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How to Troubleshoot the Gyro Instruments

Understand the workings of your aircraft's gyro instruments to improve safety of flight.

By David A. Lombardo

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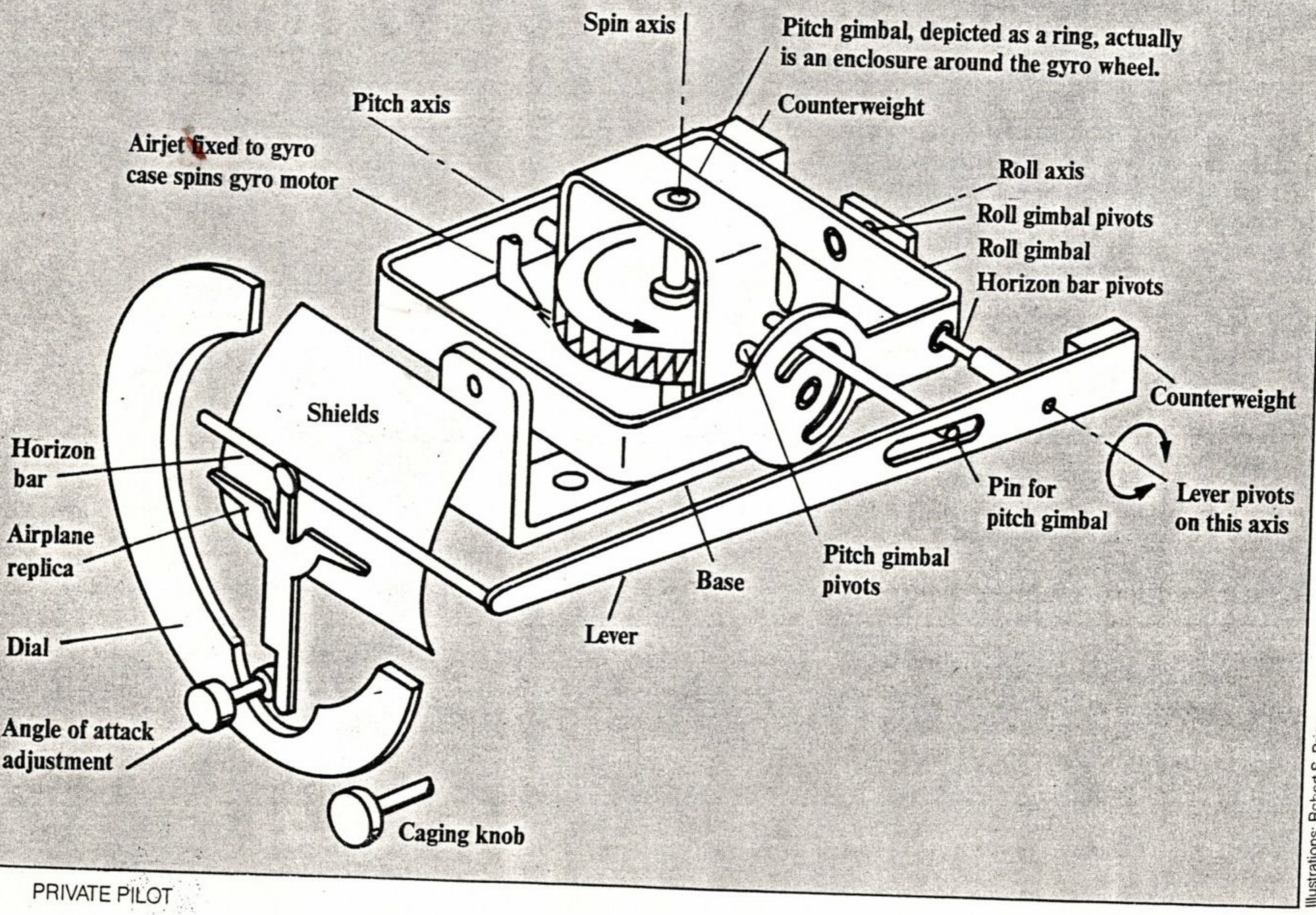
There are several problems associated with the attitude indicator, primarily in the form of bank and pitch errors. They are most significant during shallow banks and after 180° turns. The instrument will indicate slightly less than the actual bank of the aircraft and, after rollout from a 180° turn, it will indicate a slight bank in the opposite direction. The instrument also will deviate slightly in its pitch reading, causing the uninformed pilot to fly the airplane into a shallow descent. It is imperative that

