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The Six-Pack Instrument Scan.

What each of the six primary flight instruments actually measures, the plumbing and gyros behind them, how they fail, and how to scan them without fixating on any single one.

Written by pilots, for people learning to fly.
Flightline Studios

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Contents

CHAPTER 01

Why the Six-Pack Is Arranged the Way It Is

Six round instruments, arranged the same way in almost every piston aircraft built since the 1930s, and the arrangement itself, not just the instruments, is what makes a fast scan possible.

Figure 1.1: A real six-pack panel in the basic T. The attitude indicator sits at the crossing point, airspeed to its left, altitude to its right, heading directly below.

The logic behind the layout

The attitude indicator sits at the center of the T because it's the single instrument most representative of what the airplane is actually doing in space, pitch and bank together, in one glance. Airspeed sits to its left and the altimeter to its right, the two performance numbers a pilot cross-checks against attitude most often. The heading indicator sits directly below, and the turn coordinator and vertical speed indicator fill the two remaining corners.

KEY IDEA

The T isn't decorative. It puts the instrument that changes fastest, and matters most, at the pivot point of the scan, with the instruments a pilot checks it against arranged for the shortest possible eye movement.

The rest of this guide covers each instrument individually, the two systems that power them, how each one fails, and finally the scanning technique that ties all six together.

CHAPTER 02

The Airspeed Indicator

The airspeed indicator doesn't measure speed directly. It measures a pressure difference, and translates that difference into a number that looks like a speedometer reading.

What it's actually comparing

Air rushing into the pitot tube creates ram, or impact, pressure. Static pressure, the ambient air pressure around the aircraft, is measured separately through the static port. The airspeed indicator compares the two: ram pressure minus static pressure. The faster the aircraft moves through the air, the greater that difference becomes, and the needle moves accordingly.

> **TIP**
>
> Because the airspeed indicator depends on air density as well as speed, the number it shows, indicated airspeed, isn't the same as true airspeed once you're away from sea level on a standard day. That gap widens the higher and hotter you fly.

Reading the color arcs

The face of the airspeed indicator is marked with colored arcs that turn a bare number into an operating limit at a glance.

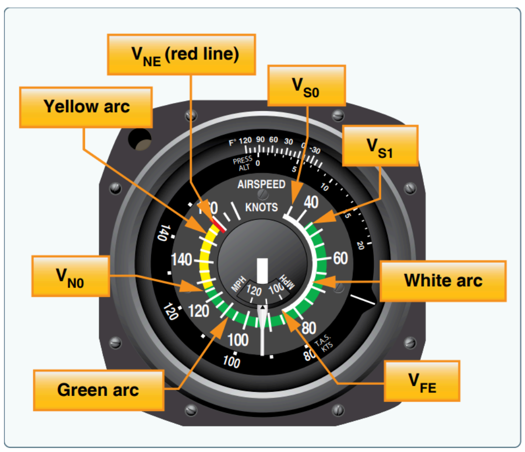

Figure 2.1: A labeled airspeed indicator face from the FAA Pilot's Handbook of Aeronautical Knowledge.

MARKING	SPEED	MEANING
Bottom of white arc	Vso	Stall speed in landing configuration, flaps extended
Top of white arc	Vfe	Maximum flap extended speed
Bottom of green arc	Vs1	Stall speed in clean configuration, flaps and gear retracted
Top of green arc	Vno	Maximum structural cruising speed
Red line	Vne	Never-exceed speed; structural failure becomes a real risk above it

> **COMMON MISTAKE**
>
> Treating the yellow arc as a normal cruise range since it's still below the red line. It's a caution range, safe only in smooth air, since gust loads combined with high speed are what actually threaten the airframe.

CHAPTER 03

The Attitude Indicator

The attitude indicator shows pitch and bank relative to the horizon, using a gyroscope that stays fixed in space while the aircraft, and the instrument case around it, moves around that fixed reference.

