APÉNDICE G

HOJA DE CUBIERTA

INFORME DEL PILOTO DE COPA SOBRE INDICACIONES ERRÓNEAS DEL ADI, ENERO 14, 1994

June 7, 1994 Model: 737

To: Dennis Rodrigues M/S 14-HM

From: Ike Maeda M/S 2H-30

Subject: COPA Pilot Report on ADI Erroneous Indications dated January 14, 1994 received from G. Phillips, NTSB

The above referenced translation of COPA Pilot's Report states that COPA Flight 1400 on January 3, 1994 experienced both Attitude Directional Indicators (ADIs) showing 10 degrees right bank when the Standby Horizon Indicator indicated straight and level. Subsequently, under VMC conditions, the flight crew confirmed that the Standby Horizon Indicator indeed showed correct attitude information. Further, placing the Attitude Transfer Switch from 'Normal' to 'Both on 1' or to 'Both on 2' did not correct the primary attitude indications on Captain's ADI nor First Officer's ADI to agree with the Standby Horizon Indicator. The flight was completed without incident. Both ADIs' indications returned to normal after both Vertical Gyro (VG) circuit breakers were reset following the completion of the flight.

The conditions described in the COPA Pilot's Report fit the scenario where the Vertical Gyros erect to a 'false vertical' while the aircraft is subjected to velocity changes or heading changes. Errors can occur following low level accelerations for long periods of time. This phenomena is described in Sperry (Honeywell) Technical Newsletter titled 'Vertical Gyro Dynamic Performance' dated September 29, 1980, a copy of which is attached. These errors will correct themselves after a period of straight and level flight. The error in the ADI will be unpredictable and will be affected by heading and acceleration changes.

A similar report of ADI indications as a result of Vertical Gyros erecting to a false vertical was reported by another 737 operator. Boeing has issued an 'In-Service Activities Report' describing this condition. (ISAR No. 94-06-3425-10 for Model 727 dated May 27, 1994.) A similar Model 737 ISAR No. 94-07-3425-10 is to be published in July 1994.

I believe that the following clarification should be made to the translated Pilot's Report.

1) The second paragraph, where it states 'While the aircraft (HP-1195CMP) was in straight-and-level flight at FL210, both ADIs showed ***suddenly*** 10 degrees right bank, ***remaining frozen*** ...'

Firstly, I do not believe that both ADI's ***suddenly*** moved to 10 degrees right bank from a level attitude as it implies. More than likely, the aircraft performed a maneuver which ended up in level flight. The ADI's continued to provide attitude indication but when the aircraft came to a level flight, both ADI's indicated 10 degrees right bank since both VG's erected to a 'false vertical'.

Secondly, the report indicates that both ADIs ***remained frozen***. I believe that the ADI indications did not change from 10 degrees right bank because the aircraft remained in a level flight attitude. During their approach using the Standby Horizon Indicator, I would assume that both ADI's did not remain ***frozen***, however they did provide roll indications offset by 10 degrees right bank, again a result of erecting to a 'false vertical'.

2) The third paragraph, where it states 'the VG Switch on the BOTH ON 1 position. The situation remained the same, except for the fact that GYRO flag on ADI # 2 was showing (it was not showing ...).'

There are no explanations for the ADI No. 2 GYRO Flag appearing only when 'BOTH ON 1' position is selected. Regardless of the VG Switch position, F/O's ADI GYRO Flag power comes from the Instrument Amplifier No. 2 through the VG Transfer Relay No. 2. NOTE

3) The last paragraph of the report states that 'Because this scenario is very similar to one involving the tragic (COPA) flight 201 on June 6, 1992, I regard it as ...'

The conditions encountered by the crew of COPA Flight 1400 on January 4, 1994 are not similar to the conditions encountered by the crew of Flight 201. As stated above, when the VG erects to a false vertical, the ADI indication is not frozen or stuck. There are no malfunctions of the VG or the ADI involved in this case. If the ADI has assumed an indication of 10 degrees right bank while in level flight due to the VG erecting to a 'false vertical', and the aircraft makes a 5 degree right bank from a level attitude, the ADI would initially indicate a 10 degree right bank and move in a continuous and smooth manner to an indication of15 degrees right bank. If the aircraft was to return to level flight from that position, the ADI would move smoothly back to 10 degrees right bank from 15 degrees right bank. It is true that the primary attitude indication on the ADIs are not correct and do not correspond to the actual aircraft attitude. NOTE

The Flight Data Recorder trace from Flight 201 on the other hand shows indications that the ADI froze or stuck at two different positions, i.e. the roll attitude did not change to correspond with acutal airplane movement.

FILE

BOEING 727

Customer Services Division

IN-SERVICE ACTIVITIES

FIELD SERVICE ENGINEERING ☐ BOEING COMMERCIAL AIRPLANE GROUP ☐ P.O. BOX 3707 ☐ SEATTLE ☐ WASHINGTON 98124-2207

Report No. 94-06
May 27, 1994

THIS REPORT SUMMARIZES SELECTED IN-SERVICE ACTIVITIES
AND IS FOR BOEING CUSTOMER INFORMATION ONLY

FLEET STATISTICS

(Through February 28, 1994)

Airplanes in Service	1,659
Total Flight Hours	85,464,087
Total Flight Cycles	64,951,445
High Flight Hours	77,767
High Flight Cycles	71,524

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for R. G. Entz
Director
Service Engineering
707/727/737/757
Customer Services Division

For additional information on any of these in-service items, please contact the local Boeing Customer Services Representative. If unable to contact the local Boeing Customer Services Representative, please direct queries to Airline Support Group, 707/727/737/757 Service Engineering, Mail Stop 2H-95, Boeing Commercial Airplane Group, Customer Services Division, P. O. Box 3707, Seattle, Washington 98124; Telephone (206) 544-7500; Fax (206) 544-9696; Telex 329430 BOE STA 617.

NO APPLIC.

94-06-2312-10 (727) COMMUNICATIONS - VHF COMMUNICATION SQUELCH BREAK

An operator reported a VHF communication squelch break when both AlliedSignal (formerly King) VHF communication transceivers, P/N 064-1005-02/-04 (Model KTR 9100A), on the same airplane, were tuned exactly 10.000 MHz apart. The squelch break also has been observed at airports where the tower frequencies are 10.000 MHz different from the operator's company frequency.