Figure 1—Air-Driven Attitude Indicator



Illustrations: Robert S. Price

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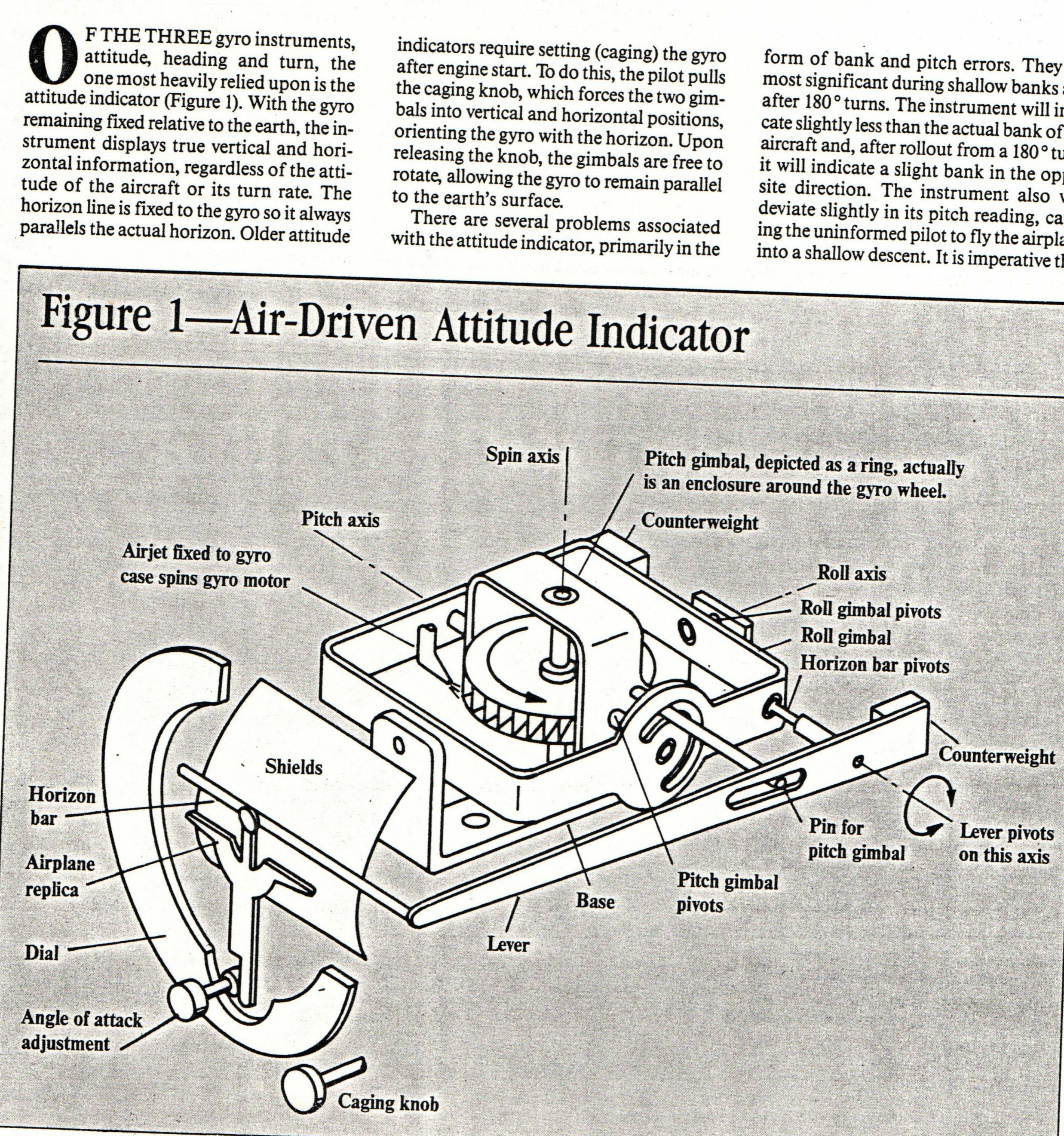


Illustrations: Robert S. Brig

information derived from the attitude indicator always be substantiated with a good cross-check of other instruments. Fortunately, the errors are very small and a built-in erecting mechanism will correct them quickly once straight-and-level flight has been re-established.

There also are acceleration and deceleration errors: as the aircraft accelerates, the attitude indicator tends to give an erroneous, slightly nose-up indication; deceleration has the opposite effect. It is important to realize that the attitude indicator only *approximates* the actual aircraft attitude, however pilots traditionally have relied excessively on the instrument, occasionally finding themselves helpless without it. Several years ago, while flying over Atlanta, Georgia, on a clear morning, I chanced to overhear a student pilot declare an in-flight emergency. When the controller asked the nature of the emergency, the student somewhat shakily explained that the aircraft's attitude indicator had just failed and he was lost over the city on his first solo flight. The controller had to explain to him that he could parallel the airplane's wing struts with the ground to make turns and he would be safe.

The heading indicator, which is not a magnetic (north-seeking) instrument, must be set to a compass (Figure 2). The gyro then holds its position while the aircraft literally moves around it. The instrument needs to be reset periodically, because of both random and apparent drift. Random drift is caused by bearing friction and slight imbalances in the gyro and its gimbals.

Apparent drift is caused by several things. The rotation of the Earth is responsible for some apparent drift. At the equator, there is zero effect, but as the aircraft operates farther and farther away from the equator, the drift increases until, at the north and south poles, there is as much as 15° of drift per hour.

The slip indicator is an inclinometer and is not connected to the gyro system at all.

A second cause of apparent drift is the aircraft changing positions over the Earth. To minimize this, the instrument technician balances the gimbal rings to compensate for local drift. If the aircraft is flown to the opposite hemisphere, or even a different part of the country, the error may become quite pronounced. Changes in excess of 50° latitude necessitate recalibration of the instrument.

It is worth noting that checking for precession (drift) is not quite as simple as one might think. The average pilot will set the heading indicator before takeoff and check it against the magnetic compass 15 or 20 minutes later. Based on the comparison, a judgment as to the instrument's accuracy is made, which is like comparing apples and oranges as the saying goes.

To accurately check for gyroscopic precession, the pilot should turn the aircraft to the same heading used to set the heading indicator originally. This is because compass deviation varies with heading; the error you are seeing may be the result of a different compass deviation at the present heading.

There also is compass variation, the result of crossing isogonic lines. If you are flying cross-country, this definitely should be taken into account when calculating the amount of precession.

