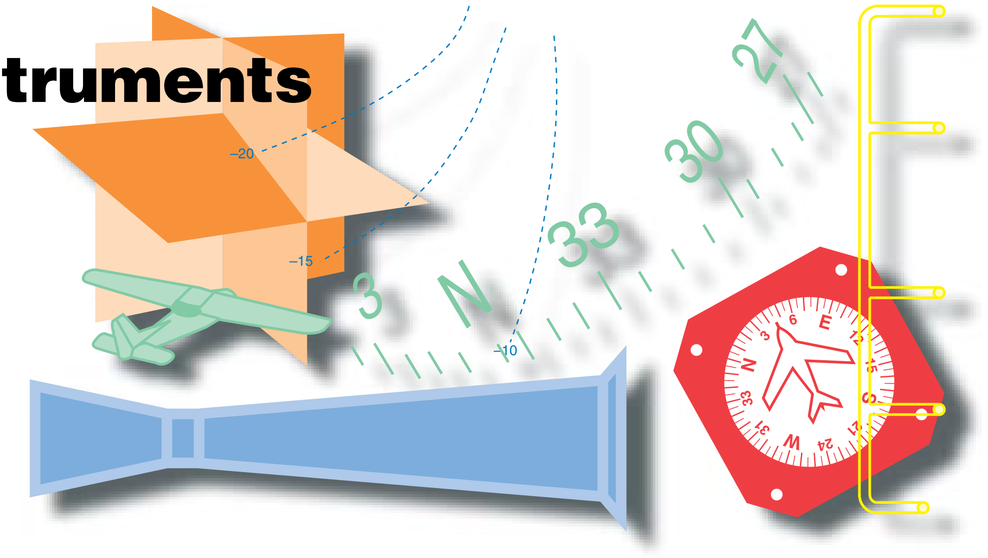
Chapter 3

Flight Instruments



Introduction

Aircraft became a practical means of transportation when accurate flight instruments freed the pilot from the necessity of maintaining visual contact with the ground. Safety was enhanced when all pilots with private or higher ratings were required to demonstrate their ability to maintain level flight and make safe turns without reference to the outside horizon.

The basic flight instruments required for operation under visual flight rules (VFR) are an airspeed indicator, an altimeter, and a magnetic direction indicator. In addition to these, operation under instrument flight rules (IFR) requires a gyroscopic rate-of-turn indicator, a slip-skid indicator, a sensitive altimeter adjustable for barometric pressure, a clock displaying hours, minutes, and seconds with a sweep-second pointer or digital presentation, a gyroscopic pitch-and-bank indicator (artificial horizon), and a gyroscopic direction indicator (directional gyro or equivalent).

Aircraft that are flown in instrument meteorological conditions (IMC) are equipped with instruments that provide attitude and direction reference, as well as radio navigation instruments that allow precision flight from takeoff to landing with limited or no outside visual reference.

The instruments discussed in this chapter are those required by Title 14 of the Code of Federal Regulations (14 CFR) part 91, and are organized into three groups: pitot-static instruments, compass systems, and gyroscopic instruments. The chapter concludes with a discussion of how to preflight these systems for IFR flight.

Pitot-Static Systems

Three basic pressure-operated instruments are found in most aircraft instrument panels. These are the sensitive altimeter, airspeed indicator (ASI), and vertical speed indicator (VSI). All three receive the pressures they measure from the aircraft pitot-static system.

Flight instruments depend upon accurate sampling of the ambient atmospheric pressure to determine the height and speed of movement of the aircraft through the air, both horizontally and vertically. This pressure is sampled at two or more locations outside the aircraft by the pitot-static system.

The pressure of the static, or still air, is measured at a flush port where the air is not disturbed. On some aircraft, this air is sampled by static ports on the side of the electrically heated **pitot-static head**, such as the one in figure 3-1. Other aircraft pick up the **static pressure** through flush ports on the side of

Pitot-static head: A combination pickup used to sample pitot pressure and static air pressure.

Static pressure: Pressure of the air that is still, or not moving, measured perpendicular to the surface of the aircraft.

the fuselage or the vertical fin. These ports are in locations proven by flight tests to be in undisturbed air, and they are normally paired, one on either side of the aircraft. This dual location prevents lateral movement of the aircraft from giving erroneous static pressure indications. The areas around the static ports may be heated with electric heater elements to prevent ice forming over the port and blocking the entry of the static air.

Pitot pressure, or impact air pressure, is taken in through an open-end tube pointed directly into the relative wind flowing around the aircraft. The pitot tube connects to the airspeed indicator, and the static ports deliver their pressure to the airspeed indicator, altimeter, and VSI. If the static ports should ice over, or in any other way become obstructed, the pilot is able to open a static-system alternate source valve to provide a static air pressure source from a location inside the aircraft. [Figure 3-2] This may cause an inaccurate indication on the pitot-static instrument. Consult the Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) to determine the amount of error.

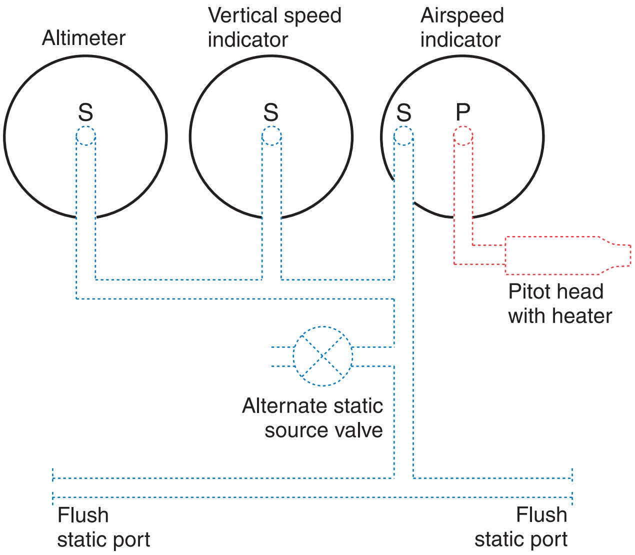


Figure 3-2. *A typical pitot-static system.*

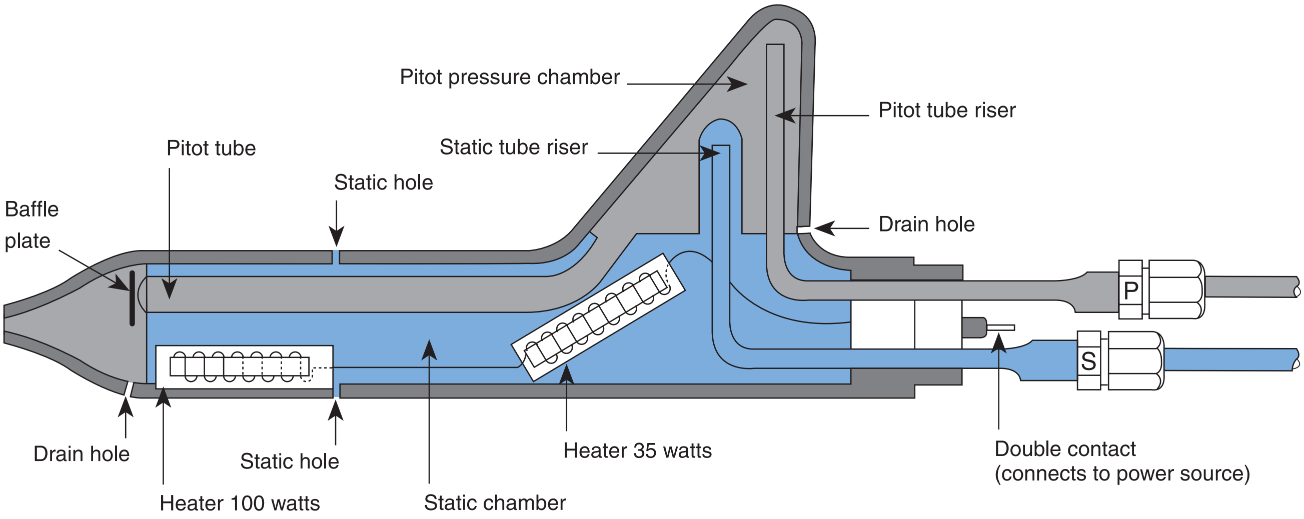


Figure 3-1. *A typical electrically heated pitot-static head.*

Pitot pressure: Ram air pressure used to measure airspeed.

Position Error

The static ports are located in a position where the air at their surface is as undisturbed as possible. But under some flight conditions, particularly at a high angle of attack with the landing gear and flaps down, the air around the static port may be disturbed to the extent that it can cause an error in the indication of the altimeter and airspeed indicator. Because of the importance of accuracy in these instruments, part of the certification tests for an aircraft is a check of **position error** in the static system.

The POH/AFM contains any corrections that must be applied to the airspeed for the various configurations of flaps and landing gear.

Pitot-Static Instruments

Sensitive Altimeter

A sensitive altimeter is an aneroid barometer that measures the absolute pressure of the ambient air and displays it in terms of feet or meters above a selected pressure level.

Principle of Operation

The sensitive element in a sensitive altimeter is a stack of evacuated, corrugated bronze aneroid capsules like those shown in figure 3-3. The air pressure acting on these aneroids tries to compress them against their natural springiness, which tries to expand them. The result is that their thickness changes as the air pressure changes. Stacking several aneroids increases the dimension change as the pressure varies over the usable range of the instrument.

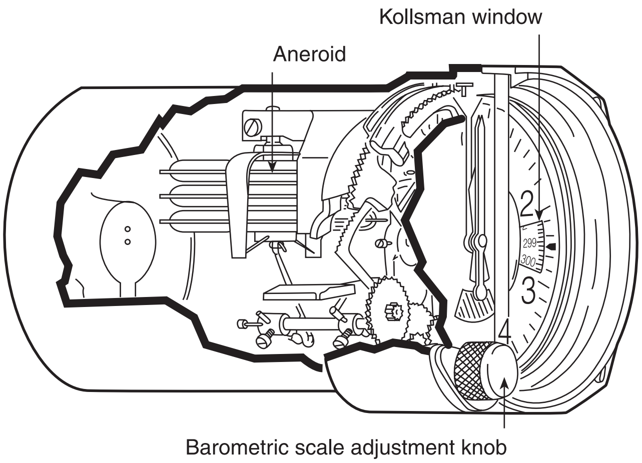


Figure 3-3. *Sensitive altimeter components.*

Position error: Error in the indication of the altimeter, ASI, and VSI caused by the air at the static system entrance not being absolutely still.

Below 10,000 feet, a striped segment is visible. Above this altitude, a mask begins to cover it, and above 15,000 feet, all of the stripes are covered. [Figure 3-4]

Another configuration of the altimeter is the drum-type, like the one in figure 3-5. These instruments have only one pointer that makes one revolution for every 1,000 feet. Each number represents 100 feet, and each mark represents 20 feet. A drum, marked in thousands of feet, is geared to the mechanism that drives the pointer. To read this type of altimeter, first look at the drum to get the thousands of feet, and then at the pointer to get the feet and hundreds of feet.

Figure 3-4. *Three-pointer altimeter.*

Figure 3-5. *Drum-type altimeter.*

A sensitive altimeter is one with an adjustable barometric scale that allows you to set the reference pressure from which the altitude is measured. This scale is visible in a small window, called the **Kollsman window**. The scale is adjusted by a knob on the instrument. The range of the scale is from 28.00 to 31.00" Hg, or 948 to 1,050 millibars.

