AIRCRAFT INSTRUMENTATION

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Lecture notes on Aircraft Instrumentation

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INDEX

Aim & objectives: To study the various instruments displays and panels in the aircraft and to discuss the cock pit layout. The objective of the study of aircraft instrumentation is to know the functions of all the flight, gyroscopic and power plant instruments in the aircraft and enable the learners to rectify the problems occurring in the aircraft.

Prerequisite: Basic electronics, Measurements and Instruments

SYLLABUS:

UNIT I: Introduction

Classification of aircraft ~instrumentation -instrument displays, panels, cock- pit layout.

UNIT-ll: Flight Instrumentation

Static & pitot pressure source -altimeter -airspeed indicator -machmeter -maximum safe speed indicator- accelerometer.

UNIT-III: Gyroscopic Instruments

Gyroscopic theory -directional gyro indicator, artificial horizon -turn and slip indicator.

UNIT-IV: Aircraft Computer Systems

Terrestrial magnetism, aircraft magnetism, Direct reading magnetic components- Compass errors gyro magnetic compass.

UNIT- V : Power Plant Instruments

Fuel flow -Fuel quantity measurement, exhaust gas temperature measurement and pressure measurement.

TEXT BOOKS

1. Pallett, E.B.J ., : "Aircraft Instruments -Principles and applications", Pitman and sons, 1981.
2. "Aircraft Instrumentation and systems", S.Nagabhushana, L.K.Sudha. I.K. International Publishing House Pvt., Ltd., S-25, Green Park Extensions, Uphaar Cinema Market, New Delhi – 110016(India), Info@ik international .com, ISBN : 978-93-80578-35-4

UNIT I – INTRODUCTION

Classification of aircraft ~instrumentation -instrument displays, panels, cock- pit layout

Aim & Objectives: To study the various instrument displays and panels in the aircraft and to discuss the cock pit layout.

Pre MCQ Test

1. Airframe of an aircraft is its __________ structure.
   a) Electrical
   b) Mechanical
   c) Thermal
   d) Hydraulic
   Answer: b) Mechanical

2. Which was the first commercial aircraft with 50% of its structure weight made of carbon-fiber composite?
   a) Boeing 777
   b) Boeing 787
   c) Boeing 747
   d) Airbus A380
   Answer: b) Boeing 787

3. Wings are responsible for creating lift.
   a) True
   b) False
   Answer: a) True

4. What material is used for aircraft fuselage?
   a) Aluminum alloys
   b) Titanium alloys
   c) Silver alloys
   d) Metal alloys
   Answer: a) Aluminum alloys

THEORY

1.1 Introduction

An aircraft is truly a multidisciplinary system involving almost all branches of physics, chemistry and engineering. Modern aircraft tends to be highly efficient, very reliable and eco-friendly, with all branches of science contributing synergistically to achieve the optimum flying machine, capable of transporting more than 600 passengers non-stop from Bombay to Los Angeles. An aircraft consists of (i) main frame—fuselage to carry passengers or payloads, (ii) wings to provide lifting force to overcome weight of the aircraft, (iii) propulsion system (jet engine or turboprop or propeller engine) and (iv) sophisticated avionics system including instrumentation system, navigation systems, communication systems and warning systems. Modern avionics suite includes many digital computers to increase safety, reduce pilot workload and enhance reliability.

1.2 Control Surfaces

An aircraft has two types of control surface:

1. Primary control surfaces and
2. Secondary control surfaces.

The primary control surfaces are shown in Fig. 1.1(a) and these control the pitch, roll and yaw of the aircraft. The secondary control surfaces include air brakes spoilers, trims for roll, pitch and yaw, as shown in Fig. 1.1(b).

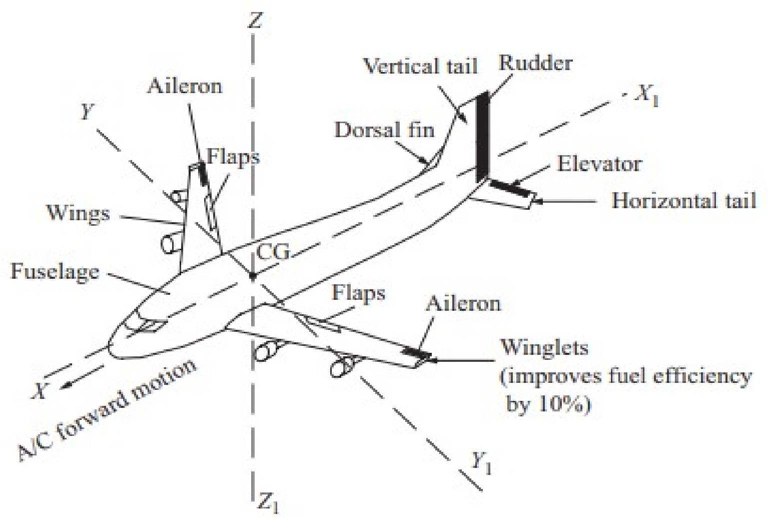


Fig 1.1 a) Primary controls surfaces

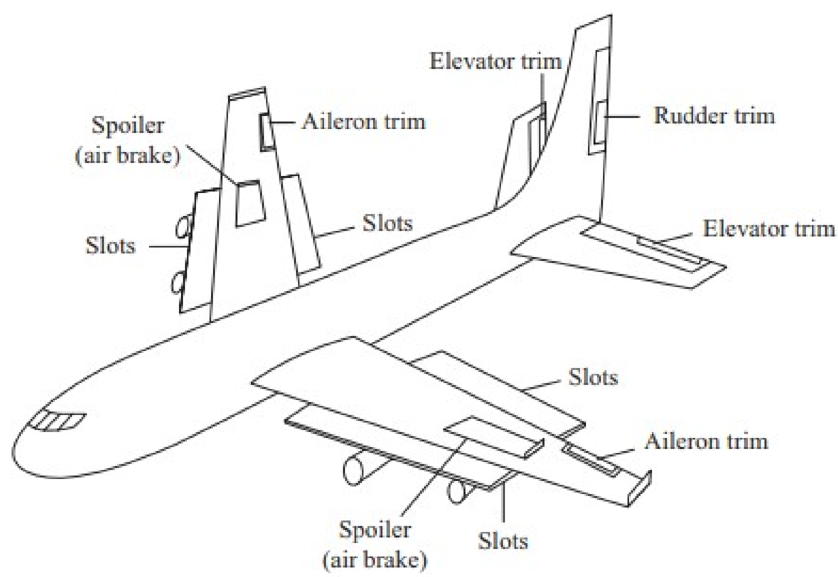


Fig 1.1 b) Secondary controls surfaces

1.3 Forces, Moments and Angle of Attack (AOA)

There are three forces and three moments as shown in Fig. 1.2, that should be considered. In order to deal with the motion of an aircraft, it is essential to define a suitable coordinate system.

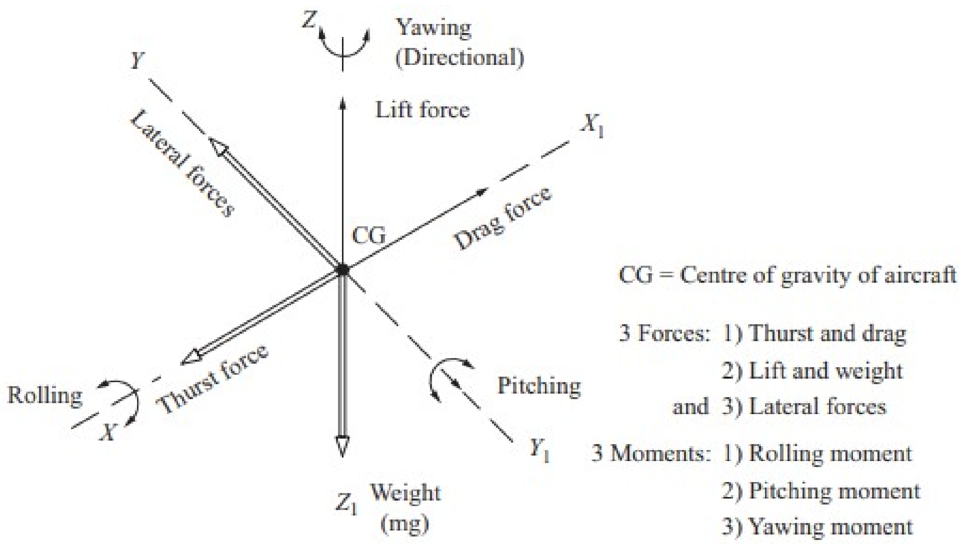


Fig. 1.2 Forces and moments in an aircraft.

There are two coordinate systems:

(i) First coordinate system—inertial coordinate system is fixed to the earth and is used for aircraft motion analysis, with respect to earth.

(ii) Second coordinate system—body coordinate system is fixed to the moving aircraft.

Fig. 1.3 shows the two right-handed coordinate systems.

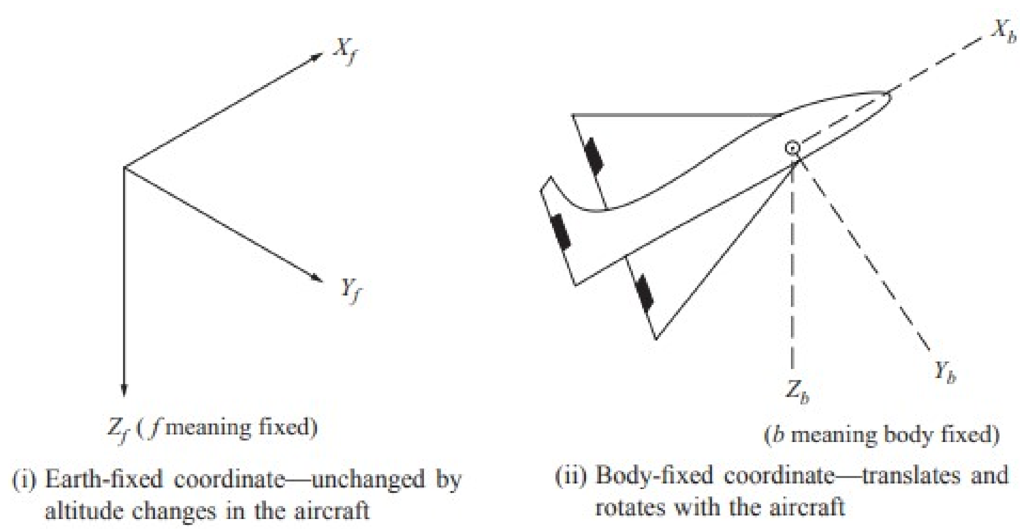


Fig. 1.3 Two right-handed coordinate systems.