Rigidity in space

A spinning gyroscope resists changes to the orientation of its spin axis, a property called rigidity in space. Mounted inside the attitude indicator, the gyro stays oriented to the horizon regardless of how the aircraft pitches or rolls around it. A miniature horizon bar, attached to the gyro's frame, appears to move against a fixed miniature airplane symbol, when in reality it's the instrument case, and the real airplane around it, doing the moving.

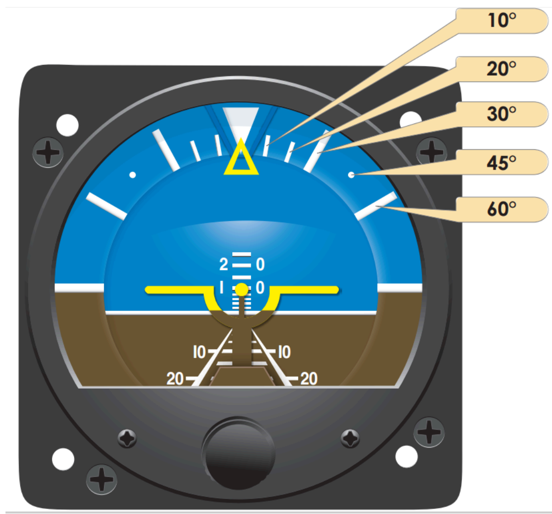

Figure 3.1: The attitude indicator face from the FAA Instrument Flying Handbook, with its bank-angle index marks labeled at 10°, 20°, 30°, 45°, and 60°.

> **KEY IDEA**
>
> The attitude indicator is the only instrument in the six-pack that shows both pitch and bank in a single glance, which is exactly why it sits at the center of the T and functions as the primary control instrument in the scanning technique covered in Chapter 12.

Depending on the aircraft, this gyro is spun by engine-driven vacuum suction (Chapter 9) or by an electrical source. Either way, the instrument depends entirely on that spin being maintained, which is why a slow spin-down produces one of the more dangerous, easy-to-miss failures covered in Chapter 11.

CHAPTER 04

The Altimeter

The altimeter is, at its core, a barometer with a dial calibrated in feet instead of inches of mercury. It measures static air pressure and converts that pressure into an altitude reading.

Why it needs to be set

Because atmospheric pressure at a given altitude changes with weather, the altimeter has an adjustable setting, the Kollsman window, that lets a pilot dial in the current local altimeter setting. Without that adjustment, the same physical altitude could display a different number depending on the day's pressure, which is why altimeter settings are updated and cross-checked throughout a flight, especially during descent and approach.

COMMON MISTAKE

Treating the altimeter as a direct, infallible measurement of height above the ground. It measures pressure, converted to altitude using an assumed standard atmosphere and whatever local setting is currently dialed in. Both of those are approximations, not perfect measurements.

The number on the dial isn't the only altitude

"Altitude" actually refers to several distinct values, and the altimeter only ever shows one of them directly.

TYPE	WHAT IT IS
Indicated altitude	The number read directly off the altimeter with the current local setting dialed in
True altitude	Actual height above mean sea level, what charted terrain and obstacle heights are expressed in
Absolute altitude	Height above the ground directly below the aircraft, in feet AGL
Pressure altitude	Height above the standard datum plane, read with 29.92 dialed in regardless of the actual local setting
Density altitude	Pressure altitude corrected for non-standard temperature, the figure that actually governs aircraft performance

The altimeter shares its static pressure source with the airspeed indicator and the vertical speed indicator, which is exactly why a static system problem, covered in Chapter 10, affects all three at once rather than just one.

CHAPTER 05

The Turn Coordinator

The turn coordinator does two jobs in one instrument: a miniature airplane symbol shows rate of roll and rate of turn together, and an inclinometer ball underneath shows whether that turn is actually coordinated.

Rate, not angle

Unlike the attitude indicator, which shows bank angle, the turn coordinator's gyro is mounted at roughly a 30-degree angle to the aircraft's longitudinal axis, which makes it sensitive to rate of roll as well as rate of turn. A standard rate turn, 3 degrees per second, a full 360-degree turn in exactly two minutes, is marked directly on the instrument, giving a pilot a specific, repeatable target rather than an abstract bank angle.