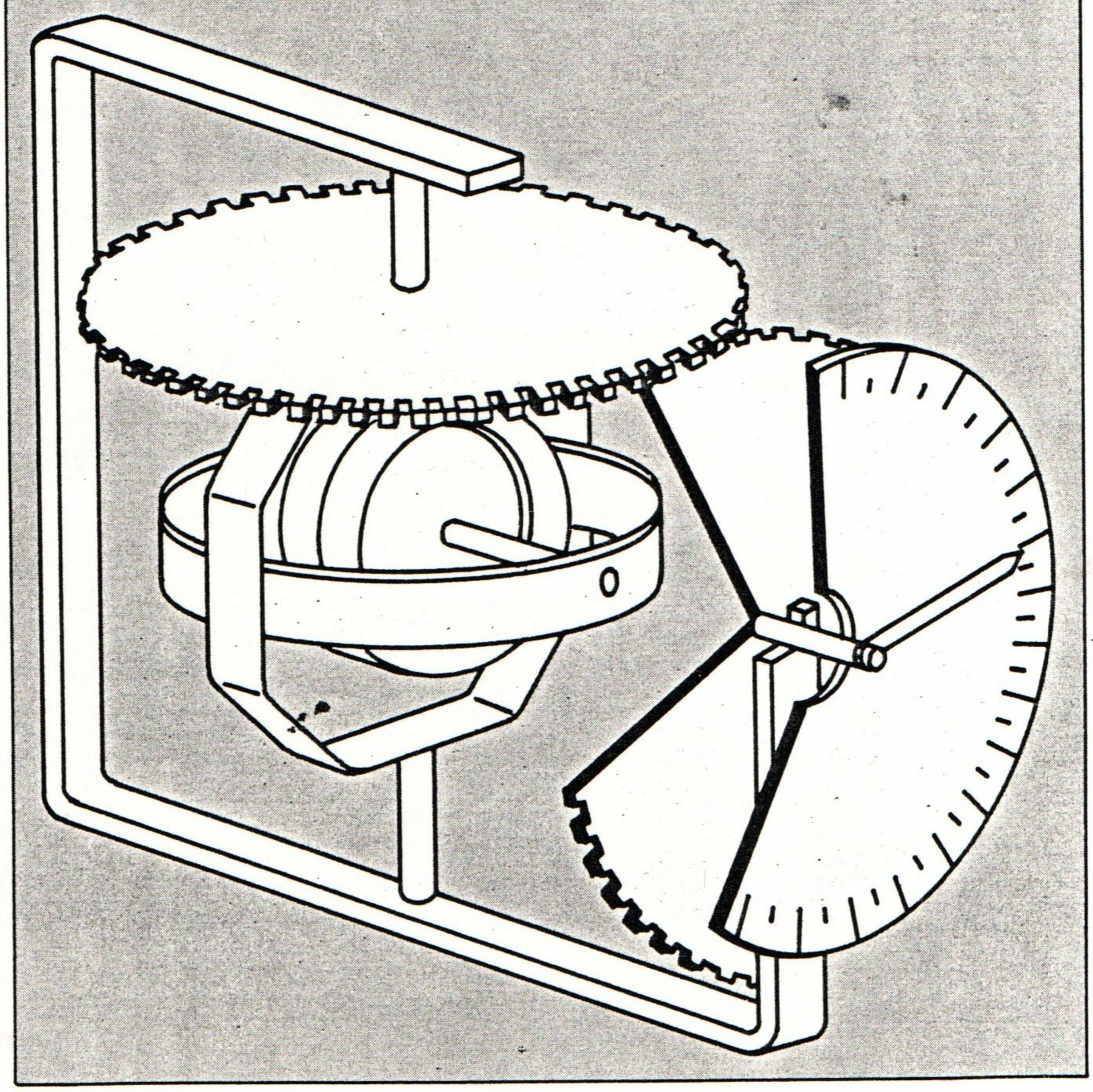
For the pilot who is fortunate enough to have a synchronized gyro, there is no need to worry about precession. The gyroscope heading indicator is electromechanically "slaved" to a magnetic sensing element. Remotely mounted, typically in the wingtip, the element is isolated from local magnetic disturbances. This provides a constant magnetic update to the gyro, preventing precession and precluding the need to reset the indicator after engine start.

The granddaddy of gyro instruments is the turn indicator (Figure 3). It usually is driven by a power source different from the other gyro instruments. If the attitude indicator is air-driven, the turn indicator typically will be electric. On some newer aircraft, one may be powered by AC, while the other by DC.

The most common turn indicator is the turn-and-slip, or what many call the needle/ball. This instrument actually senses rotation about the vertical axis (yaw) only. The turn actually must be in process before it is sensed! The instrument is calibrated to a standard rate of turn, which in light aircraft is 3° per second, producing a complete circle in two minutes. Faster aircraft have instruments calibrated at 1.5° per second, or a four-minute turn.

The slip indicator is an inclinometer and not connected to the gyro system at all. It merely indicates if the amount of rudder is correct for the angle of bank (coordinated). The ball, usually made of black agate or steel, is placed in a curved, kerosene-filled glass tube. Because it is heavier than the liquid, the ball rolls to the low point of the tube; the liquid provides a damping action to slightly resist the ball's rolling tendency. In straight flight, with the airplane leaning to the right, the ball rolls to the right, indicating a slip. This is the result of one wing being low or one engine having less power. In a coordinated turn, centrifugal force and gravity combine to produce an apparent gravity, so the ball stays in the center. If there is excessive bank for the right turn, the ball rolls to the right (low)

Figure 2—Heading Indicator



GYRO

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side; if there is insufficient bank, the ball rolls to the left (outside). To assure a coordinated turn, the pilot should keep the ball in the center at all times. The old saying is "step on the ball," meaning if the ball is displaced to the right, apply more right rudder pressure; if it is to the left, use more left rudder.