AlliedSignal Component Service Bulletin KTR 9100A-10, dated February 28, 1979, provided instructions for modifying the KTR 9100A VHF communication transceiver to correct the reported condition. However, this condition was unaffected by the incorporation of the service bulletin. This modification added a ground strap internally between the antenna coax at the unit disconnect connector and a screw on the connector. This ground strap was to ensure improved grounding of the antenna coax within the unit, and prevent escape of local oscillator radiation from the transceiver. AlliedSignal has advised that this service bulletin will be revised and superseded by Component Service Bulletin KTR 9100A-19 to include ferrite beads on various wires connecting the voltage control oscillator, receiver/transmitter buffer, and digital buffer to further reduce the local oscillator radiation escaping from the KTR 9100A VHF communication transceiver. Boeing has reviewed and approved this modification. Component Service Bulletin KTR 9100A-19 is scheduled to be released in the third quarter of 1994.

NO APPLIC.

94-06-2822-00 (727) FUEL - THERMAL RELIEF VALVE ALTERNATE TEST PROCEDURE

An operator reported that they lacked appropriate hydrostatic test equipment to perform the inspection/check of a newly installed thermal pressure relief valve, Parker Aircraft P/N 1352-568395 (typical IPC 28-20-0-4, Item 123) per Maintenance Manual Section 28-22-5, page block 600.

Boeing reviewed the inspection requirements and determined that a bench test of this valve is an acceptable alternative for testing this valve for proper operation and leaks. Performance of the entire inspection check procedure with the hydrostatic tester is preferred because it also tests a portion of the fuel feed system for leaks. Also, using the hydrostatic tester precludes the possibility of damaging the relief valve or changing its setpoints due to mechanical shock during the installation of the valve.

Note: The thermal relief valve, P/N 2R2732, manufactured by Crissair, is listed in the IPC as being interchangeable with the Parker Aircraft valve.

94-06-3425-10 (727) NAVIGATION - ATTITUDE INDICATION ERRORS DUE TO VERTICAL GYRO CHARACTERISTICS

The following event occurred on a Model 737-200 airplane and is included in this report since the vertical gyro is also used on Model 727 airplanes. A similar report will be issued for Model 737-100/-200 airplanes.

An operator reported that both attitude direction indicators (ADI) on an airplane exhibited a 10 degree pitch indication error during approach. The operator also reported that similar attitude errors had occurred on four other airplanes.

Boeing is aware of a characteristic of vertical gyros that can cause both ADIs to give the same false indication. The false indication can be caused by slow longitudinal acceleration or deceleration, or prolonged shallow turns.

These errors result from the function of the gyro erection circuits. The vertical gyros are slaved to verticality sensors in the units, so the gyros are being continuously erected to vertical during operation. The gyros also have erection cut off circuits that stop this continuous erection and put the gyros into a free state during airplane acceleration and banks. The erection cut off is necessary because during fore and aft acceleration and during turning flight, the acceleration of the airplane sets up a false vertical. If the gyros erect to this false vertical, errors in airplane attitude indication result. Slow gentle airplane maneuvers below the threshold of the erection cut off circuits do not cut off gyro erection, so the gyros erect to a false vertical during slow maneuvers. These errors can accumulate. Errors of up to 15 degrees have been reported and attributed to a series of slow maneuvers and prolonged acceleration.

Accelerations of 50 knots per minute or less and bank angles of six degrees or less will not cut off gyro erection. A few minutes of flight in gentle maneuvers will result in attitude indication errors. If the airplane is flown straight and level following maneuvers that cause errors, the erection circuits will correct the attitude errors. The period of straight and level flight required to correct the errors may be five minutes to allow the cut off timer to elapse plus enough time for the error to correct at an erection rate of approximately two degrees per minute.

Another aspect of these errors is that they will transfer from the pitch axis to the roll axis or roll axis to the pitch axis when the airplane is turned.

SPERRY
FLIGHT SYSTEMS

TECHNICAL NEWSLETTER

23-3212-06 September 29, 1980

NAVIGATION
VERTICAL GYROS, VG-300 SERIES

Vertical Gyro Dynamic Performance

Introduction

Accuracy of conventional vertical gyros is governed to a large extent by the way in which aircraft are flown. Errors between a gyro's reference axis, i.e., the axis about which the gyro wheel spins, and true vertical occur whenever an aircraft is in accelerated flight, either through velocity changes or heading changes. The magnitude of error depends on the time duration of acceleration - fairly large errors can result from long-term accelerations. It is possible to maintain low level accelerations for long periods of time before reaching performance limitations of an aircraft. Therefore, maneuvers involving low level accelerations - gentle maneuvers - have the potential for inducing the largest errors.

Gentle maneuvers should be avoided. Aircraft turns of more than a few seconds' duration should be made at bank angles of at least 10 degrees. Velocity changes of more than a few knots should be made with acceleration (or deceleration) of at least 1 knot per second.

The last few pages of this paper describe how large errors can occur during gentle maneuvers when gyros are operating within their performance specifications. The earlier pages describe the vertical gyro's erection reference, its erection system, apparent drift, and error commutation in turns. Understanding of these earlier pages is necessary if one wishes to understand why dynamic inaccuracies occur.

The Gyro - a Slaved Short-Term Reference

In the practical application of gyros used for aircraft attitude reference and control, the gyro serves only as a short-term reference for another sensor. The gyros are aligned, or slaved, to the other sensors (which are the long-term references) and act as integrators of disturbances which affect the basic sensors.

In the case of a vertical gyro, the long-term reference is a pendulum. The pendulum is the device which senses the direction of gravity, which is the direction of vertical with respect to the earth's surface.

In the case of a directional gyro, the long-term reference is a magnetic field sensor or flux valve. The flux valve is the device which senses the earth's magnetic field.

Vertical Gyros

Vertical gyros are used in aircraft to provide references of pitch and roll attitude. As the aircraft maneuvers with climbs, dives, and turns, the gyro base, which is fixed to the aircraft structure, moves about the gyro wheel, which is trying to maintain its spin axis fixed in space.

The vertical gyro is installed in such a way that the inner gimbal axis is aligned with the lateral axis of the airplane. This gyro axis senses pitch attitude.