Figure 5.1: A real turn coordinator face. The miniature airplane banks to show roll and turn rate; the doghouse marks show where to level the wings for a standard rate turn.

The ball underneath

The inclinometer ball responds to the balance between gravity and the centrifugal force of the turn. A centered ball means the turn is coordinated, both forces balanced. A ball displaced to the inside of the turn means the turn is slipping; displaced to the outside means it's skidding.

> **TIP**
>
> "Step on the ball" is the standard memory aid: apply rudder pressure on whichever side the ball has moved toward to recenter it and coordinate the turn.

CHAPTER 06

The Heading Indicator

The heading indicator, also called the directional gyro, uses a gyroscope's rigidity in space the same way the attitude indicator does, but oriented to display compass heading instead of pitch and bank.

A gyro that's built to drift

Two things cause the heading indicator to drift away from actual heading over time: internal friction, and the simple fact that the earth itself is rotating underneath a gyro that's staying fixed in space. Left uncorrected, that drift accumulates at a rate of roughly 15 degrees per hour, meaning a heading indicator can be off by several degrees after just fifteen or twenty minutes.

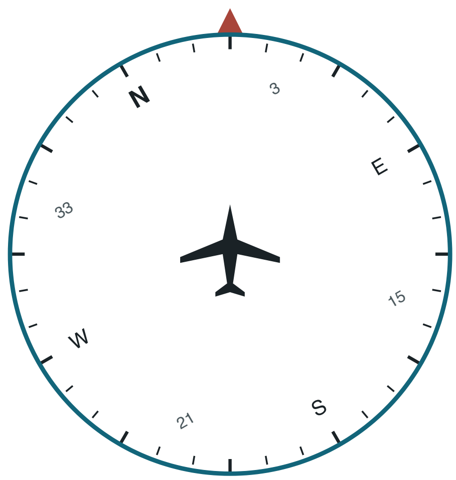

Figure 6.1: Shown reading roughly 030°. The card itself rotates underneath a fixed miniature airplane, the reverse of how the attitude indicator's symbol works.

> **KEY IDEA**
> This drift isn't a malfunction, it's an inherent property of how the instrument works. Every heading indicator needs periodic realignment against the magnetic compass, roughly every 15 minutes, as a routine part of flying, not a response to a problem.

Because the magnetic compass itself is subject to its own errors in turns and during acceleration, the realignment is best done in stable, straight-and-level, unaccelerated flight.

Why the compass needs stable flight to be trusted

The magnetic compass has two well-known errors, both caused by magnetic dip pulling the compass card toward the earth. Two memory aids sum them up. UNOS: undershoot north, overshoot south, meaning the compass lags the turn when rolling out on a northerly heading and leads it on a southerly one, so the roll-out point has to be adjusted accordingly. ANDS: accelerate north, decelerate south, meaning on an east or west heading, simply speeding up or slowing down makes the compass swing as though the aircraft were turning, even in perfectly straight flight.

> **TIP**
> Both errors are why the heading indicator gets realigned to the compass only in stable, unaccelerated, straight-and-level flight. Realigning during a turn or right after a speed change means aligning the more reliable instrument to the less reliable one at exactly the moment the less reliable one is wrong.

CHAPTER 07

The Vertical Speed Indicator

The vertical speed indicator measures the rate at which static pressure is changing, and displays that rate as feet per minute of climb or descent.

A rate instrument, not a position instrument

Where the altimeter shows a static pressure reading converted to a specific altitude, the VSI shows how quickly that pressure, and therefore altitude, is changing. Because it depends on the rate of change rather than an instantaneous value, the VSI typically lags a few seconds behind an actual change in climb or descent rate, settling onto an accurate trend rather than snapping to it instantly.

> **TIP**
>
> That short lag makes the VSI most useful as a trend instrument, confirming a climb or descent is stabilizing at the rate you intend, rather than as the first instrument you check to notice that a climb or descent has started. The altimeter and attitude indicator typically show that first.