A newer type of turn indicator which is replacing the turn-and-slip is the turn coordinator. This instrument senses rotation about the vertical (yaw) axis and the longitudinal (roll) axis. As soon as one wing becomes lower than the other, it senses the turn and immediately displays it to the pilot. This makes it easier for the pilot to coordinate with rudder.

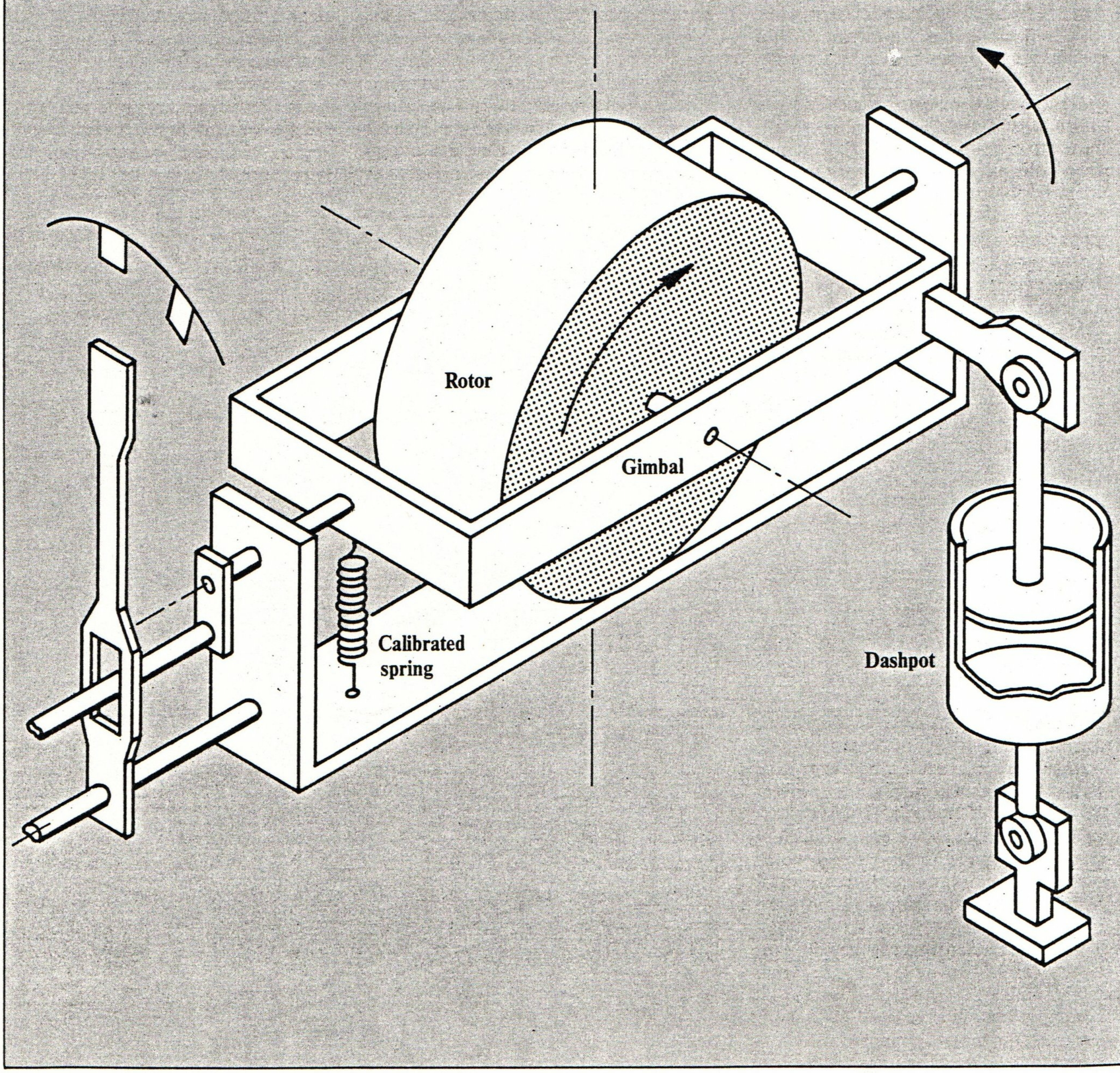
Rigidity in Space

All gyros operate under the same physical properties: rigidity in space and precession. The faster a gyro spins, the greater is its tendency to keep its spin axis in the same direction. Quite literally, the gyro inside the instrument maintains a constant position while the airframe moves around it. It is this "rigidity in space" that provides a fixed point of reference for the pilot, whose senses are easily misled when outside visual contact is lost.

The gyro wheel has its bearings in a ring called a gimbal. Gyro instruments are gimballed to permit the gyros to move in specific directions and prevent motion in others, depending on the purpose of the instrument. The force that causes the gyro to spin may be either air or electricity. Older aircraft—before electrical systems—used a venturi mounted outside the airplane as a source of vacuum. While it was Bernoulli's principle in its simplest form, there were some significant problems. It was designed to operate at cruise, approximately 87 knots, which prevented any form of preflight check or calibration until after the aircraft was airborne!