The outer gimbal axis is aligned with the longitudinal axis of the aircraft so that it senses roll attitude.

Erection System

The mechanical alignment of the gyro gimbal system with the aircraft axes is easy. The trick with vertical gyros is how to keep the spin axis - which is the reference for pitch and roll attitude measurement - vertical.

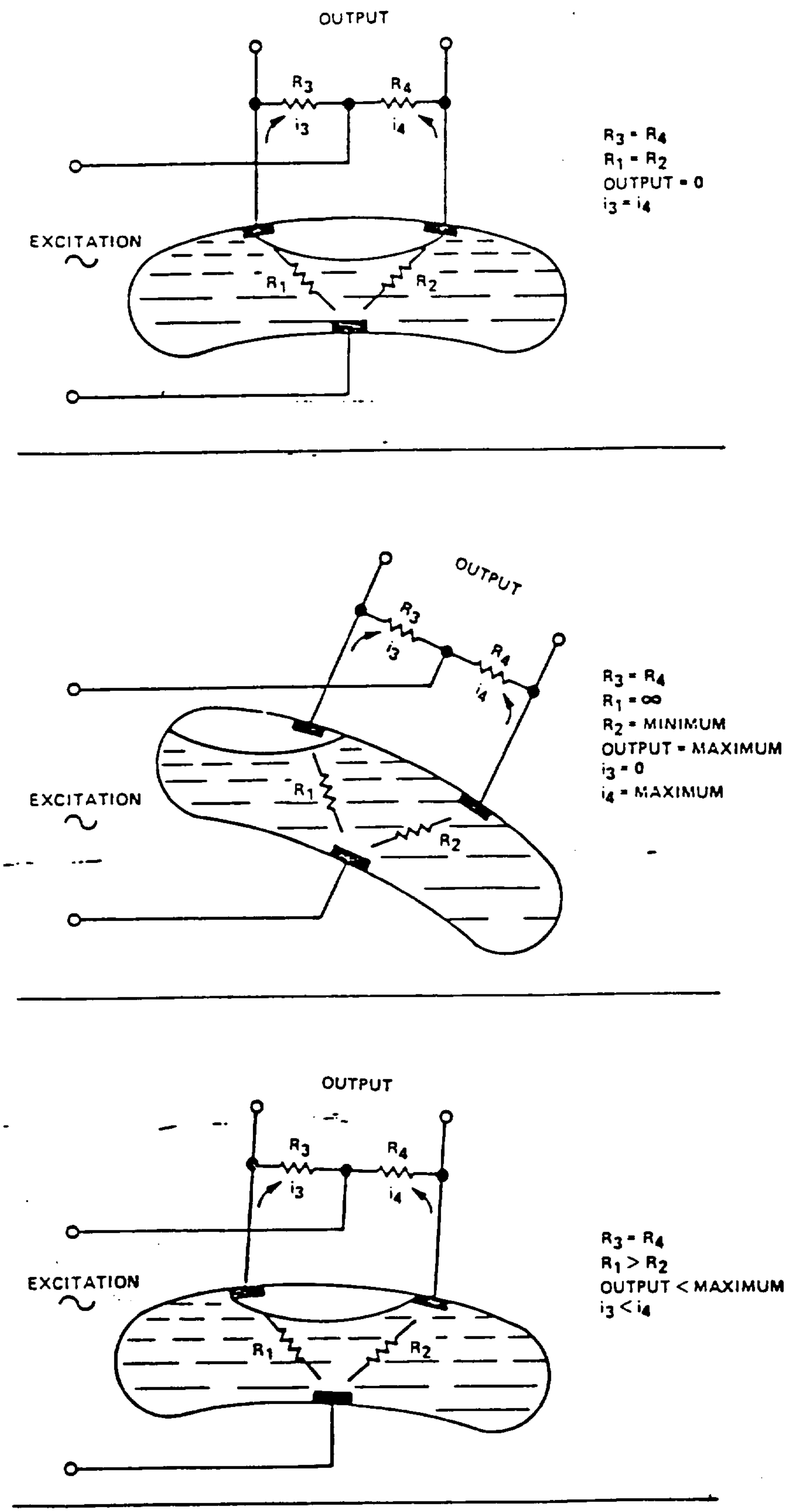
The pendulum to which the gyro is aligned is a liquid level. A common type of liquid level is similar to a carpenter's level. It is a curved vial which is partially filled with conducting liquid; it has electrodes which give it electrical characteristics as shown in figures 1 and 2.

The liquid level is connected in the gyro circuits to serve as an automatic erection reference as shown in figure 3.

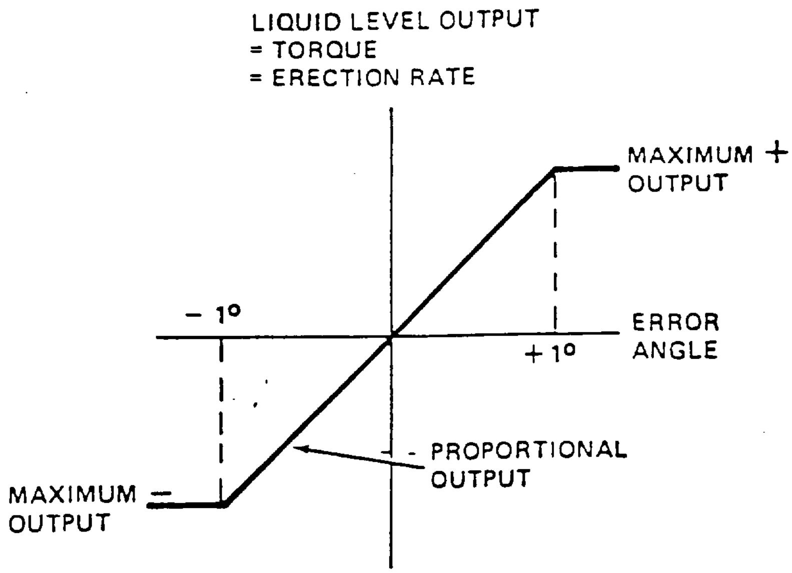
Liquid levels are used for each axis of the vertical gyro - one for roll and one for pitch. Each is aligned precisely with the gyro spin axis when its electrical output is zero so that it will cause its respective torque motor to apply torque to the gyro gimbal to precess the spin axis until it is vertical.