Rotating the knob changes both the barometric scale and the altimeter pointers in such a way that a change in the barometric scale of 1" Hg changes the pointer indication by 1,000 feet. This is the standard pressure lapse rate below 5,000 feet. When the barometric scale is adjusted to 29.92" Hg, or 1,013.2 millibars, the pointers indicate the pressure altitude. When you wish to display indicated altitude, adjust the barometric scale to the local altimeter setting. The instrument then indicates the height above the existing sea level pressure.

Altimeter Errors

A sensitive altimeter is designed to indicate standard changes from standard conditions, but most flying involves errors caused by nonstandard conditions, and you must be able to modify the indications to correct for these errors. There are two types of errors: mechanical and inherent.

A preflight check to determine the condition of an altimeter consists of setting the barometric scale to the altimeter setting transmitted by the local automated flight service station (AFSS). The altimeter pointers should indicate the surveyed elevation of the airport. If the indication is off more than 75 feet from the surveyed elevation, the instrument should be referred to a certificated instrument repair station for recalibration. Differences between ambient temperature and/or pressure will cause an erroneous indication on the altimeter.

Figure 3-6 shows the way nonstandard temperature affects an altimeter. When the aircraft is flying in air that is warmer than standard, the air is less dense and the pressure levels are farther apart. When the aircraft is flying at an indicated altitude of 5,000 feet, the pressure level for that altitude is higher than it would be in air at standard temperature, and the aircraft will be higher than it would be if the air were cooler.

If the air is colder than standard, it is denser, and the pressure levels are closer together. When the aircraft is flying at an indicated altitude of 5,000 feet, its true altitude is lower than it would be if the air were warmer.

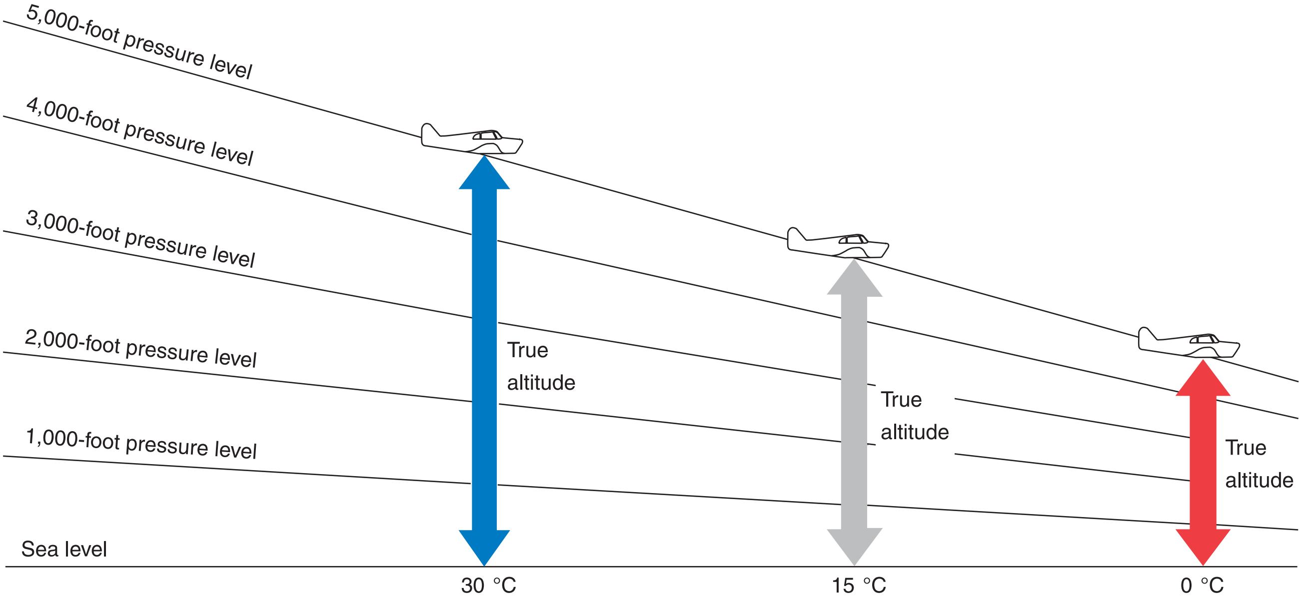


Figure 3-6. *Effects of nonstandard temperature on an altimeter.*

Kollsman window: A barometric scale window of a sensitive altimeter.

ICAO Cold Temperature Error Table

The cold temperature induced altimeter error may be significant when considering obstacle clearances when temperatures are well below standard. Pilots may wish to increase their minimum terrain clearance altitudes with a corresponding increase in ceiling from the normal minimum when flying in extreme cold temperature conditions. Higher altitudes may need to be selected when flying at low terrain clearances. Some flight management systems (FMS) with air data computers may implement a capability to compensate for cold temperature errors. Pilots flying with these systems should ensure they are aware of the conditions under which the system will automatically compensate. If compensation is applied by the FMS or manually, ATC must be informed that the aircraft is not flying the assigned altitude. Otherwise, vertical separation from other aircraft may be reduced creating a potentially hazardous situation. The following table, derived from ICAO standard formulas, shows how much error can exist when the temperature is extremely cold. To use the table, find the reported temperature in the left column, then read across the top row to the height above the airport/reporting station (e.g.: subtract the airport elevation from the altitude of the final approach fix). The intersection of the column and row is the amount of possible error.

Example: -10° Celsius and the FAF is 500 feet above the airport elevation. The reported current altimeter setting may place the aircraft as much as 50 feet below the altitude indicated by the altimeter.

	Height above Airport in Feet													
Reported Temp C°	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000	5000
+10	10	10	10	10	20	20	20	20	20	30	40	60	80	90
0	20	20	30	30	40	40	50	50	60	90	120	170	230	280
-10	20	30	40	50	60	70	80	90	100	150	200	290	390	490
-20	30	50	60	70	90	100	120	130	140	210	280	420	570	710
-30	40	60	80	100	120	130	150	170	190	280	380	570	760	950
-40	50	80	100	120	150	170	190	220	240	360	480	720	970	1210
-50	60	90	120	150	180	210	240	270	300	450	590	890	1190	1500

Figure 3-7. *Cold temperature corrections chart.*

Extreme differences between ambient and standard temperature must be taken into consideration to prevent controlled flight into terrain (CFIT). [Figure 3-7]

Any time the barometric pressure lapse rate differs from the standard of 1" Hg per thousand feet in the lower elevations, the indicated altitude will be different from the true altitude. For example, figure 3-8 shows an airplane at point A flying in air in which conditions are standard — the altimeter setting is 29.92" Hg. When the altimeter indicates 5,000 feet, the true altitude is also 5,000 feet.

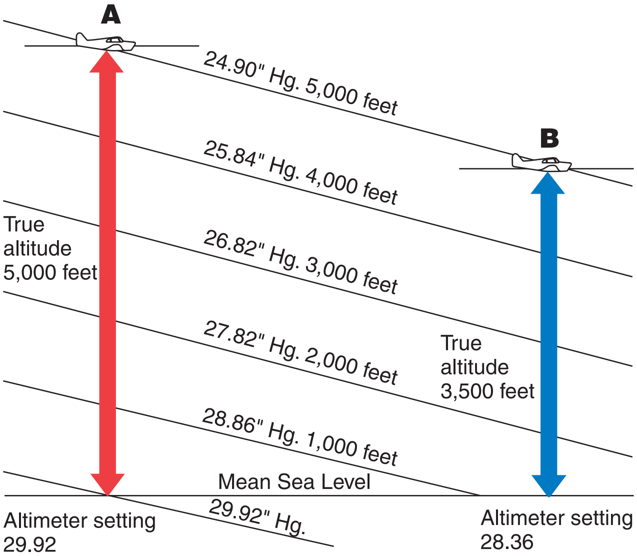


Figure 3-8. *Effects of nonstandard pressure on an altimeter.*

The airplane then flies to point B, where the pressure is lower than standard, and the altimeter setting is 28.36" Hg, but the pilot does not change the altimeter to this new altimeter setting. When the altimeter shows an indicated altitude of 5,000 feet, the true altitude, or the height above mean sea level, is only 3,500 feet.

The fact that the altitude indication is not always true lends itself to the memory aid, "When flying from hot to cold, or from a high to a low, look out below."

Memory Aid:
When flying from hot to cold, or from a high to a low, look out below!

Encoding Altimeter

It is not sufficient in the airspace system for only the pilot to have an indication of the aircraft's altitude; the air traffic controller on the ground must also know the altitude of the aircraft. To provide this information, the aircraft may be equipped with an encoding altimeter.

When the ATC **transponder** is set to Mode C, the **encoding altimeter** supplies the transponder with a series of pulses identifying the flight level (in increments of 100 feet) at which the aircraft is flying. This series of pulses is transmitted to the ground radar where they appear on the controller's scope as an alphanumeric display around the return for the aircraft. The transponder allows the ground controller to identify the aircraft under his/her control and to know the pressure altitude at which each is flying.

A computer inside the encoding altimeter measures the pressure referenced from 29.92" Hg and delivers this data to the transponder. When the pilot adjusts the barometric scale to the local altimeter setting, the data sent to the transponder is not affected. 14 CFR part 91 requires the altitude transmitted by the transponder to be within 125 feet of the altitude indicated on the instrument used to maintain flight altitude.

Absolute Altimeter

The absolute altimeter, also called a radar or radio altimeter, measures the height of the aircraft above the terrain. It does this by transmitting a radio signal, either a frequency-modulated continuous-wave or a pulse to the ground, and accurately measuring the time used by the signal in traveling from the aircraft to the ground and returning. This transit time is modified with a time delay and is converted inside the indicator to distance in feet.

Most absolute altimeters have a provision for setting a decision height/decision altitude (DH/DA) or a minimum descent altitude (MDA) so that when the aircraft reaches this height above ground, a light will illuminate and/or an aural warning will sound. Absolute altimeters are incorporated into ground proximity warning systems (GPWS) and into some flight directors.

Transponder: The airborne portion of the ATC radar beacon system.

Encoding altimeter: A sensitive altimeter that sends signals to the ATC transponder, showing the pressure altitude the aircraft is flying.

Airspeed Indicators

An airspeed indicator is a differential pressure gauge that measures the dynamic pressure of the air through which the aircraft is flying. Dynamic pressure is the difference in the ambient static air pressure and the total, or ram, pressure caused by the motion of the aircraft through the air. These two pressures are taken from the pitot-static system.

The mechanism of the airspeed indicator in figure 3-9 consists of a thin, corrugated phosphor-bronze aneroid, or diaphragm, that receives its pressure from the pitot tube. The instrument case is sealed and connected to the static ports. As the pitot pressure increases, or the static pressure decreases, the diaphragm expands, and this dimensional change is measured by a rocking shaft and a set of gears that drives a pointer across the instrument dial. Most airspeed indicators are calibrated in knots, or nautical miles per hour; some instruments show statute miles per hour, and some instruments show both.