Using it to plan a descent

Beyond confirming a stabilized climb or descent, the VSI is the instrument most directly used to plan one. A simple rule of thumb, dividing the altitude to lose by the minutes available, or multiplying groundspeed by a target descent gradient, gives a target vertical speed that can be dialed in and held, turning "start descending at some point" into a specific, repeatable number to fly.

Like the altimeter and airspeed indicator, the VSI draws from the static side of the pitot-static system, covered next.

CHAPTER 08

The Pitot-Static System

Three of the six instruments, airspeed, altitude, and vertical speed, all draw from the same physical plumbing: a pitot tube for ram air pressure, and one or more static ports for ambient air pressure.

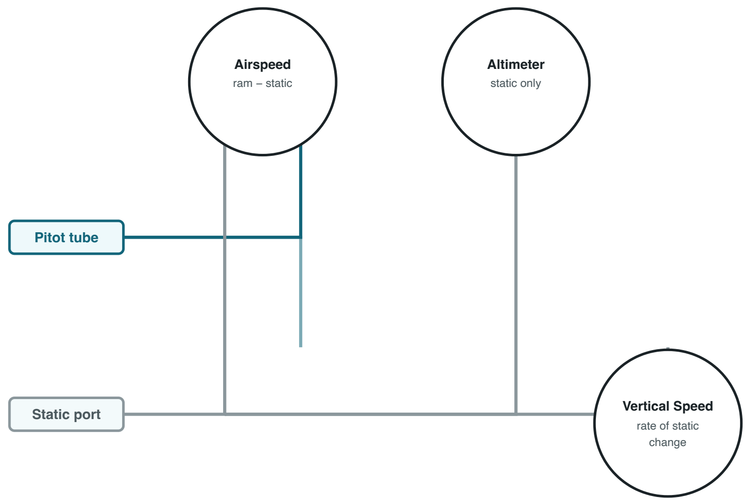

Figure 8.1: One pitot line and one static line, plumbed to three separate instruments. Only the airspeed indicator uses both pressures at once.

Split at the source, shared downstream

The pitot line runs only to the airspeed indicator, since that's the only instrument that needs ram air pressure. The static line runs to all three: the airspeed indicator, where it's compared against ram pressure, and the altimeter and VSI, where static pressure is the only input.

> **KEY IDEA**
> Because the static line feeds three instruments at once, a static system problem rarely affects just one gauge. That shared plumbing is exactly why Chapter 10 groups pitot-static failures by which line is blocked, not by which instrument is acting up.

Most aircraft also include pitot heat, to prevent ice from blocking the pitot tube, and an alternate static source, an alternate air path a pilot can select from inside the cabin if the primary static port becomes blocked. Both are covered as failure responses in Chapter 10.

CHAPTER 09

The Vacuum System

The attitude indicator and heading indicator both rely on a spinning gyroscope, and in most piston singles, that spin is produced not by an electric motor but by suction: the vacuum system.

How suction spins a gyro

An engine-driven vacuum pump lowers the pressure inside each gyro instrument's case. Filtered outside air is then drawn in through a small nozzle aimed at cups machined around the edge of the gyro rotor, and the pressure differential accelerates the rotor to a high operating speed, the same basic principle as a small air-driven turbine.

> **TIP**
>
> The turn coordinator's gyro, by contrast, is almost always electrically driven rather than vacuum driven in most general aviation singles. That's a deliberate redundancy: a single vacuum pump failure takes out the attitude and heading indicators but leaves the electrically powered turn coordinator working, giving a pilot at least one reliable gyroscopic reference.

Because both major gyro instruments on most panels can share the same vacuum pump, a vacuum failure is a single point of failure with two consequences at once, which is exactly why it's treated as its own category of failure in Chapter 11 rather than folded into pitot-static issues.

CHAPTER 10

Pitot-Static Failures

Because the pitot and static lines are separate but shared, the effect of a blockage depends entirely on which line it's in, and whether the drain hole on the pitot tube stays open.