Flight Acceleration Effects

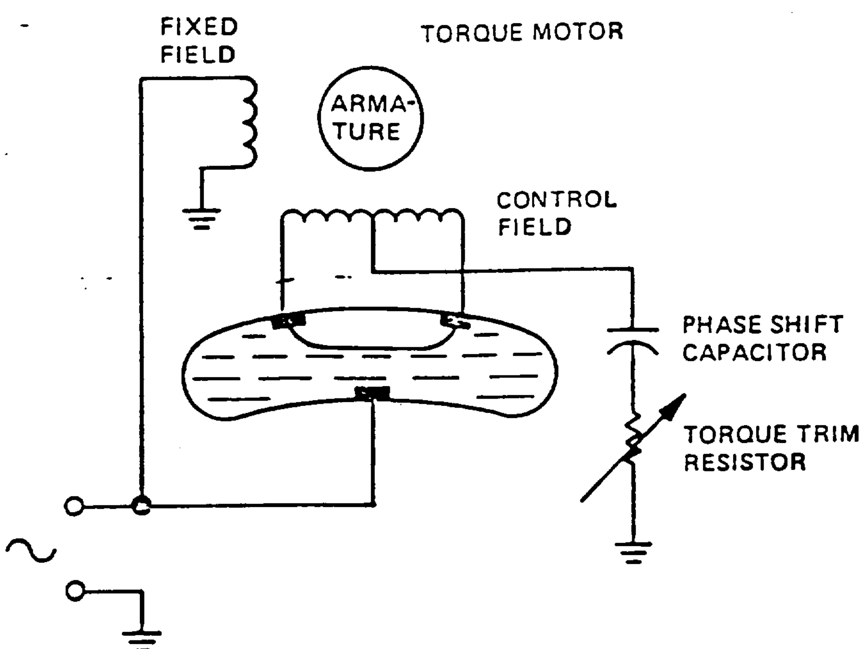
There is one drawback to the pendulum as a vertical reference. It cannot distinguish between gravity force and a total force vector if horizontal accelerations are present. When an aircraft changes its velocity, fore or aft accelerations are present, and when an aircraft turns, lateral accelerations are present. The forces from these accelerations and their vector addition to gravity force are shown in figure 4.



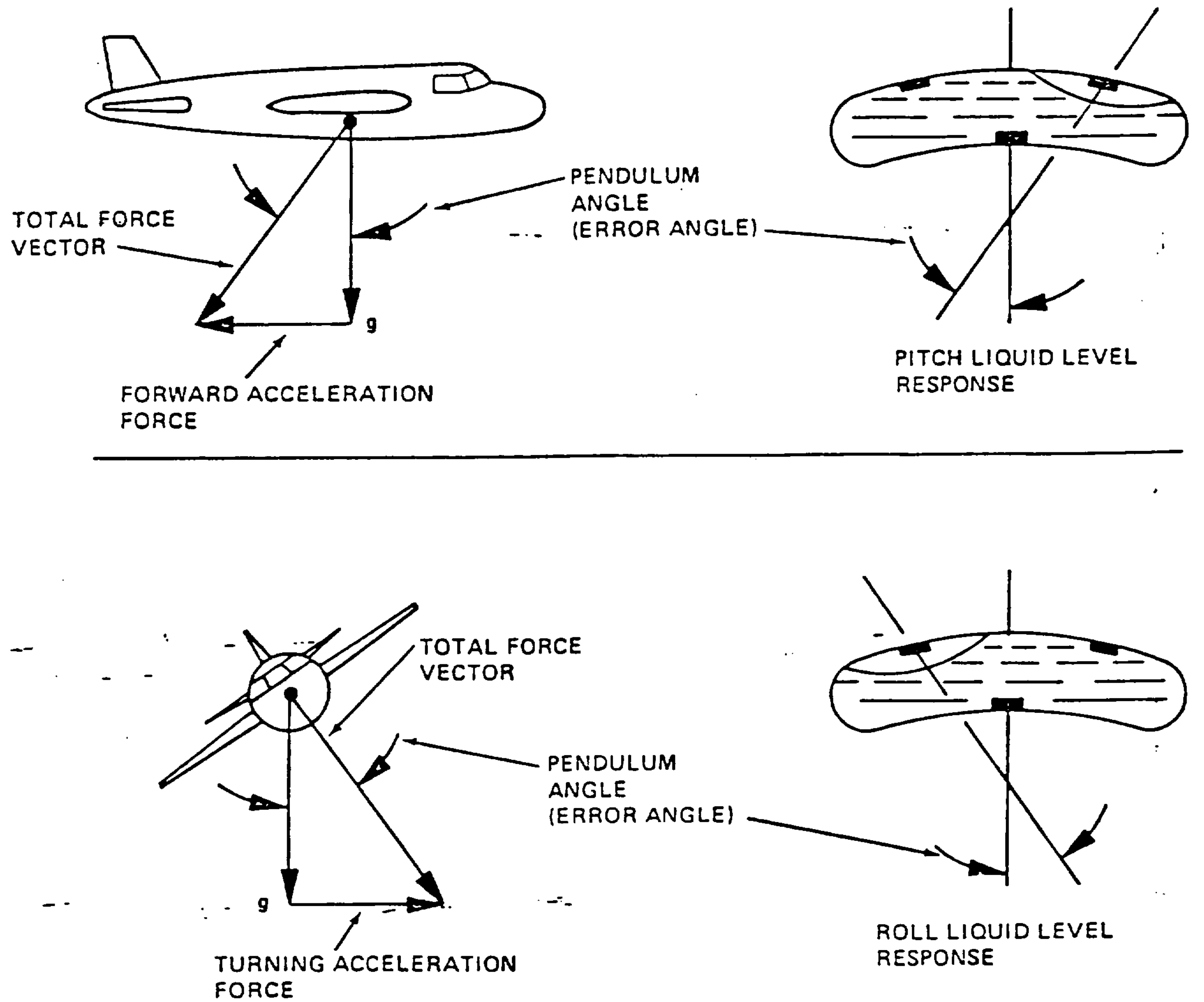
Liquid Level Operation
Figure 1



Liquid Level Output
Figure 2



Vertical Gyro Erection Circuit
Figure 3



Acceleration Force Vectors and Liquid Level Response
Figure 4

The pendulum (or liquid level) will sense the resultant total vector and the vertical gyro will be precessed into error if measures are not taken to prevent it.