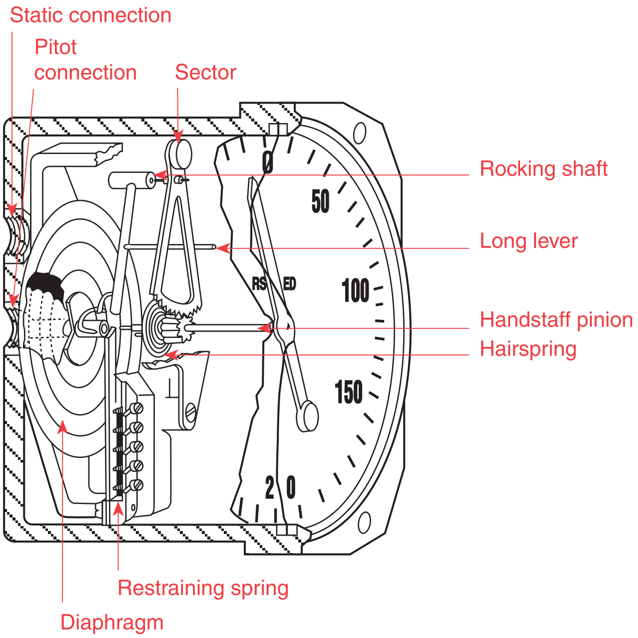


Figure 3-9. *Mechanism of an airspeed indicator.*

Types of Airspeed

Just as there are many types of altitude, there are many types of airspeed: indicated airspeed (IAS), calibrated airspeed (CAS), equivalent airspeed (EAS), and true airspeed (TAS).

Indicated Airspeed

Indicated airspeed is shown on the dial of the instrument, uncorrected for instrument or system errors.

Calibrated Airspeed

Calibrated airspeed is the speed the aircraft is moving through the air, which is found by correcting IAS for instrument and position errors. The POH/AFM has a chart or graph to correct IAS for these errors and provide the correct CAS for the various flap and landing gear configurations.

Equivalent Airspeed

Equivalent airspeed is CAS corrected for compression of the air inside the pitot tube. Equivalent airspeed is the same as CAS in standard atmosphere at sea level. As the airspeed and pressure altitude increase, the CAS becomes higher than it should be and a correction for compression must be subtracted from the CAS.

True Airspeed

True airspeed is CAS corrected for nonstandard pressure and temperature. True airspeed and CAS are the same in standard atmosphere at sea level. But under nonstandard conditions, TAS is found by applying a correction for pressure altitude and temperature to the CAS.

Some aircraft are equipped with true airspeed indicators that have a temperature-compensated aneroid bellows inside the instrument case. This bellows modifies the movement of the rocking shaft inside the instrument case so the pointer shows the actual TAS.

The true airspeed indicator provides both true and indicated airspeed. These instruments have the conventional airspeed mechanism, with an added subdial visible through cutouts in the regular dial. A knob on the instrument allows you to rotate the subdial and align an indication of the outside air temperature with the pressure altitude being flown. This alignment causes the instrument pointer to indicate the true airspeed on the subdial. [Figure 3-10]

Figure 3-10. *A true airspeed indicator allows the pilot to correct indicated airspeed for nonstandard temperature and pressure.*

Mach Number

As an aircraft approaches the speed of sound, the air flowing over certain areas of its surface speeds up until it reaches the speed of sound, and shock waves form. The indicated airspeed at which these conditions occur changes with temperature. Therefore airspeed, in this case, is not entirely adequate to warn the pilot of the impending problems. Mach number is more useful. Mach number is the ratio of the true airspeed of the aircraft to the speed of sound in the same atmospheric conditions. An aircraft flying at the speed of sound is flying at Mach 1.0.

Most high-speed aircraft are limited as to the maximum Mach number they can fly. This is shown on a Machmeter as a decimal fraction. [Figure 3-11] For example, if the Machmeter indicates .83 and the aircraft is flying at 30,000 feet where the speed of sound under standard conditions is 589.5 knots, the airspeed is 489.3 knots. The speed of sound varies with the air temperature, and if the aircraft were flying at Mach .83 at 10,000 feet where the air is much warmer, its airspeed would be 530 knots.

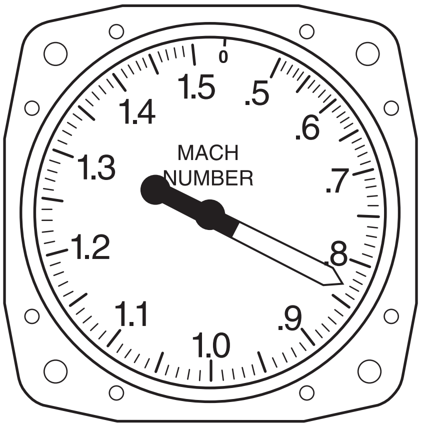


Figure 3-11. *A Machmeter shows the ratio of the speed of sound to the true airspeed the aircraft is flying.*

Maximum Allowable Airspeed

Some aircraft that fly at high subsonic speeds are equipped with maximum allowable airspeed indicators like the one in figure 3-12. This instrument looks much like a standard airspeed indicator, calibrated in knots, but has an additional pointer, colored red, checkered, or striped. The maximum airspeed pointer is actuated by an aneroid, or altimeter mechanism, that moves it to a lower value as air density decreases. By keeping the airspeed pointer at a lower value than the maximum pointer, the pilot avoids the onset of transonic shock waves.

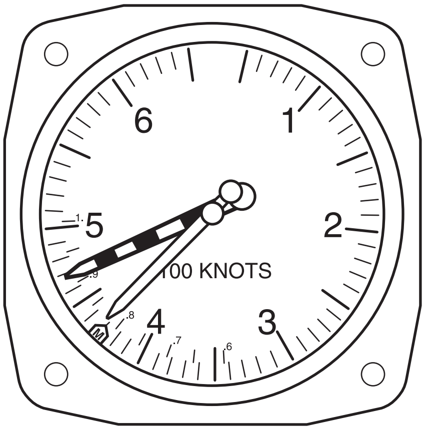


Figure 3-12. *A maximum allowable airspeed indicator has a movable pointer that indicates the never-exceed speed, which changes with altitude to avoid the onset of transonic shock waves.*

Airspeed Color Codes

The dial of an airspeed indicator is color coded to alert you, at a glance, of the significance of the speed at which the aircraft is flying. These colors and their associated airspeeds are shown in figure 3-13.

White arc	Flap operating range
Bottom	Flaps-down stall speed
Top	Maximum airspeed for flaps-down flight
Green arc	Normal operating range
Bottom	Flaps-up stall speed
Top	Maximum airspeed for rough air
Blue radial line	Airspeed for best single-engine rate-of-climb
Yellow arc	Structural warning area
Bottom	Maximum airspeed for rough air
Top	Never-exceed airspeed
Red radial line	Never-exceed airspeed

Figure 3-13. *Color codes for an airspeed indicator.*

Vertical Speed Indicators (VSI)

The vertical speed indicator (VSI) in figure 3-14 is also called a vertical velocity indicator (VVI) and was formerly known as a rate-of-climb indicator. It is a rate-of-pressure change instrument that gives an indication of any deviation from a constant pressure level.

Figure 3-14. *Vertical speed indicator shows the rate of climb or descent in thousands of feet per minute.*

Inside the instrument case is an aneroid very much like the one in an airspeed indicator. Both the inside of this aneroid and the inside of the instrument case are vented to the static system, but the case is vented through a **calibrated orifice** that causes the pressure inside the case to change more slowly than the pressure inside the aneroid. As the aircraft ascends, the static pressure becomes lower and the pressure inside the case compresses the aneroid, moving the pointer upward, showing a climb and indicating the number of feet per minute the aircraft is ascending.

When the aircraft levels off, the pressure no longer changes, the pressure inside the case becomes the same as that inside the aneroid, and the pointer returns to its horizontal, or zero, position. When the aircraft descends, the static pressure increases and the aneroid expands, moving the pointer downward, indicating a descent.

The pointer indication in a VSI lags a few seconds behind the actual change in pressure, but it is more sensitive than an altimeter and is useful in alerting the pilot of an upward or downward trend, thereby helping maintain a constant altitude.

Some of the more complex VSIs, called instantaneous vertical speed indicators (IVSI), have two accelerometer-actuated air pumps that sense an upward or downward pitch of the aircraft and instantaneously create a pressure differential. By the time the pressure caused by the pitch acceleration dissipates, the altitude pressure change is effective.

Compass Systems

The Earth is a huge magnet, spinning in space, 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.

Lines of magnetic flux have two important characteristics: any magnet that is free to rotate will align with them, and an electrical current is induced into any conductor that cuts across them. Most direction indicators installed in aircraft make use of one of these two characteristics.

Magnetic Compass

One of the oldest and simplest instruments for indicating direction is the magnetic compass. It is also one of the basic instruments required by 14 CFR part 91 for both VFR and IFR flight.

A magnet is a piece of material, usually a metal containing iron, that attracts and holds lines of magnetic flux. Every magnet regardless of size 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.

An aircraft magnetic compass, such as the one in figure 3-15, has two small magnets attached to a metal float sealed inside a bowl of clear compass fluid similar to kerosene. A graduated scale, called a card, is wrapped around the float and viewed through a glass window with a **lubber line** across it. The card is marked with letters representing the cardinal directions, north, east, south, and west, and a number for each 30° between these letters. The final "0" is omitted from these directions; for example, 3 = 30°, 6 = 60°, and 33 = 330°. There are long and short graduation marks between the letters and numbers, with each long mark representing 10° and each short mark representing 5°.

Calibrated orifice: A hole of specific diameter used to delay the pressure change in the case of a vertical speed indicator.

Lines of flux: Invisible lines of magnetic force passing between the poles of a magnet.

Lubber line: The reference line used in a magnetic compass or heading indicator.

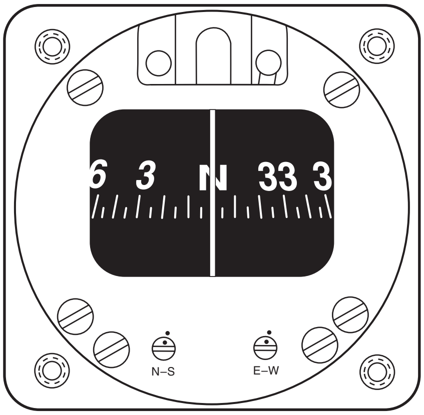


Figure 3-15. *A magnetic compass.*

The float and card assembly has a hardened steel pivot in its center that rides inside a special, spring-loaded, hard-glass jewel cup. The buoyancy of the float takes most of the weight off the pivot, and the fluid damps the oscillation of the float and card. This jewel-and-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.

The compass housing is entirely full of compass fluid. To prevent damage or leakage when the fluid expands and contracts with temperature changes, the rear of the compass case is sealed with a flexible diaphragm, or in some compasses, with a metal bellows.

The magnets align with the Earth's magnetic field and the pilot reads the direction on the scale opposite the lubber line. In figure 3-15, the pilot sees the compass card from its back side. When you are flying north as the compass shows, east is to your right, but on the card "33" which represents 330° (west of north) is to the right of north. The reason for this apparent backward graduation is that the card remains stationary, and the compass housing and the pilot turn around it, always viewing the card from its back side.

A compensator assembly mounted on the top or bottom of the compass allows an aviation maintenance technician (AMT) to create a magnetic field inside the compass housing that cancels the influence of local outside magnetic fields. This is done to correct for deviation error. The compensator assembly has two shafts whose ends have screwdriver slots accessible from the front of the compass. Each shaft rotates one or two small compensating magnets. The end of one shaft is marked E-W, and its magnets affect the compass when the aircraft is pointed east or west. The other shaft is marked N-S and its magnets affect the compass when the aircraft is pointed north or south.

Compass Errors

The magnetic compass is the simplest instrument in the panel, but it is subject to a number of errors that must be considered.

Variation

The Earth rotates about its geographic axis, and maps and charts are drawn using meridians of longitude that pass through the geographic poles. Directions measured from the geographic poles are called true directions. The north magnetic pole to which the magnetic compass points is not colocated with the geographic north pole but is some 1,300 miles away, and directions measured from the magnetic poles are called magnetic directions. In aerial navigation, the difference between true and magnetic directions is called **variation**. This same angular difference in surveying and land navigation is called declination.

