Department of Transportation

FEDERAL AVIATION ADMINISTRATION

IFR PILOT EXAM-O-GRAM* NO. 24

THE ATTITUDE INDICATOR

An instrument pilot should have a working knowledge of the operating principles, limits, and errors of the flight instruments he is using. It is apparent from written test responses and interviews with instrument pilot examiners that many student instrument pilots are lacking in knowledge concerning the attitude indicator. Attitude indicators are either vacuum-driven or electric motor driven instruments. The principles of operation are basically the same for both types. Since the vacuum-driven instrument is still in more common use among light general aviation aircraft, it will be described in more detail in this Exam-O-Gram. The attitude indicator is a reliable and ingenious instrument. It provides an immediate, direct and corresponding indication of any change of aircraft pitch and bank attitude in relation to the natural horizon.

THE OPERATION OF THE ATTITUDE INDICATOR DEPENDS ON WHAT GYROSCOPIC PRINCIPLE?

The principle is "rigidity in space" which is based on Newton's first and second laws of motion. A universally mounted gyroscope (wheel or rotor mounted in three gimbals) turning at high speed tends to remain in a constant plane of rotation regardless of the movement of its base. The rotors of both vacuum-driven and electric instruments rotate in a horizontal plane. The horizon bar is linked to the gyroscope and thus also tends to remain in a constant plane regardless of aircraft attitude (Fig. 1).

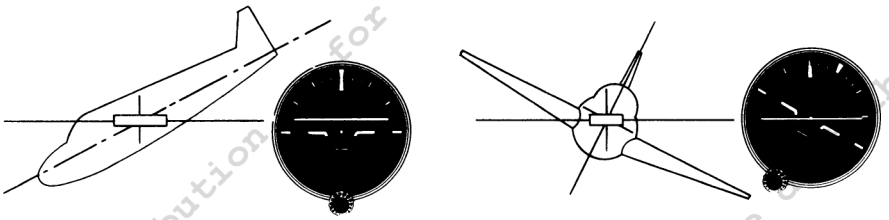
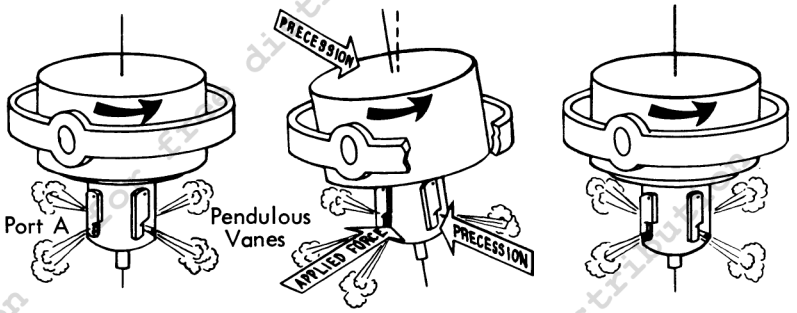


Fig. 1

WHAT IS THE EFFECT OF "PRECESSION" ON THE ATTITUDE INDICATOR?

A second principle of the gyroscope may be defined as follows: when a deflective force is applied to a rotating gyro, the resultant force will act at a point 90 degrees ahead and in the direction of rotation. Due to imperfections of the gyro mechanism and to forces applied to it, the rotor of the attitude indicator is constantly precessing from its proper plane of rotation. Without an erecting mechanism to correct for precession, the attitude indicator would be useless.

Vacuum-driven instrument -- Figure 2 is a diagrammatic view of the erecting device. Differential air flow from ports partially covered by pendulous vanes exerts a precessing force on the rotor to erect it.



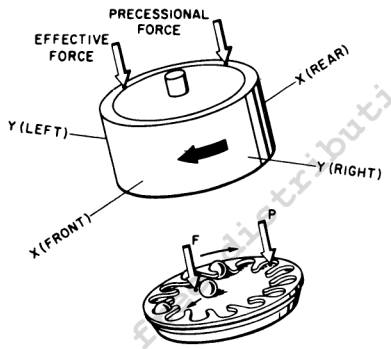
Exhaust Air Equal In All Directions Erect.

Gyro Precesses Increasing Exhaust From Port A.

Precessing Force At Port A Erects Gyro Exhaust Air Again Equal At All Ports.

Fig. 2

Electric instrument -- The erection system of a representative type is shown in Fig. 3.



POINT "F" Is The Center Of Gravity Of The Balls Where The Effective Erecting Force Is Applied.

POINT "P" Is The Precessional Force (Force "F" Rotated 90° In The Direction Of Rotation) Which Erects The Gyro.

Fig. 3

WHAT ARE THE ERRORS OF THE VACUUM-DRIVEN ATTITUDE INDICATOR?

Certain errors are always present in an attitude indicator due to the characteristics of the gyroscope and its erecting mechanism. Other errors may be caused by low suction, dirt, unbalance and worn bearings.