Erection Cutoff

The measures which are taken to prevent the erection system from precessing the gyro to the total force vector, usually called the dynamic vertical or false vertical, is to employ an erection cutoff circuit activated by acceleration-sensitive switches mounted on the gyro gimbals.

The gyro circuits and operation of erection cutoff are shown in figure 5. In this case, a power SCR is the erection cutoff switch. It opens when its gate voltage is removed by the trigger transistor if either of the acceleration-sensitive switches is conducting. Two switches are used for each axis of the gyro. For the pitch axis, one switch senses forward accelerations, and one switch senses aft accelerations. For the roll axis, one switch senses left turn accelerations and one switch senses right turn accelerations. The switches are liquid level type switches, similar to the erection liquid levels. They are mounted on the gyro gimbals, inclined at the angle of dynamic vertical for which they are intended to cut off their respective erection circuit.

In the case of the illustrated gyro, the thresholds of erection cutoff are reached when the dynamic vertical is 2.5 degrees fore-aft or 6 degrees laterally from the gyro spin axis alignment.

Erection cutoff timing control is included in the pitch erection circuit. The purpose of this timer is to return erection voltage to the pitch torque motor in the event error angles are sustained for unusually long periods.

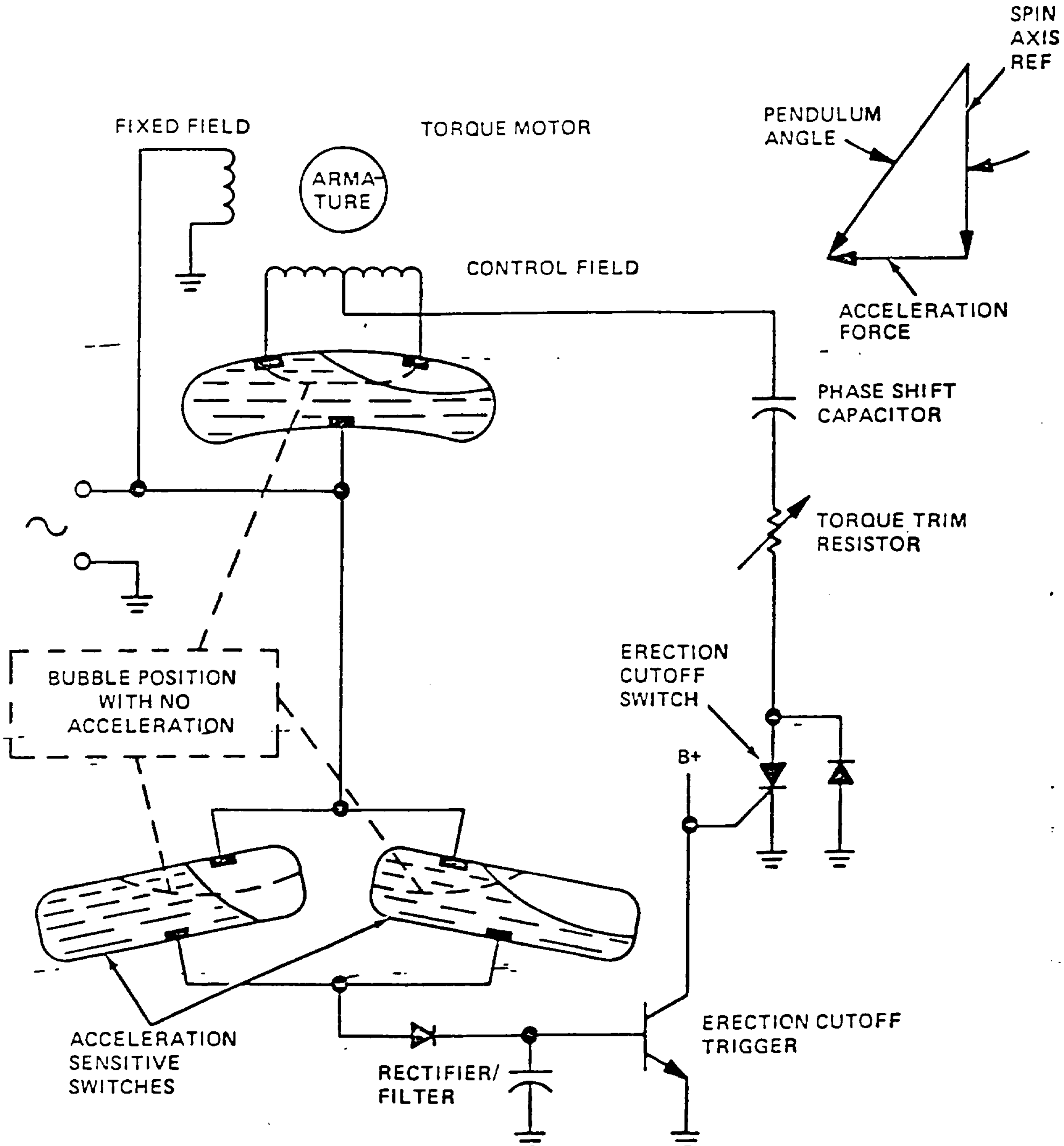
Most normal flight maneuvers would not call for accelerations or decelerations which produce a dynamic vertical greater than 2.5 degrees to be sustained longer than 3 minutes. Since the pendulum to which the gyro axis is aligned cannot distinguish between gravity force and total force vector (including the vector addition of acceleration or deceleration force), it is concluded that a long-term pitch error signal is the result of the gyro axis actually being misaligned with gravity. The function of the erection cutoff timer, then, is to return erection voltage to the pitch torque motor, regardless of the error signal, when the pitch error signal has exceeded 2.5 degrees for 3 minutes.

Apparent Drift

If the gyro were perfect and had no unwanted torques, it would have no drift rate and it would need no continuous erection system or erection cutoff circuit. All that would be necessary to use it as a good vertical reference would be to align it initially on the ground and then to expect it to remain accurate until power is shut off.

Right?

Wrong!