FAILURE	EFFECT
Pitot tube blocked, drain hole open	Airspeed indicator drops to and stays at zero; altimeter and VSI unaffected
Pitot tube and drain hole both blocked	Airspeed indicator behaves like a second altimeter, rising in a climb and falling in a descent, with no accurate airspeed reading at all
Static port blocked	Altimeter and VSI both freeze at the pressure trapped when the blockage occurred; airspeed reads low above that altitude and high below it
Alternate static source selected	Altimeter and airspeed both read slightly higher than actual, VSI shows a momentary climb, due to lower pressure inside an unpressurized cabin

COMMON MISTAKE

Assuming a frozen altimeter reading means the aircraft has actually stopped climbing or descending. A frozen altimeter during a static blockage means the instrument is reporting old, trapped pressure, not that altitude has stopped changing.

KEY IDEA

A static blockage affects three instruments simultaneously in ways that don't obviously look related at first glance, altimeter frozen, VSI frozen at zero, airspeed reading wrong in a specific direction. Recognizing that pattern across three instruments at once, rather than troubleshooting each one separately, is what actually points to a static system problem.

CHAPTER 11

Vacuum and Gyroscopic Failures

A vacuum pump failure is dangerous specifically because it's gradual. The gyro doesn't stop instantly, it spins down slowly, and the attitude indicator can continue giving a plausible, subtly wrong picture for several minutes.

COMMON MISTAKE

Trusting the attitude indicator by default without cross-checking it. A slowly failing gyro can show a believable, gently wrong attitude for long enough that a pilot flying purely by that one instrument doesn't notice anything is wrong until the error has become significant.

Most aircraft equipped with a vacuum system include a vacuum gauge or a suction warning flag, and checking it periodically is the most direct way to catch a failing pump before the gyro instruments themselves start drifting. Cross-checking the attitude indicator against other instruments, airspeed trend, altimeter trend, turn coordinator, rather than treating it as unquestionable, is the practical defense described further in Chapter 12's scanning technique.

TIP

Because the turn coordinator is typically electrically powered rather than vacuum powered, it often remains reliable through a vacuum failure and becomes one of the few working cross-checks for bank and turn rate until the aircraft is back on the ground.

CHAPTER 12

Scanning the Panel

Six instruments are useless if a pilot stares at only one of them. The scan is what turns six separate readings into a single coherent picture of what the airplane is doing.

Control and performance instruments

One useful way to organize a scan is to divide instruments into two roles. Control instruments, primarily the attitude indicator, show the aircraft's current pitch and bank and are used to set and hold a desired attitude. Performance instruments, airspeed, altimeter, heading indicator, turn coordinator, and VSI, show the result of that attitude and confirm whether it's producing the outcome intended.

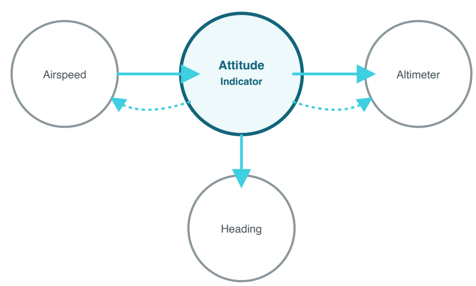

Figure 12.1: The scan radiates out from the attitude indicator and back, rather than moving instrument to instrument around the panel.

Radiating out, and back

Rather than moving eyes around the panel in a fixed loop, an effective scan keeps returning to the attitude indicator between glances at each performance instrument, checking one, confirming it against the attitude being held, then returning to center before checking the next. Which instrument gets checked most often shifts with what the aircraft is doing: a climb weights the airspeed indicator and altimeter more heavily, a turn to a heading weights the turn coordinator and heading indicator more heavily.

> **TIP**
>
> A scan that lingers too long on any single instrument, including the attitude indicator itself, is a fixation, and fixation is one of the most common ways small errors on other instruments go unnoticed until they've become large ones.

