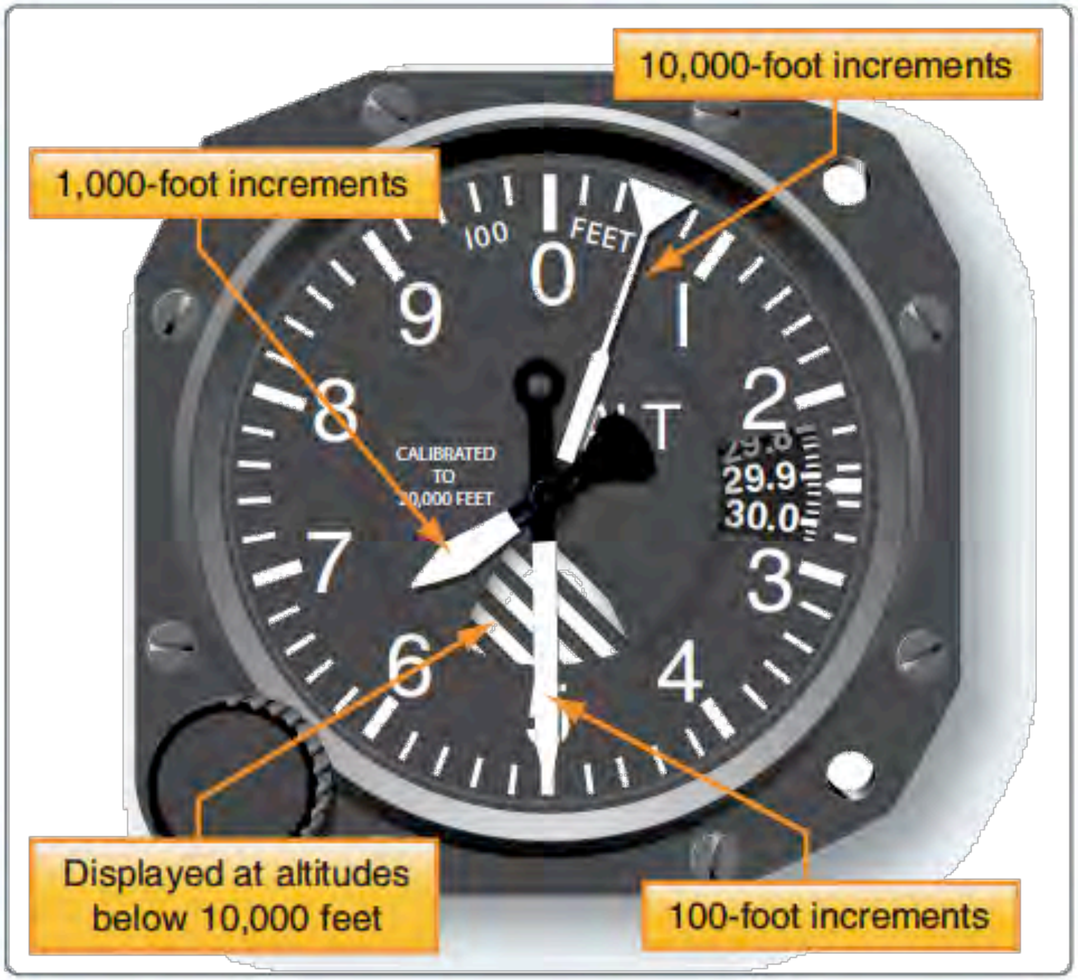


Figure 10-32. *A sensitive altimeter with three pointers and a cross-hatched area displayed during operation below 10,000 feet.*

Altimeters

- Measures the height above sea level
  - If the altimeter says 11,000 feet and you are flying over a 10,000 foot mountain, there is only 1,000 feet between you and the mountain
- Measures static pressure
- Pilot must adjust for atmospheric pressure
  - "Baro" metric adjustment knob is used to set barometric or Kollsman window readout
  - All aircraft flying over 18,000 feet use 29.92 inches of mercury
- May include altitude encoder for transponder

Altimeters

- Pitot-Static system usually has an alternate static source
- If static line becomes disconnected in a pressurized aircraft:
  - Instruments will read cabin pressure
  - Cabin pressure is at a lower altitude than the aircraft
  - Altimeter and airspeed indicator will read low
- When the altimeter is set to 29.92 inches of Hg, the altimeter is measuring "pressure altitude"

Radar Altimeters

- Bounces radio signals off the ground to measure the distance between the ground and aircraft
- Very accurate
- Display the distance above the ground
  - Not above sea level

Vertical Speed Indicators

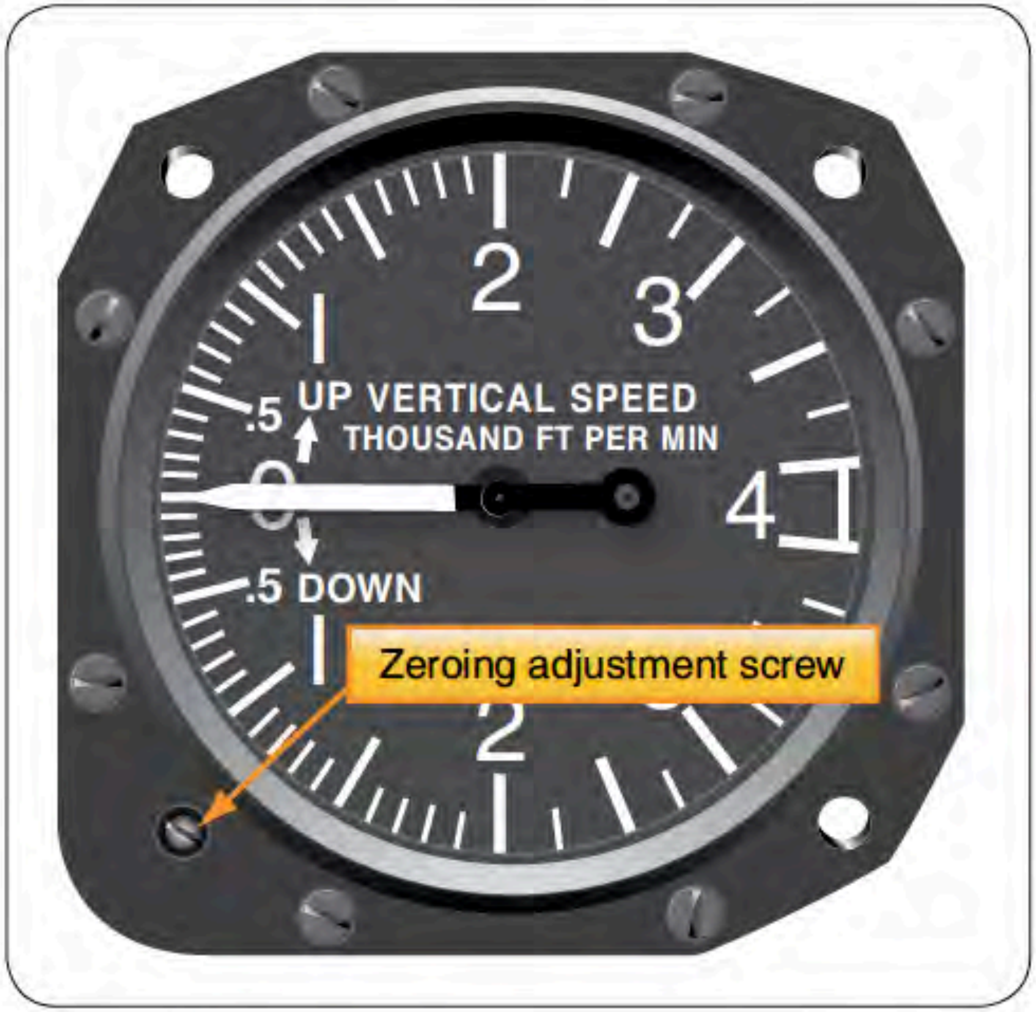
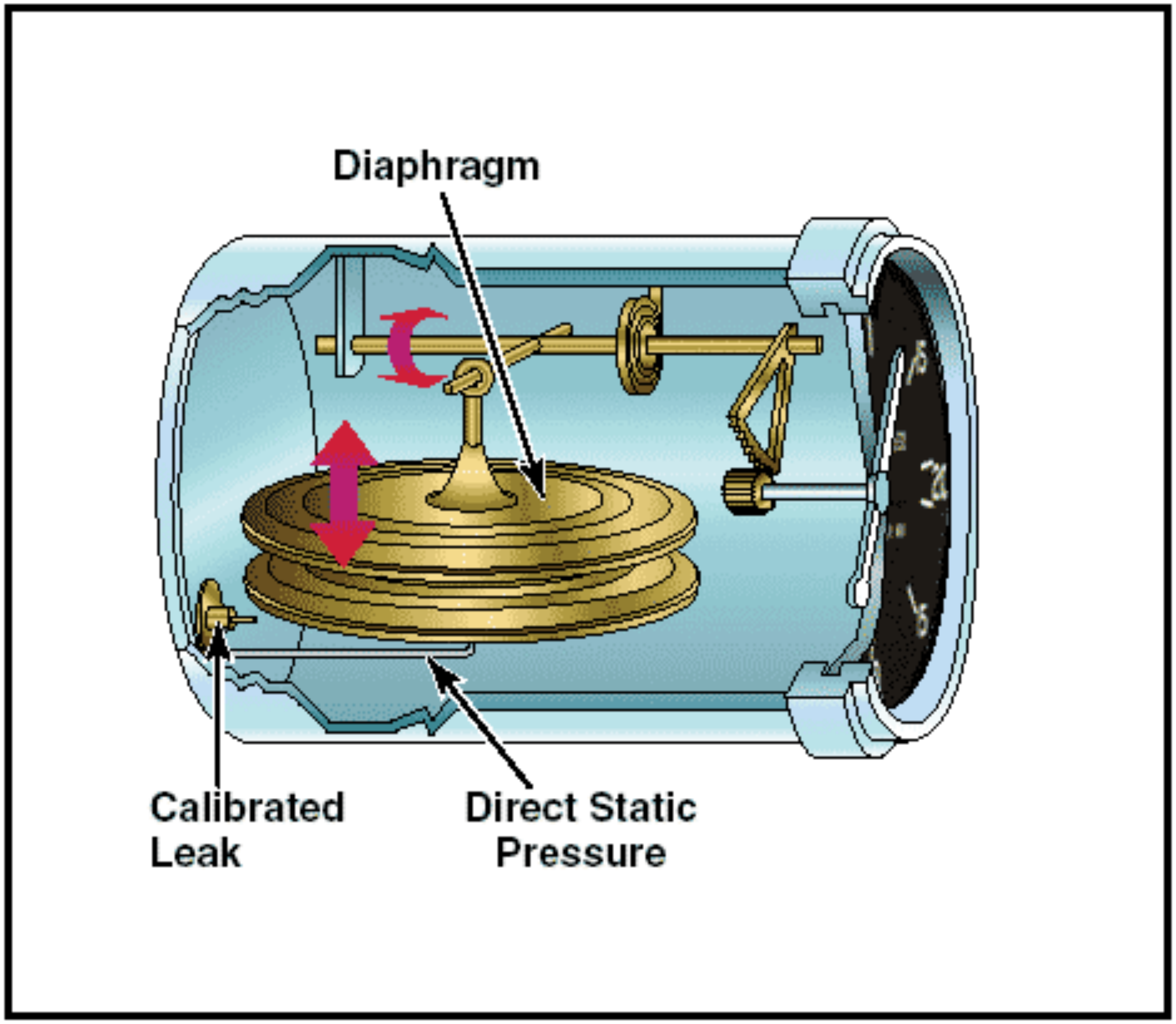


Figure 10-38. *A typical vertical speed indicator.*

Vertical Speed Indicators



Vertical Speed Indicators

- Also called a rate-of-climb indicator
- Measures the rate of change of the static air pressure
- Lags the actual change

Airspeed Indicators

Figure 10-43. *An analog true airspeed indicator. The pilot manually aligns the outside air temperature with the pressure altitude scale, resulting in an indication of true airspeed.*

Airspeed Indicator

- Measures the difference between pitot and static air pressure
- True airspeed indicator is temperature corrected
- Indicated speed (IAS) has errors because of the way the it is measured
  - The pilot must check the POH or flight computer to find the true air speed (TAS)
- High speed aircraft use Mach numbers

Pitot/Static Review

- Pitot pressure is always higher than static pressure when the aircraft is moving
  - Think ram air
- Airspeed is the difference between pitot and static pressures
  - The higher the difference, greater the speed.
- The static pressure drops as the altitude goes up.
  - The pressure at 30,000 ft is less than 8,000 ft
  - When the static tube broke, the pitot/static difference was less, so the airspeed dropped

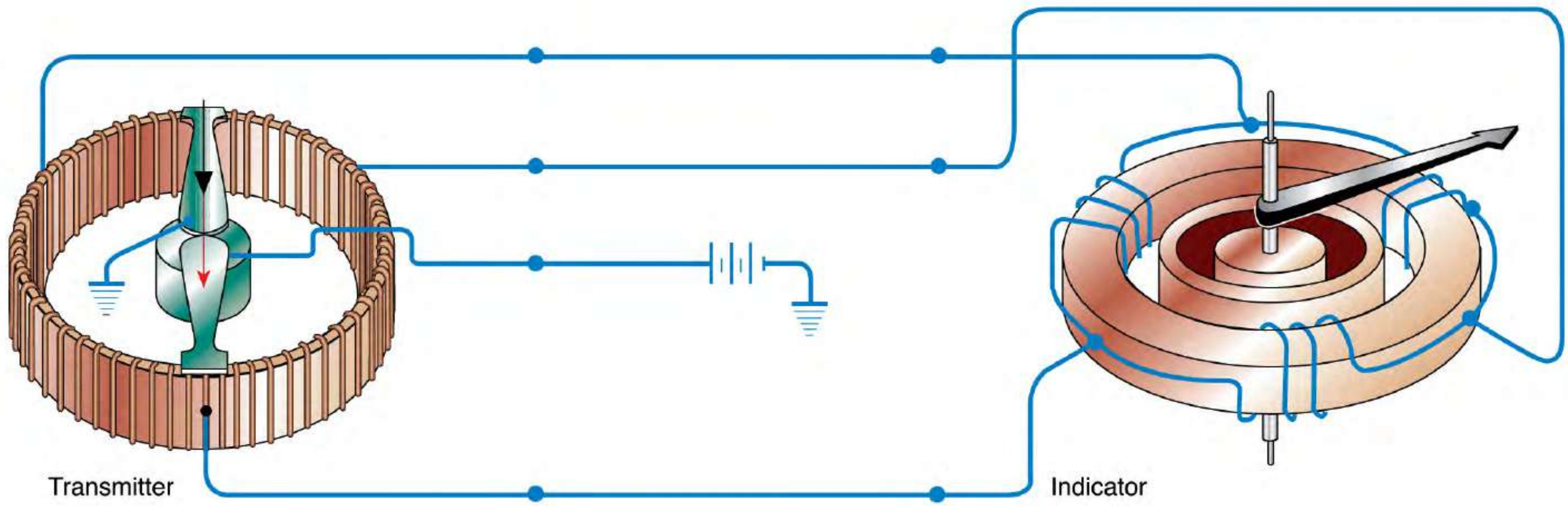
Synchro Systems

- Measures an items position – more detail than just Open/Close
  - Flap position
  - Trim position
  - Stabilizer position
  - Remote compass
- Three types
  - DC Selsyn
  - AC Magnesyn
  - AC Autosyn

DC Selsyn

- A variable resistor that varies the amount of current with position changes
- Indicator changes position with amount of current

DC Selsyn



AC Magnesyn

- Transmitter and indicator have permanent magnets
- AC current is apply to transmitter
- The transmitter magnet moves as the object moves
- Transmitter magnet changes current flow as position changes
- Indicator position reflects current change
- Transmitter and indicator are connected with wires

AC Magnesyn

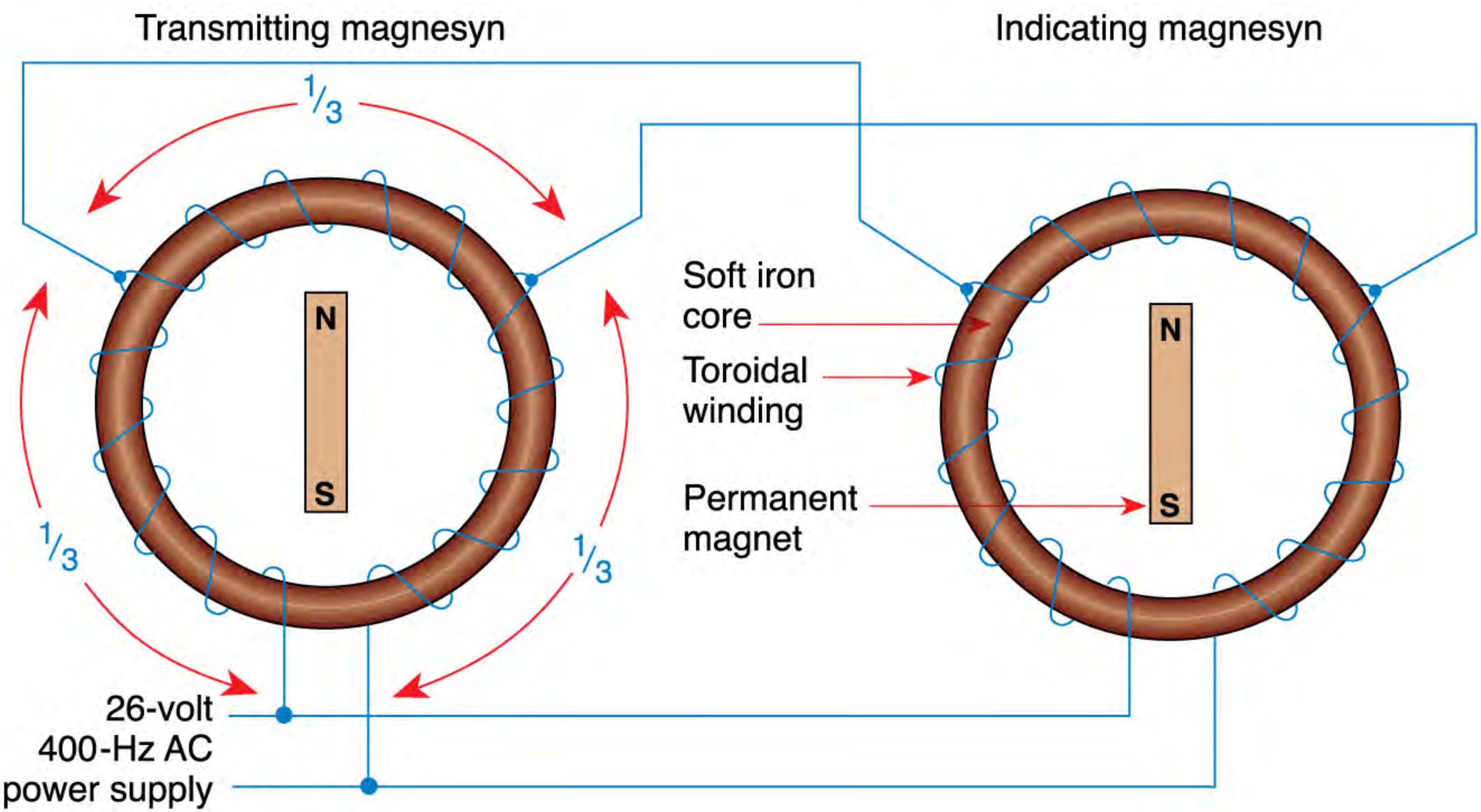


Figure 10-21. A simplified circuit of a Magnesyn remote position indicating system.