Vertical Gyro Erection Circuit
with Erection Cutoff during Acceleration
Figure 5

If the perfect gyro were built, it would still appear to drift from its initial alignment due to the earth's rotation and due to the motion of the gyro over the earth's surface. These Apparent Drifts are called Earth Rate Drift and Earth Profile Drift.

The generation and magnitude of earth rate drift is shown in figure 6.

The generation and magnitude of earth profile drift is shown in figure 7.

Erection Rates

One item not yet discussed is the magnitude of erection rate for the vertical gyro.

The typical gyro has average Real Drift Rates, due to mechanical imperfections, of 5 to 20 degrees per hour in an aircraft flight environment. Combining these rates with the Apparent Drift due to earth rate and aircraft velocity, the total drift of an accurately calibrated gyro can be 30 to 45 degrees per hour. Allowing for some real drift degradation during the service life of a gyro and adding a factor for dynamic effects and a little safety margin, the erection rates of most modern vertical gyros have been established between 60 and 180 degrees per hour - or between 1 and 3 degrees per minute.

Higher erection rates are undesirable because the gyro would then respond too quickly to accelerations of the flight environment and be less accurate as a short-term reference.

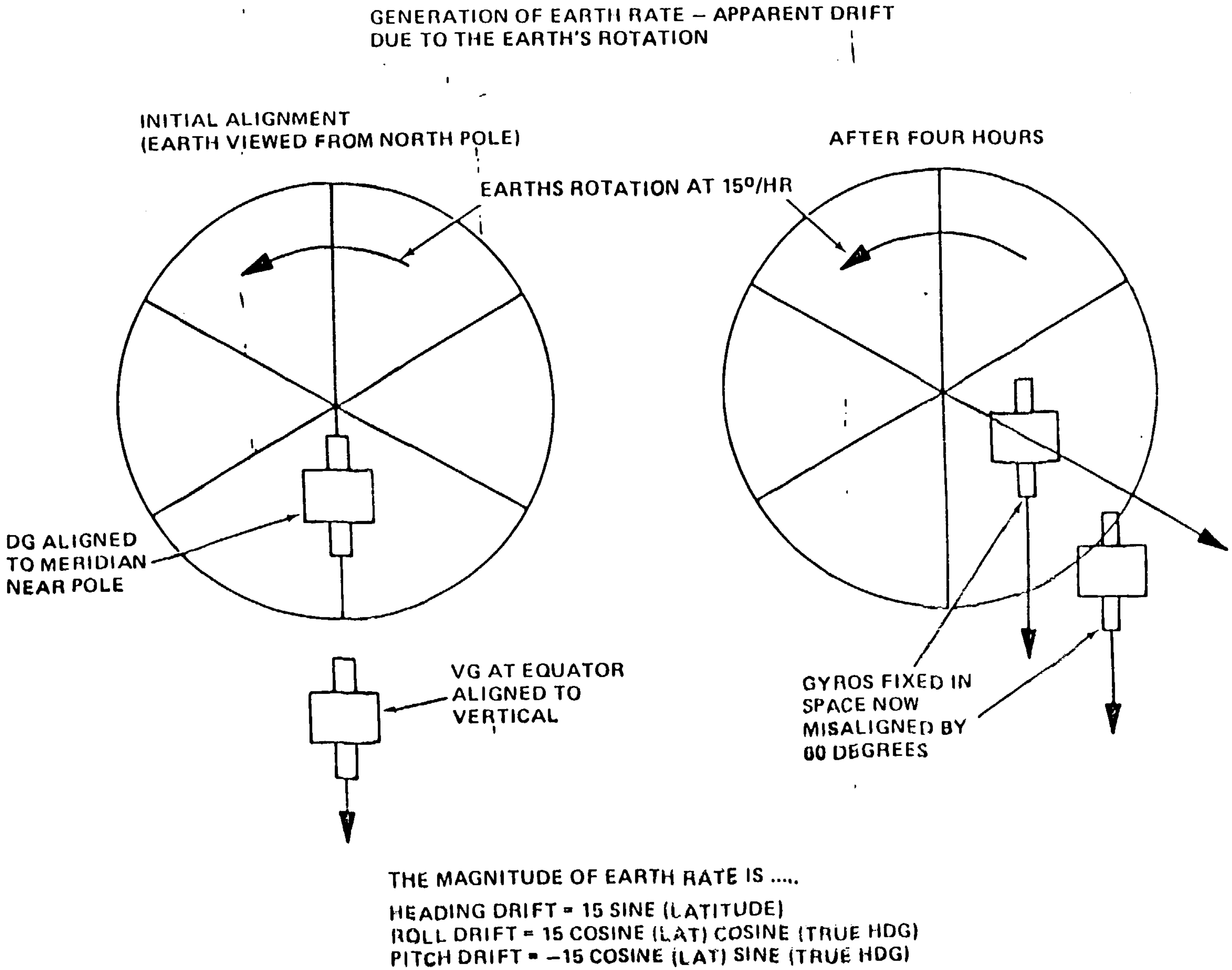
Commutation of Error During Turns

Another peculiarity of the vertical gyro is that error which may occur between spin axis position and true vertical does not remain in a fixed direction with respect to the gimbal system if the aircraft is maneuvering. The best way to describe this peculiarity is with an example.

