# ADI
## Attitude Directional Indicator

BY RALPH GRAVES

While there are many versions of the attitude directional indicator (ADI) that provides the pilot with verity of flight information, one thing that is common to all of them is their ability to indicate the aircraft's attitude in pitch and roll in relation to the surface of the earth

The basic functions of this flight instrument have been with us for a very long time and have carried a variety of names such as, Attitude Gyro, Gyro Horizon, Artificial Horizon and others. I like the name Artificial Horizon because it best describes the primary function of the instrument. That is, to provide the pilot or pilots with an artificial horizon when the true horizon is not visible to them.

In the AID indicator (center) is a recent panel-mounted ADI. The two cut-a-way instruments are from an era past, when manufacturers wanted their customers to see what their products were made of.

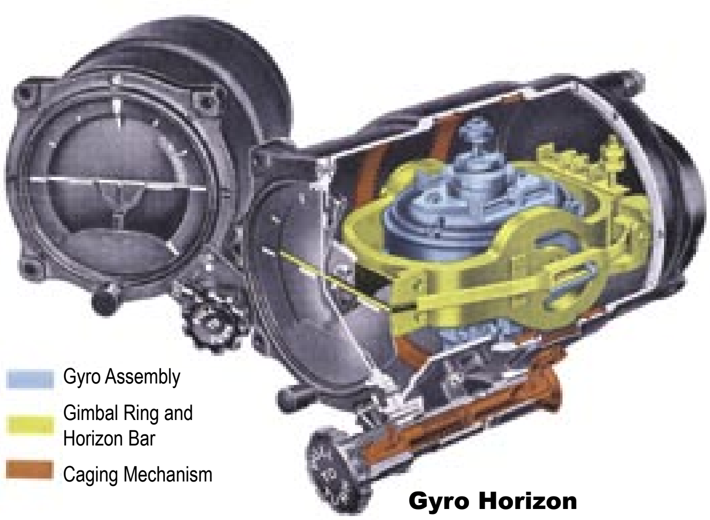
It has been my conception that the ADI is the most widely used and the least understood of the flight instruments. This is for good reason on both counts. It gives the pilot a visual indication of the aircraft's attitude in relation to the surface of the earth, and has more factors affecting its operation than any instrument in the aircraft.

To aid us in understanding the operation of the ADI we need to start with some basic aircraft instrument theory. The primary purpose of any instrument system is the transformation of certain information or condition into a useful visual indication on the aircraft instrument. In most cases, there are at least two parts to any indicating system: the "Sensor" that senses or measures the information for the indicator; and the "indicator" that converts this information into a visual analog or digital display. Like most systems, any instrument system is only as good as its weakest point.

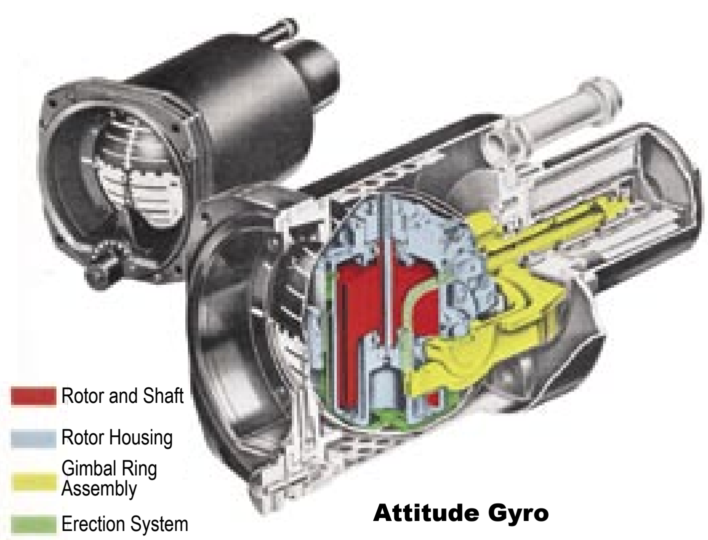
I think it could be said that all aircraft instruments could be classified as differential instruments because they indicate changes from some established or known point to the desired unknown, and provide us with a visual indication of some measurement from this known, established reference point. If this established, or known reference point changes, so does the visual indication of the instrument, providing us with an erroneous pictorial indication.