AC Autosyn

- Works like a AC magnesyn
- Main difference is the rotor
  - Uses a electromagnet in place of the permanent magnet in the AC magnesyn
- Uses a three phase connection

AC Autosync

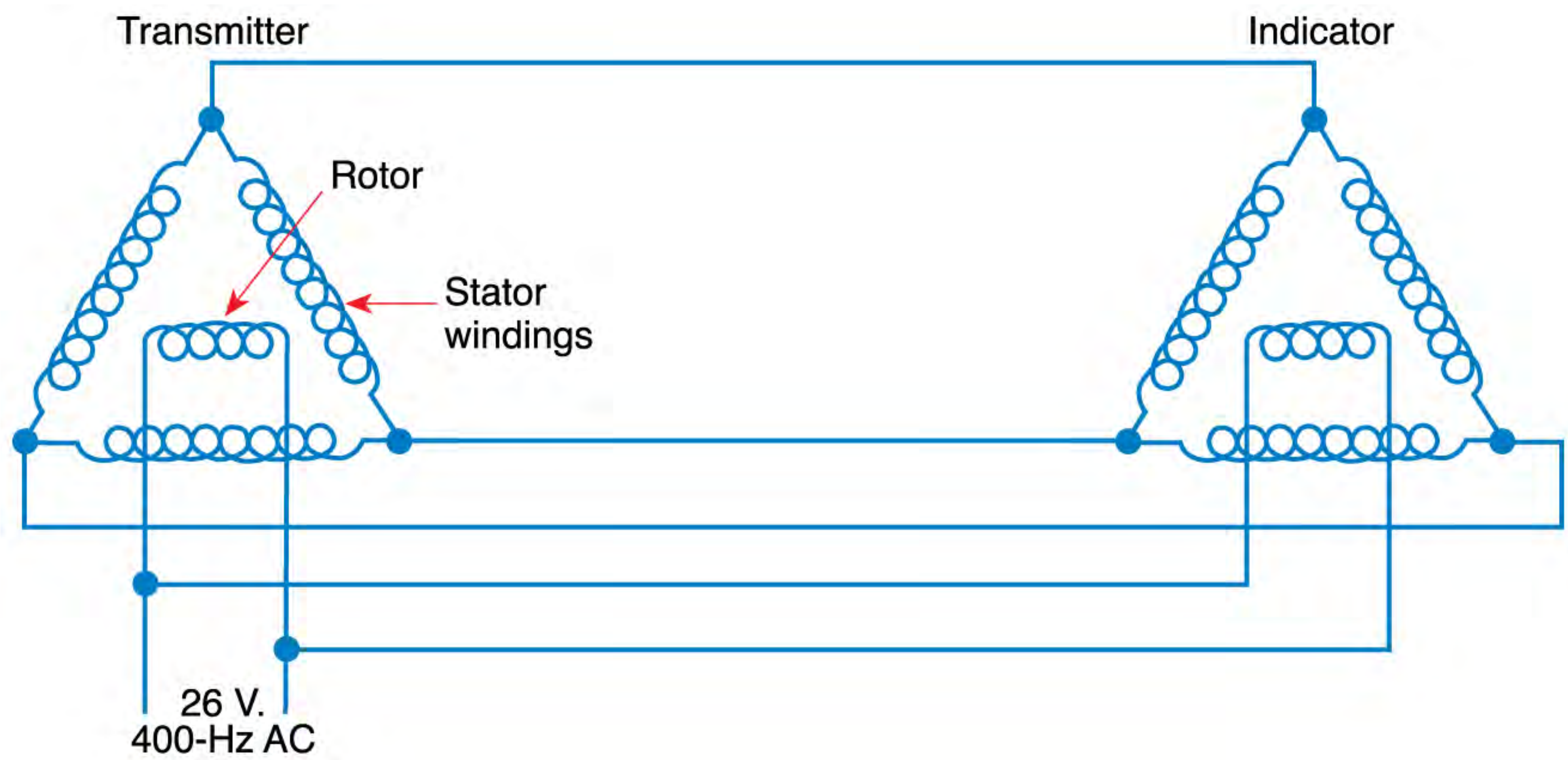
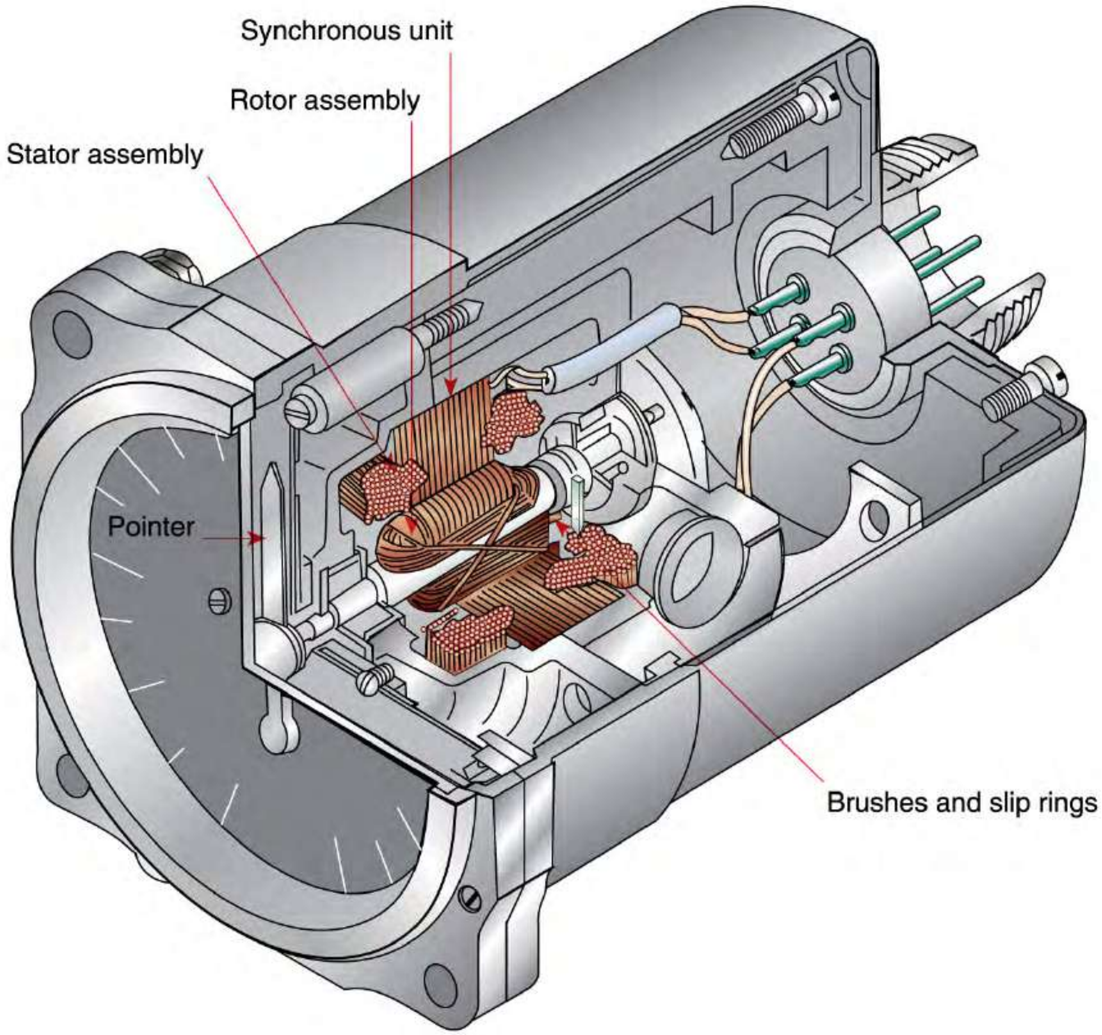


Figure 10-22. A simplified circuit of an Autosyn remote position indicating system.

AC Autosync


Synchronous unit
Rotor assembly
Stator assembly
Pointer
Brushes and slip rings

Tachometer

- Shows RPM
  - Reciprocating engine – Revolutions per minute
  - Turbine engine – compressor speed in percentage of rated RPM
  - Helicopter main rotor – Revolutions per minute
- Types:
  - Mechanical
  - Electrical

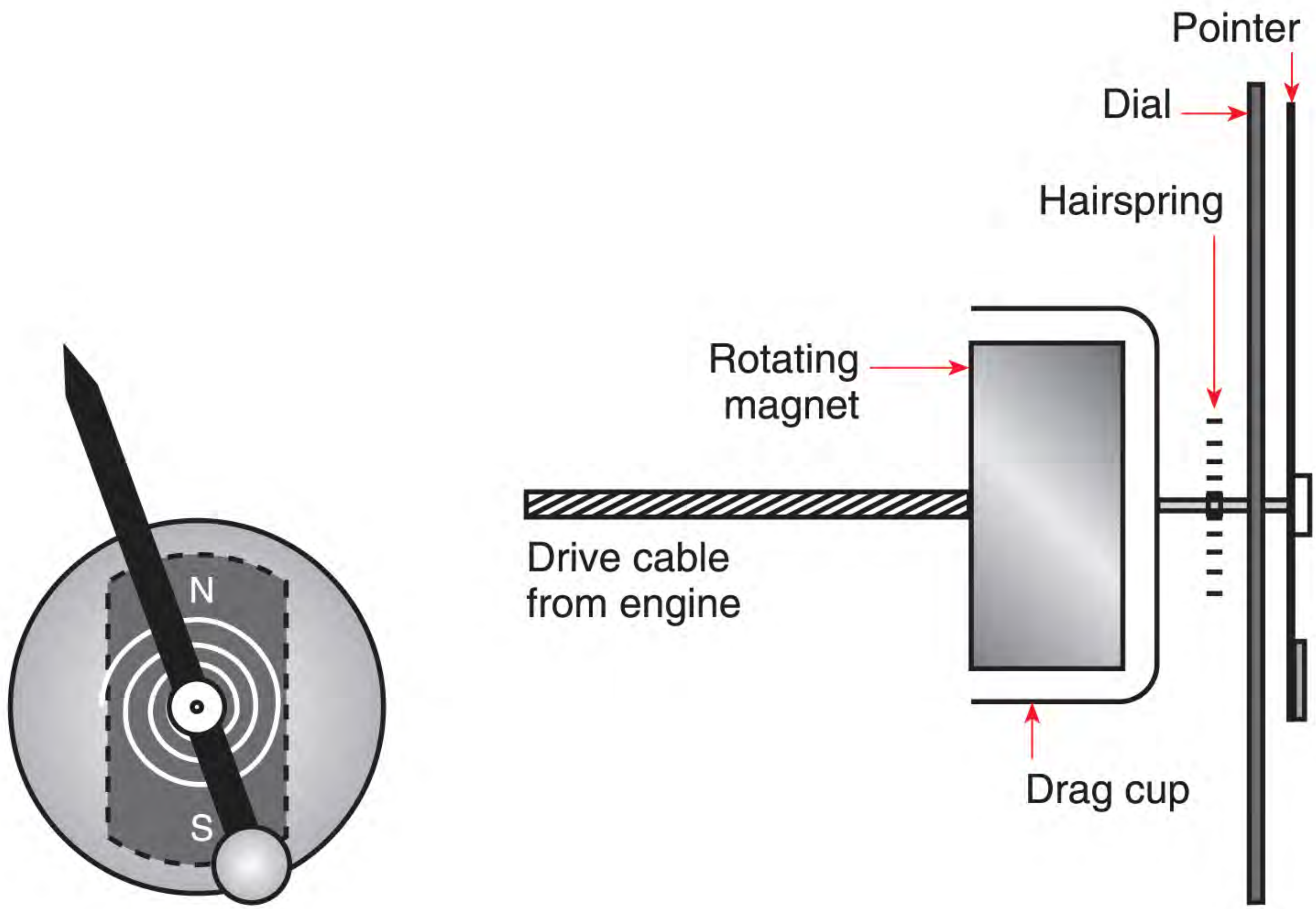
Mechanical Tachometer

- Cable runs from engine to indicator
- Cable rotates indicator magnet at engine speed or half speed
- The faster the rotation, the more eddy current generated
- The eddy current causes an aluminum drag cup to want to turn
- The drag cup is held into place by a hairspring
- The more eddy current, the more the drag cup moves

Mechanical Tachometer

- Indicator pointer is connected to the drag cup
- An hour meter may be included in the tachometer
  - Calibrated to the cruise RPM
  - When replacing the tachometer, match the cruise RPM & RPM markings
- Internal magnet can deteriorate
  - Check accuracy over time

Mechanical Tachometer



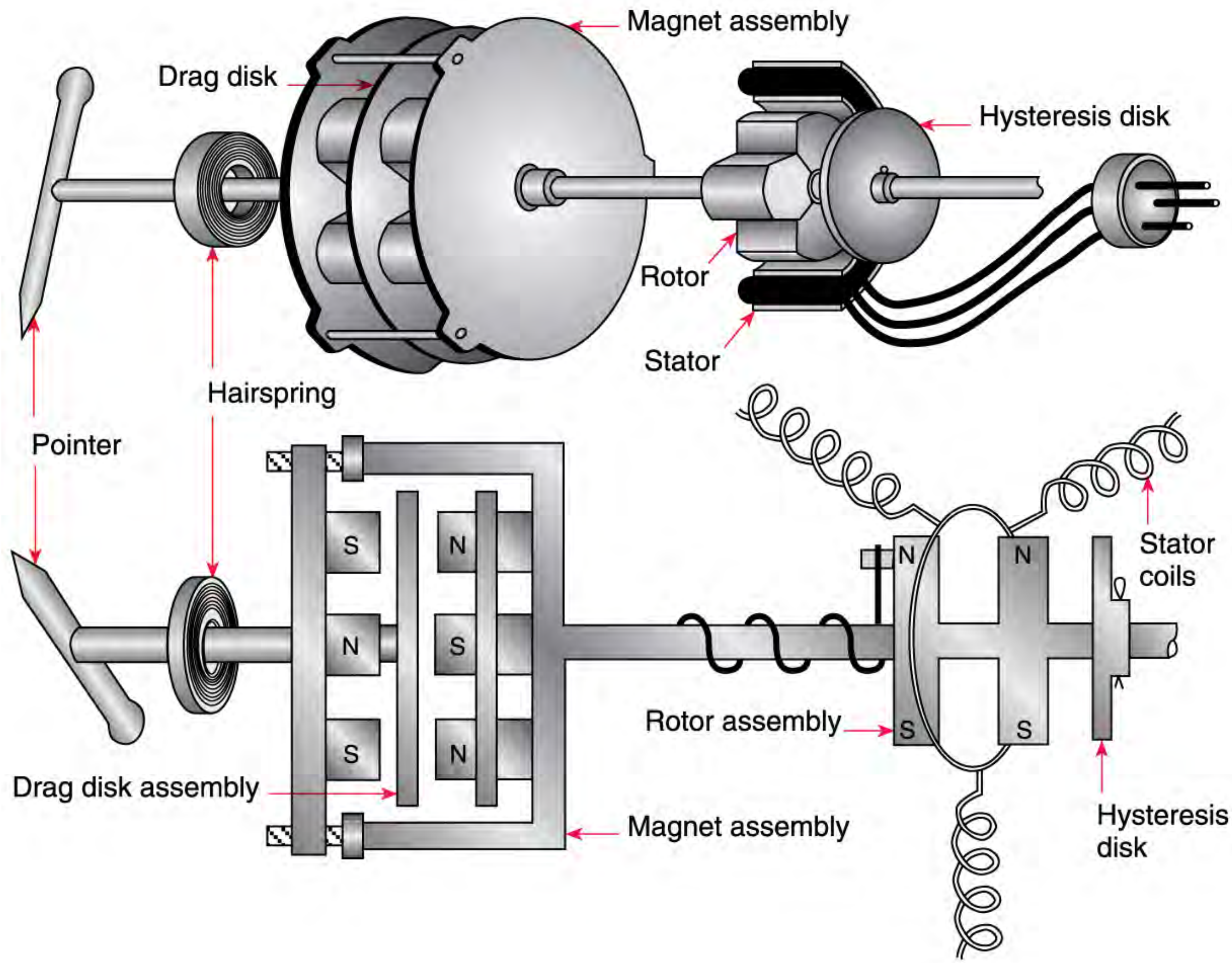
A simplified diagram of a mechanically operated magnetic drag tachometer.