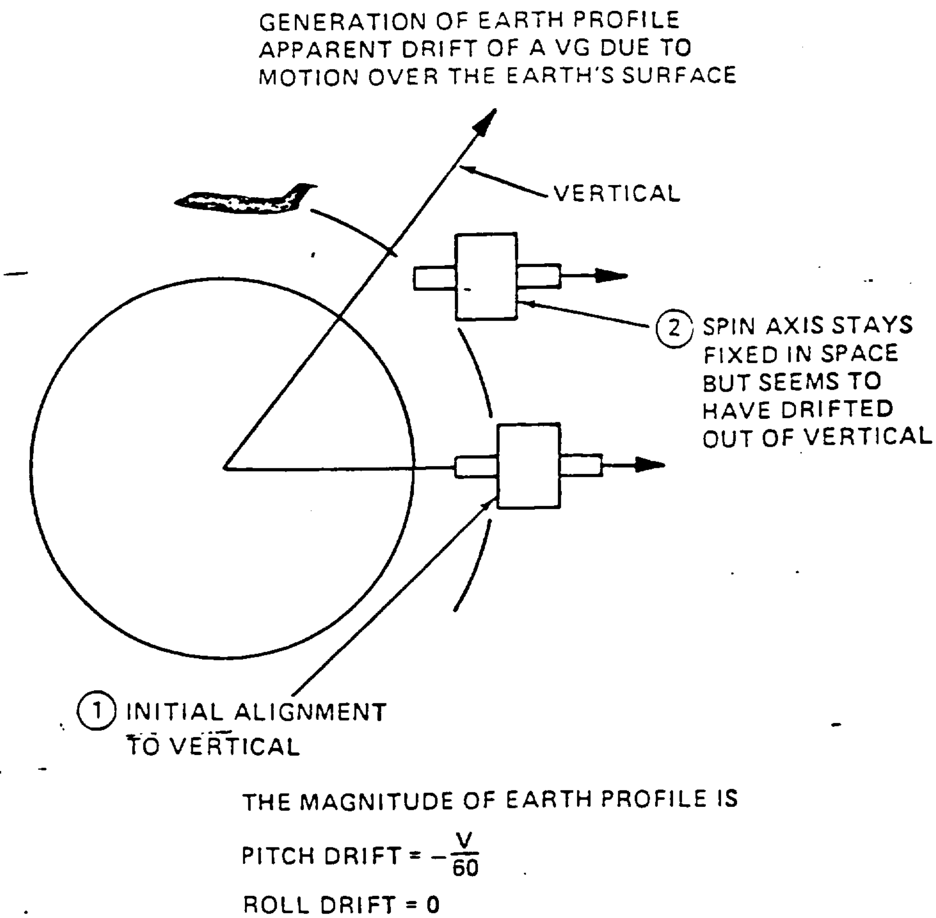
Assume that an aircraft flying north has a vertical gyro with its spin axis in error in such a way that the top of the spin axis is tilted toward north. The gyro will be giving an indication to the pilot - or autopilot - that the aircraft is climbing, even though it is in level flight.

Now further assume that the aircraft makes a left turn and rolls out on a heading of west before the erection system can correct the error. What is the gyro now telling the pilot that the aircraft attitude is when the aircraft is actually level?

It is indicating left wing low and level in pitch!



Generation of Earth Rate Drift
Figure 6



Generation of Earth Profile Drift
Figure 7

Why?

Remember that the gyro spin axis tries to stay fixed in space. Its spatial orientation is changed by drift or by the erection system relatively slowly compared to the time required for the aircraft to make the left turn.

When the aircraft rolls level on a west heading, the top of the spin axis is still inclined toward north but now the error is a roll axis error and the pitch axis is indicating level flight.

This characteristic of gyro error changing from pitch axis to roll axis or vice versa is called Error Commutation or Error Transfer. If not understood by pilots or systems engineers, error commutation can be confusing when trying to analyze system performance anomalies in flight.

Steady State and Dynamic Accuracy --

With all of the foregoing discussion about

Drift

Apparent Drift

Torque

Precession

Erection Rate

Erection Cutoff

Error Commutation

taken into account, what can you expect the accuracy of a vertical gyro to be during bench test or in an aircraft on the ground or in flight?

For the VG-311, which has been the example gyro in the discussions, test bench performance is as follows:

- Verticality is ± 0.25 degree.

  This is the accuracy with which the spin axis is aligned to the null position of the liquid level.

- Synchro Alignment is ± 0.1 degree.

  This is the accuracy with which the spin axis is aligned to the synchro transmitter null.

- Vertical Error is ± 0.5 degree.

  This is the electrical signal output from the synchro transmitters when the mounting surface of the gyro is level with respect to the horizon; i.e., perpendicular to true vertical. Vertical Error includes Verticality Alignment, Synchro Alignment, and the effect of earth's rate.

- Drift Rate is ± 12 degrees per hour in roll and ± 18 degrees per hour in pitch.

  This is measured with the erection system in cutoff.

- Erection Rate is 2.1 ± 0.3 degrees per minute.

  This is the rate the erection system precesses the gyro toward vertical when an error greater than 1 degree exists.

- Pitch Erection Cutoff Threshold is 2.5 ± 0.25 degrees.

  This is the angle of dynamic vertical which causes the pitch erection system to cut off during fore-aft accelerations. It is equivalent to 50 knots per minute change of ground speed.

- Roll Erection Cutoff Threshold is 6 ± 0.25 degrees.

  This is the angle of dynamic vertical which causes the roll erection system to cut off during turns; it is equivalent to 0.1g lateral acceleration which occurs at a 6 degree bank angle when the aircraft is in coordinated flight.

The performance parameters outlined on the preceding page are measured with oscillatory motion or low level vibration applied to the gyro in order to minimize the effects of frictional torques inherent in bearings and slip-rings.

When the gyro is operating in an aircraft which is parked on the ground and no motion or vibration is present, the performance may degrade considerably; for example:

- Verticality may be as high as 0.7 or 0.8 degree.
- Vertical Error may be 1 degree or more.
- Drift Rate may be as high as 75 or 100 degrees per hour.
- Erection Rate may be as low as 0.2 or 0.3 degree per minute.

These performance changes are caused by the fact that static friction coefficients are often much higher than "dynamic" friction coefficients. The latter are applicable when motion or vibration are applied.

How about in flight?

Fortunately, an airplane in flight, even though it may be at constant airspeed with wings level and in very smooth air, is never completely without oscillatory motion. In addition to small vibrations from engines and other equipment, all airplanes have natural periods of oscillatory motions in roll, pitch, and yaw. These motions are hard to detect by the eye watching the horizon or other landmarks, but they are present. The minimum angular oscillations known for any modern jet transport aircraft are about 10 arc minutes, and the periods may be as long as 20 or 30 seconds. This motion is enough, however, to maintain friction coefficients near dynamic values rather than static values. Additionally, the oscillatory nature of the motions tends to average any precession effects on the gyro from frictional torques. In-flight performance, therefore, should be approximately equivalent to bench test performance when the aircraft is in steady state cruising flight.