The venturi, which operates fundamentally the same as a carburetor, suffered from another formidable problem: its high susceptibility to inflight icing similar to

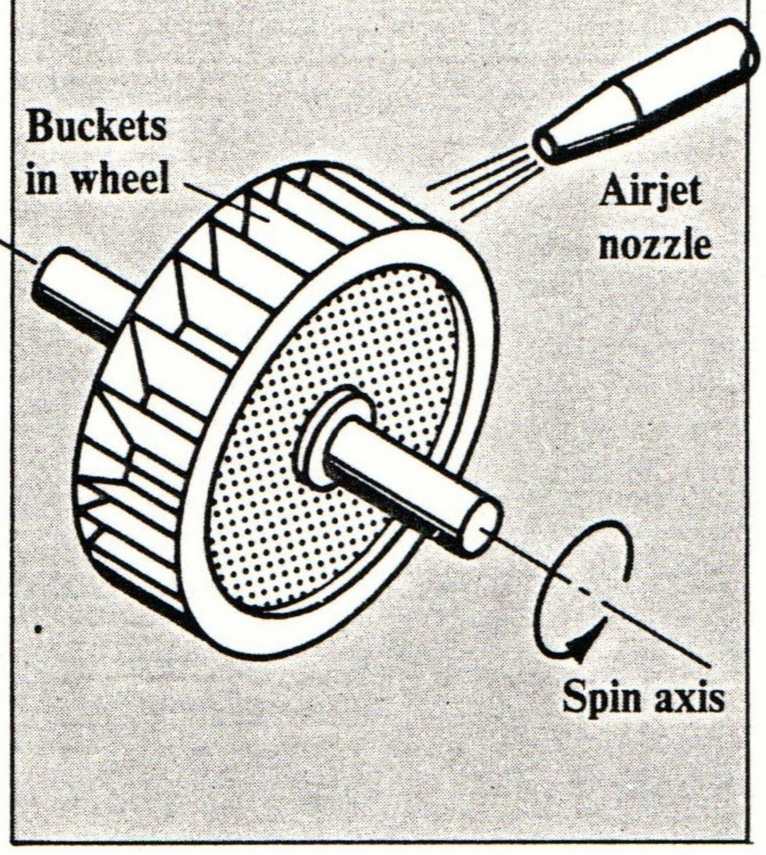
Figure 3—Turn Indicator



carburetor ice. There also was the problem of potential foreign-object damage. As aircraft became more sophisticated, the venturi was replaced with an engine-driven vacuum pump which still is in use today. Some aircraft use a pressure system rather than vacuum, but they essentially operate the same way.

The vacuum pump draws air from the gyro case, causing a partial pressure. The opposite side of the gyro case has an air inlet that allows cabin air, passing through one or more filters, to enter the case through a small jet nozzle. The jet directs the airflow toward the gyro rim, where there are buckets (vanes) that catch it, causing the gyro to spin, much like a waterwheel (Figure 4). The optimum speed varies from 8000 to 18,000 rpm, depending on type of gyro and manufacturer, and is controlled by the vacuum pressure setting. Because, the reliability of the instrument depends on the gyro spinning at the prescribed speed, it is important that the vacuum be set correctly. There is a controlling device in the turn indicator to reduce the vacuum, so the pilot should expect to see gauge readings appropriate to the attitude and heading indicators. In the electric-driven gyro, the rotating mass of the gyro typically is the rotor of the motor itself, forming a neat, compact package (Figure 5). AC-driven systems operate at speeds as high as 24,000 rpm.

Figure 4—Jet Nozzle and Buckets



It is imperative that information from the attitude indicator be substantiated with a cross-check of other instruments.

Precession

A rotating gyro resists any force that tries to alter its spin axis; that rigidity in space is what makes it useful to flying. The spin axis will move somewhat, but because of the rotation, it will move 90° to the applied force in the direction of rotation (Figure 6).

To pilots, the best known example of this phenomena is the increased need for right rudder when you lift the nose of the airplane on takeoff. The clockwise rotating propeller acts as a gyro and the tilting action of rotation attempts to alter its spin axis, causing a nose-left tendency. In the gyroscope heading indicator, this antiproductive force causes the heading to drift slightly. Even in straight-and-level flight, there always will be some precession due to bearing friction, but excessive precession indicates an incorrectly operating instrument and is unreliable.