Coordinate System Three Forces

The aircraft experiences longitudinal force, lateral force and vertical (normal) force. Likewise, there are three moments:

1. Pitching moment about lateral axis,
2. Rolling moment about longitudinal axis, and
3. Yawing moment about vertical axis.

The three forces and moments are shown in Fig. 1.2.

Angle of Attack (AOA)

Angle of attack (AOA) is one of the most important parameters in the aircraft. Angle of attack (AOA, α Greek letter alpha) is the angle between the chord line (see Fig. 1.4) of an aerofoil and the vector representing the relative motion of aerofoil and the surrounding air.

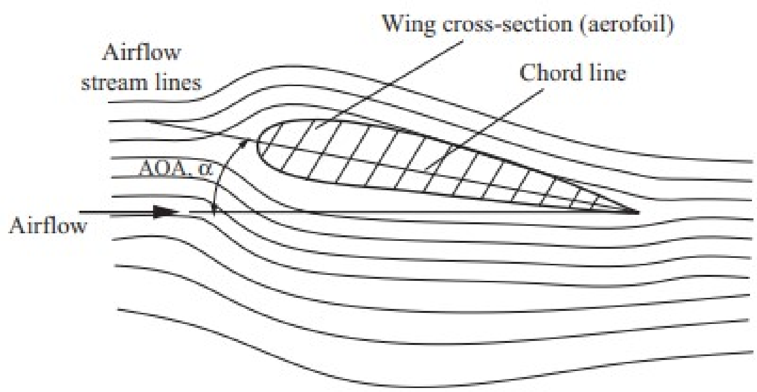


Fig. 1.4 Angle of attack of an aerofoil (wing cross-section).

There is another related angle, called pitch angle which is different from angle of attack—pitch angle is measured with respect to the horizon, whereas AOA is measured with respect to the direction of local airflow.

The lift coefficient, C_L of a fixed-wing aircraft is directly related to AOA. Increasing α increases C_L up to the maximum lift, after which lift decreases as shown in Fig. 1.5.

As the AOA increases beyond α_{max}, separation of the airflow from the upper surface of the wing becomes more significant, causing the reduction of C_L. At the critical AOA, the wing is unable to support the weight of the aircraft, causing the aircraft to descend, which in turn, causes the AOA to increase further. This is known as STALL.

An aircraft always stalls at the same α_{crit}, rather than at the same airspeed. The airspeed at which the aircraft stalls depends on many factors like—weight of the aircraft, the load factor* at the time and the thrust from engine. The critical AOA is typically at 15° for many aerofoils.

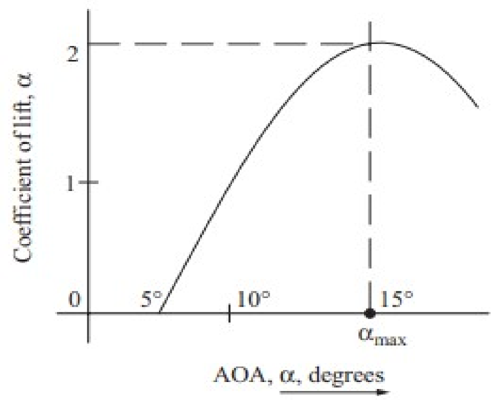


Fig. 1.5 Lift coefficient vs. Angle-of-attack curve.

Stall condition is a very dangerous situation, particularly at low flight altitude. Most of the modern aircraft have a stall warning system typically a tactile (control column shaking) and aural synthesized voice warning. Sometime, stall conditions are automatically corrected by a stick pusher system, which acts on the elevator control to prevent the AOA reaching α_{crit}. The stall warning system gives warning about the incipient stall condition, by alerting the pilot even before stall conditions are reached.

1.4. Instrument Displays

The most common forms of data display applied to aircraft instruments are

(a) Quantitative, in which the variable quantity being measured is presented in terms of a numerical value and by the relative position of a pointer or index, and

(b) Qualitative, in which the information is presented in symbolic or pictorial form.

1.4.1. QUANTITATIVE DISPLAYS

There are three principal methods by which information may be displayed:

a) the circular scale, or the 'clock' type of scale,

b) straight scale, and

c) digital or counter.

a) Circular Scale

The method of displaying information in quantitative form is illustrated in Fig 1.6

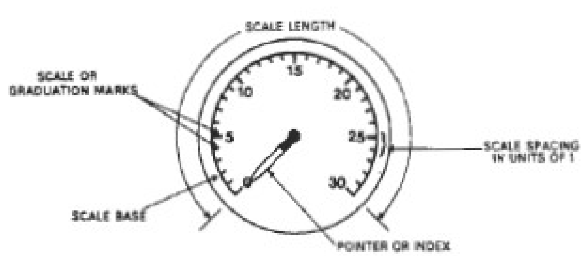


Figure 1.6 Circular scale quantitative display

The **scale base**, or graduation circle, refers to the line, which may be actual or implied, running from end to end of the scale and from which the scale marks and line of travel of the pointer are defined.

Scale marks, or graduation marks, are the marks which constitute the scale of the instrument.

As far as quantitative-display aircraft instruments are concerned, a simple rule followed by manufacturers is to divide scales so that the marks represent units of 1, 2 or 5 or decimal multiples thereof. The sizes of the marks are also important and the general principle adopted is that the marks which are to be numbered are the largest while those in between are shorter and usually all of the same length.

Spacing of the marks fall into two distinct groups, **linear and non-linear**; in other words, scales with marks evenly and non-evenly spaced. Typical examples are illustrated in Fig 1.7, from which it will also be noted that nonlinear displays may be of the square-law or logarithmic-law type, the physical laws in this instance being related to airspeed and rate of altitude change respectively.

The sequence of numbering always increases in a clockwise direction, thus conforming to what is termed the 'visual expectation' of the observer. In an instrument having a centre zero is only apply to the positive scale. In the case of marks, numbering is always in steps of 1, 2, or 5 or decimal multiples thereof. The numbers may be marked on the dial either inside or outside the scale base; the latter method is preferable since the numbers are not covered by the pointer during its travel over the scale.

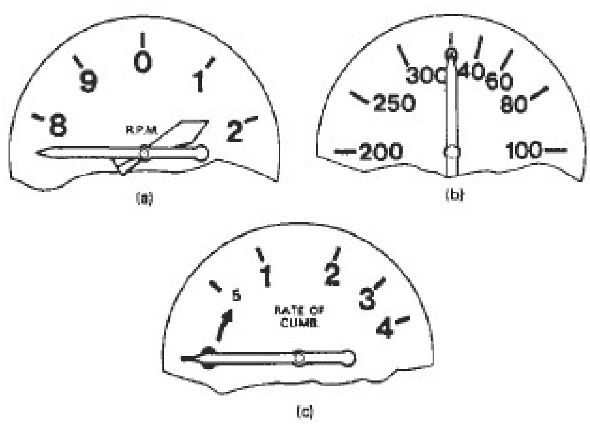


Figure 1.7 Linear and nonlinear scales. (a) Linear; (b) square-law; (c) logarithmic.

The distance between the centers of the marks indicating the minimum and maximum values of the chosen range of measurement, and measured along the scale base, is called the **scale length.**

High-Range Long-Scale Displays

In Fig 1.8, The display shown at (a) is perhaps the simplest way of accommodating a lengthy scale; by splitting it into two concentric scales the inner one is made a continuation of the outer. A single pointer driven through two revolutions can be used to register against both scales, but as it can also lead to too frequent mis-reading, a presentation by two interconnected pointers of different sizes is much better. A practical example of this presentation is to be found in some current designs of turbine-engine rev.min. indicator. In this instance a large pointer rotates against the outer scale to indicate hundreds of rev./min. and at the same time it rotates a smaller pointer against the inner scale indicating thousands of rev./min.

Fig 1.8 (b), employed in airspeed indicator has the design; a single pointer rotates against a circular scale and drives a second scale instead of a pointer. This rotating scale, which records hundreds of miles per hour as the pointer rotates through complete revolutions, is visible through an aperture in the main dial.

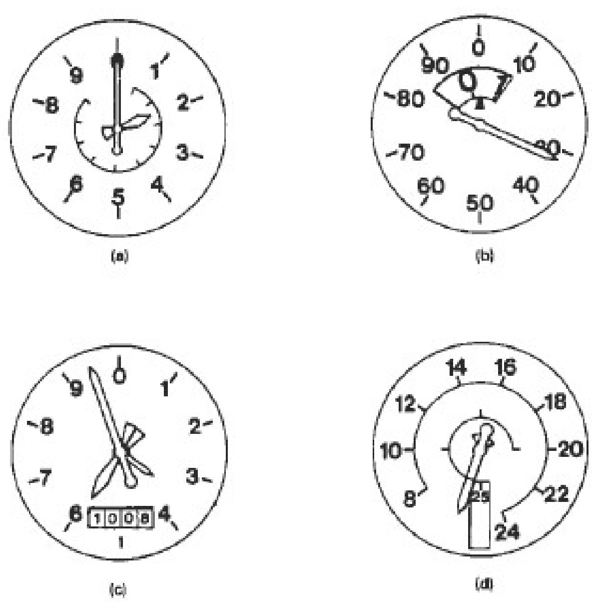


Fig. 1.8 High-range long scale displays. (a) Concentric scales; (b) fixed and rotating scales; (c) common scale, triple pointers; (d) split pointer.

Fig shown at 1.8 (c), is one in which three concentric pointers of different sizes register against a common scale. In altimeter dial design, the large pointer indicating hundreds, the intermediate pointer thousands and the small pointer tens of thousands of feet. This method suffers disadvantages that it takes too long to interpret a reading and gives rise to too frequent and too serious mis-reading.