Mechanical Tachometer

Electric Tachometer

- Types:
  - Generator
    - Faster RPM, more voltage or current
    - Internal magnet deteriorates with time
  - Synchronous motor
    - Three phase AC system that measures frequency not voltage
    - Very accurate
  - Pulse detection
    - Usually measures the time between pulses (pulse width)
    - May use magneto P lead

Electric Tachometer



Simplified diagram of a three-phase AC tachometer.

Synchroscope

- Special type of tachometer
- Measures the difference in RPM between multiple engines/props
- Helps pilot synchronize prop RPMs
  - Reduces noise and vibrations
- Indicator can be a disk with light and dark markings
  - When the disk stops rotating, the props are synchronized
  - The faster the disk moves, the more out of sync the props are

Synchroscope

Figure 10-59. *This synchroscope indicates the relative speed of the slave engine to the master.*

Angle of Attack (AOA) Indicator

- Measures angle of attack by measuring airflow around the fuselage
  - ❖ Pressure difference between different points on the fuselage
    - Differential pressure at a point where the airstream flows in a direction not parallel to the true angle of attack of the aircraft
  - ❖ Alternative is moveable paddles
- Pilot can tell when the aircraft will stall at any speed

Angle of Attack (AOA) Indicator

- Stall Warning
  - Simple form of AOA – only warns of an impending stall
  - Usually an audio alert
    - Mechanical reed-type
    - Electrical stall warning switch
- AOA indicators are common on military and large aircraft
- FAA has special case for AOA
  - Their installation is considered a minor alteration

Reed –Type Stall Warning

Stall Warning Switch

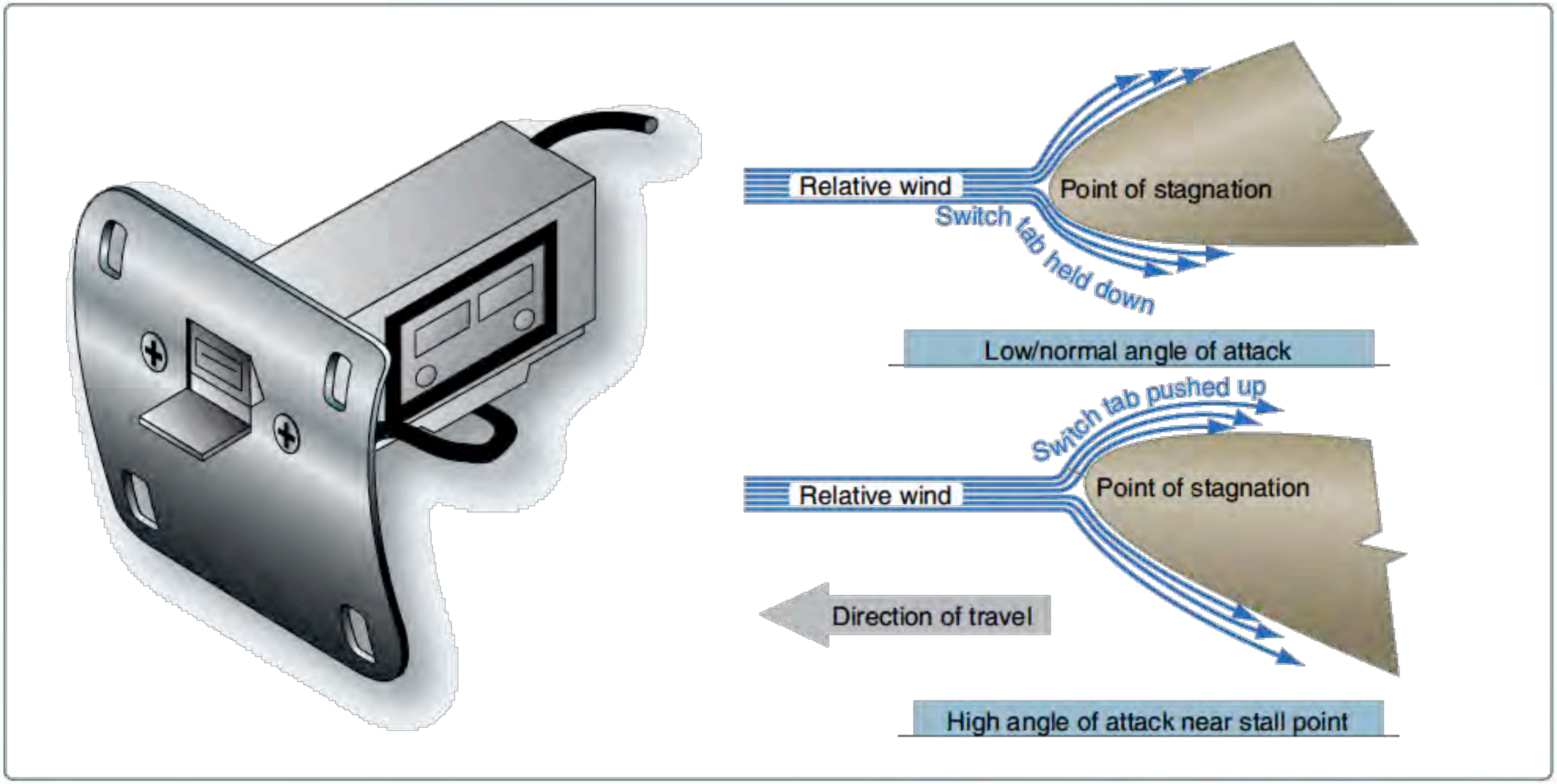


Figure 10-62. *A popular stall warning switch located in the wing leading edge.*

Angle of Attack (AOA) Indicator

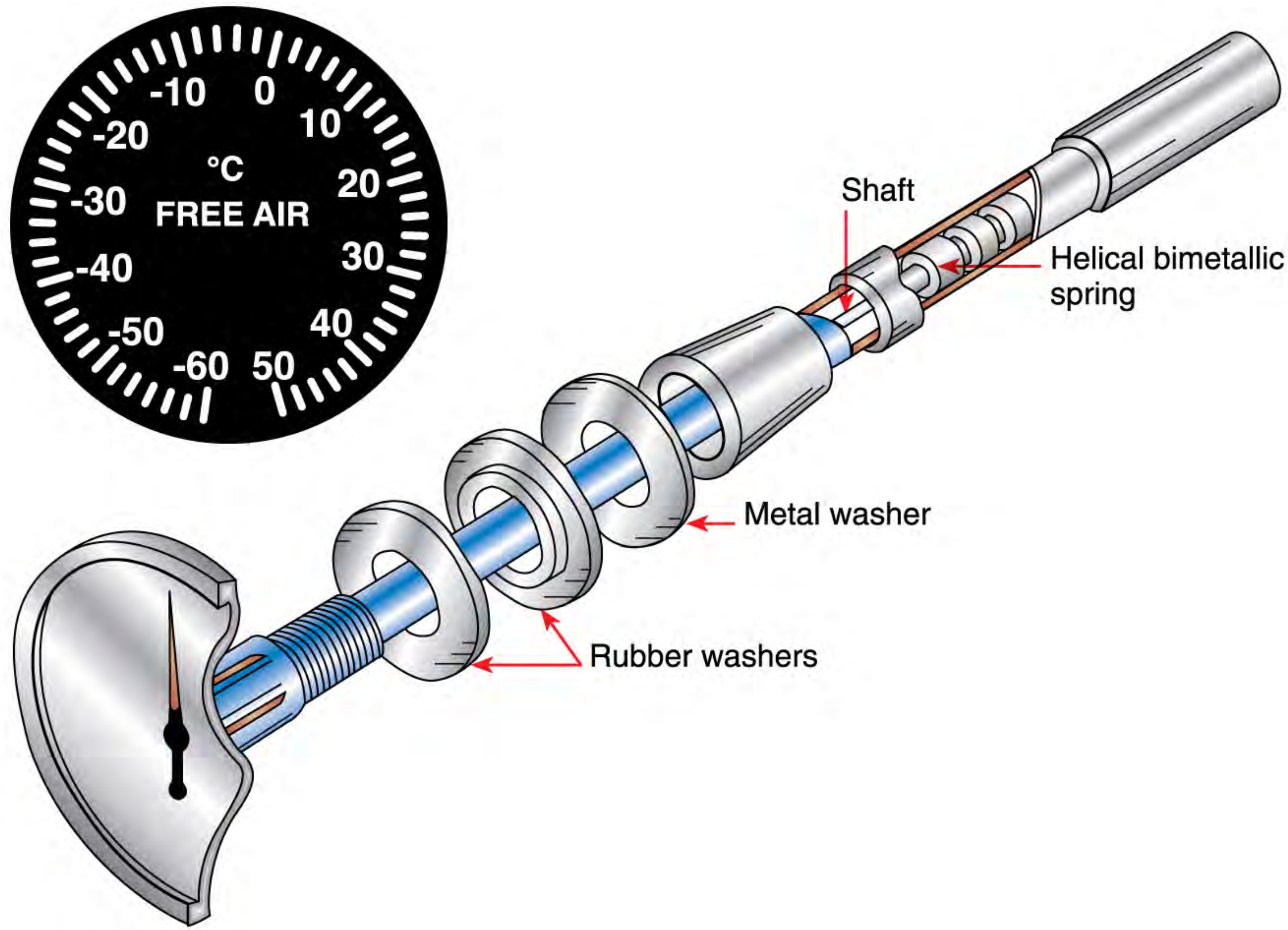
Temperature Measuring

- Three types
  - Nonelectric
  - Resistance-change
  - Thermocouple

Nonelectric

- Two different metal type instruments
  - Bimetallic thermometer
  - The metals expand at different rates
  - Expansion causes indicator needle to move
- Liquid filled thermometers
- Bourdon tube based
  - Filled with a volatile liquid

Nonelectric

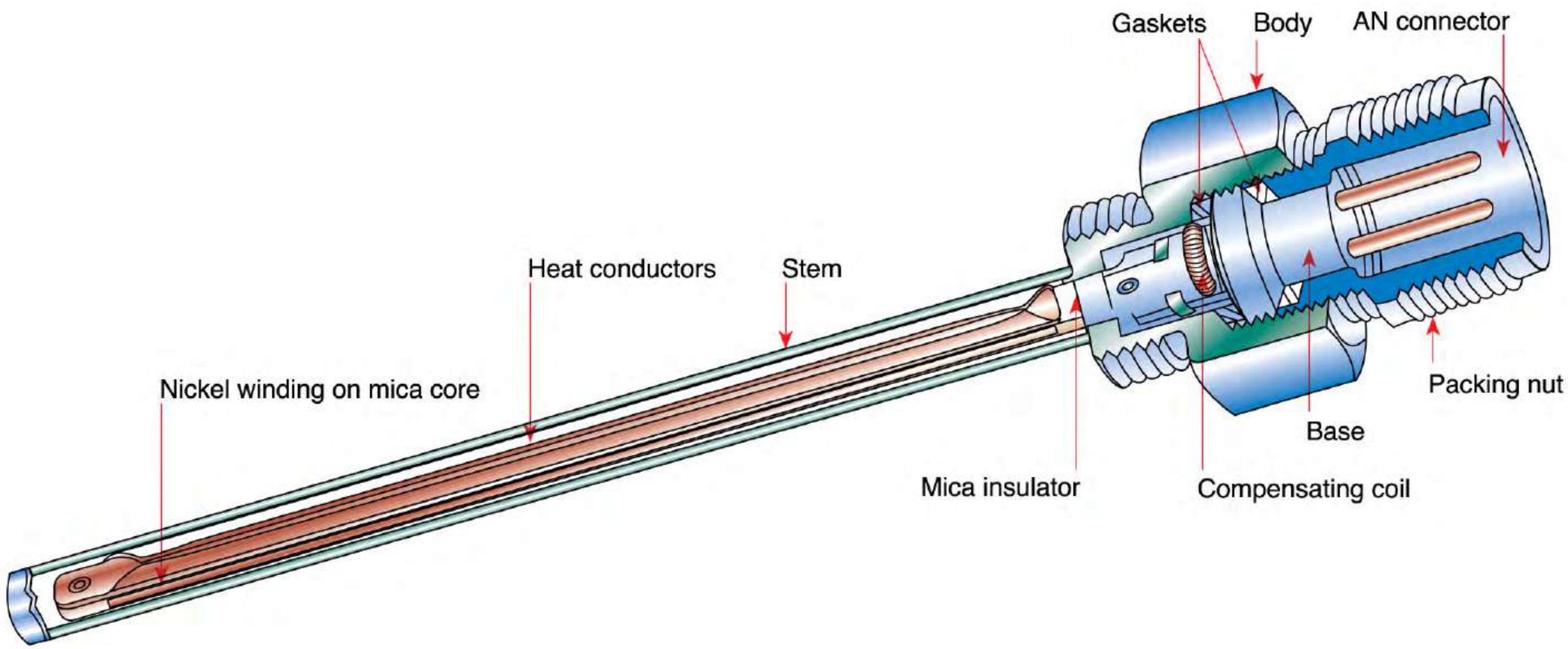


This simple outside air temperature gage measures temperature as a bimetallic strip, to which the pointer is attached, warps as its temperature changes.

Resistance Change Instruments

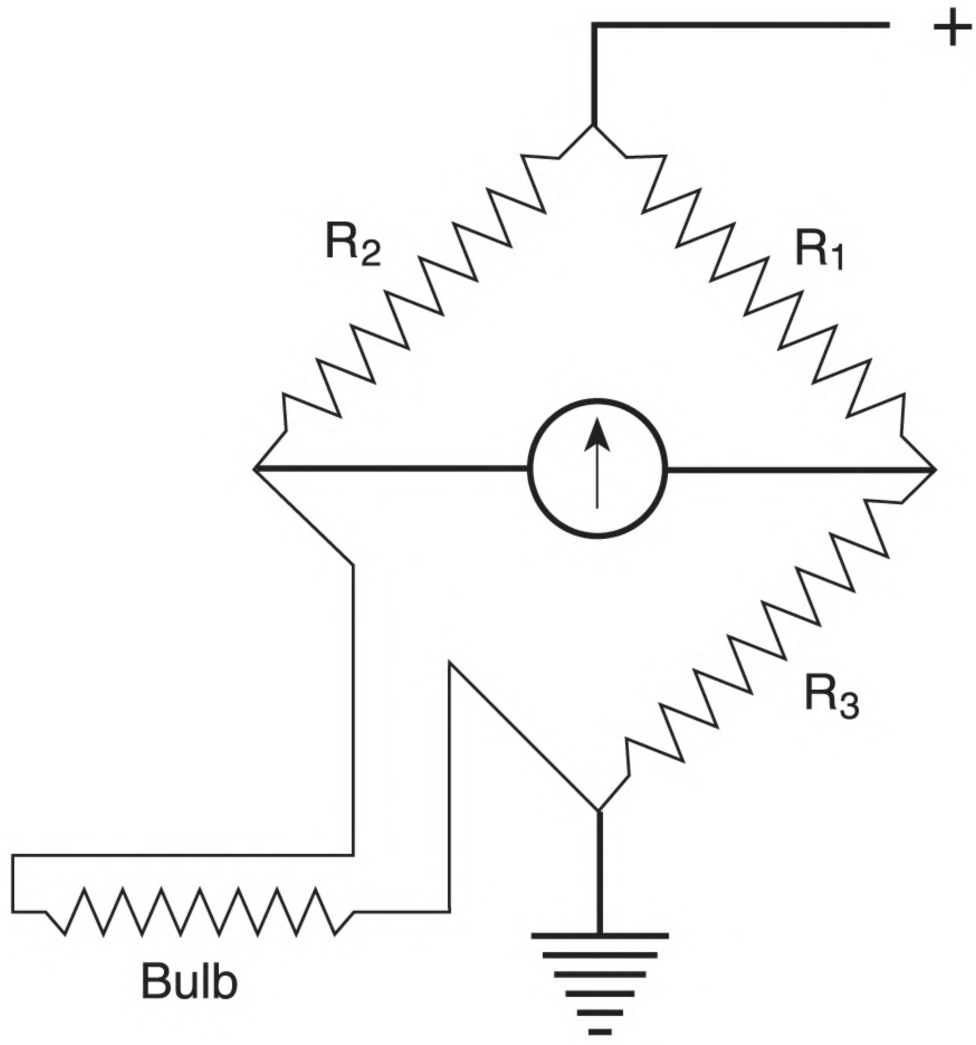
- Sensor changes resistance with temperature changes
- Requires external power
- Usual used for low temperature applications
  - ❖ Air temperature, Carburetor air, Coolant (engine) & Oil temperature
- Measuring Circuits
  - ❖ Wheatstone Bridge
  - ❖ Ratiometer
    - Moving coil
    - Move magnet

Resistance Change Instruments



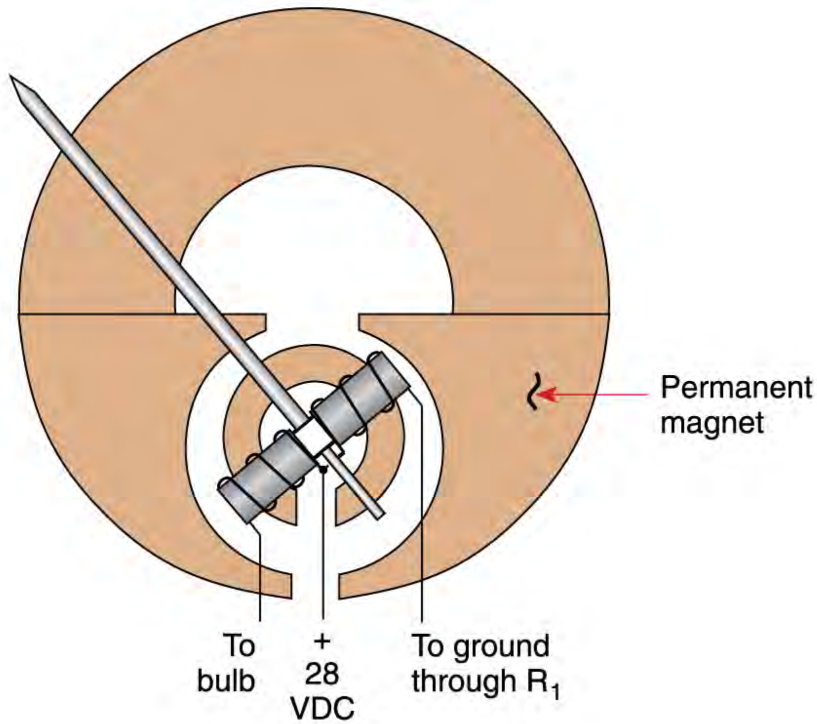
A resistance bulb contains a length of nickel wire whose resistance changes linearly with changes in its temperature.