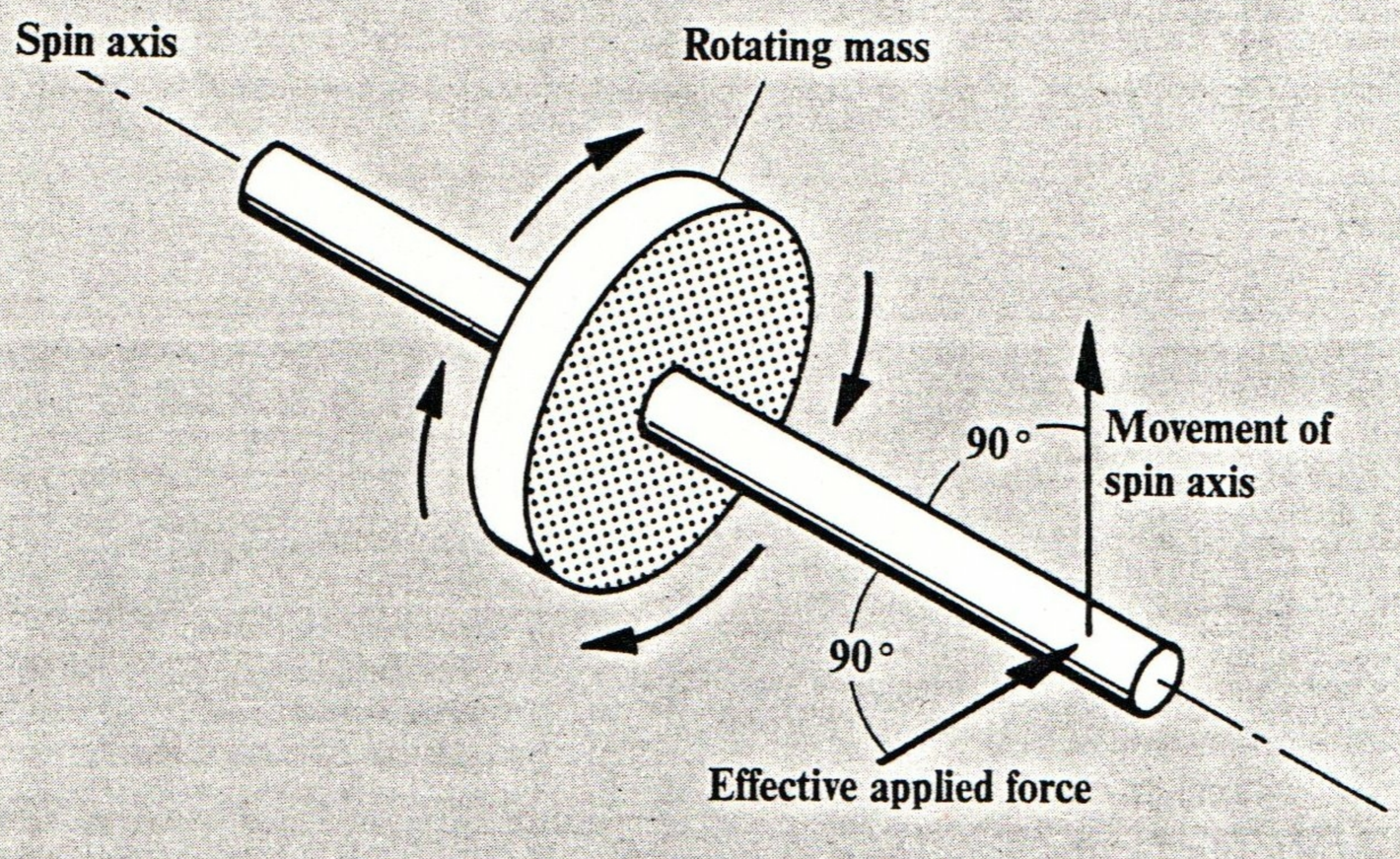
Preflight

It is important to allow sufficient time for gyro instruments to spin up to the correct rpm before relying on their accuracy. For air-driven instruments, that means at least five minutes; electric driven, three minutes. This is especially important during cold weather operation when lubricant and contamination within the instrument can form a sludge that may significantly resist spinning.

The attitude indicator should be monitored during taxi. It should not display more than 5° change in pitch or bank unless you are taxiing on very hilly terrain. There was a time when instructors taught students to make an abrupt stop while taxiing to cause the airplane to sharply pitch down. During this maneuver, the pilot was supposed to watch the attitude indicator and see if the pitch changed accordingly. Such a procedure should be avoided as any hard braking is bad for the aircraft and may cause significant bearing damage to the gyros.

The miniature airplane on the attitude indicator is adjustable vertically, allowing the pilot to calibrate it as a reference for straight-and-level flight; leave it alone when you are not flying. The previous position probably will serve as a good guide for the next flight, at least until after level off

Figure 6—Gyroscopic Precession



Vacuum Gauge Readings

In inches Hg.

Instrument	Minimum	Desired	Maximum
Attitude indicator	3.5	4.0	5.0
Heading indicator	3.5	4.0	5.0
Turn indicator	1.8	1.9	2.1

GYRO

continued

when you may recalibrate it. Because airspeed, load and ambient conditions will vary the exact pitch setting, it essentially is impossible to set it correctly on the ground. The procedure is to establish straight-and-level flight by reference to airspeed and altitude, then calibrate the miniature airplane; changes in airspeed will require recalibration. Many pilots will set it for straight-and-level cruise and use it as a reference for all other configurations. For instance, one bar width up may produce a 500-fpm climb at cruise power and one bar width below a 500-fpm descent.

Prior to an instrument takeoff, never do a fast 90° taxi turn. Both the heading and attitude indicators will precess, providing unreliable information during one of the most critical phases of flight. This precession lasts about one minute and can be avoided by taxiing slowly or waiting a minute while lined up with the runway before takeoff.

Preflight of the heading indicator includes setting it to a reliable magnetic reference. This should be done while on the ground, preferably prior to taxi. Once set, the pilot should observe it during taxi to assure it is changing heading appropriately. Don't taxi or fly with the heading indicator caged; it can damage the bearings.

Use the caging mechanism only to reset the gyro in straight-and-level flight or when stopped on the ground. If the heading immediately changes after setting, the instrument is unreliable; however, the instrument needs approximately five minutes after start-up before setting the heading to assure it is up to speed.