Fig. 1.8 (d) applied to airspeed measurement. It will be noted that an outer and an inner scale are adopted and also what appears to be a single pointer. There are, however, two pointers which move together and register against the outer scale during their first revolution. When this has been completed, the tip of the longer pointer of the two is covered by a small plate and its movement beyond this point of the scale is arrested. The shorter pointer continues its movement to register against the inner scale.

Angle of Observation

Another factor which has an important bearing on the choice of the correct scale length and case size is the angle at which an instrument is to be observed. When observing an instrument at an angle errors due to parallax are possible, the magnitude of such errors being governed principally by the angle at which the relevant part of its scale is observed , and also by the clearance distance between the pointer and dial plate.

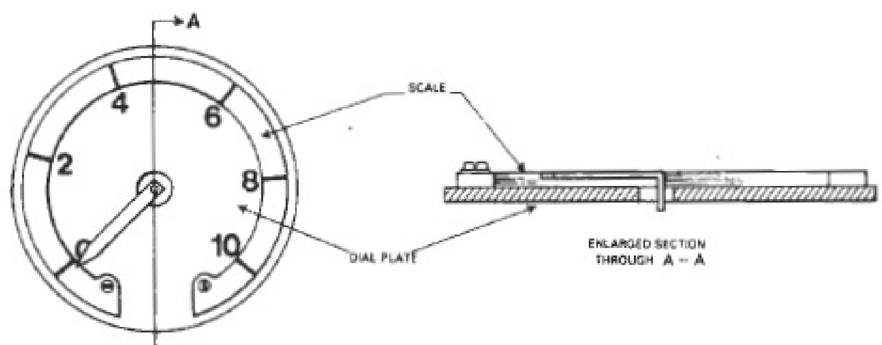
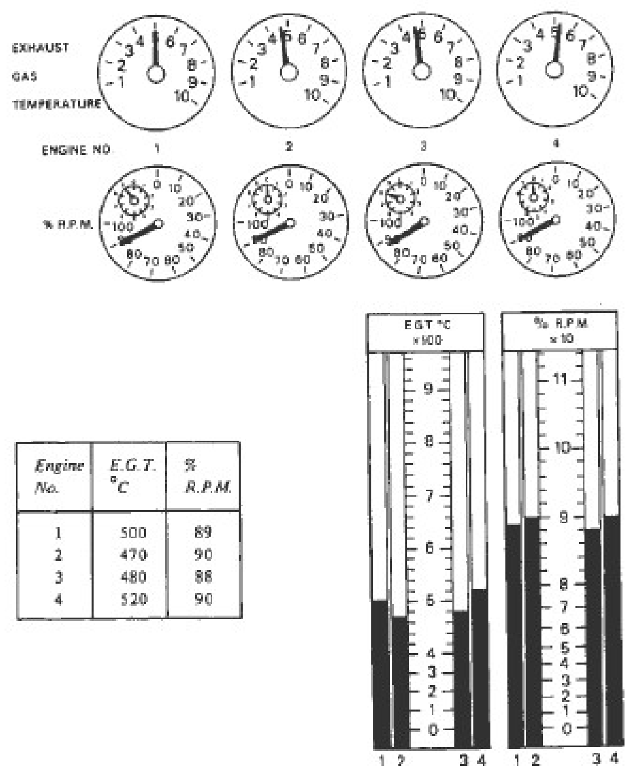


Fig.1.9. Platform Scale

This problem like so many others in the instrument field has not gone unchallenged and the result is the **'platform' scale** designed for certain types of circular display instruments. In Fig 1.9, the scale marks are set out on a circular platform which is secured to the main dial plate so that it is raised to the same level as the tip of the pointer.

b) Straight Scale

In addition to the circular scale presentation, a quantitative display may also be of the straight scale (vertical or horizontal) type.



Engine No.	E.G.T. °C	% R.P.M.
1	500	89
2	470	90
3	480	88
4	520	90

Fig. 1.10 Comparison between moving-tape and circular scale displays.

For the same reason that the sequence of numbering is given in a clockwise direction on a circular scale, so on a straight scale the sequence is from bottom to top or from left to right. the moving-tape or 'thermometer' display and is illustrated in Fig 1.10 as it would be applied to the measurement of two parameters vital to the operation of an aircraft powered by four turbojet engines.

Each display unit contains a servo-driven white tape in place of a pointer, which moves in a vertical plane and registers against a scale in a similar manner to the mercury column of a thermometer. As will be noted there is one display unit for each parameter, the scales being common to all four engines. By scanning across the ends of the tapes or columns, a much quicker and more accurate evaluation of changes in engine performance can be obtained than from the classical ·circular scale and pointer display. This fact, and the fact that panel space can be considerably reduced, is also clearly evident from Fig 1.10.

c) Digital Display

A digital or *veeder-counter* type of display is one in which data are presented in the form of letters or numbers-alpha-numeric display, as it is technically termed. In aircraft instrument practice, the latter presentation is the most common and a counter is generally to be found, operating in combination with the circular type of display. Typical examples are shown in Fig 1.11. In the application to the altimeter there are two counters; one presents a fixed pressure value which can be set mechanically by the pilot as and when required, and is known as a static counter display; the other is geared to the altimeter mechanism and automatically presents changes in altitude, and -is therefore known as a dynamic counter display.

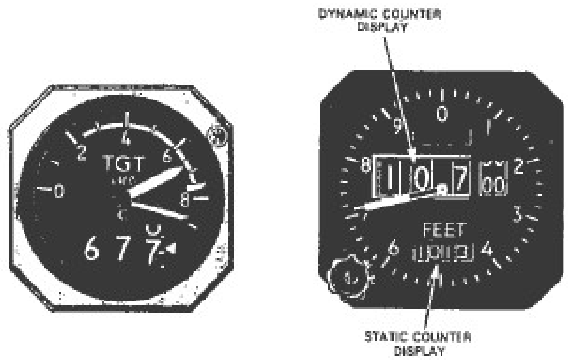


Fig 1.11 Digital displays.

Dual-Indicator Displays

Dual-indicator displays are designed principally as a means of conserving panel space, particularly where the measurement of the various quantities related to engines is concerned. They are normally of two basic forms: one in which two separate indicators and scales are embodied in one case; and the other, also having two indicators in one case, but with the pointers registering against a common scale. Typical examples of display combinations are illustrated in Fig 1.12.

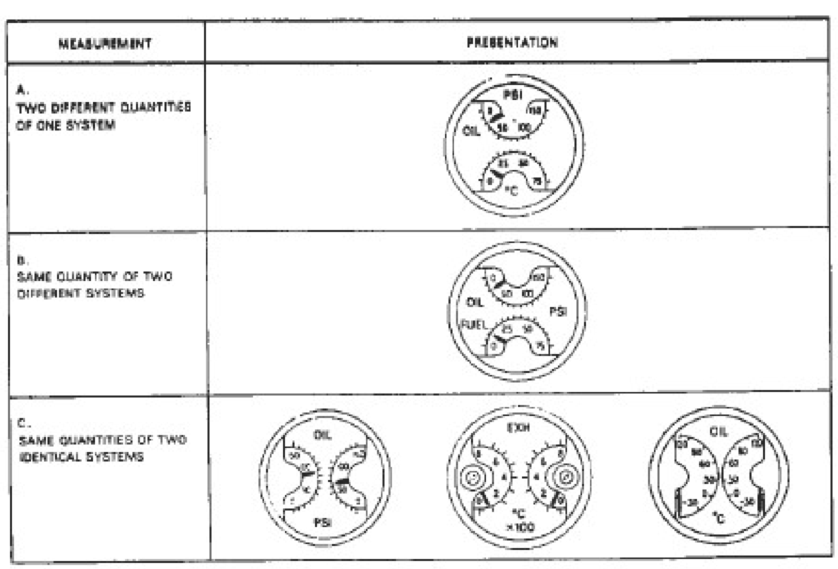


Fig. 1.12 Examples of dual-Indicator displays.

Coloured Displays

The use of colour in displays can add much to their value; not, of course from the artistic standpoint, but-as a means of indicating specific operational ranges of the systems with which they are associated and to assist in making more rapid assessment of conditions prevailing when scanning the instruments.

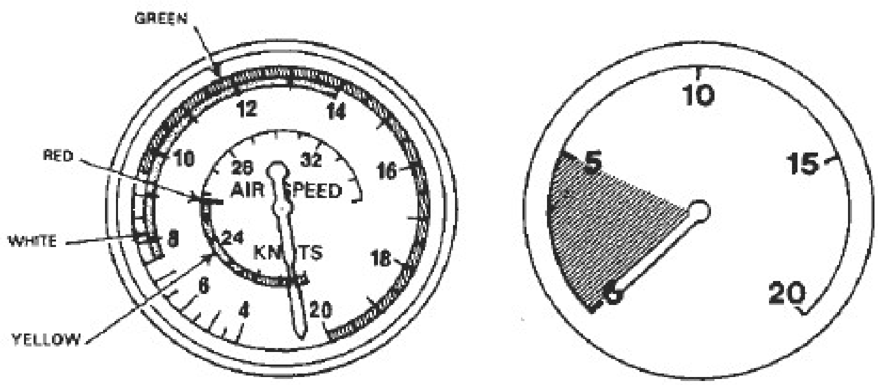


Figure 1.13 Use of colour in instrument displays.

White arc 75-140; Green arc 95-225; Yellow arc 225-255; Red radial line 255.

Colour may be applied to scales in the form of sectors and arcs which embrace the number of scale marks appropriate to the required part of the range, and in the form of radial lines coinciding with appropriate individual scale marks. A typical example is illustrated in Fig 1.13. It is usual to find that coloured sectors are applied to those parts of a range in which it is sufficient to know that a certain condition has been reached rather than knowing actual quantitative values.

The colours chosen may be red, yellow or green depending on the condition to be monitored. For example, in an aircraft oxygen system it may be necessary for the cylinders to be charged when the pressure has dropped below to 500 lbf/in^2. The system pressure gauge would therefore have a red sector on its dial embracing the marks from 0 to 500; thus, if the pointer should register within this sector, this alone is sufficient indication that recharging is necessary and that it is only of secondary importance to know what the actual pressure is. Arcs and radial lines are usually called range markings, their purpose being to define values at various points in the range of a scale which are related to specific operational ranges of an aircraft, its power plants and systems. The definitions of these marks are as follows:

RED radial line	Maximum and minimum limits
YELLOW arc	Take-off and precautionary ranges
GREEN arc	Normal operating range
RED arc	Range in which operation is prohibited

1.4.2. QUALITATIVE DISPLAYS

These are of a special type in which the information is presented in a symbolic or pictorial form to show the condition of a system, whether the value of an output is increasing or decreasing, and the movement of a component and so on. In Fig 1.14., the synchroscope is used in conjunction with a rev./min. indicating system of an aircraft having a multiple arrangement of propeller-type engines, and its pointers, which symbolize the propellers, only rotate to show the differences of speed between engines.