ADI

There is a misconception accepted by many of those personnel who use and service aircraft instrument systems. In our modern aviation society, and the public in general, there is a general

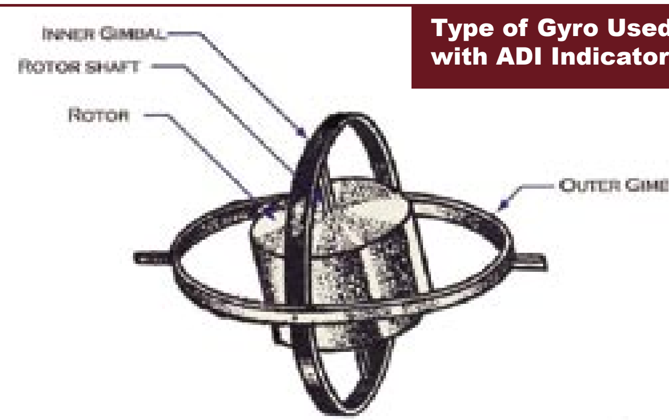


Gyro Horizon



Attitude Gyro

consensus that any digital indicator is much more accurate than any analog indicator. This theory does have merit; in most cases when the accuracy issue is restricted to the indicators only, the digital indicators are the best in almost every case. In many cases, the sensing portion of the instrument system is the same if it is used with a digital or analog indicator and will indicate the same correct or incorrect information on either type of instrument display.



**Type of Gyro Used with ADI Indicators**

## Aircraft Gyros

They may use different names, but at least in theory there are only three basic types of gyros with a rotor that provide us with a reference point to measure the attitude of the aircraft, in relation to the earth.

One is a universally-mounted three-axes gyro with the rotor axes parallel to the earth's surface, used in the directional gyro to establish a reference point to measure change in direction of the aircraft around its vertical (yaw) axis. The directional gyro has no direction seeking properties and must be set to or slaved to a magnetic compass heading. Once it has been set or slaved to a heading, it will sense deviations from that reference point.

Second is a universally-mounted three-axes gyro with the rotor axes perpendicular to the earth's surface. It is used in the ADI to establish a reference point to measure change in the attitude of the aircraft around the aircraft's longitudinal (roll) axis and the literal (pitch) axis of the aircraft. Any movement of the aircraft around the pitch or roll axis of the aircraft will be transferred mechanically or electronically to a miniature airplane and an artificial horizon on the face of the ADI indicator, mimicking the actual relation of the aircraft to the true horizon.

The third type of aircraft gyro is the rate gyro. This consists of a rotor mounted in gimbal ring 90 degrees to the axis of the gimbal ring. A spring holds the gimbal ring in a neutral position. When the rotor axis is turned left or right and parallel to the gimbal axis, the gimbal will rotate in a direction that is 90 degrees from the rotor axis. The rigidity of the rotor and the tension of the spring will determine the amount and rate of gimbal ring rotation. This change and rate of the change is transferred mechanically or electronically to the aircraft instruments or autopilot. This is most often used in, but not restricted to, turn and banks or turn coordinators.

In a perfect world, this is all one would need to know about the gyro instrument systems in our aircraft. How-