Wheatstone Brige

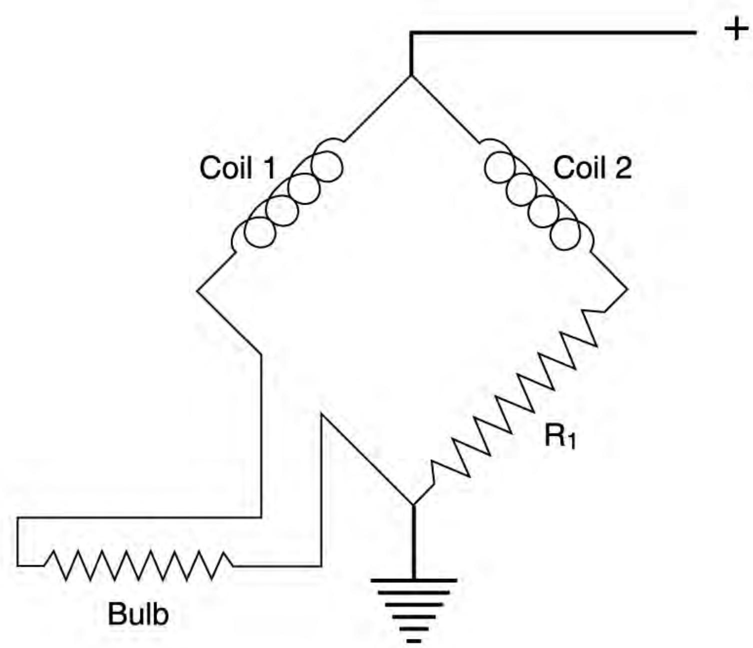


A Wheatstone bridge circuit used to measure temperature.

Moving-Coil Ratiometer.



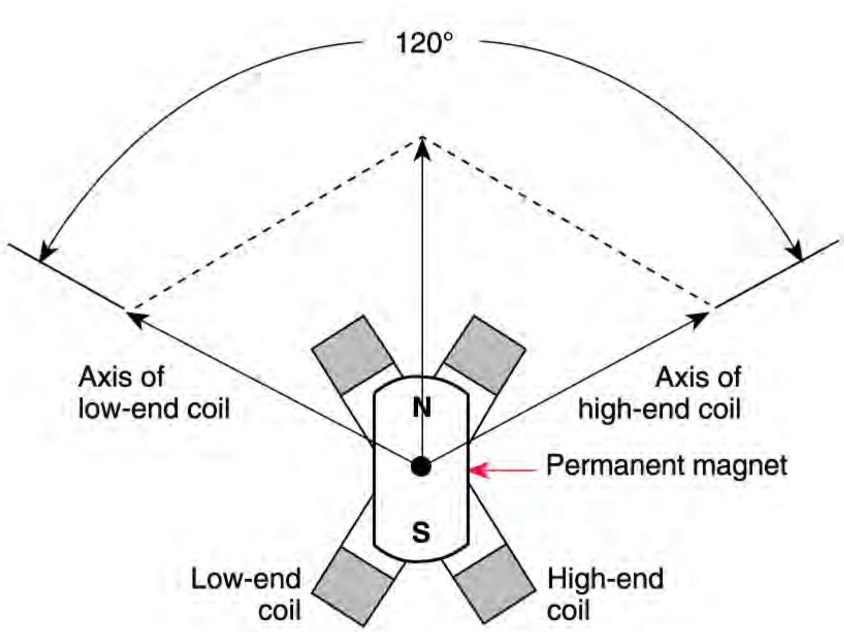
A Indicator has two coils mounted on its needle. These coils rotate over C-shaped core inside the strong magnetic field of the permanent magnet.



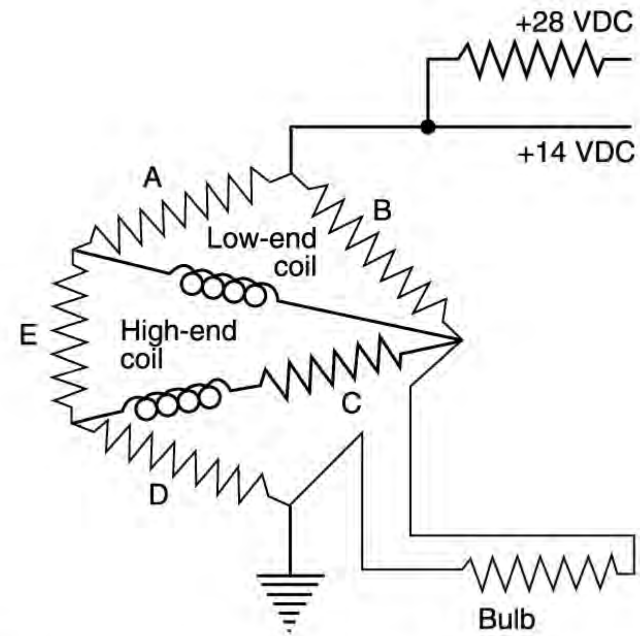
B Basic electrical circuit of the moving-coil ratiometer

Moving-coil ratiometer.

Moving-Magnet Ratiometer



A Indicator has two fixed coils whose magnetic fields determine position of a small permanent magnet to which indicator needle is attached.



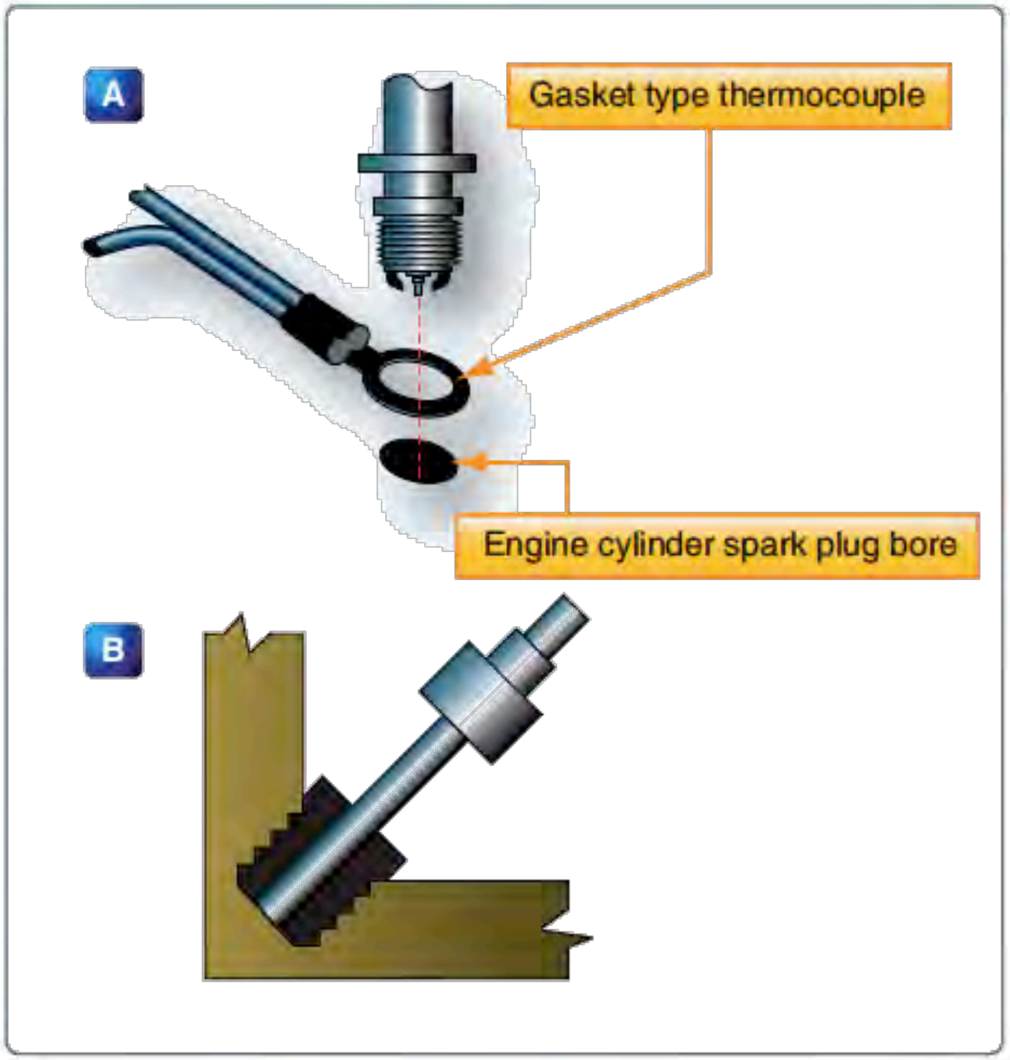
B Basic electrical circuit of a moving-magnet ratiometer

A moving-magnet ratiometer.

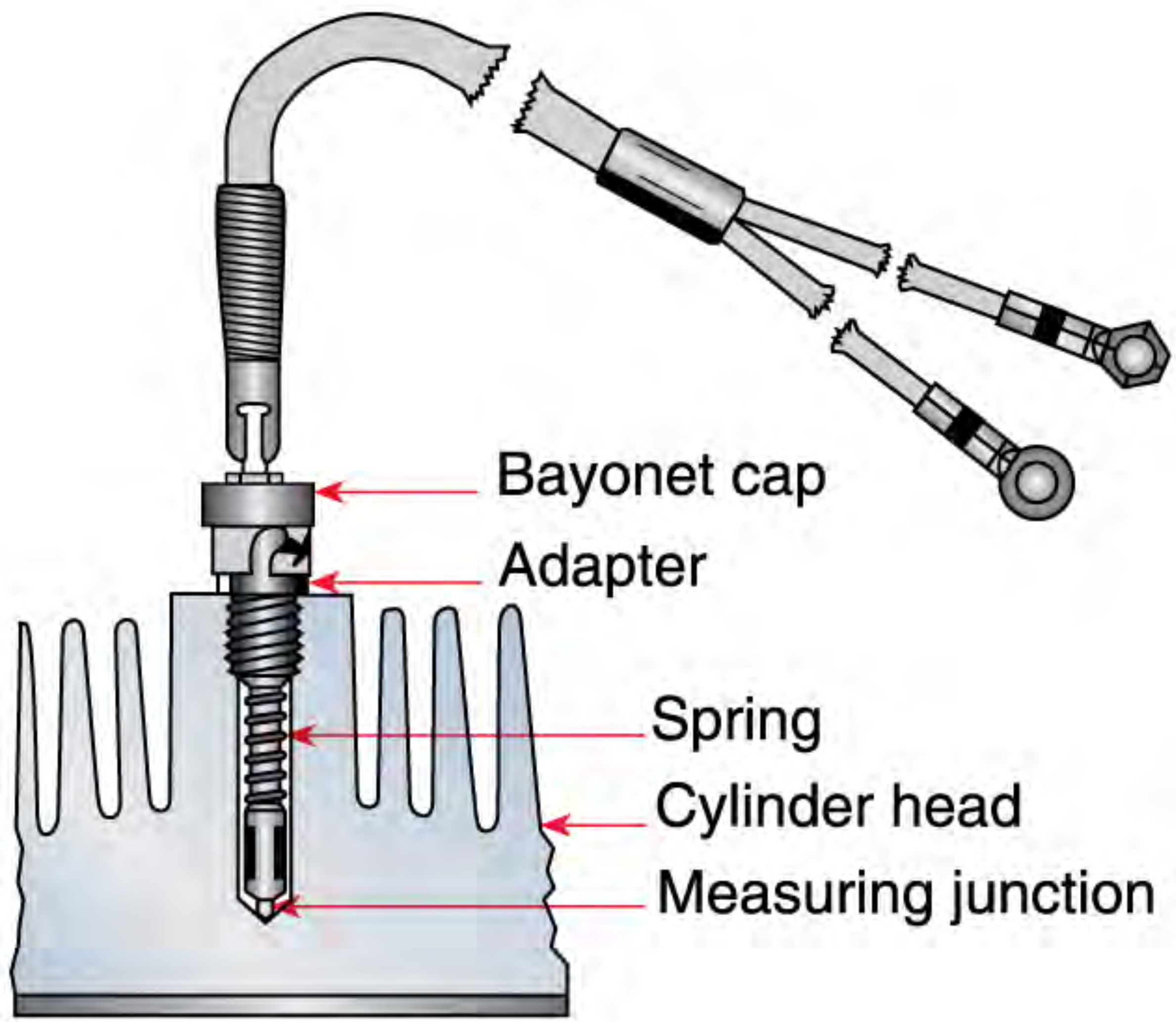
Thermocouple Instruments

- Thermocouple – sensing unit
  - Made from two different metals
    - Chromel/alumel used for high temperature applications like turbine engines
- Temperature change generates current
- No external power needed
- Don't modify leads or lead length
- Leads are polarized and can't be switched
- Lead may have built in resistance
  - Don't change

Cylinder Head Thermocouple



Cylinder Head Thermocouple

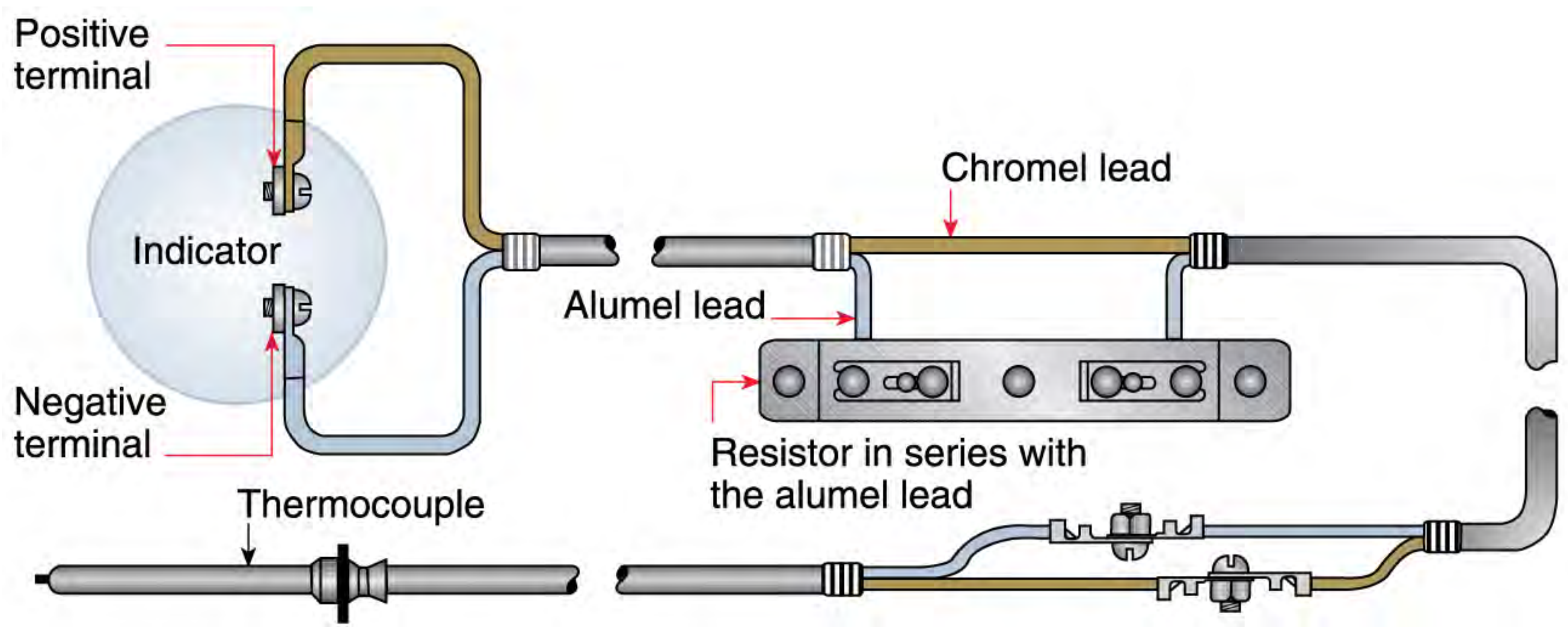


Spark Plug Thermocouple

Cylinder Head Thermocouple

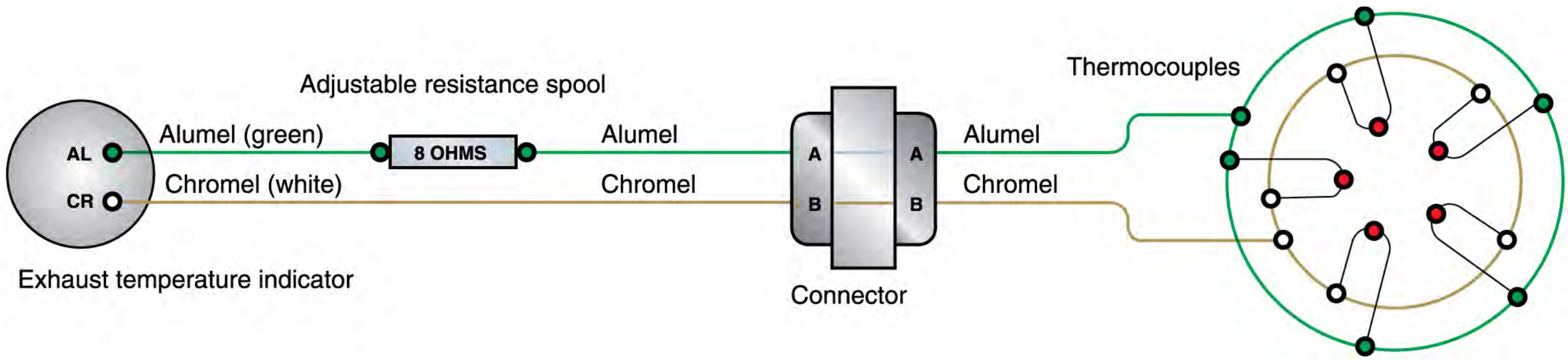
Exhaust Gas Temperature Thermocouple

Exhaust Gas Thermocouple



A typical exhaust gas temperature indication system for installation on a reciprocating engine.