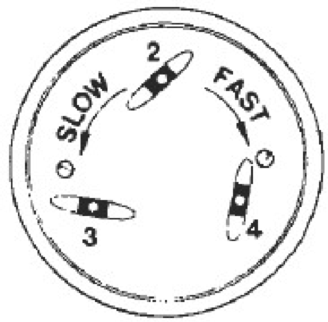


Fig.:1.14 Qualitative displays. Engine synchronizing;

a) Director displays

Director displays are those which are associated principally with flight attitude and navigational data and presenting it in a manner which indicates to a pilot what control movements he must make either to correct any departure from a desired flight path, or to cause the aircraft to perform a specific manoeuvre. The instrument pointer movements should be in the 'natural' sense in order that the pilot may obey the 'directives' or 'demands' of the display.

The gyro horizon which has been in use for many years utilizes in basic form a director display of an aircraft's pitch and bank attitude. In this instrument there are three elements making up the display: a pointer registering against a bank-angle scale, an element symbolizing the aircraft, and an element symbolizing the natural horizon. Both the bank pointer and natural horizon symbol are stabilized by a gyroscope. As the instrument is designed for the display of attitude angles, and as also one of the symbolic elements can move with respect to the other, then it has two reference axes, that of the case which is fixed with respect to the aircraft, and that of the moving element. Assuming that the aircraft's pitch attitude changes to bring the nose up, then the horizon display will be shown as in Fig 1.15 (a), thus directing or demanding the pilot to 'get the nose down'. Similarly, if the bank attitude should change whereby the left wing goes down, then the horizon display would be as shown at (b), directing or demanding the pilot to 'bank the aircraft to the right.' In both cases, the demands would be satisfied by the pilot moving his controls in the natural sense.

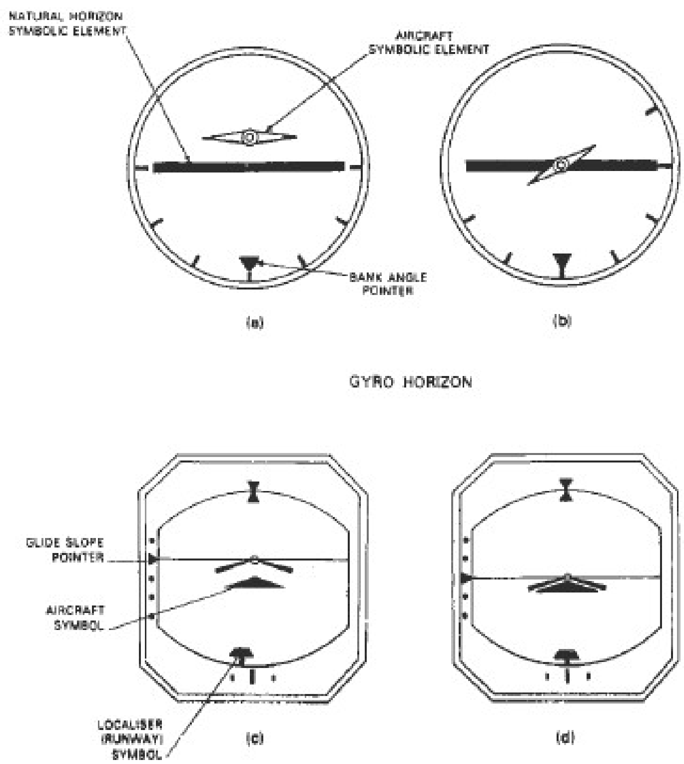


Fig. 1. 15 Examples of director display. (a) 'Fly down' directive; (b) 'bank right' directive; (c) 'fly left' and 'fly up' directive; (d) response matches directive.

Another example of a director display is that utilized in an indicator used in conjunction with the Instrument Landing System (ILS); this is a radio navigation system which aids a pilot in maintaining the correct position of his aircraft during the approach to land on an airport runway. Two radio signal beams are transmitted from the ground; one beam is in the vertical plane and at an angle to the runway to establish the correct approach or glide slope angle; while the other, known as the localizer, is in the horizontal plane; both are lined up with the runway centre-line.

A receiver on board the aircraft receives the signals and transmits them to two meters contained within the indicator; one meter controls a glide slope pointer, and the other a localizer pointer. When the aircraft is on the approach to land and is, say, below the glide slope beam, the glide slope pointer of the instrument will be deflected upwards as shown in Fig 1.15 (c). Thus, the pilot is directed to 'fly the aircraft up' in order to intercept the beam. Similarly, if the aircraft is to the right of the localizer beam the localizer pointer will be deflected to the left thus directing the pilot to 'fly the aircraft left'. As the pilot responds to the instrument's directives the pointers move back to their centre positions indicating that the aircraft is in the correct approach position for landing.(Fig 1.15 (d)).

b) Head-up displays

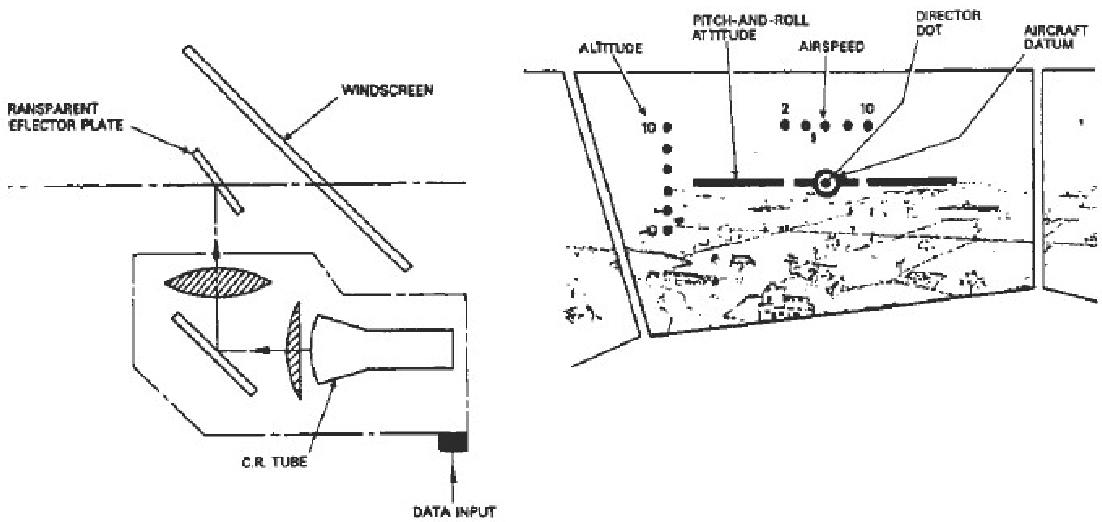


Fig. 1.16 Head-up display system.

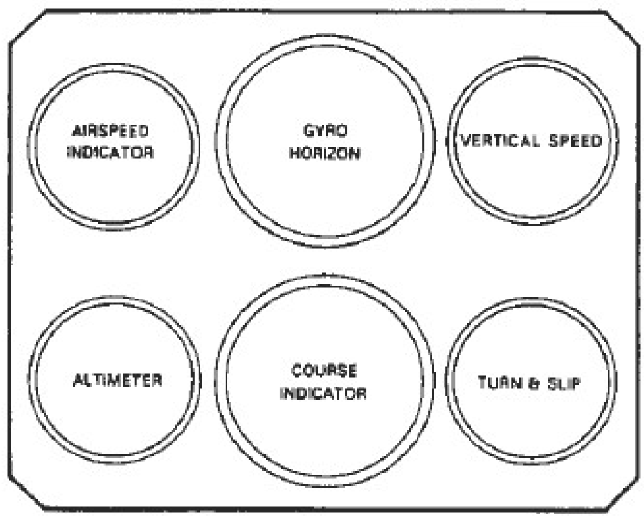
In the critical approach and landing phase, a pilot must transfer his attention more frequently from the instruments to references outside the aircraft, and back again; a transition process which is time-consuming and fatiguing as result of constant re-focusing of the eyes.

A method of alleviating these problems the vital flight data are presented at the same level at the pilot's line-of-sight when viewing external references, i.e. when his maintaining a 'head-up' position. The principle of the method is to display the data on the face of a special cathode-ray tube and to project them optically as a composite symbolic image on to a transparent reflector plate, or directly on the windscreen. The components of a typical head-up display system are shown in Fig 1.16.

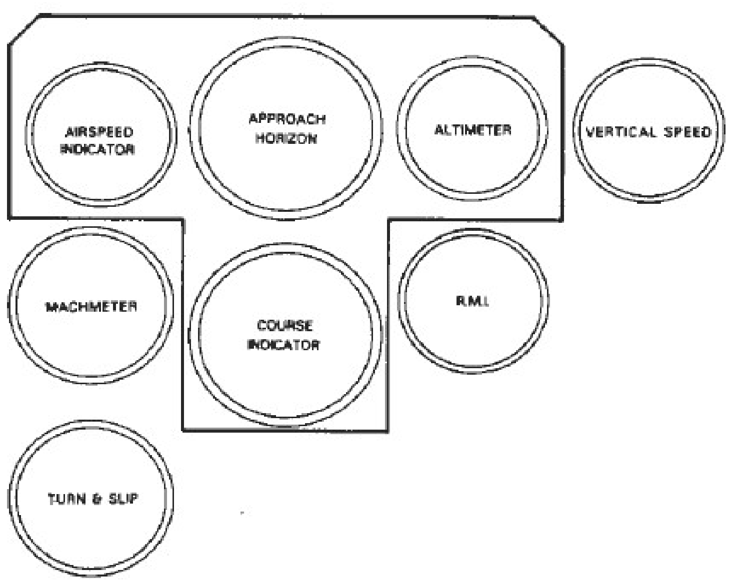
The data are transmitted from a data computer unit to the cathode-ray tube the presentation of which is projected by the optical system to infinity. It will be noted that the attitude presentation resembles that of a normal gyro horizon, and also that airspeed and altitude are presented by markers which register against linear horizontal and vertical scales. The length or range, of the scales is determined by operational requirements, but normally they only cover narrow bands of airspeed and altitude information. This helps to reduce irrelevant markings and the time taken to read and interpret the information presented.