Figure 3-16 shows the **isogonic lines** that identify the number of degrees of variation in their area. The line that passes near Chicago is called the **agonic line**, and anywhere along this line the two poles are aligned, and there is no variation. East of this line, the magnetic pole is to the west of the geographic pole and a correction must be applied to a compass indication to get a true direction.

When you fly in the Washington, DC area, for example, the variation is 10° west, and if you want to fly a true course of south (180°), the variation must be added to this and the magnetic course to fly is 190°. When you fly in the Los Angeles, CA area, the variation is about 15° east. To fly a true course of 180° there, you would have to subtract the variation and fly a magnetic course of 165°. The variation error does not change with the heading of the aircraft; it is the same anywhere along the isogonic line.

Variation: The compass error caused by the difference in the physical locations of the magnetic north pole and the geographic north pole.

Isogonic lines: Lines drawn across aeronautical charts connecting points having the same magnetic variation.

Agonic line: An irregular imaginary line across the surface of the Earth along which the magnetic and geographic poles are in alignment and along which there is no magnetic variation.

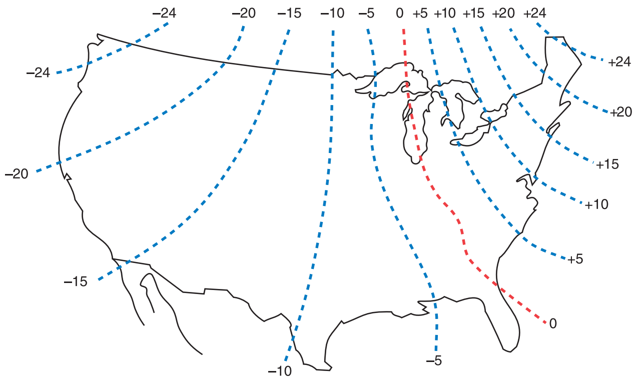


Figure 3-16. *Isogonic lines are lines of equal variation.*

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, in nearby wiring or any magnetized part of the structure, will conflict with the Earth's magnetic field and cause a compass error called **deviation**.

Deviation, unlike variation, is different on each heading, but it is not affected by the geographic location. Variation error cannot be reduced nor changed, but deviation error can be minimized when an AMT performs the maintenance task, "swinging the compass."

Most 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° as shown in figure 3-17.

The AMT aligns the aircraft on each magnetic heading and adjusts the compensating magnets to minimize the difference between the compass indication and the actual magnetic heading of the aircraft. Any error that cannot be removed is recorded on a compass correction card, like the one in figure 3-18, and placed in a card holder near the compass. If you want to fly a magnetic heading of 120°, and the aircraft is operating with the radios on, you would have to fly a compass heading of 123°.

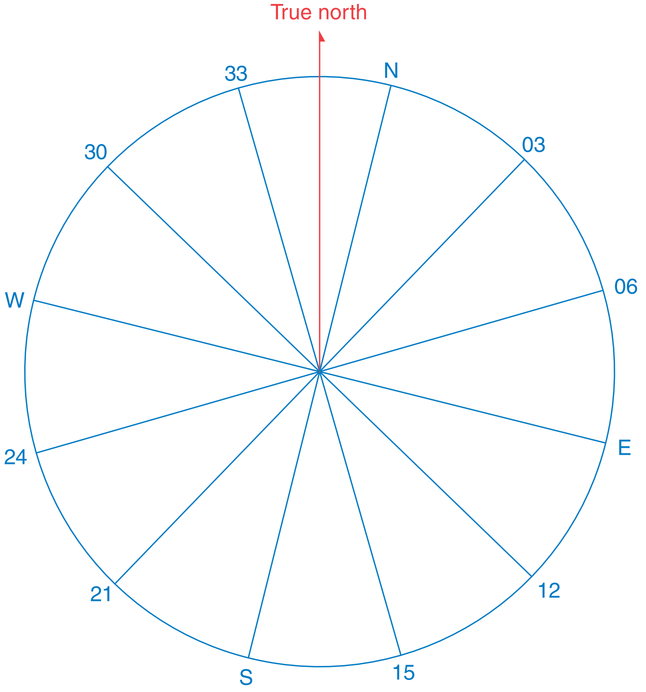


Figure 3-17. *A compass rose upon which deviation error is compensated for.*

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

Figure 3-18. *A compass correction card shows the deviation correction for any heading.*

The corrections for variation and deviation must be applied in the correct sequence. To find the **compass course** when the true course is known:

True Course ± Variation = Magnetic Course ± Deviation
= Compass Course

Deviation: A magnetic compass error caused by local magnetic fields within the aircraft. Deviation error is different on each heading.

Compass course: A true course corrected for variation and deviation errors.

Mnemonic aid for calculating magnetic course:
East is least (subtract variation from true course), west is best (add variation to true course).

To find the true course that is being flown when the compass course is known:

Compass Course ± Deviation = Magnetic Course ± Variation = True Course

Dip Errors

The lines of magnetic flux are considered to leave the Earth at the magnetic north pole and enter at the magnetic south pole. At both locations the lines are perpendicular to the Earth's surface. At the magnetic equator, which is halfway between the poles, the lines are parallel with the surface. The magnets in the compass align with this field, and near the poles they dip, or tilt, the float and card. The float is balanced with a small dip-compensating weight, so it stays relatively level when operating in the middle latitudes of the northern hemisphere. This dip along with this weight causes two very noticeable errors: northerly turning error and acceleration error.

The pull of the vertical component of the Earth's magnetic field causes northerly turning error, which is apparent on a heading of north or south. When an aircraft, flying on a heading of north, makes a turn toward east, the aircraft banks to the right, and the compass card tilts to the right. The vertical component of the Earth's magnetic field pulls the north-seeking end of the magnet to the right, and the float rotates, causing the card to rotate toward west, the direction opposite the direction the turn is being made. [Figure 3-19]

If the turn is made from north to west, the aircraft banks to the left and the card tilts to the left. The magnetic field pulls on the end of the magnet that causes the card to rotate toward east. This indication is again opposite to the direction the turn is being made. The rule for this error is: when starting a turn from a northerly heading, the compass indication lags behind the turn.

When an aircraft is flying on a heading of south and begins a turn toward east, the Earth's magnetic field pulls on the end of the magnet that rotates the card toward east, the same direction the turn is being made. If the turn is made from south toward west, the magnetic pull will start the card rotating toward west—again, in the same direction the turn is being made. The rule for this error is: When starting a turn from a southerly heading, the compass indication leads the turn.

In acceleration error, the dip-correction weight causes the end of the float and card marked N (this is the south-seeking end) to be heavier than the opposite end. When the aircraft is flying at a constant speed on a heading of either east or west, the float and card are level. The effects of magnetic dip and the weight are approximately equal. If the aircraft accelerates on a heading of east (as in figure 3-20), the inertia of the weight holds its end of the float back, and the card rotates toward north. As soon as the speed of the aircraft stabilizes, the card swings back to its east indication.