CHAPTER 13

Common Mistakes and Practical Tips

Most of the trouble pilots run into with the six-pack isn't a knowledge gap about any single instrument. It's a handful of habits that break the scan itself.

- **Fixating on one instrument.** Usually the attitude indicator, sometimes the altimeter during a critical descent, but any instrument held too long stops functioning as part of a scan.
- **Skipping the heading indicator realignment.** A gyro drifting 15 degrees an hour compounds fast if it's not checked against the compass regularly.
- **Trusting a slowly failing attitude indicator.** A vacuum pump dying gradually doesn't announce itself, cross-checking against other instruments is what catches it.
- **Misreading a frozen altimeter as level flight.** A static blockage freezes the display, it doesn't freeze the airplane.
- **Forgetting the ball.** A coordinated turn depends on the inclinometer as much as the miniature airplane above it.

> **TIP**
>
> The six-pack has looked the same for nearly a century for a reason: it rewards a scan built on repetition and cross-check, not on staring hardest at whichever gauge feels most important in the moment.

The next section covers every term from this guide in one place, followed by practice questions covering all thirteen chapters.

Glossary

Six-pack
The six primary flight instruments: airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, and vertical speed indicator.

Basic T
The standard panel layout placing the attitude indicator at the center, airspeed left, altimeter right, heading below.

Pitot tube
A forward-facing probe that measures ram, or impact, air pressure.

Static port
A port measuring ambient, undisturbed air pressure.

Vso
Stall speed in the landing configuration with flaps extended; the bottom of the white arc.

Vfe
Maximum flap extended speed; the top of the white arc.

Vs1
Stall speed in the clean configuration; the bottom of the green arc.

Vno
Maximum structural cruising speed; the top of the green arc and start of the yellow caution range.

Vne
Never-exceed speed, marked with a red line; structural failure becomes a real risk above it.

Rigidity in space
A spinning gyroscope's tendency to resist changes to its spin axis orientation.

Precession
The gradual drift of a gyroscopic instrument's reading, caused by friction and the earth's rotation.

Standard rate turn
A turn at 3 degrees per second, completing a 360-degree turn in exactly two minutes.

Inclinometer
The ball-in-tube instrument beneath the turn coordinator's miniature airplane, showing coordinated, slipping, or skidding flight.

UNOS
Undershoot north, overshoot south: the compass's turning error on northerly and southerly headings.

ANDS
Accelerate north, decelerate south: the compass's acceleration error on east or west headings.

Indicated altitude
The altimeter reading with the current local setting dialed in.

True altitude
Actual height above mean sea level.

Density altitude
Pressure altitude corrected for non-standard temperature; the figure that governs actual aircraft performance.

Vacuum system
An engine-driven suction system that spins the attitude and heading indicator gyros.

Alternate static source
A backup static pressure source, usually drawing from inside the cabin, selected when the primary static port is blocked.

Control instrument
An instrument, primarily the attitude indicator, used to set and hold a desired aircraft attitude.

Performance instrument
An instrument that shows the result an attitude is producing, used to confirm and refine the control instrument's setting.

Fixation
Lingering on one instrument too long during a scan, allowing errors elsewhere to go unnoticed.

Practice Questions

Sixteen questions covering everything in this guide. Answers and explanations follow on the next page.