1.5. Instrument Grouping - Flight Instruments

Basically there are six flight instruments whose indications are so co-ordinated as to create a 'picture' of an aircraft's flight condition and required control movements; they are airspeed indicator, altimeter, gyro horizon, direction indicator, vertical speed indicator and turn-and-bank indicator. It is therefore most important for these instruments to be properly grouped to maintain co-ordination and to assist a pilot to observe them with the minimum of effort. The first real attempt at establishing a standard method of grouping was the 'blind flying panel' or 'basic six' layout shown in Fig 1.17 (a).



(a)



(b)

Fig 1.17 (a) 'Blind flying panel' (b) Basic T arrangement

The gyro horizon occupies the top centre position, and since it provides positive and direct indications of attitude, and attitude changes in the pitching and rolling planes, it is utilized as the master instrument. As ·control of airspeed and altitude are directly related to attitude, the airspeed indicator, altimeter and vertical speed indicator flank the gyro horizon and support the interpretation of pitch attitude. Changes in direction are initiated by banking an aircraft, and the degree of heading change is obtained from the direction indicator; this instrument therefore supports the interpretation of roll attitude and is positioned directly below the gyro horizon. The turn-and bank indicator serves as a secondary reference instrument for heading changes, so it too supports the interpretation of roll attitude.

With the development and introduction of new types of aircraft, flight instruments and integrated instrument systems, it became necessary to review the functions of certain instruments and their relative positions within the group. As a result a grouping known as the 'basic T' was introduced (Fig 1. 17 (b)). The theory behind this method is that it constitutes a system by which various items of related flight information can be placed in certain standard locations in all instrument panels regardless of type or make of instrument used. In this manner, advantage can be taken of integrated instruments which display more than one item of flight information.

It will be noted that there are now four 'key' instruments, airspeed indicator, pitch and roll attitude indicator, an altimeter forming the horizontal bar of the 'T', and the direction indicator forming the vertical bar. As far as the positions flanking the direction indicator are concerned, they are taken by other but less specifically essential flight instruments, and there is a certain degree of freedom in the choice of function. From Fig 1 .17 it can be seen, for example, that a Machmeter and a radio magnetic indicator can take precedence over a tum-and-bank indicator and a vertical-speed indicator.

Border lines are usually painted on the panel around the flight instrument groups. These are referred to as 'mental focus lines’, their purpose being to assist pilots in focusing their attention on and mentally recording the position of instruments within the groups.

1.6. INSTRUMENT PANELS AND LAYOUTS

All instruments essential to the operation of an aircraft are accommodated on special panels the number and distribution of which vary in accordance with the number of instruments, the size of aircraft and cockpit layout. A main instrument panel positioned in front of pilots is a feature common ·to all types of aircraft, since it is mandatory for the primary flight instruments to be installed within the pilots' normal line of vision. Typical positions of other panels are: overhead, at the side, and on a control pedestal located centrally between the pilots.

Fig 1.18 Flight instruments inside the Cockpit

Panels are invariably of light alloy of sufficient strength and rigidity to accommodate the required number of instruments, and are attached to the appropriate parts of the cockpit structure. The attachment methods adopted vary, but all should conform to the requirement that a panel or an individual instrument should be easily installed and removed.

Main instrument panels, which may be of the single-unit type or made up of two or three sub-panel assemblies, are supported on shockproof mountings since they accommodate the flight instruments and their sensitive mechanisms. The number, size and disposition of shockproof mountings required are governed by the size of panel and distribution of the total weight.

All panels are normally mounted in the vertical position, although in some current aircraft types the practice of sloping main instrument panels forward at about 15° from the vertical is adopted to minimize parallax errors. Instrument and all other control panels which for many years were painted black, are now invariably finished in matt grey, a colour which apart from its 'softer' effects provides a far better contrasting background for the instrument dials and thus contributes to easier identification.

1.7. Methods of Mounting Instruments

The two methods most commonly used for the panel mounting of instruments are the

a) flanged case method, and

b) the clamp method.

The flanged case method requires the use of screws inserted into locking nuts which, in some instruments, are fitted integral with the flange. Since flanged-type indicators are normally mounted from the rear of the panel, it is clear that the integrally fixed locking nuts provide for much quicker mounting of an instrument and overcome the frustration of trying to locate a screw in the ever-elusive nut!

As a result of the development of the hermetic sealing technique for instruments, the cases of certain types are flangeless, permitting them to be mounted from the front of the instrument panel. In order to secure the instruments special clamps are provided at each cut-out location. The clamps are shaped to suit the type of case, i.e. circular or square, and they are fixed on the rear face of the panel so that when an instrument is in position it is located inside the clamp. Clamping of the instrument is effected by rotating adjusting screws which draw the clamp bands tightly around the case.

1.8. BLACK BOXES – COCKPIT VOICE RECORDER & FLIGHT DATA RECORDER

CVR records the pilots' voice and any other sounds audible in the cockpit.

INTRODUCTION:

Commercials airlines are mandated to carry two "Black box", which record the information about a particular flight .Both cockpit voice recorder (CVR) and Flight data recorder (FDR) are installed in the air craft so that accident-investigators are able to reconstruct the condition which cause the accident .CVR records the audible signals originating in the cockpit such as pilot voice, VHF voice communication with air traffic controller (ATC), engine sound and any other acoustic signals for a minimum duration of previous 120 minutes. Flight Data Recorder, on the other hand digitally stores aircraft data such as altitude, attitude, acceleration, air speed, temperature, heading, control surface position, landing gears position, etc., a total number of minimum 88 parameters.

The recording lasts for the previous 24 hours of the data. Both CVR and FDR are installed usually in the tail section of the aircraft since the tail is the most crash survival part. CVR and FDRs of accidented air craft have provided invaluable data so the appropriate changes in the air craft design are made. This feedback has significantly contributed to reduced accidents today.

Both recorders are painted orange (not black) with two light reflecting strips as shown in fig 1.19 and carry marking "FLIGHT RECORDERS DO NOT OPEN".

Each recorder is fitted with under water locater beacon to assist in the locating them when submerge under water after the aircraft's splash down in water. ULB is also called "pinger". When the recorder is surrounded by water ULB transmits an acoustic sonar type signal at a frequency of 37.5 KHZ, which can be detected by an ultrasonic receiver.

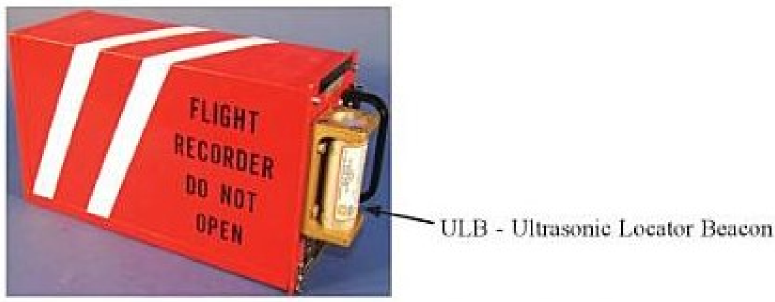


Fig.1.19. Photograph of modern CVR and FDR

Both CVR and FDR will have a fireproof and crash-proof enclosure made of titanium based alloy enclosing the memory element, containing the data. After the accident, both recorders will be recovered as soon as possible from the accident site and to investigation agency of the country over which the accident occurred.

The readout system consists of sophisticated computers and audio replay units to read and critically analyse the data stored in the memory unit. The investigating agency uses this information as one of the many sources/tools to determine the probable cause of the accident.

COCKPIT VOICE RECORDER (CVR):

CVR records the pilot' voices and any other sounds audible in the cockpit. There are four sensitive microscope one each for the pilot and the co-pilot to record the voice communication with ATC one microscope above the pilot is called the "Cockpit area microphone" and one spare which was earlier used by the flight engineers, whose tasks are now handle by the two pilots themselves.

Sounds of value to the investigation include thrust-lever clicks, door shutting, engine noise, stall warnings, landing gear extension and any other clicks and pops. The acoustic signals and their DSP analysis can give vital information such as engine rpm, system malfunctions, speed and the time at which certain critical events occurred. In addition, communications with ATC over VHF-voice link, automated radio weather briefings and conversation between the two pilots, or with other cabin crew, are also recorded. CVR always contains previous two hour's data. Earlier data is erased and lost.

Fig. 1.20. shows the schematic diagram of the CVR system

CVR data is usually treated in a different manner than the FDR recording, due to the extremely sensitive nature of the voice communication in the cockpit. The content and timing of release of the written transcript are strictly controlled by the investigating agency of the country over the accident is occurred.

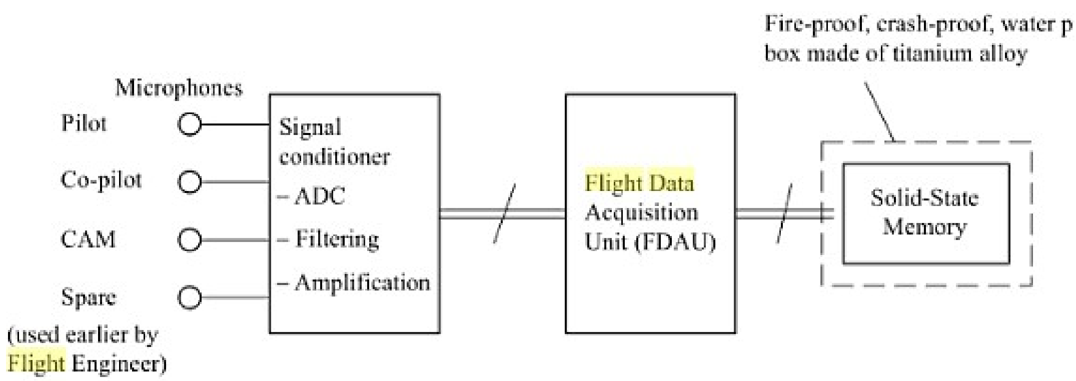


Fig1.20. Block diagram of modern cockpit voice recorder

Some of the salient specifications of CVR are:

1.	Capacity	:	30 minutes, continuous (2 hrs for modern solid – state CVR)
2.	Number of channels	:	4
3.	Impact tolerance	:	3400 G/6.5 millisecond
4.	Fire resistance	:	1100^{o} C/30 minutes
5.	Water pressure tolerance	:	submerged 4100m (20,000 ft)
6.	Under water Locator Beacon	:	- 37.5 kHz - 30 day operational capacity upon activation - Battery shelf-life of 6 years.