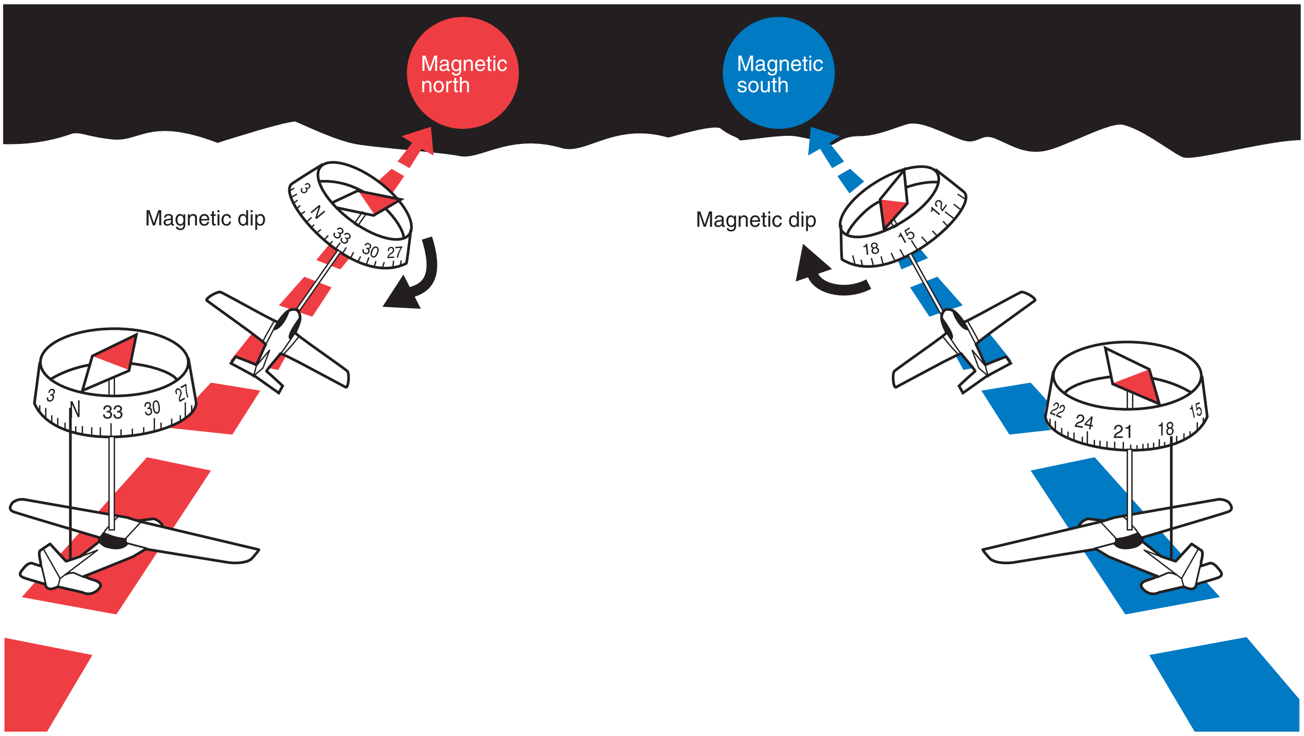


Figure 3-19. *Northerly turning error.*

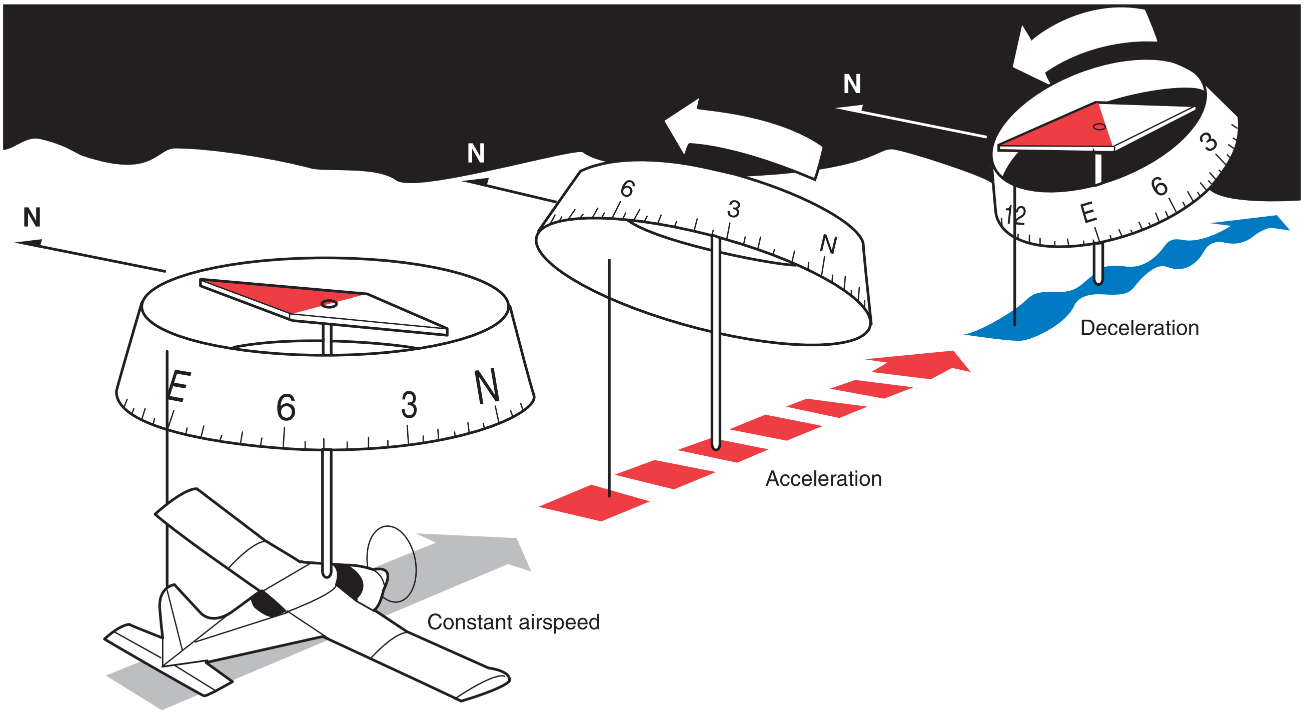


Figure 3-20. *The effects of acceleration error.*

If, while flying on this easterly heading, the aircraft decelerates, the inertia causes the weight to move ahead and the card rotates toward south until the speed again stabilizes.

When flying on a heading of west, the same things happen. Inertia from acceleration causes the weight to lag, and the card rotates toward north. When the aircraft decelerates on a heading of west, inertia causes the weight to move ahead and the card rotates toward south.

Oscillation Error

Oscillation is a combination of all of the other errors, and it 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.

Lags or Leads

When starting a turn from a northerly heading, the compass lags behind the turn. When starting a turn from a southerly heading, the compass leads the turn.

ANDS

A memory jogger for the effect of acceleration error is the word "ANDS": Acceleration causes an indication toward North, Deceleration causes an indication toward South.

Vertical Card Magnetic Compasses

The floating-magnet type of compass not only has all the errors just described, but lends itself to confused reading. It is easy to begin a turn in the wrong direction because its card appears backward. East is on the west side. The vertical card magnetic compass eliminates some of the errors and confusion. The dial of this compass is graduated with letters representing the cardinal directions, numbers every 30°, and marks every 5°. The dial is rotated by a set of gears from the shaft-mounted magnet, and the nose of the symbolic airplane on the instrument glass represents the lubber line for reading the heading of the aircraft from the dial. Oscillation of the magnet is damped by **eddy currents** induced into an aluminum damping cup. [Figure 3-21]

Eddy currents: Current induced in a metal cup or disc when it is crossed by lines of flux from a moving magnet.

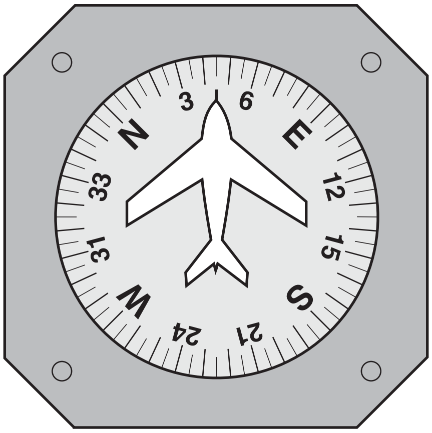


Figure 3-21. *A vertical card magnetic compass.*

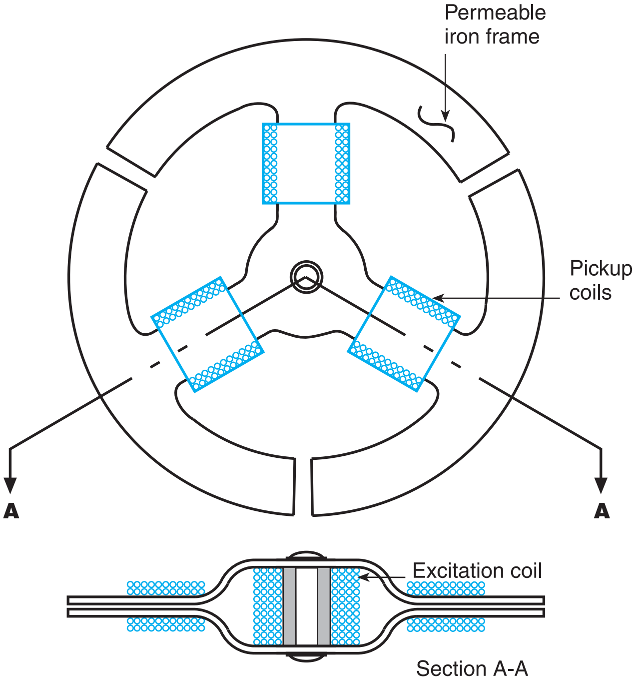


Figure 3-22. *The soft iron frame of the flux valve accepts the flux from the Earth's magnetic field each time the current in the center coil reverses. This flux causes current to flow in the three pickup coils.*

Flux Gate Compass

As mentioned earlier, the lines of flux in the Earth's magnetic field have two basic characteristics: a magnet will align with these lines, and an electrical current is induced, or generated, in any wire crossed by them.

The flux gate compass that drives slaved gyros uses the characteristic of **current induction**. The flux valve is a small segmented ring, like the one in figure 3-22, made of soft iron that readily accepts lines of magnetic flux. An electrical coil is wound around each of the three legs to accept the current induced in this ring by the Earth's magnetic field. A coil wound around the iron spacer in the center of the frame has 400-Hz alternating current (a.c.) flowing through it. During the times when this current reaches its peak, twice during each cycle, there is so much magnetism produced by this coil that the frame cannot accept the lines of flux from the Earth's field.

But as the current reverses between the peaks, it demagnetizes the frame so it can accept the flux from the Earth's field. As this flux cuts across the windings in the three coils, it causes current to flow in them. These three coils are connected in such a way that the current flowing in them changes as the heading of the aircraft changes. [Figure 3-23]

The three coils are connected to three similar but smaller coils in a **synchro** inside the instrument case. The synchro rotates the dial of a radio magnetic indicator (RMI) or a horizontal situation indicator (HSI).

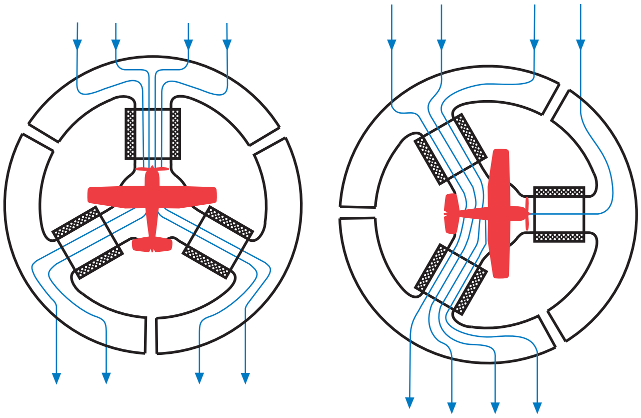


Figure 3-23. *The current in each of the three pickup coils changes with the heading of the aircraft.*

Current induction: An electrical current is induced into, or generated in, any conductor that is crossed by lines of flux from any magnet.

Synchro: A device used to transmit indications of angular movement or position from one location to another.

Remote Indicating Compass

Remote indicating compasses were developed to compensate for the errors and limitations of the older type of heading indicators. The two panel-mounted components of a typical system are the pictorial navigation indicator, and the slaving control and compensator unit. [Figure 3-24] The pictorial navigation indicator is commonly referred to as a horizontal situation indicator.

Figure 3-24. *Pictorial navigation indicator; slaving control and compensator unit.*

The slaving control and compensator unit has a pushbutton that provides a means of selecting either the "slaved gyro" or "free gyro" mode. This unit also has a slaving meter and two manual heading-drive buttons. The slaving meter indicates the difference between the displayed heading and the magnetic heading. A right deflection indicates a clockwise error of the compass card; a left deflection indicates a counterclockwise error. Whenever the aircraft is in a turn and the card rotates, the slaving meter will show a full deflection to one side or the other. When the system is in "free gyro" mode, the compass card may be adjusted by depressing the appropriate heading-drive button.

A separate unit, the magnetic slaving transmitter is mounted remotely; usually in a wingtip to eliminate the possibility of magnetic interference. It contains the flux valve, which is the direction-sensing device of the system. A concentration of lines of magnetic force, after being amplified, becomes a signal relayed to the heading indicator unit which is also remotely mounted. This signal operates a torque motor in the heading indicator unit which precesses the gyro unit until it is aligned with the transmitter signal. The magnetic slaving transmitter is connected electrically to the HSI.

There are a number of designs of the remote indicating compass; therefore, only the basic features of the system are covered here. As an instrument pilot, you should become familiar with the characteristics of the equipment in your aircraft.

As instrument panels become more crowded and the pilot's available scan time is reduced by a heavier cockpit workload, instrument manufacturers have worked towards combining instruments. One good example of this is the RMI in figure 3-25. The compass card is driven by signals from the flux valve, and the two pointers are driven by an **automatic direction finder (ADF)** and a **very-high-frequency omnidirectional range (VOR)**.

Figure 3-25. *The compass card in this RMI is driven by signals from a flux valve and it indicates the heading of the aircraft opposite the upper center index mark.*

Automatic direction finder (ADF): Electronic navigation equipment that operates in the low- and medium-frequency bands.

Very-high-frequency omnidirectional range (VOR): Electronic navigation equipment in which the cockpit instrument identifies the radial or line from the VOR station measured in degrees clockwise from magnetic north, along which the aircraft is located.

Gyroscopic Systems

Flight without reference to a visible horizon can be safely accomplished by the use of gyroscopic instrument systems and the two characteristics of gyroscopes which are: **rigidity** and **precession**. These systems include: attitude, heading, and rate instruments, along with their power sources. These instruments include a gyroscope (or gyro) which is a small wheel with its weight concentrated around its periphery. When this wheel is spun at high speed, it becomes rigid and resists any attempt to tilt it or turn it in any direction other than around its spin axis.

Attitude and heading instruments operate on the principal of rigidity. For these instruments the gyro remains rigid in its case and the aircraft rotates about it.

Rate indicators, such as turn indicators and turn coordinators, operate on the principal of precession. In this case the gyro precesses (or rolls over) proportionate to the rate the aircraft rotates about one or more of its axes.

Power Sources

Aircraft and instrument manufacturers have designed redundancy into the flight instruments so that any single failure will not deprive the pilot of his/her ability to safely conclude the flight.

Gyroscopic instruments are crucial for instrument flight; therefore, they are powered by separate electrical or pneumatic sources.

Electrical Systems

Many general aviation aircraft that use pneumatic attitude indicators use electric rate indicators and vice versa. Some instruments identify their power source on their dial, but it is extremely important that pilots consult the POH/AFM to determine the power source of all instruments to know what action to take in the event of an instrument failure.