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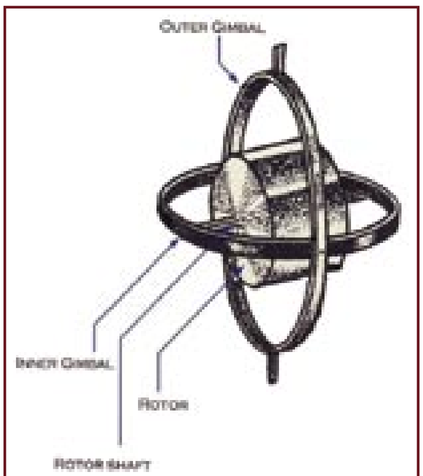
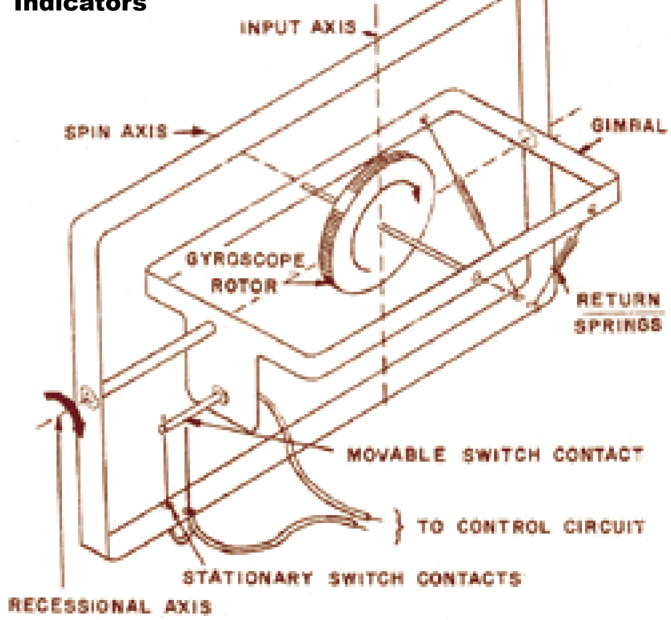


**Type of Gyro Used in Directional Indicators**

**Type of Gyro Used with T&B and T/C Indicators**





## ATTITUDE DIRECTIONAL INDICATOR

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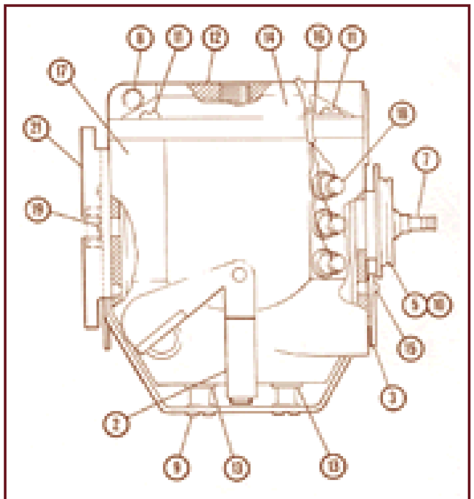