FLIGHT DATA RECORDER (FDR)

The FDR stores a large number of important aircraft parameters such as altitude, attitude, acceleration, air speed, temperature, heading, control surface position, landing gears position, etc., further FDR records the status of nearly 1000 other in flight data that can possible aid in accident investigation. Earlier records ¼" magnetic tape as the bulk storage medium. Present day FDRs use solid state flash type memory chip which are fire and crash protect as in CVR.

Fig.1.21. shows the block diagram of FDR recorder. The analog data from various aircraft sensors as well as discrete on/off type signals such as landing gears up/down, airbrakes on/off are fed into multiplexer of flight data acquisition (FDAU).

It is very laborious and the time consuming to remove the FDR and use the data for performance monitoring of the aircraft. Hence the same data is recorded in parallel by another solid state recorder, called Performance Monitoring Recorder (PMR) which can be easily removed.

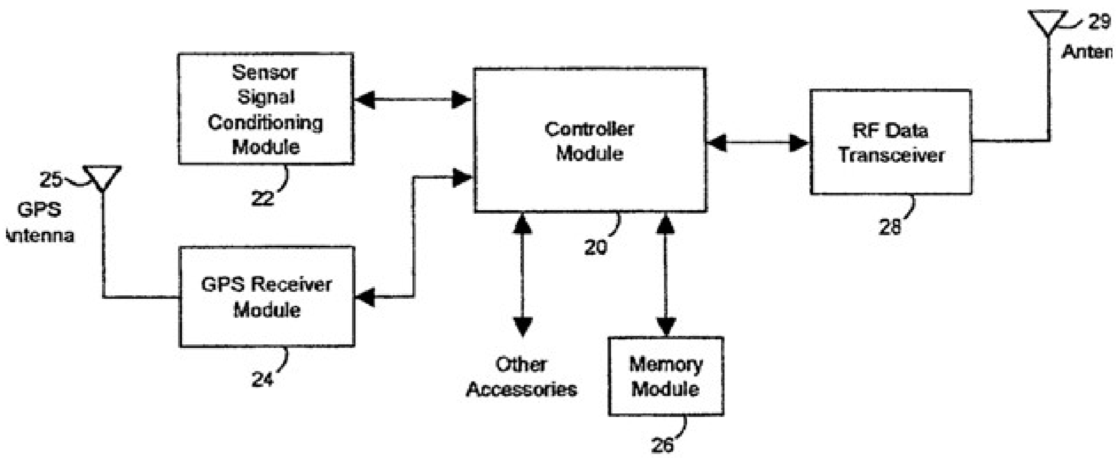


Fig.1.21. Black Boxes – COCKPIT VOICE RECORDER & FLIGHT DATA RECORDER

Post MCQ Test

1. What do winglets do?
   a) Increase thrust
   b) Reduce turbulence at the tips of an airplane's wings
   c) Decrease thrust
   d) Increase turbulence at the tips of an airplane's wings
   Answer: b) Reduce turbulence at the tips of an airplan's wings
2. The earliest aircraft were constructed primarily of __________
   a) Steel
   b) Aluminum
   c) Steel
   d) Wood
   Answer: d) Wood.
3. In How many Primary Flight Displays are present in typical civil aircraft cockpit?
   a) 1
   b) 2

c) 4
d) 3
Answer: b) 2

4. What are the 5 primary mechanical displays, a Primary Flight Display (PFD) can replace?
   a) Altimeter, turn coordinator, vertical speed indicator, artificial horizon and heading/compass indicator
   b) Altimeter, vertical speed indicator, artificial horizon, heading/compass indicator and Mach meter
   c) Altimeter, vertical speed indicator, artificial horizon, heading/compass indicator and landing gear position
   d) Altimeter, turn coordinator, artificial horizon, heading/compass indicator and Mach meter
   Answer: b) Altimeter. Turn indicator, vertical speed indicator, artificial horizon and Heading / compass indicator.
5. Which one of the following flight parameters are not present in a typical commercial head up display?
   a) Airspeed
   b) Altitude
   c) Heading
   d) Throttle position
   Answer: d)Throttle position.
6. Stabilizing tail is also known as -------------
   a) Rudder
   b) Empennage
   c) Aileron
   d) Wingtip
   Answer: b) Empennage.

Assignment

1. What do you understand by the term head up display system? With the aid of diagrams describe how basic flight data is displayed to a pilot.
2. Describe the basic T method of grouping flight instruments.
3. What is the use of black box? Explain CVR and FDR.
4. Describe cock pit layout

UNIT-II FLIGHT INSTRUMENTATION

Static & pitot pressure source -altimeter -airspeed indicator -machmeter -maximum safe speed indicator- accelerometer.

Aim & Objectives:

Describe the operating principles and features of aircraft flight instrument systems, including the pitot-static, airspeed indicator, angle-of-attack, altimeter and miscellaneous flight instrument systems.

Pre MCQ Test

1. What is the full form of VFR?
   a) Visual flight rules
   b) Visual flying rules
   c) Virtual flight rules
   d) Virtual flying rules
   Answer: a) Visual Flight Rules

2. Where is the static port mounted?
   a) On the fuselage of an aircraft
   b) On the nose of an aircraft
   c) On the engine of an aircraft
   d) On the tail of an aircraft
   Answer: a) On the fuselage of an aircraft

3. A pilot of a jet airplane needs both an airspeed indicator and a Mach meter.
   a) True
   b) False
   Answer: a) True

4. Static pressure is measured from the __________
   a) Static port
   b) Static scale
   c) Pitot scale
   d) Pitot tube
   Answer: a) Static port

THEORY

2.1. PITOT-STATIC SYSTEM

The pilot-static system of an aircraft is a system in which total pressure created by the forward motion of the aircraft and the static pressure of the atmosphere surrounding it are sensed and measured in terms of speed, altitude and rate of change of altitude (vertical speed). In other words, the system may be referred to as a manometric, or air data system.

In its basic form the system consists of a pitot-static tube, or probe, the three primary flight instruments-airspeed indicator, altimeter and vertical speed indicator-and pipelines and drains, interconnected as shown diagrammatically in Fig 2.1.

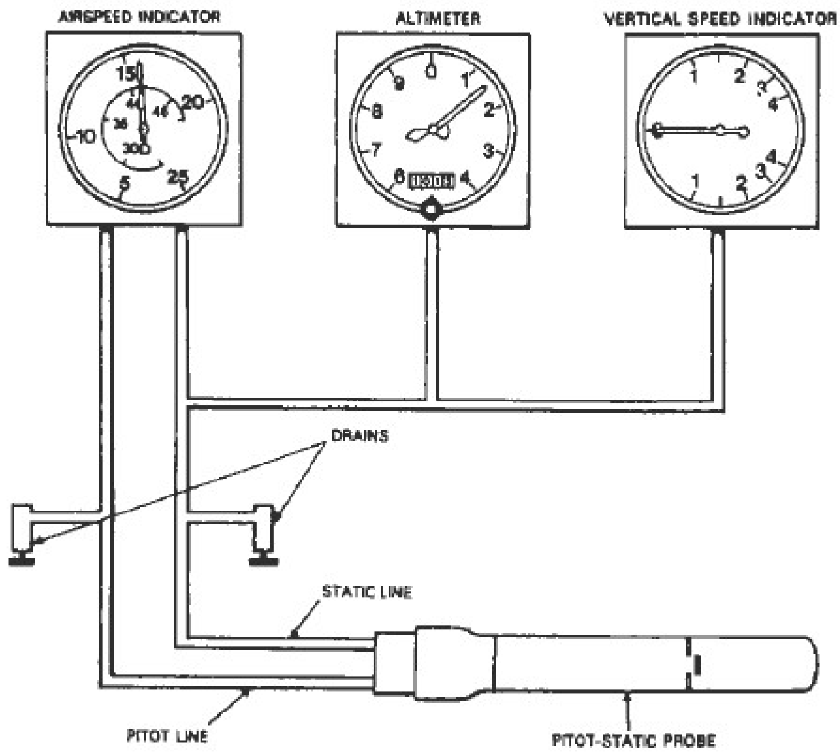


Fig. 2.1. Basic pitot-static system.

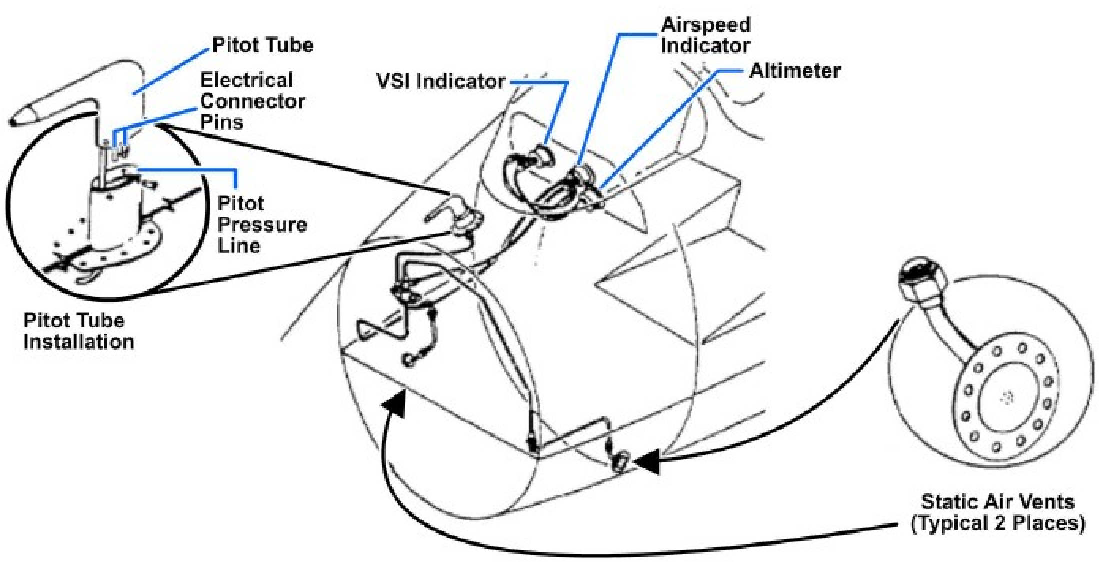


Fig 2.2. Mechanical schematic view of Pitot-static system.