Direct current (d.c.) electrical instruments are available in 14- or 28-volt models, depending upon the electrical system in the aircraft. Alternating current (a.c.) is used to operate some attitude gyros and autopilots. Aircraft that have only d.c. electrical systems can use a.c. instruments by installing a solid-state d.c. to a.c. **inverter**, which changes 14 or 28 volts d.c. into three-phase 115-volt, 400-Hz a.c.

Pneumatic Systems

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 on many aircraft by evacuating the instrument case and allowing filtered air to flow into the case through a nozzle to spin the wheel.

Venturi Tube Systems

Aircraft that do not have a pneumatic pump to evacuate the instrument cases can use **venturi tubes** mounted on the outside of the aircraft, similar to the system shown in figure 3-26. Air flowing through these tubes speeds up in the narrowest part, and according to Bernoulli's principle, the pressure drops. This location is connected to the instrument case by a piece of tubing. The two attitude instruments operate on approximately 4" Hg suction; the turn-and-slip indicator needs only 2" Hg, so a pressure-reducing needle valve is used to decrease the suction. Filtered air flows into the instruments through filters built into the instrument cases. In this system, ice can clog the venturi tube and stop the instruments when they are most needed.

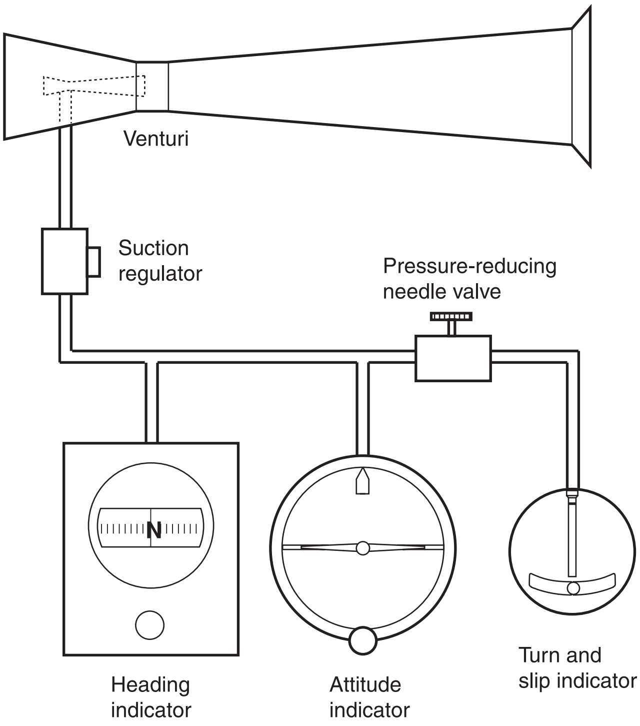


Figure 3-26. *A venturi tube provides the low pressure inside the instrument case to drive the gyros.*

Rigidity: The characteristic of a gyroscope that prevents its axis of rotation tilting as the Earth rotates.

Precession: The characteristic of a gyroscope that causes an applied force to be felt, not at the point of application, but 90° from that point in the direction of rotation.

Inverter: A solid-state electronic device that converts electrical current from d.c. into a.c. to operate a.c. gyro instruments.

Venturi tube: A specially-shaped tube attached to the outside of an aircraft to produce suction to operate gyro instruments.

Wet-Type Vacuum Pump Systems

Steel-vane air pumps have been used for many years to evacuate the instrument cases. The discharge air is used to inflate rubber deicer boots on the wing and empennage leading edges. The vanes in these pumps are lubricated by a small amount of engine oil metered into the pump and this oil is discharged with the air. To keep the oil from deteriorating the rubber boots, it must be removed with an oil separator like the one in figure 3-27.

The vacuum pump moves a greater volume of air than is needed to supply the instruments with the suction needed, so a **suction-relief valve** is installed in the inlet side of the pump. This spring-loaded valve draws in just enough air to maintain the required low pressure inside the instruments, as is shown on the suction gauge in the instrument panel. Filtered air enters the instrument cases from a central air filter. As long as aircraft fly at relatively low altitudes, enough air is drawn into the instrument cases to spin the gyros at a sufficiently high speed.

Dry-Air Pump Systems

As flight altitudes increase, the air is less dense and more air must be forced through the instruments. Air pumps that do not mix oil with the discharge air are used in high-flying aircraft.

Steel vanes sliding in a steel housing need to be lubricated, but vanes made of a special formulation of carbon sliding inside a carbon housing provide their own lubrication as they wear in a microscopic amount.

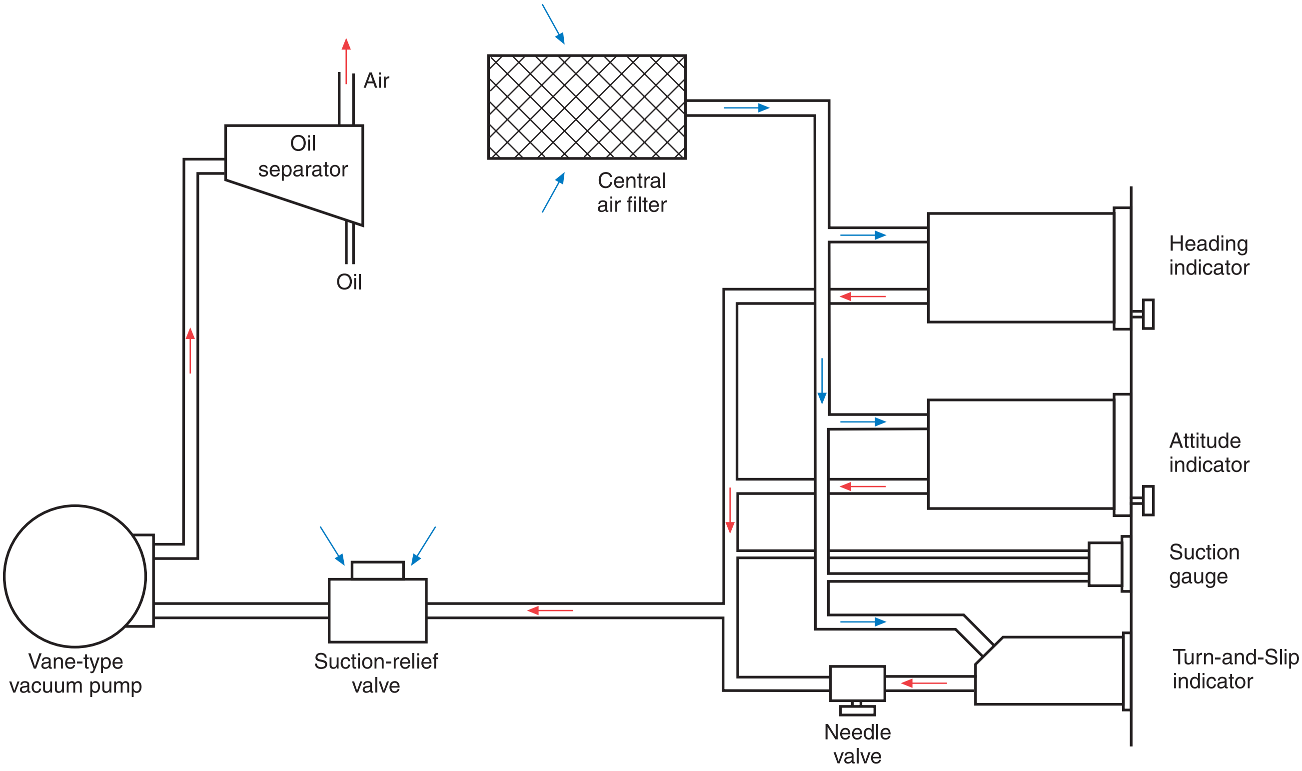


Figure 3-27. *Single-engine instrument vacuum system using a steel-vane wet-type vacuum pump.*

Suction-relief valve: A relief valve in an instrument vacuum system to maintain the correct low pressure inside the instrument case for the proper operation of the gyros.

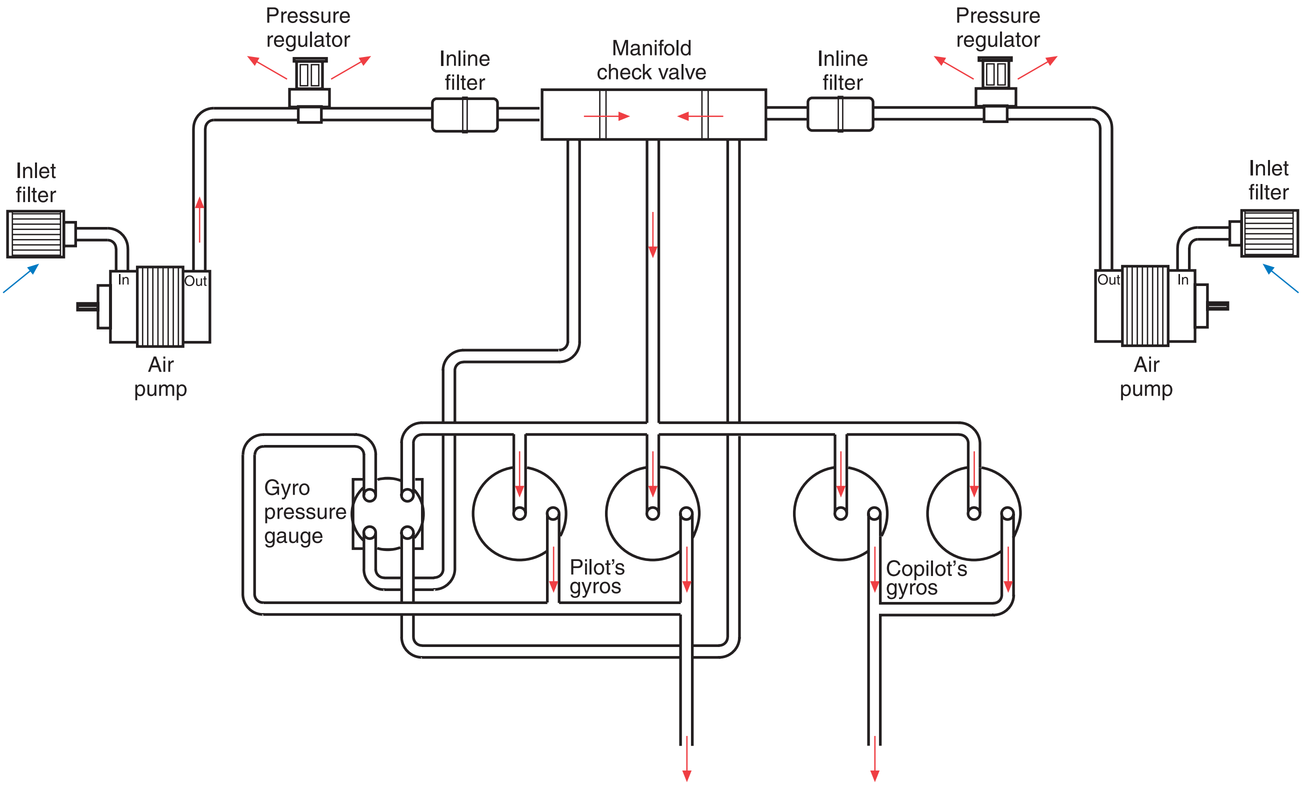


Figure 3-28. *Twin-engine instrument pressure system using a carbon-vane dry-type air pump.*

Pressure Systems

Figure 3-28 is a diagram of the instrument pneumatic system of a twin-engine general aviation airplane. Two dry air pumps are used with filters in their inlet to filter out any contaminants that could damage the fragile carbon vanes in the pump. The discharge air from the pump flows through a regulator, where excess air is bled off to maintain the pressure in the system at the desired level. The regulated air then flows through inline filters to remove any contamination that could have been picked up from the pump, and from there into a manifold check valve. If either engine should become inoperative, or if either pump should fail, the check valve will isolate the inoperative system and the instruments will be driven by air from the operating system. After the air passes through the instruments and drives the gyros, it is exhausted from the case. The gyro pressure gauge measures the pressure drop across the instruments.