Figure #1

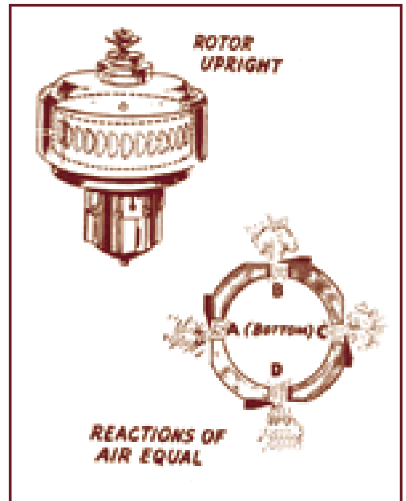


Figure #3

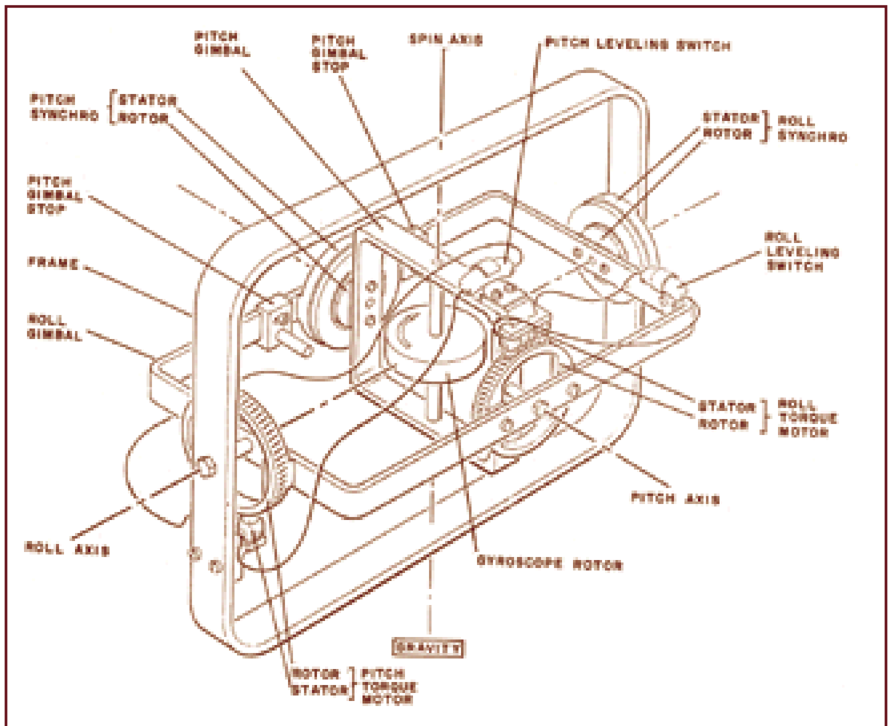


Figure #2

ever, we don't live in a perfect world so we know we have to accept some bad with the good. Gyro precession is one of those undesirable conditions of a gyro. All gyros precess to some degree and the ADI is no exception. Basically, we have two types of precession—real and apparent.

Apparent gyro precession is based on the fact that the earth rotates and the gyro maintains its position in space. In this situation it appears that the gyro is precessing, when, in fact, it is holding its position. It is only apparent that the gyro is precessing as the earth spins by its position. Although it is only apparent that the gyro is precessing, it is a factor we have to compensate for.

Real gyro precession is that property of a gyro that causes the rotor axis to be displaced, not in line with the applied force, but 90 degrees away in the direction of rotor rotation. This is caused by friction in the gyro rotor and supporting gimbal ring bearings. This resistance to the rotation of the rotor or the supporting gimbals will result in rotor precession. An out of balance condition of the rotor or supporting gimbal rings will also be the cause of rotor precession.

Rigidity is another important property of a gyro. The primary trait of a rotating gyro rotor is its rigidity in space, or gyroscope inertia. Newton's first law states in part: *A body in motion tends to move in a constant speed and direction unless disturbed by some external force*.

The rotor of the gyro instruments maintains a constant attitude in space as long as no external force changes it. This stable quality of the rotor depends on the mass and speed of that rotor. Thus, the larger and heavier the rotor and the faster we spin it, the greater the stability or rigidity. This is why most aircraft gyros' instrument rotors, both electrical and pneumatic driven, are as large and as heavy as is practical. They are also designed to spin at high speed.

To compensate for real or apparent precession in the ADI gyro, we add weight or torque to the gyro gimbals to induce a reverse precession.

In the ADI gyro, we have no direct connection to the surface of the earth to use as a perpendicular position from it. In this case we use what should be a perpendicular position from the earth's surface as the aircraft's center of gravity (CG).

All gyros precess to some degree, and the ADI gyros are no exception. The precession of the ADI gyro is constantly corrected by the erection mechanism to the aircraft's CG. Various erection mechanisms are used to correct this gyro precession, but one thing that is common to all of them is their ability to apply a force to oppose the force causing the precession. The attitude of the aircraft and the G forces on the aircraft will vary this CG. To add insult to injury, as the CG changes and G forces are added to the formula, we have changes in bearing friction, balance of the gyro and its gimbals to contend with. These factors can cause the erection mechanism to precess the rotor to position to the invalid CG, and this provides the ADI indicator with a less than true indication of the aircraft's actual attitude.

As we increase mass and speed of the rotor, the rigidity of the rotor will increase. Greater rigidity will slow the precession of the rotor. This is a condition that is good for maintaining our reference point in space. While it is a good factor for maintaining the rigidity of the rotor, it is a negative for our erection mechanism when using reverse precession to compensate for precession errors.

As the name indicates, the ADI erection mechanism on start up also erects the rotor to the perpendicular position from the surface of the earth—in line with the CG position it has been calibrated to operate in.

The exhausting air of the pneumatic erection vanes (Figure #3) or the controlling mercury switches for the torque motors (Figure #2) on the gimbal axis is the choice for most ADI rotor erection systems. Regardless of what system is used, the erection system is continually correcting the rotor axis to be in line with CG. ADI with a pneumatic driven rotor uses the pneumatic vanes, while we find both the pneumatic vanes and torque motors used with ADI having electric driven rotors. The electrical ADI lacks the airflow used to power the rotor in the pneumatic type. Instead, it uses an impeller developing air pressure that flows over the rotor, cooling it, and exhausts through pneumatic erection vanes (Figure #1).