Turbine EGT Thermocouple



A typical EGT system for a turbine engine.

Direction-Indicating Instruments

- All certificated aircraft are required to have some type of magnetic direction indicator
- Compass is the most common
- Cardinal Compass Points - the four principal directions on a compass: North, East, South, and West
- Lubber line – a reference on a magnetic compass and directional gyro that shows the direction the aircraft nose is pointing
  - If there is a crosswind, the flight path will be different than the compass heading

Compass

The deviation compensating screws on a magnetic compass.

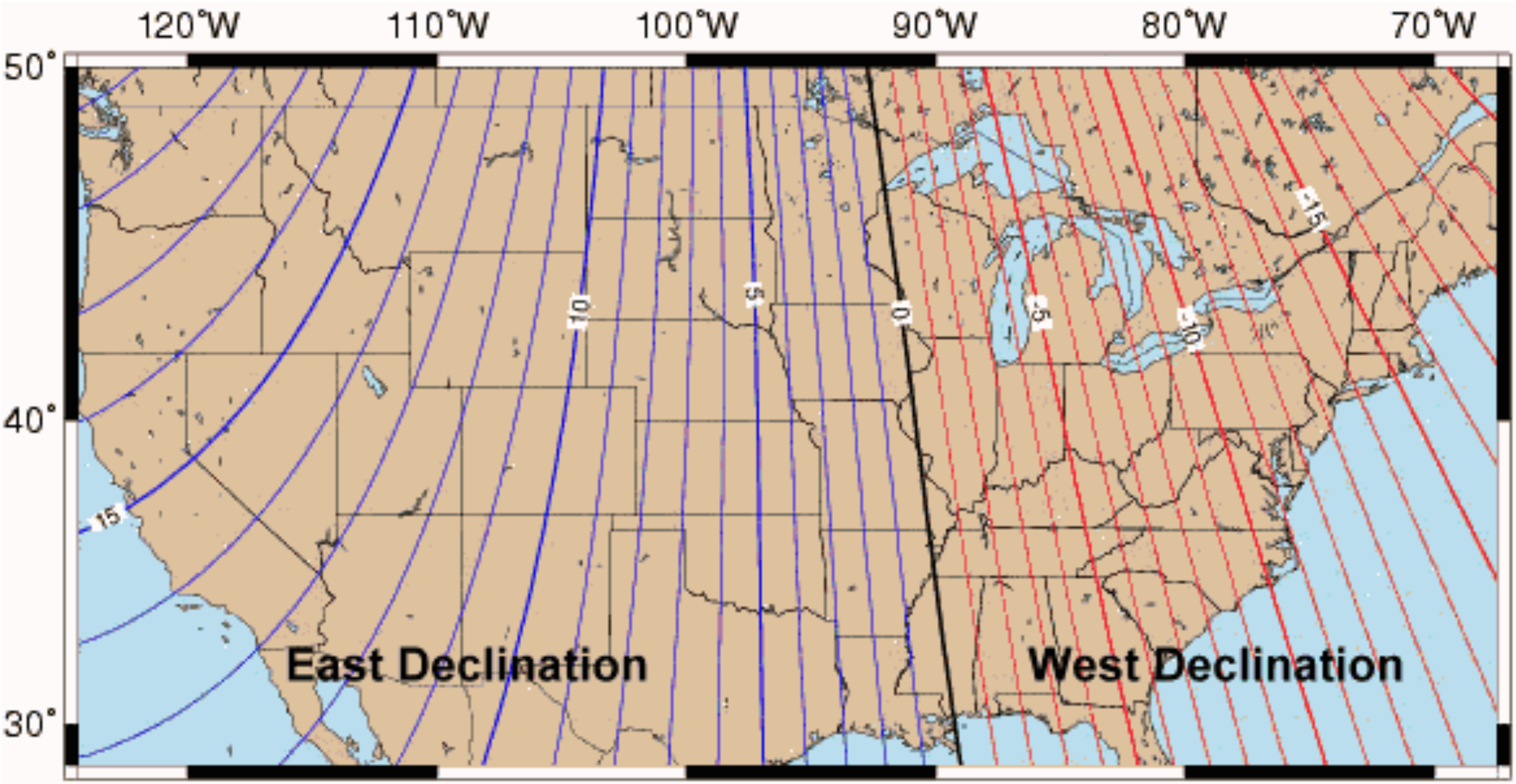
Compass

- Filled with fluid to damp the compass card (float) oscillations
- Diaphragm or bellows are used to compensate for changes in volume of the fluid as its temperature changes.

Compass Errors

- Basic errors
  - Variation
  - Deviation
  - Dip errors
- Variation - magnetic compass error caused by the fact that the earth's magnetic and true north are not at the same location
  - Maps show true north
  - West is Best, East is least
    - Add W declinations when going true to magnetic, and subtract E ones

Compass Variation



Compass Deviation

- Deviation error - an error in a magnetic compass caused by localized magnetic fields in the aircraft
  - Iron and steel can cause problems
  - Electric equipment can cause problems
- Compasses come with adjustments for deviation
- Deviation error can't be greater than 10°
- Compass must be "swung" when equipment is added that could effect compass deviation

Compass Deviation

- Deviation correction must be done with non-magnetic screw driver
  - Usually brass or bronze
- See AC 43.13-1B Section 12-37 – Compass Swing for correct procedure
- A compass correction card must be created to record errors
- If errors are affected by electrical equipment, two correction cards are needed. One with all the equipment on and one with the equipment off.

Compass Correction Card

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

A compass correction card.

Compass Dip Error

- When an aircraft turns, the compass dips and tries to align with the earth's magnetic field
- Changes in aircraft speed can also cause the compass to dip
- The dips causes an compass error

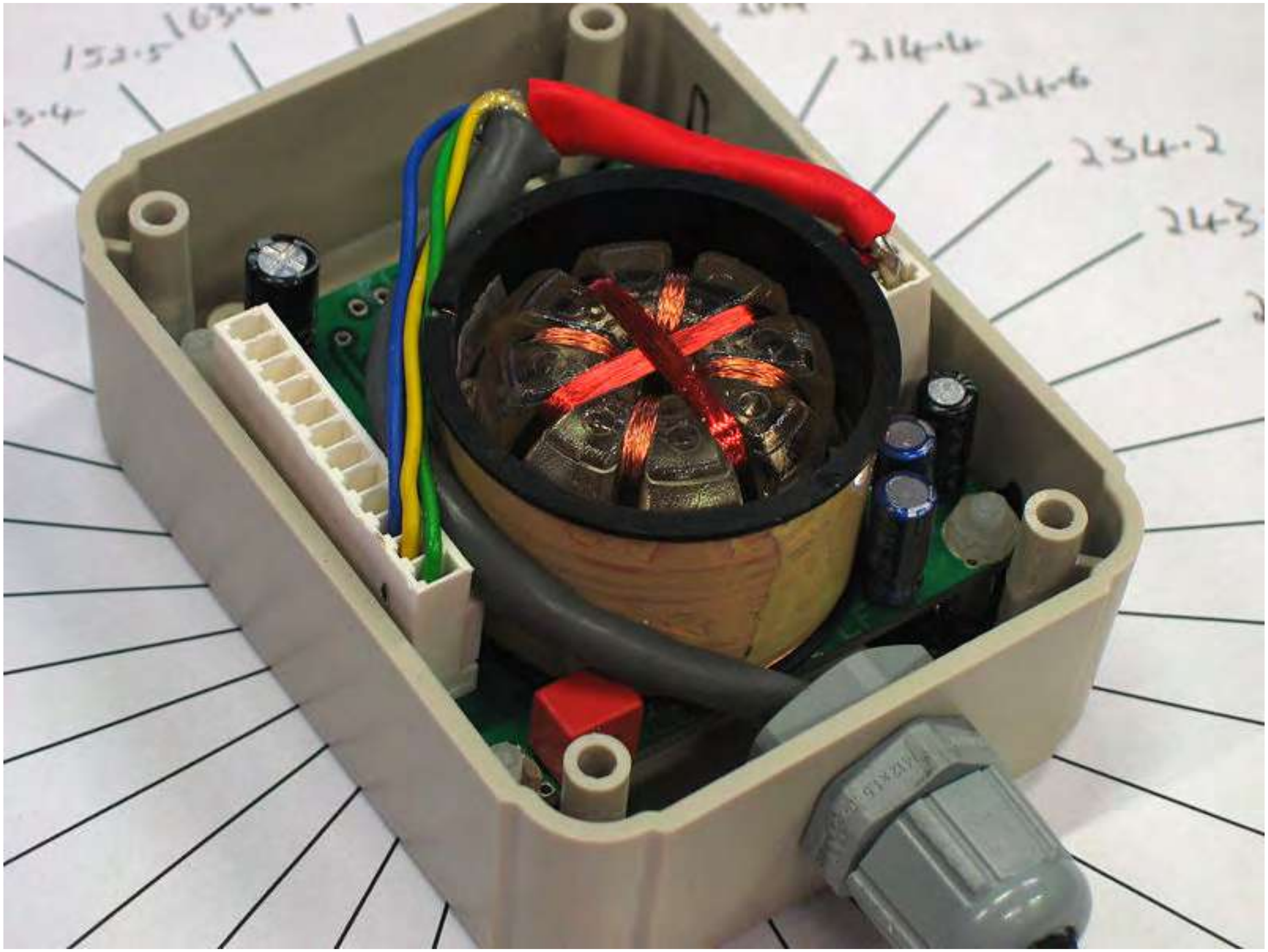
Vertical- Card Compass

A vertical-card magnetic compass minimizes the error of turning in the wrong direction to reach a desired heading.

Fluxgates

- Fluxgate - electromagnetic device that directly sense the direction of the horizontal component of the earth's magnetic field
- Used by remote compass indicators and EFIS (Electronic Flight Instrument System)
- Must be located in an area with minimal magnetic deviation

Fluxgates



Gyro Instrument Power Systems

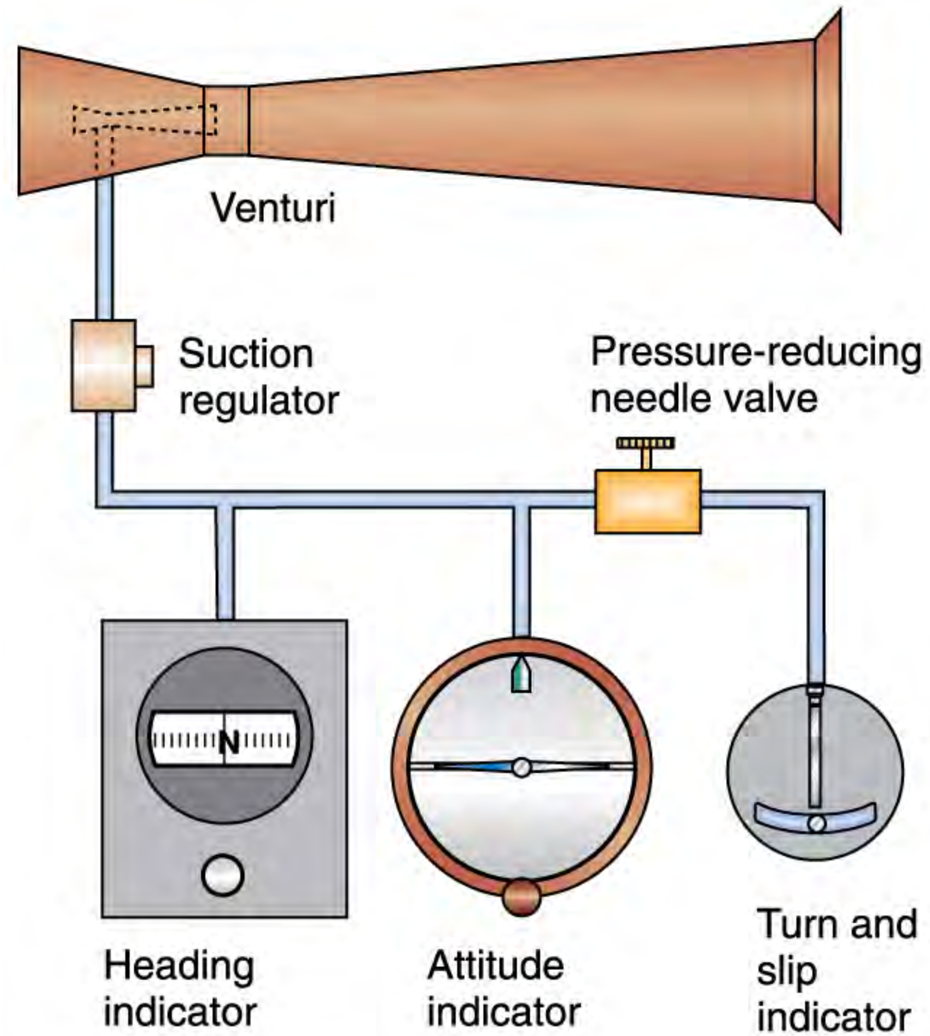
- Power:
  - ❖ Pneumatic (air)
    - Air blows on gyro wheel
  - ❖ Electric
    - Electric motor turns gyro
    - Latest – solid state gyro
- Pneumatic complimented with electric system

Venturi Systems

Venturi Systems

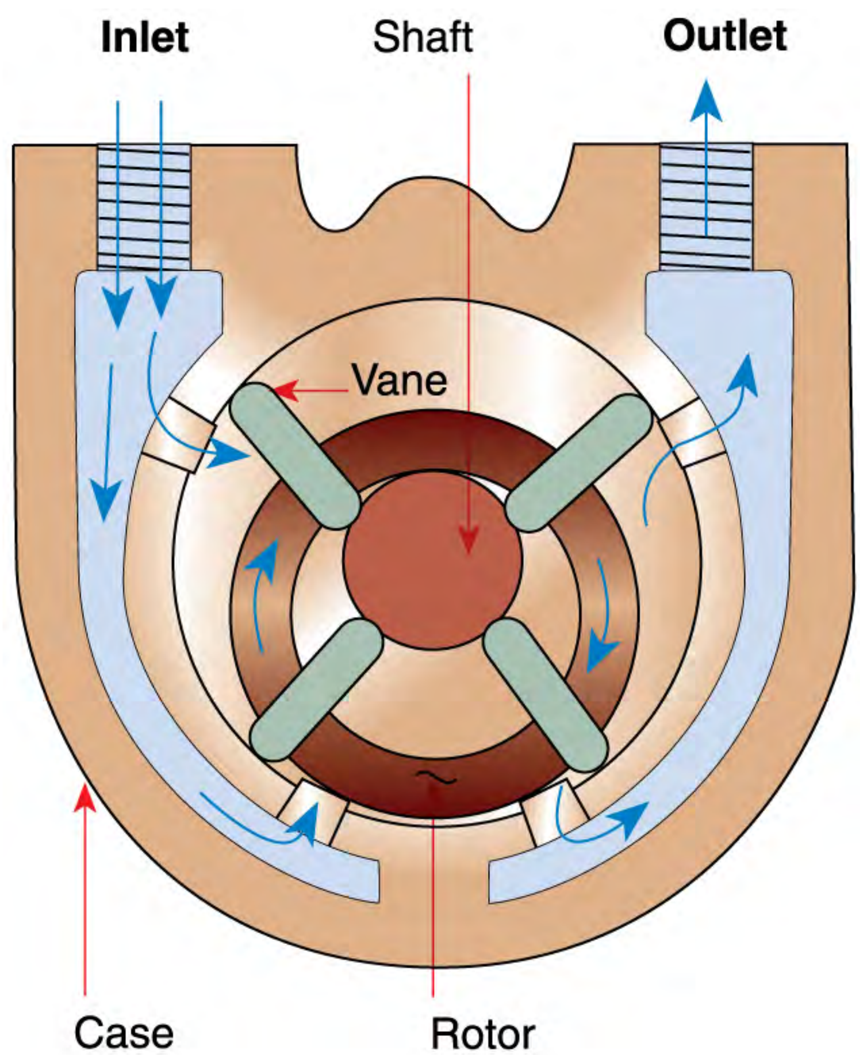
- Pneumatic system powered by an external venturi tube
- Works only when the plane is flying
- Used on older aircraft
- Can ice up and become inoperable

Venturi Systems



A gyro instrument system using a venturi tube for the source of suction.