Gyroscopic Instruments

Attitude Indicators

The first attitude instrument (AI) was originally referred to as an artificial horizon, later as a gyro horizon; now it is more properly called an attitude indicator. Its operating mechanism is a small brass wheel with a vertical spin axis, spun at a high speed by either a stream of air impinging on buckets cut into its periphery, or by an electric motor. The 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. On the early instruments, this was just a bar that represented the horizon, but now it is a disc with a line representing the horizon and both pitch marks and bank-angle lines. The top half of the instrument dial and horizon disc is blue, representing the sky; and the bottom half is brown, representing

Double gimbal: A type of mount used for the gyro in an attitude instrument. The axes of the two gimbals are at right angles to the spin axis of the gyro allowing free motion in two planes around the gyro.

the ground. A bank index at the top of the instrument shows the angle of bank marked on the banking scale with lines that represent 10°, 20°, 30°, 60°, and 90°. [Figure 3-29]

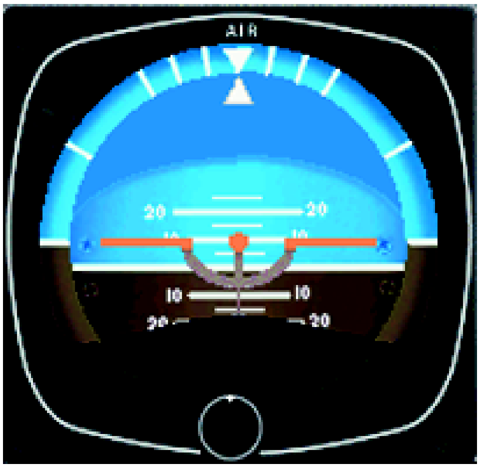


Figure 3-29. *The dial of this attitude indicator has reference lines to show pitch and roll.*

A small symbolic aircraft is mounted in the instrument case so it appears to be flying relative to the horizon. 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°.

For an AI to function properly, the gyro must remain vertically upright while the aircraft rolls and pitches around it. The bearings in these instruments have a minimum of friction; however, even this small amount places a restraint on the gyro which produces a precessive force 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.

The older artificial horizons were limited in the amount of pitch or roll they could tolerate, normally about 60° in pitch and 100° in roll. After either of these limits was exceeded, the gyro housing contacted the gimbal, applying such a precessive force that the gyro tumbled. Because of this limitation, these instruments had a caging mechanism that locked the gyro in its vertical position during any maneuvers that exceeded the instrument limits. Newer instruments do not have these restrictive tumble limits; therefore, they do not have a caging mechanism.

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 precessive 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 indicators are free from most errors, but depending upon the speed with which the erection system functions, there may be a slight nose-up indication during a rapid acceleration and a nose-down indication during a rapid deceleration. There is also a possibility of a small bank angle and pitch error after a 180° turn. These inherent errors are small and correct themselves within a minute or so after returning to straight-and-level flight.

Heading Indicators

A magnetic compass is a dependable instrument and is used as a backup instrument. But it has so many inherent errors that it has been supplemented with gyroscopic heading indicators.

The gyro in an attitude indicator is mounted in a double gimbal in such a way that its spin axis is *vertical*. It senses pitch and roll, but cannot sense rotation about its vertical, or spin, axis. The gyro in a heading indicator is also mounted in a double gimbal, but its spin axis is *horizontal*, and it senses rotation about the vertical axis of the aircraft.

Gyro heading indicators, with the exception of slaved gyro indicators, are not north-seeking, and they must be set to the appropriate heading by referring to a magnetic compass. Rigidity causes them to maintain this heading indication, without the oscillation and other errors inherent in a magnetic compass.

Older directional gyros use a drum-like card marked in the same way as the magnetic compass card. The gyro and the card remain rigid inside the case, and you view the card from the back. This allows the possibility you might start a turn in the wrong direction. A knob on the front of the instrument, below the dial, can be pushed in to engage the gimbals. This locks the gimbals and allows you to rotate the gyro and card until the number opposite the lubber line is the same as that of the magnetic compass. When the knob is pulled out, the gyro remains rigid and the aircraft is free to turn around the card.

Directional gyros are almost all 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. Bearing friction causes the gyro to precess and the indication to drift. When using these instruments, it is standard practice to reset them to agree with the magnetic compass about every 15 minutes.

Heading indicators like the one in figure 3-30 work on the same principle as the older horizontal card indicators, except that the gyro drives a vertical dial that looks much like the dial of a vertical card magnetic compass. The heading of the aircraft is shown against the nose of the symbolic aircraft on the instrument glass, which serves as the lubber line. A knob in the front of the instrument may be pushed in and turned to rotate the gyro and dial. The knob is spring-loaded so it will disengage from the gimbals as soon as it is released. This instrument should be checked about every 15 minutes to see if it agrees with the magnetic compass.

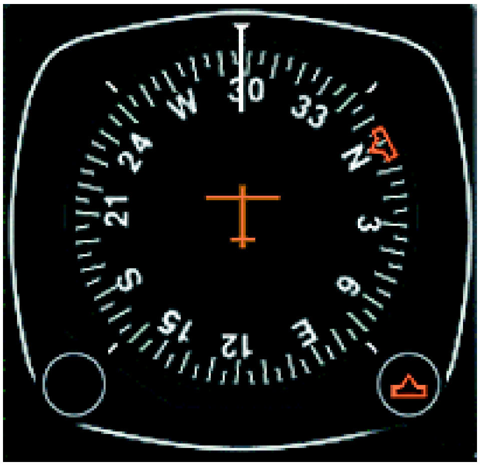


Figure 3-30. *The heading indicator is not north-seeking, but must be set to agree with the magnetic compass.*

Turn Indicators

Attitude and heading indicators function on the principle of rigidity, but rate instruments such as the turn-and-slip indicator operate on precession. Precession is the characteristic of a gyroscope that causes an applied force to produce a movement, not at the point of application, but at a point 90° from the point of application in the direction of rotation. [Figure 3-31]

Turn-and-Slip Indicator

The first gyroscopic aircraft instrument was the turn indicator in the needle and ball, or turn-and-bank indicator, which has more recently been called a turn-and-slip indicator. [Figure 3-32]

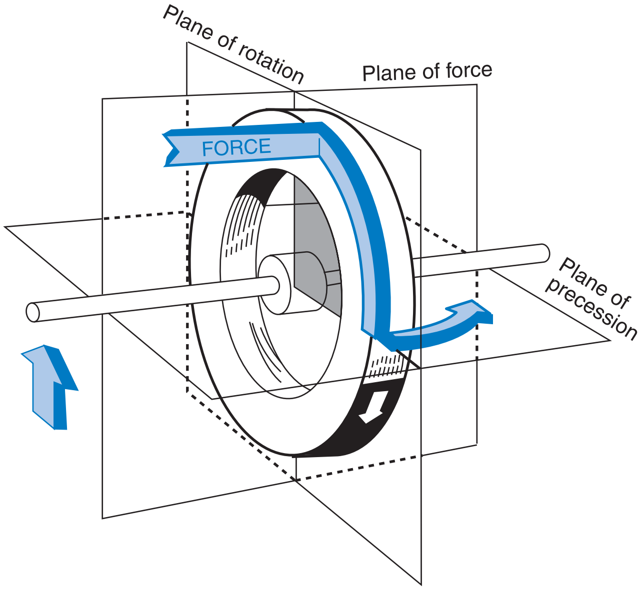


Figure 3-31. *Precession causes a force applied to a spinning wheel to be felt 90° from the point of application in the direction of rotation.*

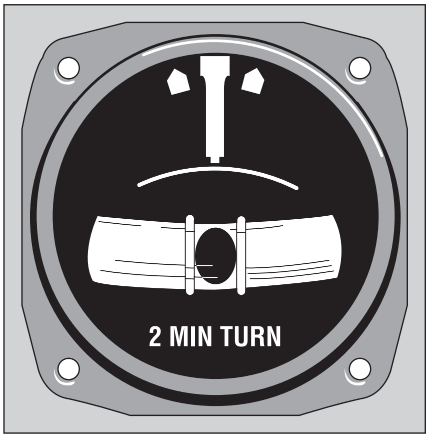


Figure 3-32. *The turn-and-slip indicator.*

The inclinometer in the instrument is a black glass ball sealed inside a curved glass tube that is partially filled with a liquid, much like compass fluid. This ball measures the relative strength of the force of gravity and the force of inertia caused by a turn. 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.

The inclinometer does not indicate the amount of bank, neither is it limited to an indication of slip; it only indicates the relationship between the angle of bank and the rate of yaw.

The turn indicator is a small gyro spun either by air or by an electric motor. The gyro is mounted in a single gimbal with its spin axis parallel to the lateral axis of the aircraft and the axis of the gimbal parallel with the longitudinal axis. [Figure 3-33]

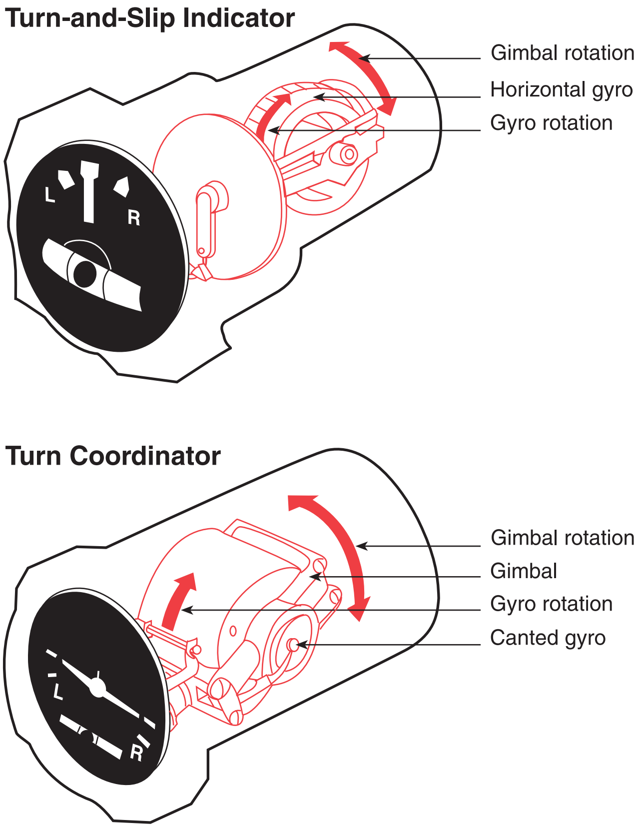


Figure 3-33. *The rate gyro in a turn-and-slip indicator and turn coordinator.*

When the aircraft yaws, or rotates about its vertical axis, it produces a force in the horizontal plane that, due to precession, causes the gyro and its gimbal to rotate about the gimbal axis. It is restrained in this rotation plane by a calibration spring; it rolls over just enough to cause the pointer to deflect until it aligns with one of the **doghouse**-shaped marks on the dial, when the aircraft is making a standard-rate turn.

The dial of these instruments is marked "2 MIN TURN." Some turn-and-slip indicators used in faster aircraft are marked "4 MIN TURN." In either instrument, a standard-rate turn is being made whenever the needle aligns with a doghouse.