1. In the basic T layout, which instrument sits at the center?

A. The altimeter
B. The attitude indicator
C. The heading indicator
D. The turn coordinator

2. The airspeed indicator displays a speed by measuring:

A. Engine RPM
B. The difference between ram and static pressure
C. GPS ground speed
D. Static pressure alone

3. The attitude indicator's gyro stays oriented to the horizon because of:

A. Magnetism
B. Rigidity in space
C. Static pressure
D. GPS correction

4. The altimeter measures altitude by measuring:

A. Ram air pressure
B. Static air pressure
C. Engine manifold pressure
D. Outside air temperature only

5. A standard rate turn is:

A. 1 degree per second
B. 3 degrees per second
C. 10 degrees per second
D. Whatever bank angle feels comfortable

6. A centered inclinometer ball indicates:

A. A skidding turn
B. A slipping turn
C. A coordinated turn
D. Straight and level flight only

7. Left uncorrected, a heading indicator typically drifts at approximately:

A. 1 degree per hour
B. 15 degrees per hour
C. 60 degrees per hour
D. It never drifts

8. The vertical speed indicator measures:

A. Ram air pressure directly
B. The rate of change of static pressure
C. Engine RPM
D. Bank angle

9. Which instruments draw from the static side of the pitot-static system?

A. Attitude indicator only
B. Turn coordinator only
C. Airspeed indicator, altimeter, and VSI
D. Heading indicator only

10. A vacuum system's primary purpose is to:

A. Cool the engine
B. Spin the gyros in the attitude and heading indicators
C. Pressurize the pitot tube
D. Power the radios

11. If the pitot tube is blocked but its drain hole remains open:

A. The airspeed indicator drops to and stays at zero
B. The airspeed indicator reads too high
C. The altimeter freezes
D. The VSI shows a false climb

12. If the static port is blocked, the altimeter will:

A. Read accurately regardless
B. Freeze at the pressure trapped when the blockage occurred
C. Immediately drop to zero
D. Only be affected during climbs

13. Selecting the alternate static source typically causes the altimeter and airspeed to:

A. Read exactly the same as before
B. Read slightly higher than actual
C. Read slightly lower than actual
D. Stop working entirely

14. A failing vacuum pump is particularly dangerous because:

A. It fails instantly with an obvious warning
B. The gyro spins down gradually, giving a plausible but wrong picture for a while
C. It only affects the turn coordinator
D. It has no effect on the attitude indicator

15. In the control and performance scanning method, the attitude indicator functions as:

A. A performance instrument only
B. The control instrument
C. An instrument that should be ignored during turns
D. A backup to the turn coordinator

16. Lingering too long on a single instrument during a scan is called:

A. Precession

B. Coordination

C. Fixation

D. Rigidity

Answer Key

1. B, the attitude indicator. It sits at the crossing point of the T, with airspeed to its left, altimeter to its right, and heading below.

2. B, the difference between ram and static pressure. The greater that difference, the higher the indicated speed.

3. B, rigidity in space. The spinning gyro resists changes to its orientation while the aircraft moves around it.

4. B, static air pressure. Converted to a displayed altitude using a standard atmosphere and the current local setting.

5. B, 3 degrees per second. A full 360-degree turn in exactly two minutes.

6. C, a coordinated turn. Gravity and centrifugal force are balanced when the ball sits centered.

7. B, approximately 15 degrees per hour. Which is why realigning against the magnetic compass roughly every 15 minutes is standard practice.

8. B, the rate of change of static pressure. Displayed as feet per minute of climb or descent.

9. C, airspeed indicator, altimeter, and VSI. The airspeed indicator also uses ram pressure; the other two use static pressure only.

10. B, spin the gyros in the attitude and heading indicators. Using engine-driven suction to accelerate the gyro rotors.

11. A, the airspeed indicator drops to and stays at zero. With the drain hole open, trapped pressure doesn't build up behind the blockage.

12. B, freeze at the pressure trapped when the blockage occurred. The VSI freezes at zero as well, since it depends on the same static pressure.

13. B, read slightly higher than actual. Because cabin pressure is slightly lower than true outside static pressure.

14. B, the gyro spins down gradually, giving a plausible but wrong picture for a while. Which is exactly why the failure is easy to miss without a deliberate cross-check.

15. B, the control instrument. Used to set and hold attitude, with the other five acting as performance instruments confirming the result.

16. C, fixation. Staying on one instrument too long lets errors elsewhere in the scan go unnoticed.

Six gauges, one picture.

None of these six instruments tells the whole story alone. Understanding what each one actually measures, and how they're wired and plumbed together, is what turns a panel scan from a habit into something you can reason through when one of them stops telling the truth.

This is the fourth release in an ongoing series of free aviation study material from Flightline Studios. More topics are on the way.

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