Vane Pump



A vane-type air pump can be used either to evacuate the instrument case or to provide a flow of pressurized air to drive the instrument gyros.

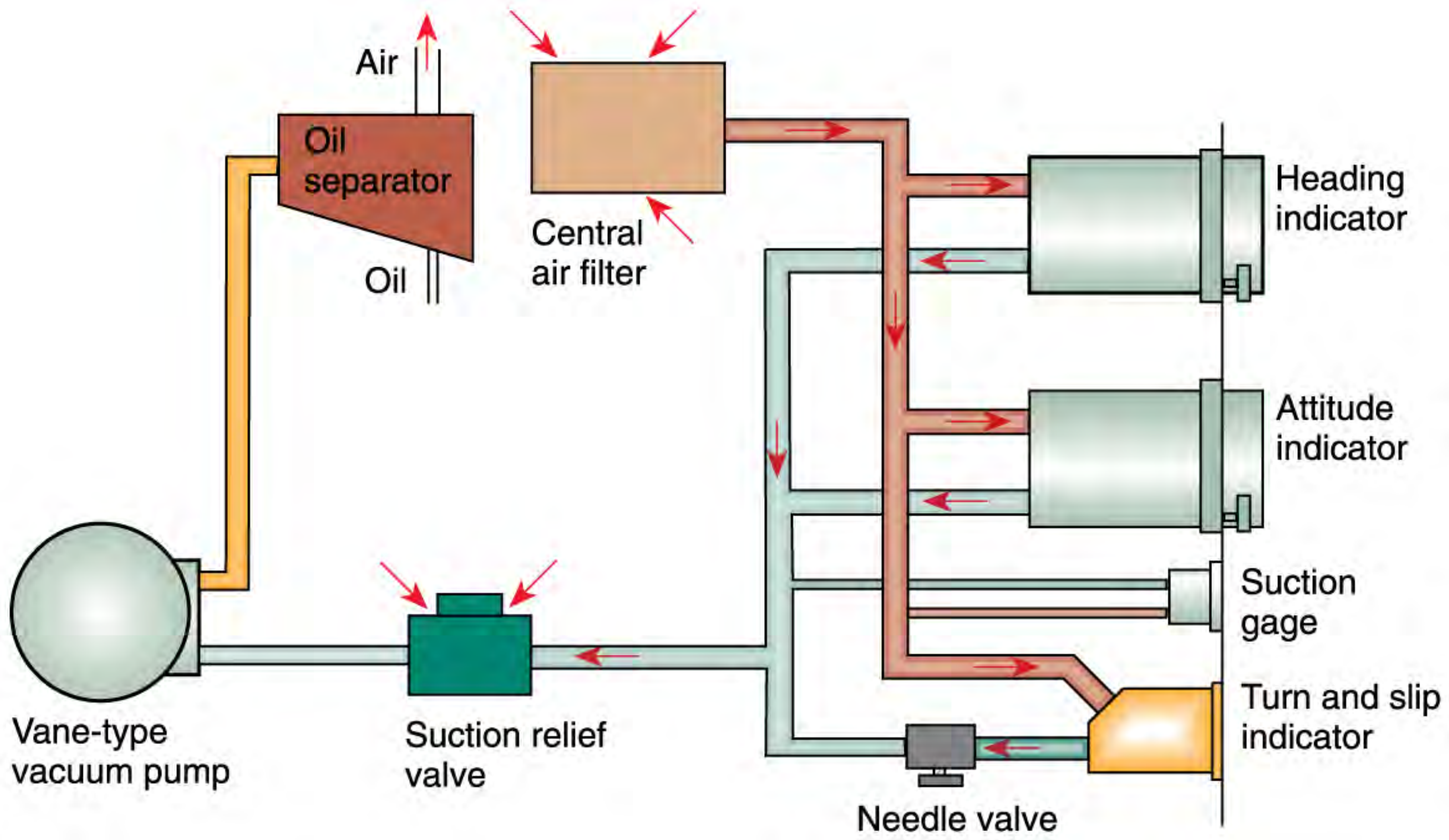
Vane Pump

- Vane Pump Video

Wet Pump

- Steel vanes in a steel case
- Lubricated by engine oil
- Exhaust air is oily
- Exhaust air routed through oil separator and oil returned to engine
- Failure mode is gradual

Wet Pump



A wet-pump vacuum system used to drive gyro instruments.

Dry Air Pump

- Lighter than wet pump
- Self lubricating
  - Rotors and vanes made of a special carbon compound
  - Wears in microscopic amounts to provide the needed lubrication
- Can be used either in vacuum or positive pressure mode
- Can fail in a catastrophic way

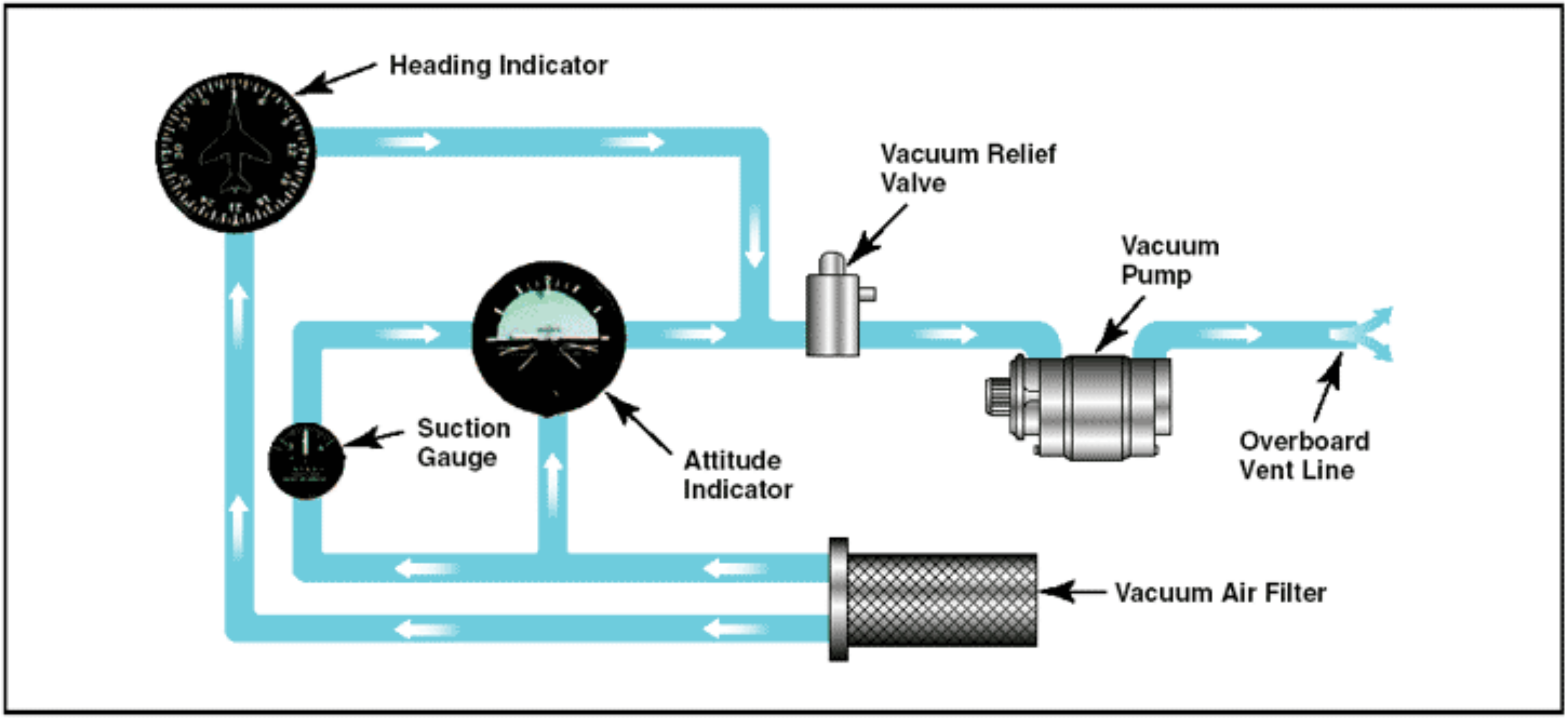
Dry Air Pump

Dry Air Pump

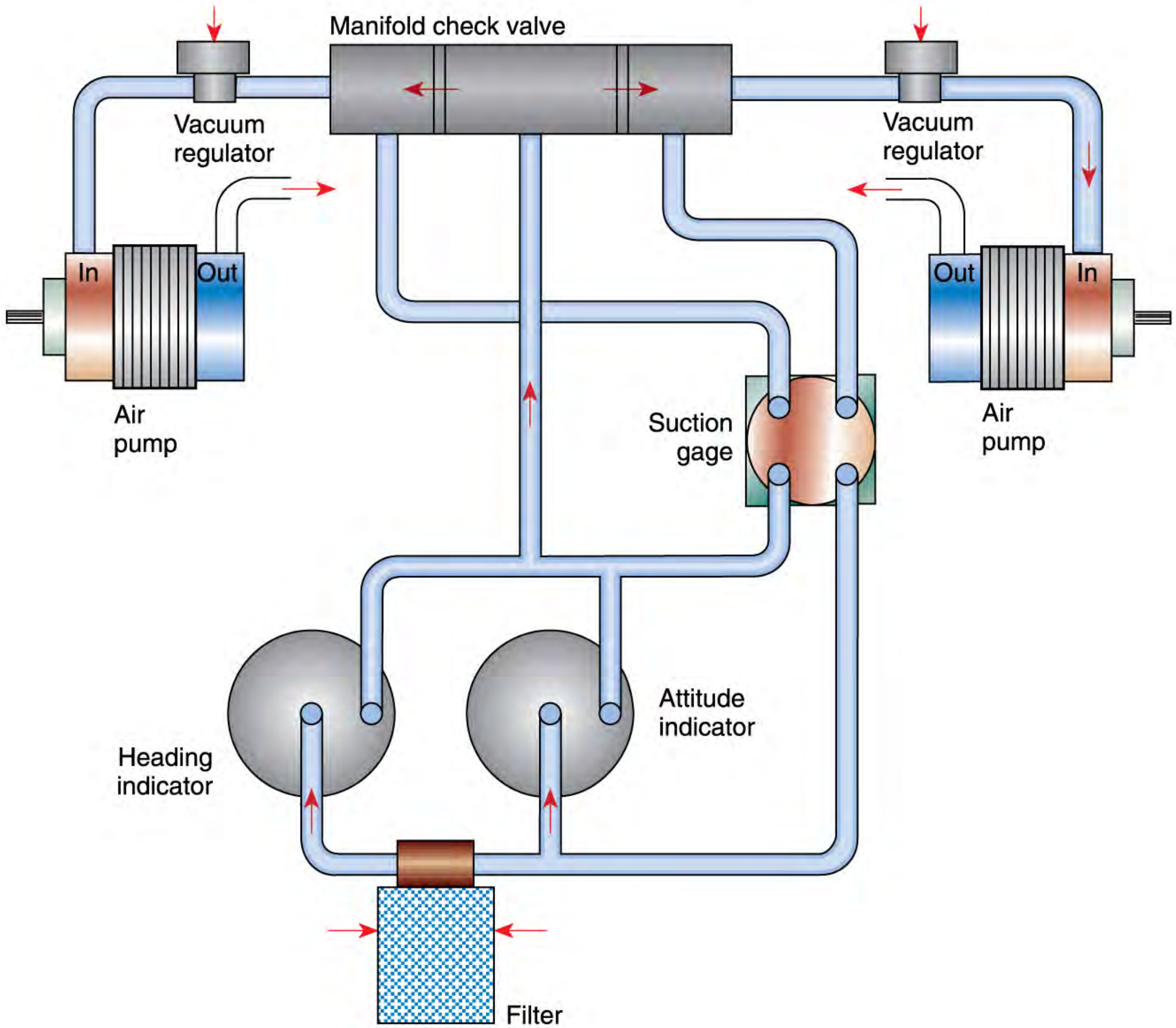
Dry Air Pump

- Engine drive couple is designed to break if pump locks up
  - Prevents engine problems
- Handle with care
- Needs complete inspection at about 500 hours
  - Follow manufacturer's instructions
- Check systems for leaks
  - Leaks can cause pump failure
- Change filters at every annual

Dry Air Pump

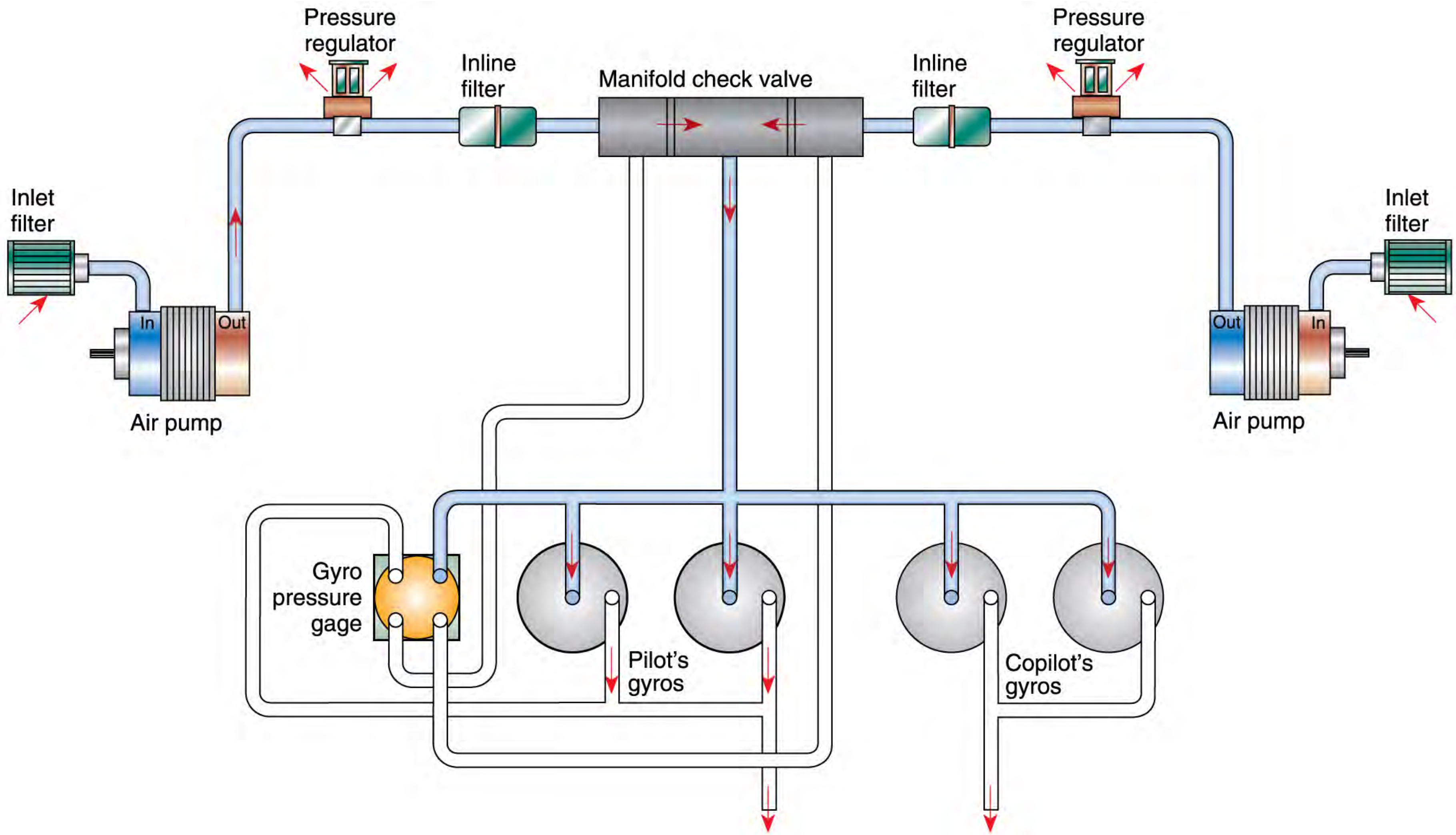

Heading Indicator
Vacuum Relief Valve
Vacuum Pump
Suction Gauge
Attitude Indicator
Overboard Vent Line
Vacuum Air Filter

Twin Engine Vacuum System



A twin-engine vacuum system for gyros.