Turn Coordinator

The major limitation of the older turn-and-slip indicator is that it senses rotation only about the vertical axis of the aircraft. It tells nothing of the rotation around the longitudinal axis, which in normal flight occurs before the aircraft begins to turn.

A turn coordinator operates on precession, the same as the turn indicator, but its gimbal frame is angled upward about 30° from the longitudinal axis of the aircraft. This allows it to sense both roll and yaw. Some turn coordinator gyros are dual-powered and can be driven by either air or electricity.

Rather than using a needle as an indicator, the gimbal moves a dial on which is the rear view of a symbolic aircraft. The bezel of the instrument is marked to show wings-level flight and bank angles for a standard-rate turn. [Figure 3-34]

Figure 3-34. *A turn coordinator senses rotation about both the roll and yaw axes.*

Doghouse: A mark on the dial of a turn-and-slip indicator that has the shape of a doghouse.

The inclinometer, similar to the one in a turn-and-slip indicator, 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.

A turn coordinator does not sense pitch. This is indicated on some instruments by placing the words "NO PITCH INFORMATION" on the dial.

Flight Director Systems

Horizontal Situation Indicator (HSI)

The HSI is a direction indicator that uses the output from a flux valve to drive the dial, which acts as the compass card. This instrument, shown in figure 3-35, combines the magnetic compass with navigation signals and a glide slope. This gives the pilot an indication of the location of the aircraft with relationship to the chosen course.

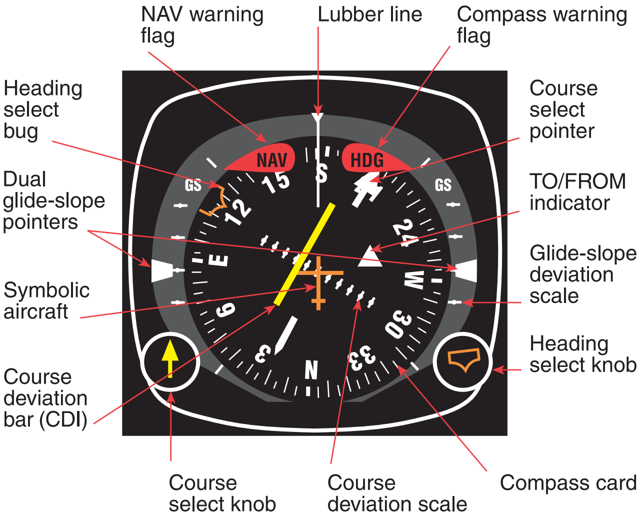


Figure 3-35. *Horizontal situation indicator (HSI).*

In figure 3-35, the aircraft heading displayed on the rotating azimuth card under the upper lubber line is 175°. The course-indicating arrowhead shown is set to 205°; the tail indicates the reciprocal, 025°. The course deviation bar operates with a VOR/Localizer (VOR/LOC) navigation receiver to indicate left or right deviations from the course selected with the course-indicating arrow, operating in the same manner that the angular movement of a conventional VOR/LOC needle indicates deviation from course.

The desired course is selected by rotating the course-indicating arrow in relation to the azimuth card by means of the course select knob. This gives you a pictorial presentation: the fixed aircraft symbol and course deviation bar display the aircraft relative to the selected course, as though you were above the aircraft looking down. The TO/FROM indicator is a triangular-shaped pointer. When the indicator points to the head of the course arrow, it shows that the course selected, if properly intercepted and flown, will take the aircraft to the selected facility. When the indicator points to the tail of the course arrow, it shows that the course selected, if properly intercepted and flown, will take the aircraft directly away from the selected facility.

The glide-slope deviation pointer indicates the relation of the aircraft to the glide slope. When the pointer is below the center position, the aircraft is above the glide slope, and an increased rate of descent is required. In some installations, the azimuth card is a remote indicating compass; however, in others the heading must be checked against the magnetic compass occasionally and reset with the course select knob.

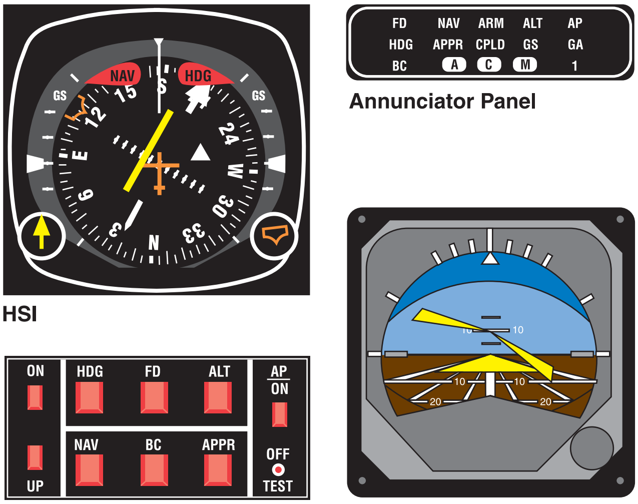
Attitude Director Indicator (ADI)

Advances in attitude instrumentation combine the gyro horizon with other instruments such as the HSI, thereby reducing the number of separate instruments the pilot must devote attention to. The attitude director indicator (ADI) is an example of such an advancement upon the attitude indicator. An integrated flight director system consists of electronic components that compute and indicate the aircraft attitude required to attain and maintain a preselected flight condition.

The ADI in figure 3-36 furnishes the same information as an attitude indicator, but has the additional feature of a set of computer-driven bowtie-shaped steering bars. Instead of the symbolic aircraft, a delta-shaped symbol represents the aircraft being flown.

The mode controller provides signals through the ADI to drive the steering bars. The pilot flies the aircraft to place the delta symbol in the V of the steering bars. "Command" indicators tell the pilot in which direction and how much to change aircraft attitude to achieve the desired result. The computed command indications relieve the pilot of many of the mental calculations required for instrument flight.

The flight director/autopilot system described below is typical of installations in some of the more complex general aviation aircraft. The components in the instrument panel include the mode controller, ADI, HSI, and annunciator panel. These units are illustrated in figure 3-36.



HSI

Annunciator Panel

Mode Controller

ADI

Figure 3-36. *Integrated flight system.*

The mode controller has six pushbutton switches for turning on the flight director system and selection of all modes, a switch for autopilot engagement, a trim switch, and a preflight test button. The ADI displays information regarding pitch-and-roll attitude, pitch-and-roll commands, and decision altitude (when used with a radar altimeter).

The HSI displays slaved gyro magnetic heading information, VOR/LOC/area navigation (RNAV) course deviation, and glide-slope deviation indications. The annunciator panel displays all vertical and lateral flight director/autopilot modes, including all "armed" modes prior to capture. Simply stated, it tells the pilot when the selected mode has been received and accepted by the system, and if an "armed" mode is selected, when capture has been initiated. It also has integral marker beacon lights and a trim failure warning.

A flight control guidance system that consists of either an autopilot with an approach coupler or a flight director system is required for Category II operations.

Instrument Systems Preflight Procedures

Inspecting the instrument system requires a relatively small part of the total time required for preflight activities, but its importance cannot be overemphasized. Before any flight involving aircraft control by instrument reference, you should check all instruments and their sources of power for proper operation.

Before Engine Start

1. Walk-around inspection—check the condition of all antennas and check the pitot tube for the presence of any obstructions and remove the cover. Check the static ports to be sure they are free from dirt and obstructions, and ensure there is nothing on the structure near the ports that would disturb the air flowing over them.
2. Aircraft records—confirm that the altimeter and static system has been checked and found within approved limits within the past 24-calendar months. Check the replacement date for the emergency locator transmitter (ELT) batteries noted in the maintenance record, and be sure they have been replaced within this time interval.
3. Preflight paperwork—check the Airport/Facility Directory (A/FD) and all Notices to Airmen (NOTAMs) for the condition and frequencies of all the navigation aids (NAVAIDs) that will be used on the flight. Handbooks, en route charts, approach charts, computer and flight log should be appropriate for the departure, en route, destination, and alternate airports.
4. Radio equipment—switches off.
5. Suction gauge—proper markings.
6. Airspeed indicator—proper reading.
7. Attitude indicator—uncaged, if applicable.
8. Altimeter—set the current altimeter setting and check that the pointers indicate the elevation of the airport.
9. Vertical speed indicator—zero indication.
10. Heading indicator—uncaged, if applicable.
11. Turn coordinator—miniature aircraft level, ball approximately centered (level terrain).
12. Magnetic compass—full of fluid and the correction card is in place and current.
13. Clock—set to the correct time.
14. Engine instruments—proper markings and readings.
15. Deicing and anti-icing equipment—check availability and fluid quantity.
16. Alternate static-source valve—be sure it can be opened if needed, and that it is fully closed.
17. Pitot tube heater—watch the ammeter when it is turned on, or by using the method specified in the POH/AFM.

After Engine Start

1. When you turn the master switch on—listen to the gyros as they spin up. Any hesitation or unusual noises should be investigated before flight.
2. Suction gauge or electrical indicators—check the source of power for the gyro instruments. The suction developed should be appropriate for the instruments in that particular aircraft. If the gyros are electrically driven, check the generators and inverters for proper operation.
3. Magnetic compass—check the card for freedom of movement and confirm the bowl is full of fluid. Determine compass accuracy by comparing the indicated heading against a known heading (runway heading) while the airplane is stopped or taxiing straight. Remote indicating compasses should also be checked against known headings. Note the compass card correction for the takeoff runway heading.
4. Heading indicator—allow 5 minutes after starting engines for the gyro to spin up. Before taxiing, or while taxiing straight, set the heading indicator to correspond with the magnetic compass heading. A slaved gyro compass should be checked for slaving action and its indications compared with those of the magnetic compass.
5. Attitude indicator—allow the same time as noted above for gyros to spin up. If the horizon bar erects to the horizontal position and remains at the correct position for the attitude of the airplane, or if it begins to vibrate after this attitude is reached and then slowly stops vibrating altogether, the instrument is operating properly.
6. Altimeter—with the altimeter set to the current reported altimeter setting, note any variation between the known field elevation and the altimeter indication. If the variation is on the order of 75 feet, the accuracy of the altimeter is questionable and the problem should be referred to a repair station for evaluation and possible correction. Because the elevation of the ramp or hangar area might differ significantly from field elevation, recheck when in the runup area if the error exceeds 75 feet. When no altimeter setting is available, set the altimeter to the published field elevation during the preflight instrument check.
7. Vertical speed indicator—the instrument should read zero. If it does not, tap the panel gently. If it stays off the zero reading and is not adjustable, the ground indication will have to be interpreted as the zero position in flight.
8. Carburetor heat—check for proper operation and return to cold position.
9. Engine instruments—check for proper readings.
10. Radio equipment—check for proper operation and set as desired.
11. Deicing and anti-icing equipment—check operation.

Taxiing and Takeoff

1. Turn coordinator—during taxi turns, check the miniature aircraft for proper turn indications. The ball should move freely. The ball should move opposite to the direction of turns. The turn instrument should indicate in the direction of the turn. While taxiing straight, the miniature aircraft should be level.
2. Heading indicator—before takeoff, recheck the heading indicator. If your magnetic compass and deviation card are accurate, the heading indicator should show the known taxiway or runway direction when the airplane is aligned with them (within 5°).
3. Attitude indicator—if the horizon bar fails to remain in the horizontal position during straight taxiing, or tips in excess of 5° during taxi turns, the instrument is unreliable. Adjust the miniature aircraft with reference to the horizon bar for the particular airplane while on the ground. For some tricycle-gear airplanes, a slightly nose-low attitude on the ground will give a level flight attitude at normal cruising speed.

Engine Shut Down

When shutting down the engine, note any abnormal instrument indications.