1. Skid error -- A skidding turn moves the pendulous vanes out of their vertical position precessing the gyro toward the inside of the turn. After return to straight-and-level flight, the miniature aircraft shows a bank in the direction opposite the skid. The maximum error is 3 to 4 degrees. When the skidding stops, the erecting mechanism soon returns the rotor to its normal plane of rotation.
2. Turn error -- During a normal coordinated turn, movement of the pendulous vanes by centrifugal force causes the gyro to precess toward the inside of the turn. The error is greatest in a steep turn. After rolling-out at the end of a 180 degree turn, the miniature aircraft shows a slight climb and a banked attitude opposite the direction of the turn. This precession error is quickly corrected by the erecting mechanism. The precession induced by a second 180 degree turn cancels the error of the first.
3. Acceleration error -- When the aircraft accelerates, the pendulous vanes of the erecting mechanism are moved out of position resulting in a precession of the gyro. The horizon bar moves down and the instrument indicates a climb.
4. Deceleration error -- Deceleration causes the erecting mechanism to react in such a manner that the horizon bar moves up, indicating a descent.
5. Haphazard error -- This error is caused by a defective erecting mechanism or low suction. There is a loss of rotor rigidity and the reaction of the instrument is unpredictable.

WHAT ARE THE ERRORS OF THE ELECTRIC ATTITUDE INDICATOR?

In normal turns, centrifugal force may cause precession errors up to 5 degrees of pitch and bank upon return to level flight. Acceleration and deceleration errors are also present. The horizon bar moves slightly down during acceleration and slightly up during deceleration. Upon return to cruising flight, the erecting mechanism quickly returns the gyro to its proper plane of rotation. The electric instrument is generally more efficient in operation and less subject to error than the vacuum-driven instrument.

WHAT ARE THE PITCH AND BANK LIMITS OF THE VACUUM-DRIVEN ATTITUDE INDICATOR?

The pitch limit is approximately 60 degrees and the bank limit is approximately 100 degrees. Rotation of the aircraft beyond these limits will cause the gyro to spill or tumble. Since these limits are beyond the attitude restrictions of "normal category" aircraft, the instrument should not tumble in normal instrument flight. An accurate and systematic cross-check of the other pitch and bank instruments will enable the pilot to recognize an "upset" attitude indicator.

WHAT ARE THE PITCH AND BANK LIMITS OF THE ELECTRIC ATTITUDE INDICATOR?

The limits depend on the design of the instrument. One type has approximately the same upset limits as the vacuum-driven instrument. Another type has full rotational freedom about both pitch and bank axes and therefore no upset limits.

DOES THE ATTITUDE INDICATOR TELL THE PILOT WHEN A TURN IS COORDINATED?

No, the pilot should always check his coordination by referring to the "ball" of the turn-and-slip indicator.

DOES THE ATTITUDE INDICATOR TELL THE PILOT HIS RATE OF TURN?

No, he determines his rate of turn by referring to the turn needle of the turn-and-slip indicator. Of course, he can establish a bank by the attitude indicator which should give him a desired rate to turn for a particular true airspeed. For example, if a turn is coordinated, a 15 degree bank will maintain a standard rate turn (3 degrees per second) at 100 knots true airspeed.

CAN THE ATTITUDE INDICATOR BE USED IN RECOVERING FROM UNUSUAL ATTITUDES?

Yes, if the instrument has not tumbled. During unusual attitude recoveries, the airspeed, altimeter, and turn needle should always be cross-checked closely to determine the accuracy of the indication given by the attitude indicator.

WHAT PRECAUTIONS SHOULD BE TAKEN WHEN CAGING AND UNCAGING THE ATTITUDE INDICATOR?

If the instrument has a caging knob and it becomes necessary to cage and uncage it in flight, be sure the aircraft is flying straight-and-level. The indications of the instrument depend on the position of a universally mounted gyro which if uncaged in an unlevel attitude tends to remain in an unlevel attitude due to rigidity. Several minutes may be required by the erecting mechanism to correct the rotor's plane of rotation. Be sure the instrument is fully uncaged otherwise the operational limits will be reduced and the gyro will tumble in otherwise safe maneuvers.

HOW IS THE ATTITUDE INDICATOR CHECKED FOR PROPER OPERATION PRIOR TO FLIGHT?

After starting the engine, make these checks: for a vacuum-driven instrument, the suction gage should read in the required range (usually between 3.75 and 5.0 inches of mercury, depending on the installation) -- for an electric instrument, check the generator and inverter for proper operation. Five minutes should be allowed for the rotor to attain normal operating speed. The horizon bar should stabilize in a horizontal position and should remain in the correct position for the attitude of the aircraft. The horizon bar should not tip more than 5 degrees during taxiing turns.

SUMMARY:

The attitude indicator is a reliable instrument. It is the single instrument that provides a direct indication of aircraft attitude. The small errors inherent in its design can readily be compensated for by an accurate cross-check with the other flight instruments and by having a knowledge of its operating principles and limits.

REFERENCES:

Instrument Flying Handbook, AC 61-27A
Instrument Pilot Exam-O-Gram No. 18

* Exam-O-Grams are non-directive in nature and are issued solely as an information service to individuals interested in Airman Written Examinations.

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