Twin Engine Positive Pressure



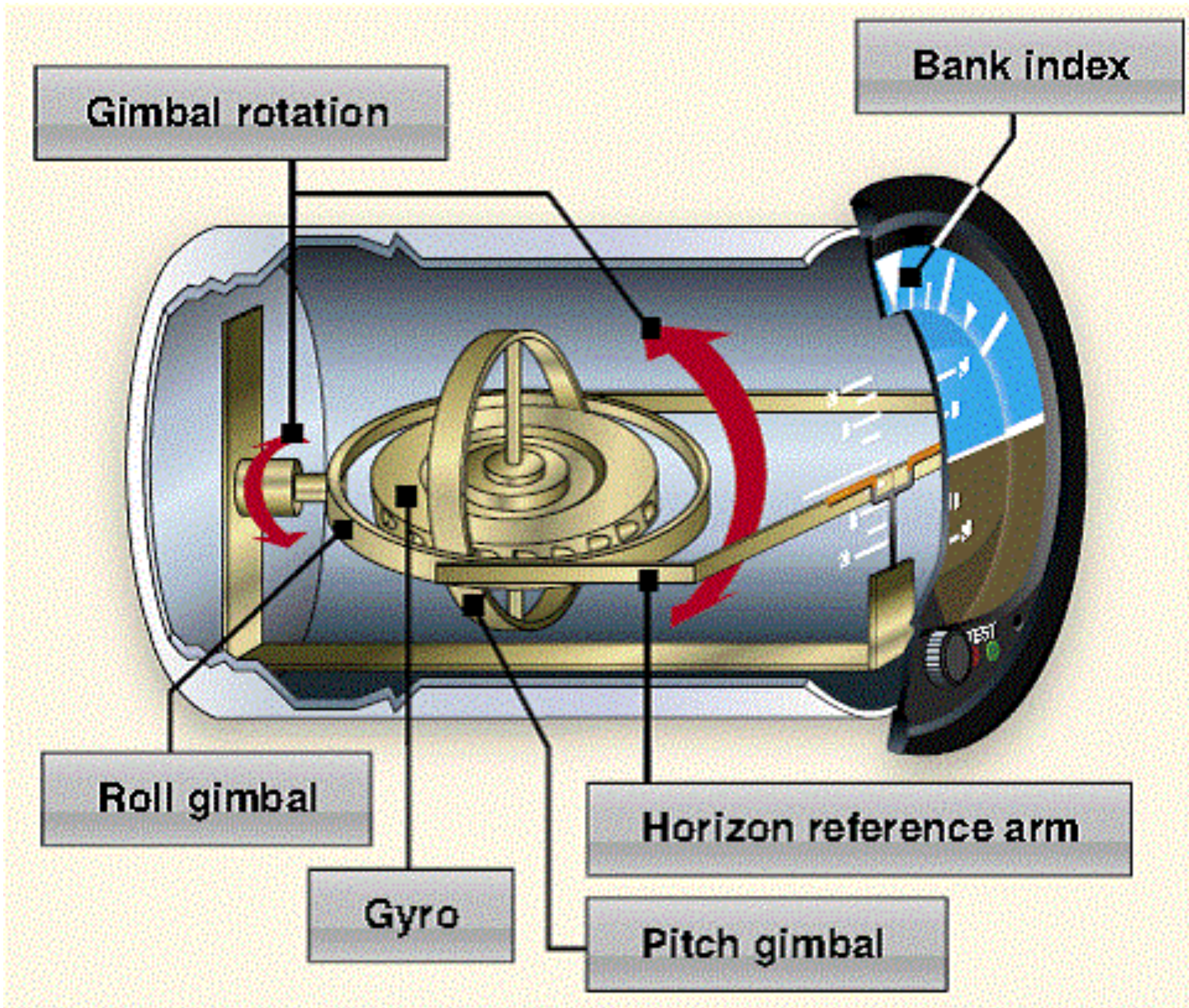
A twin-engine pressure system for gyros.

Gyroscope

- Gryroscope Video
- Gyroscopic Procession

Attitude Indicator

Attitude Indicator



Attitude indicator

Attitude Indicator

Heading Indicator

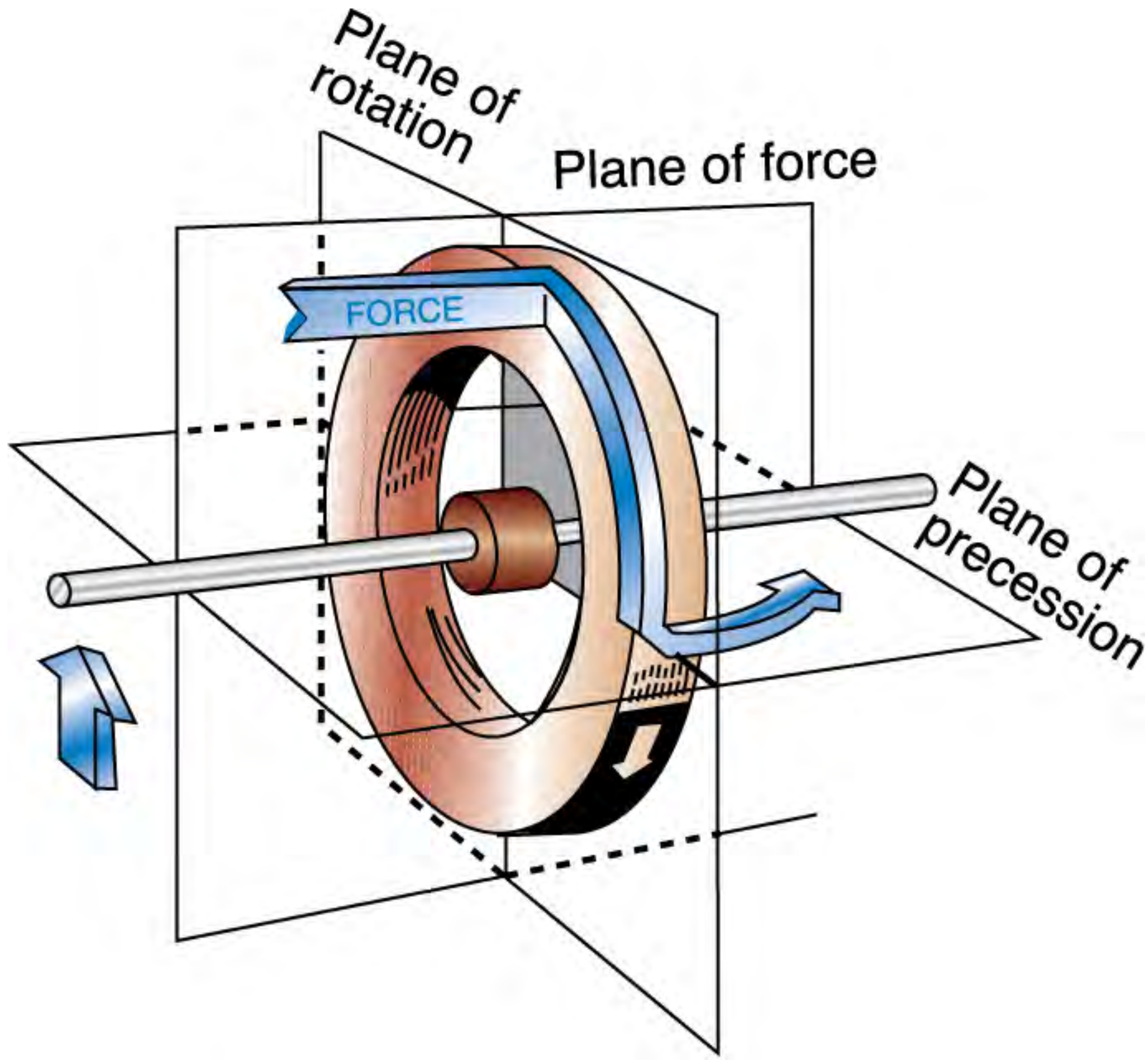
Heading Indicator

- Also Directional Gyro (DG)
- Pilot makes initial setting
- Pilot doesn’t have to worry about compass dip errors

Rate Gyro

- Mounted in single gimbals
- Operates on the characteristic of precession
    - Force acting on a spinning gyroscope is felt at a point 90°

Rate Gyro



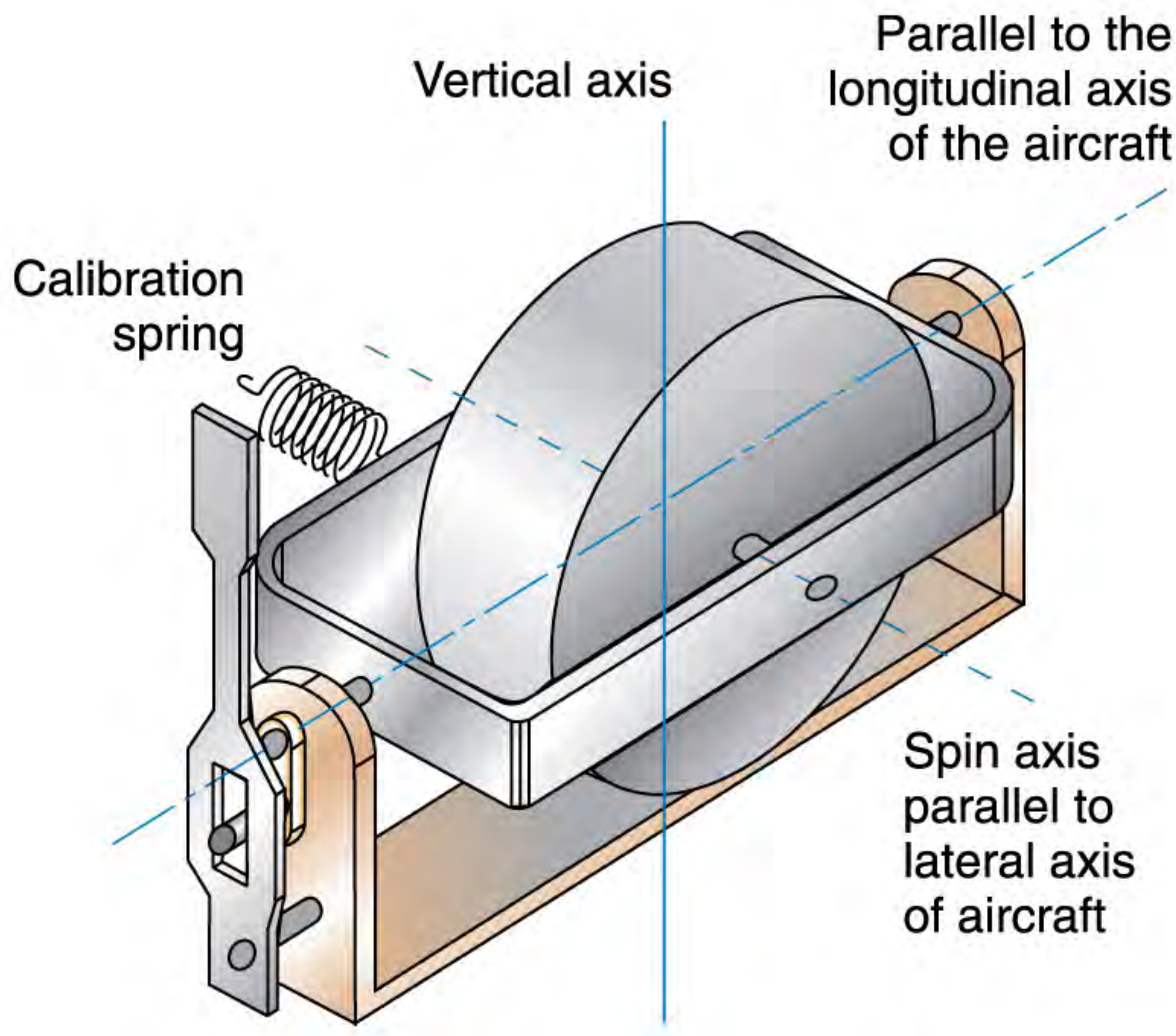
Precession of a gyroscope. An upward force on one end of the shaft causes the gyro to rotate in a counterclockwise direction as viewed from above.

Turn and Slip Indicator

Turn and Slip Indicator

- Also called a needle and ball
- Show the rate of turn
  - Measures the yaw axis
- Marks indicate “standard rate turn”
  - 360° turn in 2 minutes
    - Maybe slower for faster aircraft
- Usually electrically power
  - Serves as backup if vacuum system fails
- To stop a slip or yaw, step on the ball

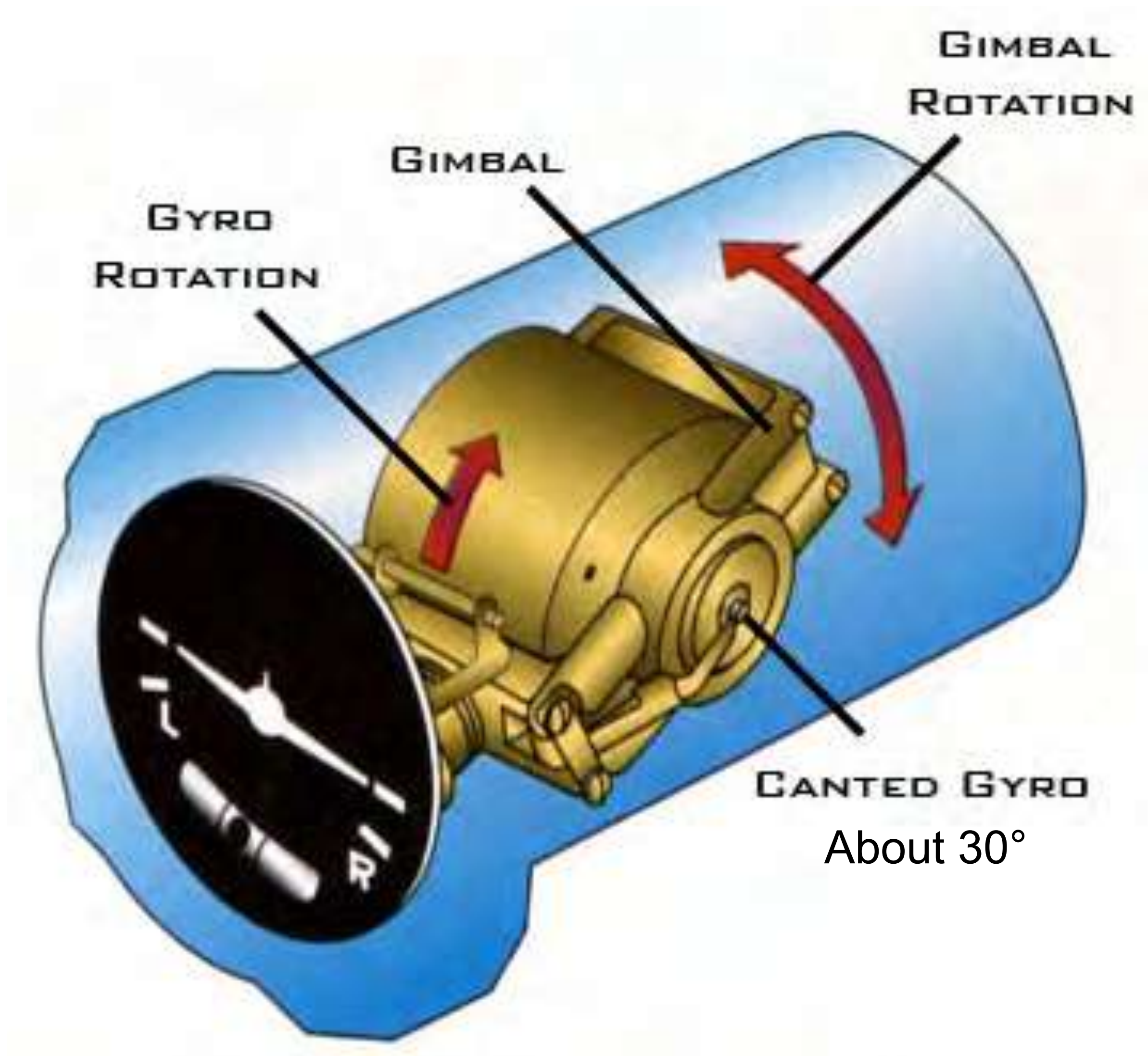
Turn and Slip Indicator



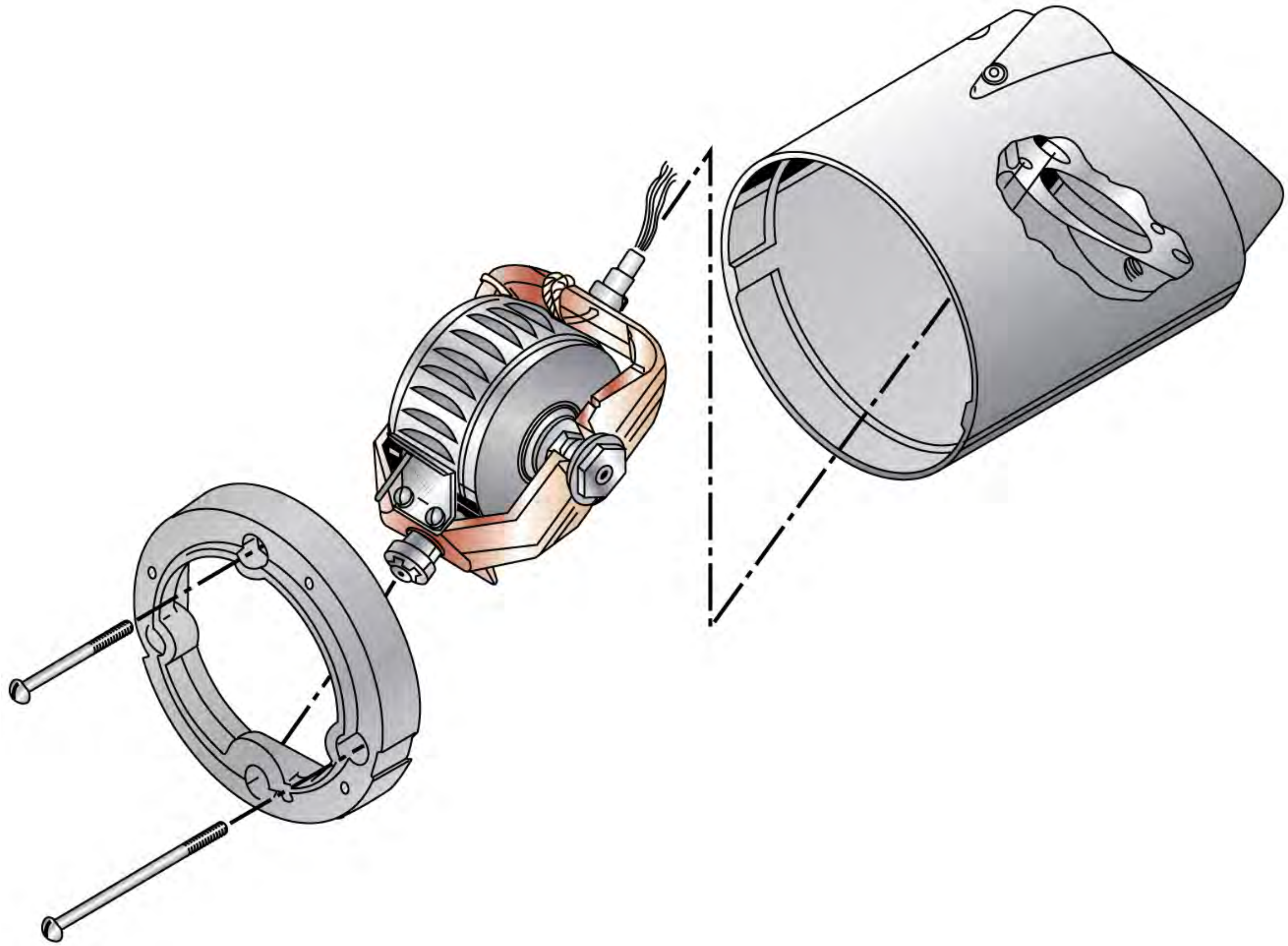
The rate gyro in a turn and slip indicator precesses an amount that is proportional to the rate of rotation about its vertical axis.