Gyro accuracy when the aircraft is maneuvering is quite a different matter at times. When an aircraft makes maneuvers involving large accelerations, such as bank angles of 10 or 20 or 30 or 40 degrees or velocity changes of 75 or 150 or 200 knots per minute, the gyro error should not exceed 2 or 3 degrees, which is tolerable. The maneuvers which can cause large errors are gentle maneuvers!

Examples

For example, look at the case when an aircraft changes its velocity from 200 knots to 240 knots in 1 minute at constant acceleration. The gyro will have a pitch error of 2 degrees when it reaches 240 knots.

Why?

Because the pitch erection rate of the gyro is 2 degrees per minute and the erection system was precessing the spin axis toward the dynamic vertical for 1 minute. Hence, the error from true vertical is 2 degrees.

Why didn't the pitch erection cutoff circuit disable the gyro's pitch erection system? - Because the threshold of pitch erection cutoff is set for a dynamic vertical of 2.5 degrees and 40 knots per minute acceleration produces a dynamic vertical of only 2 degrees.

How far will the gyro precess into error if the acceleration is sustained for another minute? The error will get no greater than 2 degrees because the dynamic vertical is only 2 degrees from true vertical as long as 40 knots per minute velocity change is maintained.

Look at what would happen when the aircraft velocity reached 240 knots if the acceleration were increased to 80 knots per minute and sustained there for 1 minute. The gyro would precess into error another 2 degrees and have a total error of 4 degrees when the aircraft reached 320 knots.

Why didn't the pitch erection cutoff circuit disable the gyro's pitch erection system when the actual dynamic vertical reached 3 degrees? That is what 80 knots per minute represents. The gyro "thought" it was aligned with true vertical because that is what its pitch liquid level was sensing when the aircraft reached 240 knots. The pitch erection cutoff switch requires the dynamic vertical to be 2.5 degrees away from the spin axis alignment before it will cut off pitch erection.

Now let the acceleration change at the end of 2 minutes to 120 knots per minute and be sustained for 1 minute. The gyro will accrue another 2 degrees of error by the time the aircraft reaches 440 knots. The total gyro error from true vertical will be 6 degrees.

If the acceleration is now stopped and the aircraft is flown at constant velocity of 440 knots, what is the condition of the gyro? Dynamic vertical is aligned with true vertical, but the gyro spin axis is misaligned with true vertical by 6 degrees. Erection will be cut off and the 6-degree error will be sustained for at least 3 minutes. That is the time constant of the pitch erection cutoff timer.

Assuming the aircraft continues to fly constant heading and velocity, the pitch erection cutoff timer will override the pitch erection cutoff trigger after 3 minutes and the erection system will begin to erect the gyro spin axis toward true vertical. The gyro will be accurate after another 3 minutes.

This example may be considered an unusual one which is not likely to actually happen, but it does illustrate that significant error can be accrued by a gyro even when it is performing without malfunction and within its specifications.

Let's look at another example involving gentle aircraft turns.

If an aircraft is flown at a bank angle of 5 degrees for 1 minute, 2 degrees of roll error will be accrued because the roll erection system is precessing the spin axis toward the dynamic vertical of 5 degrees at 2 degrees per minute. The roll erection cutoff threshold is 6 degrees of dynamic vertical from the spin axis, so roll erection cutoff will not occur. At the end of 2 minutes the roll error will be 4 degrees and at the end of 2.5 minutes the roll error will reach 5 degrees. Now assume the bank angle is increased to 10 degrees. In another 2.5 minutes the gyro will have a total of 10 degrees error in roll. Roll erection cutoff will not occur during the latter part of the turning maneuver because the actual dynamic vertical was never displaced from the spin axis position by as much as 6 degrees - which is the cutoff threshold.

Now, if the aircraft is rolled to a true level attitude with respect to the natural horizon, the vertical gyro error will cause the ADI to read 10 degrees wing down. Because the gyro spin axis angle, with respect to dynamic vertical (which corresponds to true vertical in level coordinated flight), is 10 degrees, roll erection will be cut off.

The roll erection system of the VG-311 does not have a cutoff override timer. In the example presented above, roll erection will remain cut off indefinitely unless one of three possible events occurs.

(1) If the gyro happens to drift in roll from the 10-degree error position back toward vertical so that the error is reduced to 6 degrees, roll erection will be returned and the gyro will be accurate after another 3 minutes.

(2) If a 90-degree heading change is made, the roll error will be "transferred" into a pitch error. Pitch erection will be cut off for 3 minutes, after which the override timer will return pitch erection. The pitch error will be corrected in another 5 minutes.

(3) The vertical gyro circuit breaker may be opened for 45 seconds and reset. This action causes the gyro to recycle into the fast erection mode. When in fast erection, the erection cutoff function is disabled. The gyro will erect automatically from 10 degrees roll error in about 20 seconds and the gyro valid signal will remove the ADI flag in less than one minute.

Is this another example of unusual aircraft and gyro performance? Yes, but this latter example of the low bank angle turn situation does occur more frequently than does the graduated acceleration example. And the errors can become larger before aircraft performance limitations are reached.

When vertical gyro pitch errors greater than the pitch erection cutoff threshold are recognized, there are two methods of correction a flight crew can use. One method is to fly the aircraft straight and level on constant heading and constant airspeed. The pitch erection cutoff timer will expire, returning erection voltages which will correct pitch errors at 2 degrees per minute after the timer performs the override function. The second method is to remove power from the vertical gyro by pulling the circuit breaker. Leave power off for at least 45 seconds and reset the circuit breaker. The aircraft must be flown straight and level at constant heading and constant airspeed. When the circuit breaker is reset, the gyro will be in fast erection, which will erect the spin axis to true vertical at 12 degrees per minute. When the gyro reaches vertical, slow erection will be resumed automatically a few seconds later when the gyro flag in the ADI disappears.

When vertical gyro roll errors greater than the roll erection cutoff threshold are recognized, the best method for correcting the errors is to remove power by pulling the circuit breaker for 45 seconds and resetting it as noted above. The roll axis fast erection rate is 30 degrees per minute, which will permit correction of most errors within about one minute. The aircraft must be flown straight and level at constant heading and constant airspeed while the gyro is in fast erection.

These examples are presented to illustrate basic limitations of vertical gyros having simple pendulum-referenced erection systems. These erection systems are called first-order erection systems because there is only one integration of the pendulum erection sensor - that which is done by the gyro.