The airspeed indicator shows the speed of the aircraft through the air, and the altimeter shows the altitude. The Vertical Speed Indicator (VSI) indicates how fast the aircraft is climbing or descending. All of these indicators operate on air that comes in from outside the aircraft during flight.

The pitot tube mounts on the outside of the aircraft (Figure 2.2) at a point where the air is least likely to be turbulent. The tube points in a forward direction parallel to the aircraft's line of flight. One general type of airspeed tube mounts on a streamlined mast extending below the nose of the fuselage. Another type mounts on a boom extending forward from the leading edge of the wing. Although there is a slight difference in their construction, the tubes operate identically.

The Pitot System measures impact pressure, which is the pressure of the outside air against the aircraft flying through it. The tube that goes from the pitot tube to the airspeed indicator applies the outside air pressure to the airspeed indicator. The airspeed indicator calibration allows various air pressures to cause different readings on the dial. The purpose of the airspeed indicator is to interpret pitot air pressure in terms of airspeed in knots.

Generally, static air vents (Fig. 2.2.) are small, calibrated holes in an assembly mounted flush with the aircraft fuselage. Their position is in a place with the least amount of local airflow moving across the vents when the aircraft is flying. Static means stationary or not changing. The static part of the pitot-static system also introduces outside air. However, the outside air is at its normal outside atmospheric pressure as though the aircraft were standing still in the air. The static line applies this outside air to the airspeed indicators, the altimeter, and the vertical speed indicator.

2.2. AIRSPEED INDICATORS

Readings from an airspeed indicator are used to estimate ground speed and to determine throttle settings for the most efficient flying speed. These readings also provide a basis for calculating the best climbing and gliding angles. They warn the pilot if diving speed approaches the safety limits of the aircraft's structure. Since airspeed increases in a dive and decreases in a climb, the indicator is an excellent check for maintaining level flight. Fig. 2.3, view A, shows a cutaway view of a typical airspeed indicator.

An airspeed indicator has a cylindrical, airtight case that connects to the static line from the pitot-static tube. Inside the case is a small aneroid diaphragm of phosphor bronze or beryllium copper. The diaphragm is very sensitive to changes in pressure, and it connects to the impact pressure (pitot) line. This construction allows air from the pitot tube to enter the diaphragm. The side of the diaphragm fastens to the case and is rigid. The needle or pointer connects through a series of levers and gears to the free side of the diaphragm.

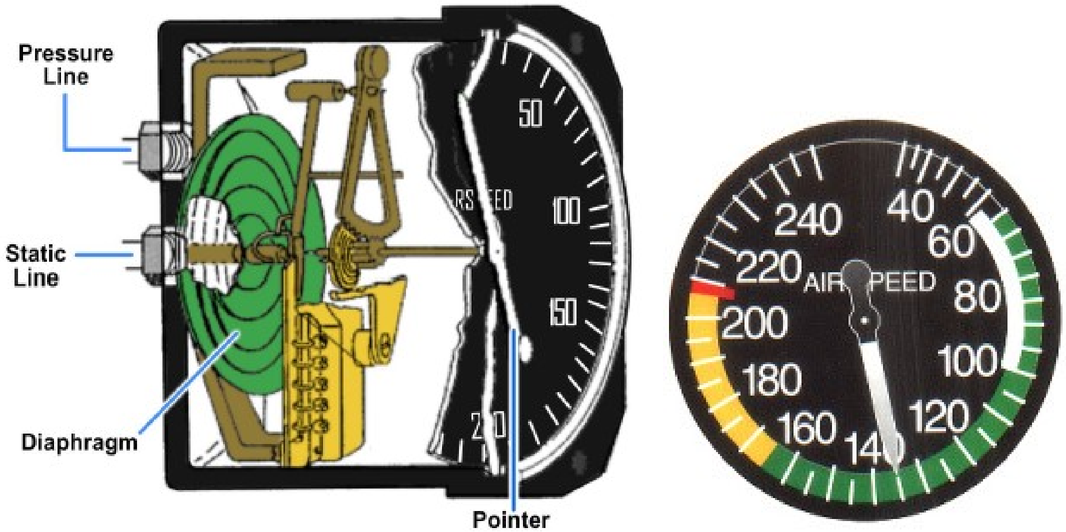


Fig 2.3. Airspeed indicator

The airspeed indicator is a differential pressure instrument. It measures the difference between the pressures in the impact pressure line and in the static pressure line. The two pressures are equal when the aircraft is stationary on the ground. Movement through the air causes pressure in the impact line to become greater than that in the static line. This pressure increase causes the diaphragm to expand. The expansion or contraction of the diaphragm goes through a series of levers and gears to the face of the instrument to regulate needle position. The needle shows the pressure differential in MPH or knots. All speeds and distances are in nautical miles.

1.2.1. Airspeed Indicator Symbology

White Arc – Flap operating Range

Green Arc – Normal Operations

Yellow Arc – Caution Area (Only use in smooth air)

Red Line – Never Exceed Speed

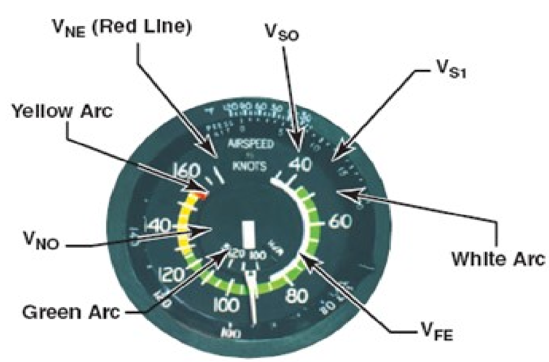


Fig 2.4.Air speed Indicator Symbology

1.2.2. Aircraft Air speeds:

Vso – Stall speed in landing configuration

Vs – Stall speed in clean (flaps up) configuration

Vy – Climb speed for the max amount of height v. time

Vx- Climb speed for the max amount of height for distance

Vfe- Flap Extension speed: Flaps should not be used above this speed

Va – Design maneuvering/rough air speed: Speed at which abrupt full control inputs can be used without risking structural damage. It should never be exceeded in rough air. Changes with weight

Vno – Max structural Cruise speed

Vne – Never Exceed Speed

1.2.3. Types of Airspeeds

i) Calibrated airspeed

Speed corrected for installation and instrument errors.

At high angle of attack, the pitot tube does not point straight into the relative wind, this tends to make the airspeed indicate lower than normal at low airspeeds.

Not usually a problem in cruise, usually we only worry about calibrate airspeed when we are converting to true airspeed.

ii) True airspeed

The actual speed of your airplane is moving through undisturbed air.

On a standard day, Calibrated airspeed will be equal to TAS.

As density altitude increases, true airspeed increases for a given CAS or amount of power.

TAS can be calculated by using CAS with temperature and pressure on your E6B

iii) Equivalent airspeed

Calibrated airspeed corrected for adiabatic compressible flow at a particular altitude.

Above 200 kts and 20,000 feet air compresses in front the pitot tube causing abnormally high airspeeds. Many flight computers are designed to compensate.

If the Pitot tube is blocked and the drain is open, speed will go to zero.

If the Pitot tube is blocked and the drain is open, it will act as an altimeter.

If the the Static vent is blocked, the airspeed will read higher than it should above altitude where it became blocked and lower than it should below.

If all three all blocked, the needle will freeze.

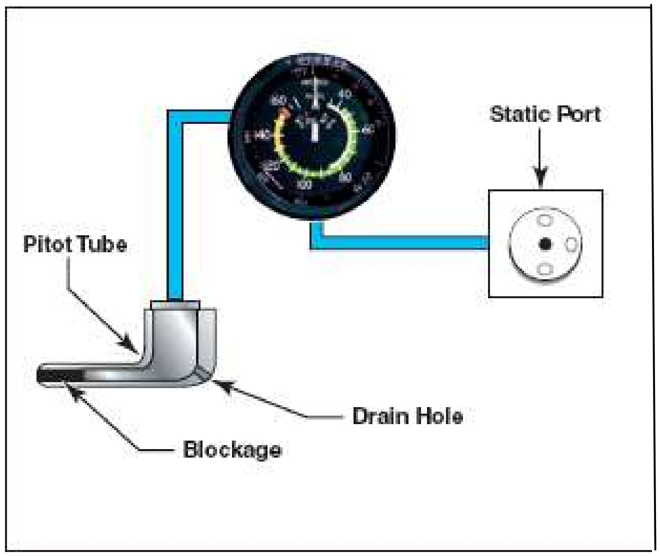


Fig 2.5.Pitot tube with Air speed indicator

Uses ram air from the pitot tube as well as static air.

Ram air pushes against a diaphragm inside the airspeed indicator, which will then be able to expand or contract accordingly. This movement of the diaphragm is then translated into needle movement.

2.3. MACH SPEED INDICATORS

In some cases, the term Mach speed is used to express aircraft speed. The Mach speed is the ratio of the speed of a moving body to the speed of sound in the surrounding medium. For example, if an aircraft is flying at a speed equal to one-half the local speed of sound, it is flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is Mach 2.

Fig. 2.6 shows the front view of a typical airspeed and Mach speed indicator. The instrument consists of altitude and airspeed mechanisms incorporated in a single housing. This instrument gives the pilot a simplified presentation of both indicated airspeed and Mach speed. Both indications are read from the same pointer.