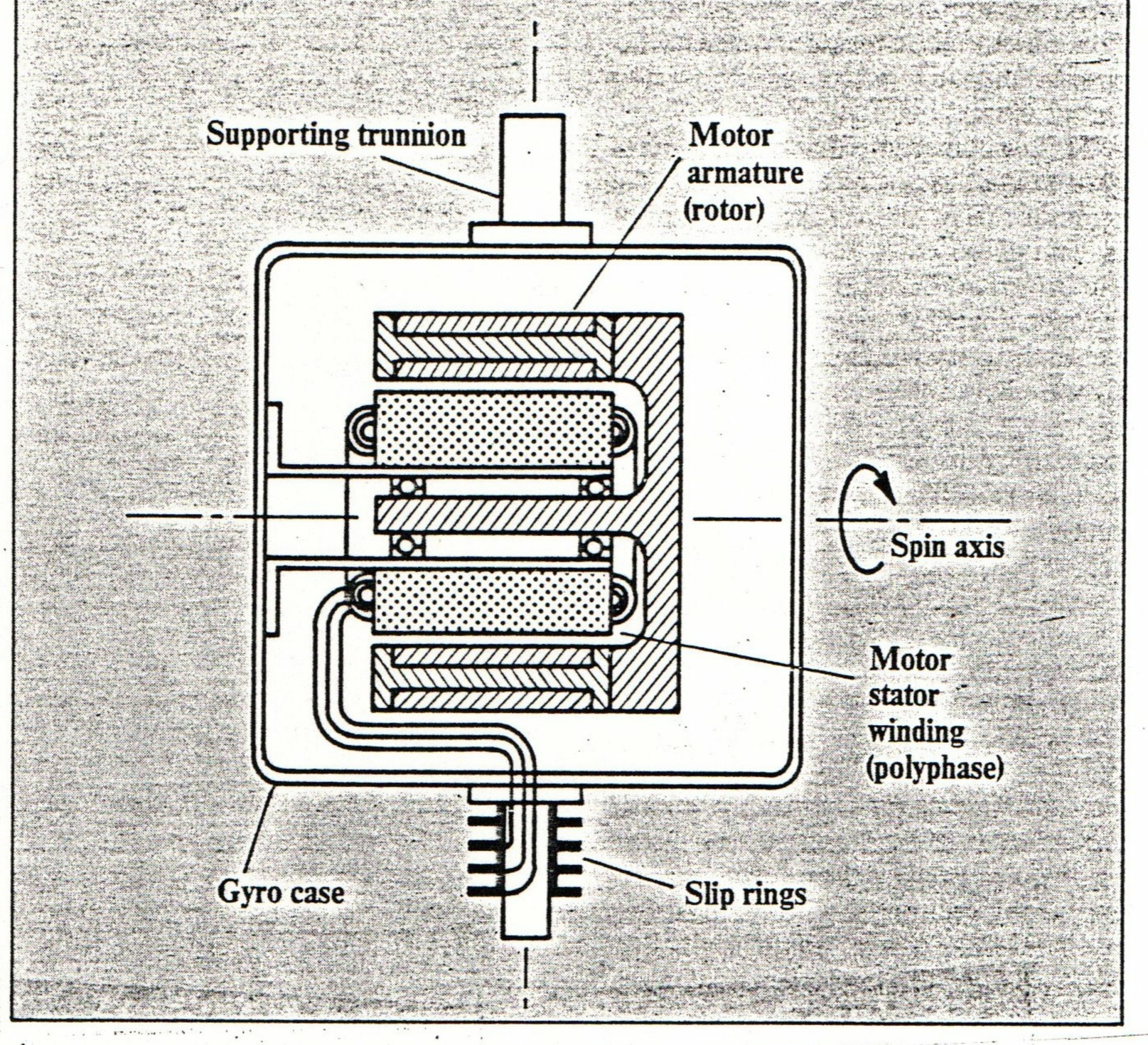
Many pilots use the runway heading to calibrate the indicator, but the runway number is not an accurate representation of actual runway heading, varying as much as 5°. Instead, a properly calibrated, undisturbed magnetic compass should be used. Prior to taking the reading, make sure there are no pens, watches, stopwatches or other magnetic articles laying near the compass that may introduce errors.

If you happen to have a gyro system that operates from a venturi, it is not accurate enough to check or set the instruments on the ground. Venturi systems are unreliable until you are in flight. This presents an additional problem to the instrument pilot, because to accurately set the heading indicator, the magnetic compass must be settled in straight-and-level flight—uncommon conditions immediately after takeoff into bad weather!

All gyro heading indicators not slaved to a magnetic compass must be compensated periodically for drift. Drift error in excess of 3° per 15 minutes signifies impending gyro failure and the instrument should be considered unreliable. The gryo should be reset in unaccelerated, straight-and-level flight while the compass is settled down.

You should allow the turn indicator five minutes to spin up to the correct speed before relying on it (three minutes for electric systems). Observe it during taxi turns, the needle should indicate correctly while the ball moves to the outside of the turn.

Figure 5—Electric Gyro Rotor



Preventive Maintenance

The single most important thing the aircraft owner can do to extend gyro life is keep the air filter clean, according to Don Bigbee, general manager of Aviation Instrument Manufacturing Corporation (AIM). He takes issue with the idea of cleaning the filter every 400-500 hours. "Don't just clean it, change it!" he said. He then hastened to add, if you operate in environments where there is a lot of dust, smoke or smog, change them even more often. According to Bigbee, the filter may look clean, but dirt gets trapped inside, works its way out and goes up the lines to the instruments. He suggested that when changing the filter, you also should check the lines going out of the filter to see if they are dirty; if they are, then the whole line is dirty and needs to be cleaned. The problem is, if any small particle finds its way into the gyro, it can lead to failure. Most pollution is human induced, with cigarette smoking probably the biggest culprit; other problem-causers are: woman's face powder and cabin cleaning materials. The simple fact is, any airborne particulate matter can deteriorate gyro bearings.