Turn Coordinator

Turn Coordinator



Turn Coordinator



A turn coordinator is a rate gyro with the gimbal axis tilted upward about 30°. This allows the instrument to sense both roll and yaw.

Automatic Flight Control Systems

- Automatically flies the airplane
  - Autopilot and more
- Collects situation information:
  - Altitude and speed
    - Measures pitot and static pressure
    - Radar altimeter
    - Speed from GPS
  - Position
    - Gyros
    - Magnetic direction

Automatic Flight Control Systems

- Collects situation information:
  - Navigation
    - VOR
    - Instrument Landing System (ILS)
    - GPS
  - Throttle position

Automatic Flight Control Systems

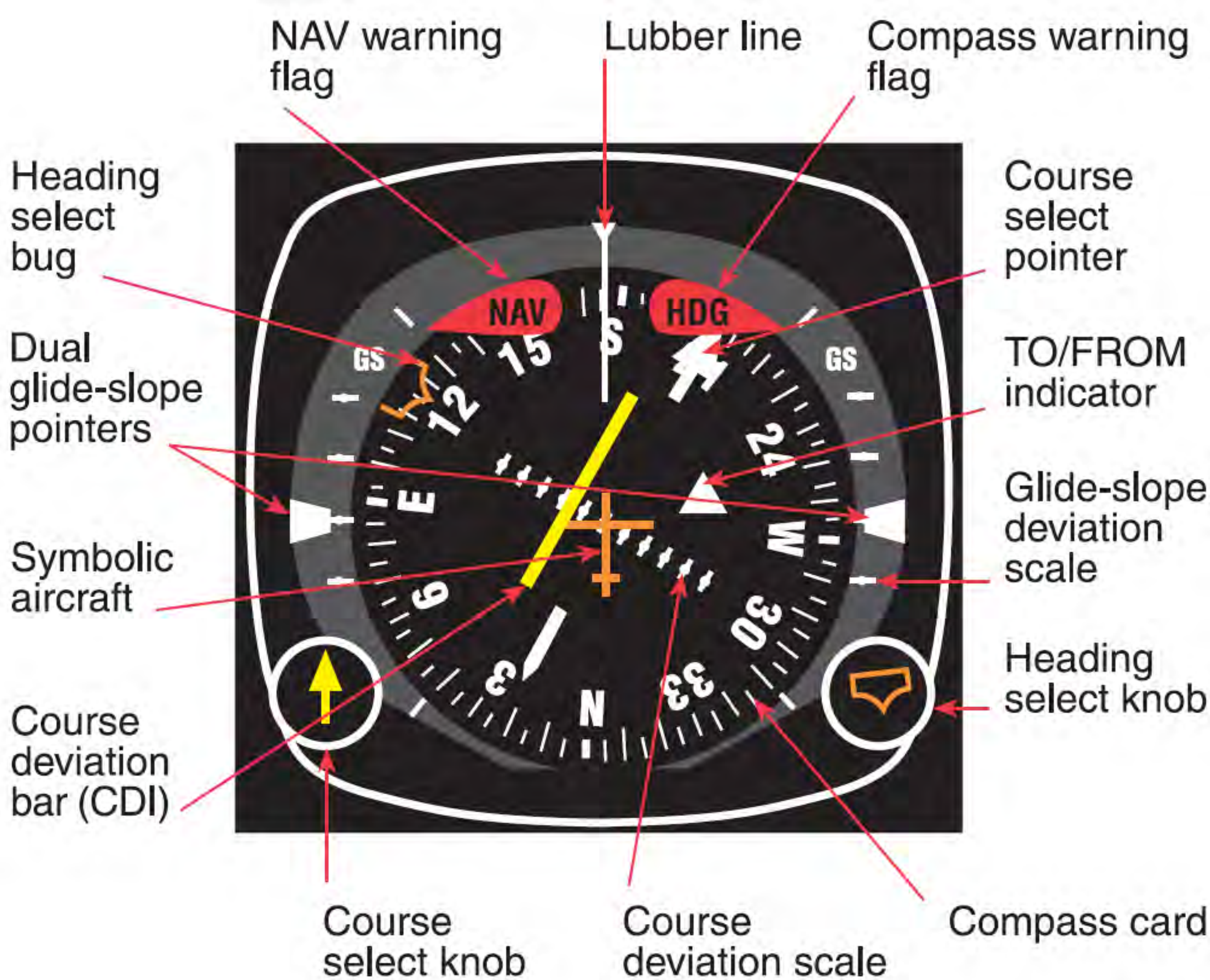
- Pilot Input
  - Simple autopilot interface
  - HSI – Horizontal Situation Indicator
  - FMS - Flight Management System
  - GPS – Global Positioning System
  - “Level” button
    - Emergency recovery system

Autopilot from 1947

Autopilot


COBHAM
FIFTY FIVE X
HDG
RDY
NAV
CWS
APR
FAIL
GPSS
REV
TRIM
ALT
GS
VS
÷ 18
VS x 100
HDG
NAV
APR
REV
ALT
VS
DECR
INCR

HSI



Horizontal Situation Indicator

HSI

- Video

FMS

Flight Management System

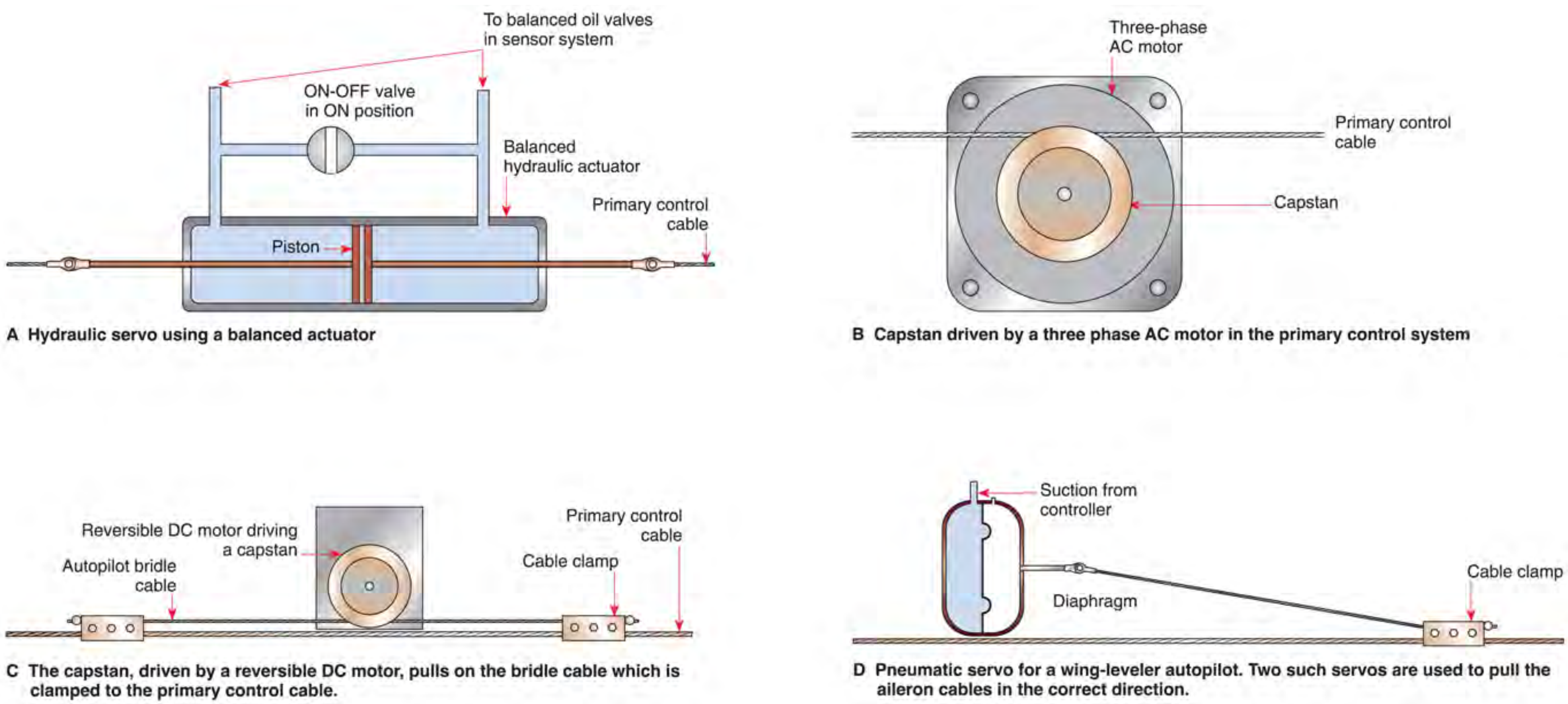
GPS

Global Positioning System

Automatic Flight Control Systems

- Results:
  - Simple wing leveling
  - Follow course
  - Hold altitude
  - Yaw damping
  - Fly complete profile
    - Takeoff to landing
  - Throttle control
  - "Stick shaker"
  - Electronic Stability and Protection
    - Safeguard pilot from mistakes

Automatic Flight Controls



Automatic flight control servos.

Instrument Markings

- Aircraft instruments are color-coded to direct attention to operational ranges and limitations
- Instrument range markings are specified in the aircrafts Type Certificate Data Sheet (TCDS)
  - Title 14 (the FARs) call this out in Part 21.41
  - FAA use this to state that the FARs are specified by Title 14

Instrument Markings

- The aircraft manufacturer defines the markings
  - Not the instrument or engine manufacturer
  - Can be found in maintenance manual or POH
- The mechanic installing an instrument is responsible to insure correct markings
- A mechanic should inspect markings and placards during 100 hour and annual inspections

Instrument Markings

- A mechanic can add markings to a instrument's face/glass
  - ❖ If external markings are added, a marking must be made to insure the glass has not moved
    - Usually a spot of white paint overlapping the glass and instrument edge
- A mechanic must mark an inoperable instrument
- A mechanic can paint the outside on an instrument
- Flags are used to indicate function failures

Airspeed Indicator Markings

- White arc
  - Flap operating speed
  - Bottom of white arc
    - VS0
    - Power off stall speed with gear and flaps down
  - Top of white arc
    - Max flap speed

Airspeed Indicator Markings

- Green arc
  - Normal operating range
  - Bottom of green arc
    - VS1
    - Power off stall speed with gear and flaps up (clean)
  - Top of green arc
    - VNO
    - Maximum structural cruising speed or maximum speed for normal operations
    - Also bottom of yellow arc

Airspeed Indicator Markings

- Yellow arc
  - Caution range
  - Aircraft should not be flown in rough or turbulent air; or with abrupt control movements

Airspeed Indicator Markings

- Red radial line or mark
  - VNE
  - Never exceed speed
- Blue radial line or mark
  - Best rate-of-climb speed of a twin engine airplane with one engine out

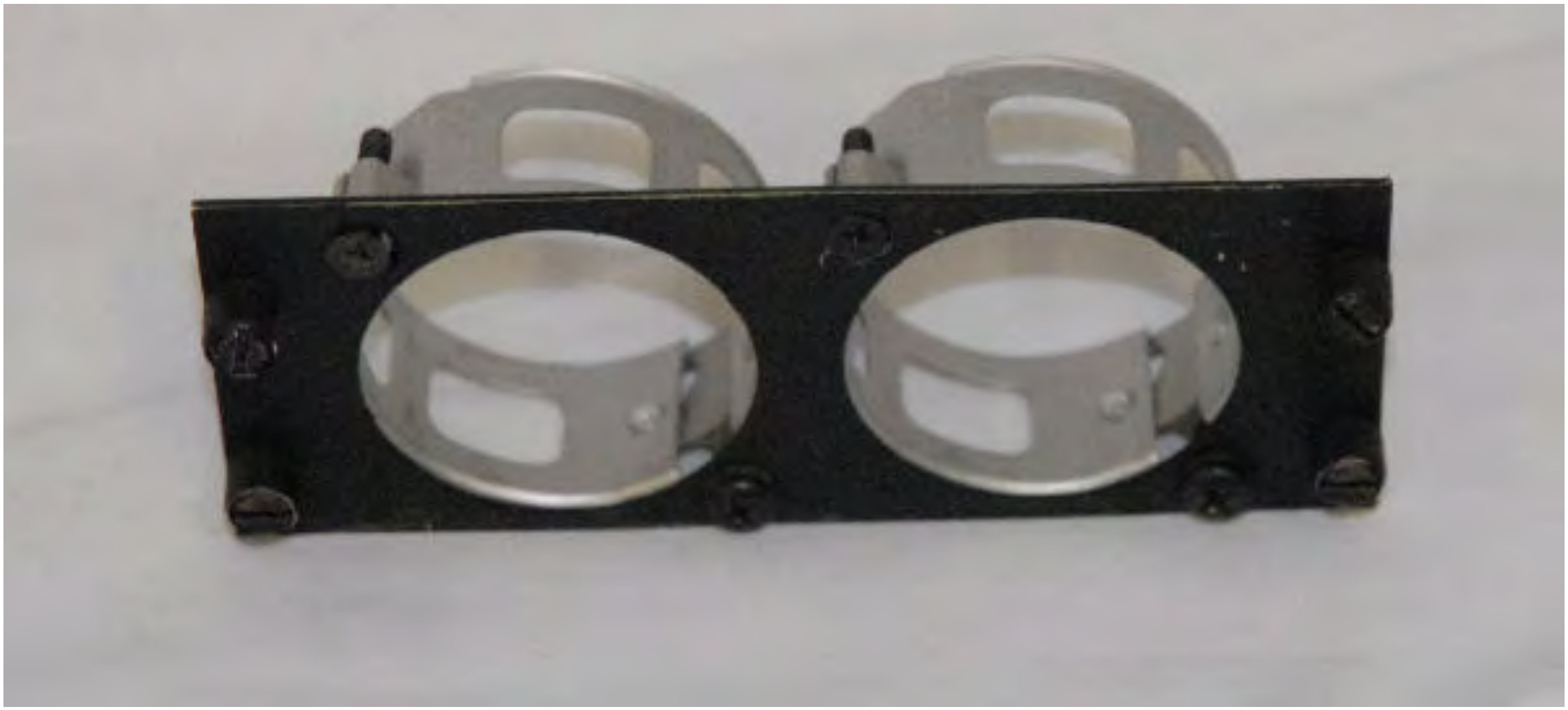
Instrument Mounting

- Instruments are shock mounted
  - Isolates low frequency, high-amplitude shocks and vibrations
- A section of a instrument panel may have a separate shock mount
  - The section must use a bonding strap to electrically bond/ground the section
  - FAA says this provides a return ground/current path for instruments
    - Most modern electronics have a separate ground

Instrument Mounting

- Mounting method will be dictated by the case design
  - Follow the manufacturers instructions
  - Flangeless instrument case are mounted with an expanding-type clamp secured to the back of the panel and tightened by a screw from the front of the instrument panel

Instrument Mounting



Electric Flight Instrument System

Electric Flight Instrument System

Electric Flight Instrument System

- EFIS or “Glass Cockpit”
- PFD – Primary Flight Display
- MFD – Multi-function Display
- AHRS – Attitude Heading Reference System
  - Solid state gyros and magnetic fluxgates
- ADAHRS - Air Data and Attitude Heading Reference System
  - AHRS plus static and pitot
  - Everything is converted to digital signals for a computer to interpret

Electric Flight Instrument System

Electric Flight Instrument System

- Technology is in a stage of rapid change
- There are limited standards
- Mechanic is allowed to upgrade software
- Repairs are line replacement
- Video

Sec. 91.411 Testing

- Test requirements outlined in FAR Part 43 Appendix E
- A vacuum (negative pressure) is applied to the static system to simulated a rise in altitude
- The maximum altitude loss permitted during an unpressurized aircraft instrument static pressure system integrity check is 100 feet in 1 minute
- Trouble shoot problems by isolated portions of a system and checking for leaks

FAA Questions

- CRT – Cathode Ray Tube
  - "TV"
  - Display alphanumeric data and representations of aircraft instruments
- Symbol generator (SG) - receive and process input signals from aircraft and engine sensors and send the data to the appropriate display
- EFIS display controller - allow the pilot to select the appropriate system configuration for the current flight situation

FAA Questions

- Cases for electrically operated instruments are made of iron or steel cases