Pneumatic driven rotors gain their operating speeds at a very slow rate. The slower speed when the erection process is taking place allows the erection mechanism to erect the rotor quickly because of less rotor rigidity. On the other hand, electrical rotors gain speed much faster, so the rotor rigidity is at its peak very quickly, making the erection process much slower than pneumatic rotors.

To aid this slow erection of the electrical rotors many manufactures have added a "Quick Erect" or "Caging" mechanism. These systems will erect the rotor and its gimbals to a zero degree pitch and roll position of the rotor axis in the ADI gyro. Under these conditions the ADI will be indicating level flight regardless of the attitude of the aircraft. **The caging or quick erect should never be used unless the aircraft is in an attitude of "0" roll and "0" pitch.** The erection mechanism will be applying a force to precess the rotor axis to be in line with the CG. In time (some erection systems will precess at a slow rate of less than three degrees per minute), the erection assembly will correct any error that had been induced by actuating the caging process.

During manufacture or servicing of these ADI gyros, balance of the gimbals is used to compensate for some unavoidable friction of the axis bearings. While high precision bearings and special lubricants are used in all three gyro axes, there is still some friction to deal with. The rotor and gimbals are precision balanced using quality balancing equipment and skilled operators.

To compensate for this friction, the bearing axis weight or the static balance of the gimbals supporting the gyro is moved to an unbalanced position. This works well when the gyro is tested in the factory or repair station, where the center of gravity is perpendicular to the surface of the earth, and we have a G force of 1. With this gyro mounted in the aircraft, and while flying at various speeds and attitudes, the G forces change the friction of the gyro's bearings and the balance of the gimbals. The corrections or calibrations that were made on the ground are no longer valid under these conditions.

During take off and climb out, the aircraft experiences the greatest amount of thrust and G force. This force changes the load of the bearings in the rotor and its gimbals, which changes the friction of the bearings. These forces also change the balance of these gimbals and rotor.

Now, the calibration that was made when the ADI was tested on the ground is no longer valid. These forces also change the aircraft's CG, and the erection mechanism of the ADI will be correcting for precession from an invalid CG; resulting in erroneous attitude indications often undetected by the flight crew.

This description is not about a poorly manufactured or serviced ADI. I am referring to one that has been manufactured or serviced to meet all the specifications that are required by the FAA to certify it airworthy. This ADI will never operate more accurately than it did when the manufacturer or service shop last tested it. The quality of this ADI indicator can only decline with age.

As a technician, did you ever have a pilot report an attitude directional indicator (ADI) error that he or she had encountered in flight that you could not reproduce with the aircraft on the ground? Or as a pilot, have you ever been unable to duplicate on the ground what you thought to be a faulty ADI indication while in flight? Maybe some of the above information can shed some light on why we have some of these conditions.

Several years ago, I was giving a lecture to a group of aircraft pilots. In reference to the ADI, I made the state-

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ment, "The ADI has the privilege of being the aircraft instrument with the highest failure rate. Any instrument rated pilot that is not capable of flying the aircraft without using the ADI should not have an instrument rating." This brought many comments, and not too many in my favor. Several pilots said they had been flying for years and never had an ADI fail, and would be lost without it. I wonder if some of these brave pilots are still with us. After several years in the servicing end of many gyro instruments I will still stand by the statement I made to these pilots.

While the ADI is less than perfect, it is the best we have (to date) for doing what it does. After many years of service and many fine tuned modifications, the ADI is a very reliable flight instrument. With the proper knowledge of the ADI limitations a pilot should be able to determine if it is operating within its designed specifications. It is a hard sell trying to list all the shortcomings of the ADI to the pilots, without destroying their overall confidence in their flight instruments.

With proper care, all our calibrations of the ADI made by the manufacturer or repair station will remain intact after it is properly installed in the aircraft. As soon as the aircraft starts to taxi, the calibrations that were made during manufacture or overhaul are no longer valid. The "G" force and the center of gravity on the aircraft and instrument have changed. ❑