Gyros also are extremely vulnerable to shock damage. One instrument repair specialist told me the part most often damaged is the bearings; the main cause is shock. Gyros should only be handled by qualified personnel and they always should be transported in shock absorbent containers—even from the airplane to the shop!

AIM has an enlightening handout on destructive shock to gyros. It discusses the amount of Gs involved in dropping one; for handling purposes, a G is defined as the dropping distance divided by the stopping distance. For instance, if you drop a gyro from a height of one inch onto a glass table (the glass is assumed to flex .005 inches), the formula would be 1/.005=200 Gs! A fall of only one inch certainly would cause the gyro bearing races to deform when the ball bearings press against them, leading to an early failure. If the gimbal bearing takes the shock, it will lead to excessive, sporadic precession.

New gyro instruments should be kept in their original shipping container as long as possible. Use the same container for transportation to other locations or when returning it to the manufacturer for repairs. Always use the protective wrap provided and do not remove the indicator cover anywhere other than a designated clean area of a certified repair facility to prevent instrument contamination.

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When removing a gyro instrument from the airplane, wait at least 10 minutes after shutdown to assure the gyro has stopped spinning—never remove a gyro while it still is running. Gyros are so sensitive to shock that other objects should not be allowed to bump against the gyro either. A good rule of thumb is, if you set down a gyro on a hard object and you can hear it, you have probably set the gyro down too hard. Reputable repair shops always work on gyros with a cushioned pad underneath.

In the airplane, gyro instruments should be caged prior to doing aerobatics—especially attitude indicators—if the instrument has a caging mechanism. The pilot always should avoid abrupt braking of the aircraft; deceleration places heavy loads on gyro bearings, another good reason for a carefully planned approach and minimum braking landing roll.

Troubleshooting

Heading indicators with excessive drift (more than 3° in 15 minutes), turn indicators with sluggish response, and attitude indicators that are slow to erect and/or which show inappropriate deviation from level flight could be suffering from any one of several problems. Probably the most common cause is worn bearings; it's the friction that causes excessive precession.

Such symptoms may also indicate insufficient power to the gyro. In an air-driven system, this could be an inoperative pump, improperly set regulator, leaking pneumatic lines or fittings, or an obstruction in the venturi. With an electric gyro, the culprit probably is low system voltage caused by an inoperative or malfunctioning generator. Check the vacuum gauge (if air-driven) or the ammeter/warning light (if electric). If those appear normal, inspect the appropriate connections to the back of the instrument case.

If you have the old venturi system, the first thing you should do is check the venturi for blockage. Worn or damaged bearings make themselves known in another way—gyro whine. If you listen carefully right after engine shutdown, you will hear the still rapidly spinning gyros whine if the bearings are going bad.

Excessively low suction-gauge readings could be the result of the pressure regulator setting being too low or a leak in a line or fitting. High readings could be the result of a high pressure-regulator setting, but be careful, it could be a clogged filter. Think of a straw in an extra thick milk shake, if the end of the straw clogs up, the harder you draw, the lower the pressure until the straw collapses. It's the same principle, so in this case the worst thing you could do would be to lower the pressure regulator setting, even less air would get to the gyro. A good rule of thumb is: never lower the pressure-regulator valve setting without first checking the filter.

Safety Precautions

The single most important safety precaution is to know the system in your aircraft. Know where appropriate circuit breakers are, have a plan for saving battery power to operate the most essential instruments and know which instruments are driven by electricity and which by vacuum or pressure. For instance, if a vacuum-pump shaft failed during an instrument takeoff, the air-driven gyros would wind down slowly. More than one pilot has followed an inoperative attitude indicator down. Always use a cross-check to assure proper instrument operation, including VSI, altimeter, airspeed and a gyro instrument of a different power source. Believe what the majority of the instruments are telling you, if one instrument disagrees, it probably is wrong. Every few scans should include a check of the vacuum (or pressure) gauge and ammeter.

If you can hear when you set down a gyro on a hard surface, you set it down too hard.

Prior to entering actual IFR conditions, observe the gyro instruments carefully to assure correct operation. Monitor the vacuum gauge and ammeter. The time to discover problems is before you are forced to compensate for them.

Tumble limits on older heading indicators are 55° to 60° of roll and pitch, but the newer horizontal card indicators are good to 80° to 85°. Heading indicators do have gimballing error on some headings during banked turns. Typically there is a 2° error at 20° of bank, 4° error at 30° of bank and 10° error at 45° of bank. Gimbal error disappears upon return to level flight.

Older attitude indicators have tumble limits between 100° and 110° of bank and 60-70° of pitch, while the newer electric three -inch horizons typically have 360° of roll and 85° of pitch up or down.

A case of tumbling gyros is bad news; it may cause significant damage to the gyro and in instrument conditions can be disastrous for the pilot. Be prepared for possible gyro failure or accidental tumbling. Your best insurance policy is to maintain partial-panel proficiency and remember the turn-and-slip indicator is your most reliable gyro: it won't drift or tumble!