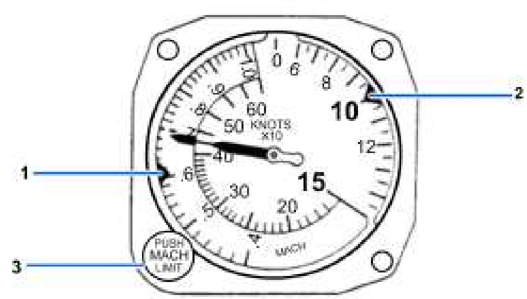


Fig. 2.6. Mach meter

INDEX	CONTROL / INDICATOR	FUNCTION
1	Mach Index	Provides a reference mark along the mach scale
2	Airspeed index	Provides a reference mark along the air speed scale
3	MACH PUSH LIMIIT knob	When pressed and rotated, it causes the mach index to move along the mach scale from 0.4 to 2.0 mach. When rotated, (not pressed) it causes the airspeed index to move along the airspeed scale from 0 to 150 knots. CAUTION To set mach limit, turn counter clockwise only.

Fig.2.7. Airspeed/Mach speed indicator

The pointer shows airspeed at low speeds, and both indicated airspeed and Mach speed at high speeds. Pitot pressure on a diaphragm moves the pointer, and an aneroid diaphragm controls the Mach speed dial. The aneroid diaphragm reacts to static pressure changes because of altitude changes. Fig. 2-6 is a mechanical schematic of an airspeed and Mach speed indicator.

The range of the instrument is 80 to 650 knots indicated airspeed and from 0.5 to 2.0 Mach speed. Its calibrated operating limit is 50,000 feet of altitude. A stationary airspeed dial masks the upper range of the movable Mach dial at low altitudes. The stationary airspeed dial is graduated in knots. The instrument incorporates a landing speed index and a Mach speed setting index. You can adjust both indexes by a knob on the lower left-hand corner of the instrument. You can adjust the landing speed index over a range of 80 to 150 knots. The index operates with the knob in its normal position. The Mach speed index is to be adjusted over the entire Mach range. The index adjusts by depressing the knob and turning it.

2.4. ALTIMETER

An altimeter is an instrument that measures static pressure. Before you can understand how the altimeter works, you need to understand altitude. Remember, even though the altimeter reads in feet, it is actually measuring pressure. The word altitude is vague, so it needs further defining. The term altitude includes altitude above Mean Sea Level (MSL) and altitude Above Ground Level (AGL). It also includes pressure altitude, indicated altitude, density altitude, and elevation.

i) **MEAN SEA LEVEL** – Since about 80 percent of the earth's surface is water, it is natural to use sea level as an altitude reference point. The pull of gravity is not the same at sea level all over the world because the earth is not perfectly round and because of tides. To adjust for this, an average (or mean) value is set; this is the mean sea level. Mean sea level is the point where gravity acting on the atmosphere produces a pressure of 14.70 pounds per square inch. This pressure supports a column of mercury in a barometer to a height of 29.92 inches. This is the reference point from which you measure all other altitudes. See Figs.2.8. The altitude read from an altimeter refers to MSL.

ii) ELEVATION AND TRUE ALTITUDE – Elevation is the height of a land mass above MSL. Elevation is measured with precision instruments that are far more accurate than the standard aircraft altimeter. You can find elevation information on charts or, for a particular spot, painted on a hangar near an aircraft ramp or taxi area. True altitude is the actual number of feet above MSL. A ruler or yardstick is used to measure the altitude. In standard day conditions, pressure altitude and true altitude are the same.

iii) ABSOLUTE ALTITUDE – Absolute altitude is the distance between the aircraft and the terrain over which it is flying. It is referred to as the altitude Above Ground Level (AGL).

Due to variations in terrain, AGL is typically unreliable information. However, it is useful when flying near the ground, such as in a takeoff or landing pattern. AGL can be found by subtracting the elevation of the terrain beneath the aircraft from the altitude read on the altimeter (MSL). A radar altimeter indicates actual altitude above the terrain. This indication is radar altitude.

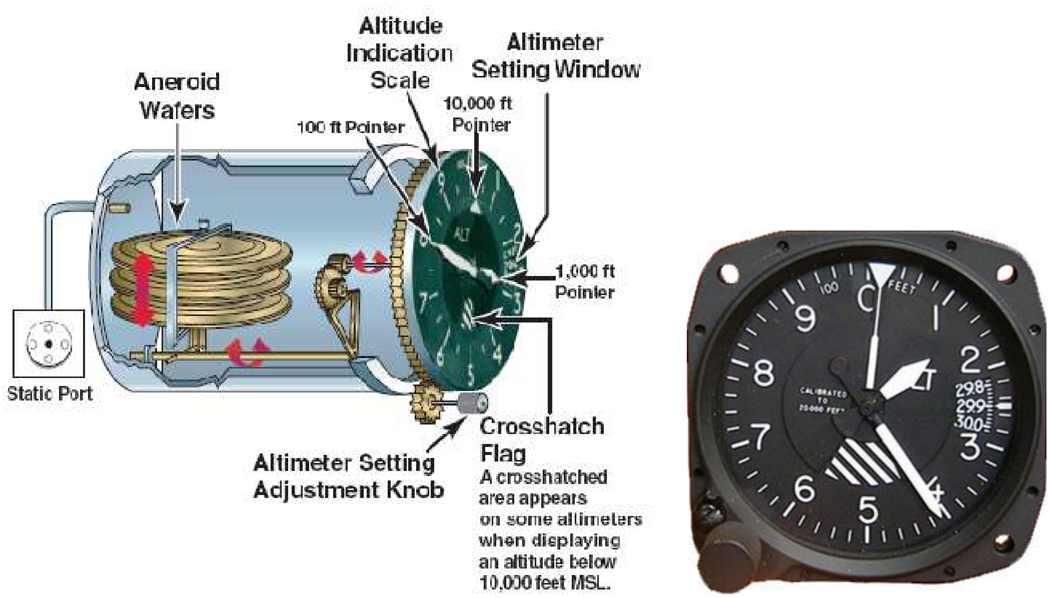


Fig 2.8. Altimeter

iv) PRESSURE ALTITUDE – To measure altitude, instruments sense air pressure and compare it to known values of standard air pressure at specific, measured altitudes. The altitude you read from a properly calibrated altimeter referenced to 29.92 inches of mercury (Hg) is the pressure altitude. Refer back to Fig. 2.8. If a pressure altimeter senses 6.75 pounds per square inch pressure with the altimeter set to sea level and barometric pressure 29.92 inches of mercury, the altimeter indicates 20,000 feet. This reading does not mean that the aircraft is exactly 20,000 feet above MSL. It means the aircraft is in an air mass exerting a pressure equivalent to 20,000 feet on a standard day. Here that pressure altitude is not true altitude.

v) INDICATED AND CALIBRATED ALTITUDE – Unfortunately, standard atmospheric conditions very seldom exist. Atmospheric conditions and barometric pressure can vary considerably. A pressure change of one-hundredth (0.01) of an inch of mercury represents a 9-foot change in altitude at sea level. Barometric pressure changes between 29.50 and 30.50 are not uncommon (a pressure change of about 923 feet).Indicated altitude is the uncorrected reading of a barometric altimeter. Calibrated altitude is the indicated altitude corrected for inherent and installation errors of the altimeter. On an altimeter without such errors, indicated altitude and calibrated altitude are identical. Assume that this is the case for the rest of this discussion.

When flying below 18,000 feet, the aircraft altimeter must be set to the altimeter setting (barometric pressure corrected to sea level) of a selected ground station within 100 miles of the aircraft. Altitude read from an altimeter set to local barometric pressure is indicated altitude. The accuracy of this method is limited because you must assume a standard lapse rate; that is, for a given number of feet of altitude, an exact change in pressure occurs. This exact change seldom happens, which limits the accuracy of the altimeter. Above 18,000 feet, all altimeters are set to 29.92 (pressure altitude). Although the altimeter is not accurate, as long as all aircraft have the same barometric pressure setting, aircraft vertical separation is controlled.

vi) DENSITY ALTITUDE – A very important factor in determining the performance of an aircraft or engine is the density of the air. The denser the air, the more horsepower the engine can produce. Also, there is more resistance to the aircraft when flying resulting in airfoils producing more lift, and propellers producing more thrust. Pressure, temperature, and moisture content all affect air density. Measurements of air density are in weight per unit volume (for example, pounds per cubic foot). However, a more convenient measurement of air density for the pilot is density altitude. This is that altitude in the standard atmosphere which corresponds to a particular air density.

Density altitude is the pressure altitude corrected for temperature deviations from the standard atmosphere. In basic terms, it is the altitude that the aircraft "thinks" it's at. An increase in density altitude corresponds to reduced air pressure felt by the aircraft. This results in airfields at higher elevations, particularly when warm temperatures are present to require more runways for aircraft to take off. Additionally, aircraft will have a reduced rate of climb and a faster approach and will experience a longer landing roll.

Density altitude does not show on an instrument. It is usually taken from a table or computed by comparing pressure, altitude, and temperature. Although moisture content affects air density, its effect is negligible."

Several kinds of altimeters are in use today. They are all constructed on the same basic principle as an aneroid. They all have pressure responsive elements (aneroid wafers) that expand or contract with the pressure changes of different flight levels. The heart of a pressure altimeter is its aneroid mechanism (Fig. 2.8), which consists of one or more aneroid wafers. The expansion or contraction of the aneroid wafers with pressure changes operates the linkage. This action moves the indicating hand/counter to show altitude. Around the aneroid mechanism of most altimeters is a device called the bimetal yoke. As the name implies, this device is composed of two metals. It performs the function of compensating for the effect that temperature has on the metals of the aneroid mechanism. The altimeter discussed in the following paragraphs is a simple one. Several complex altimeters are discussed later in this chapter, along with the automatic altitude system.

2.5. COUNTER POINTER PRESSURE ALTIMETER

The purpose of the counter pointer pressure altimeter (Fig 2.9) is to show aircraft height. By studying the dial of the indicator, you can easily understand the procedure for determining the height of the aircraft. A description of the mechanical operation of this altimeter follows. Atmospheric changes cause movement of the two aneroid diaphragm assemblies.

These assemblies move two similar rocking shaft assemblies mutually engaged with the main pinion assembly. This movement goes to the hand staff assembly, which operates the hand assembly and drives the counter mechanism through a disk. Because of the special design of the hand assembly, the counter indication is never obscured. An internal vibrator minimizes friction during the instrument's operation.

Fig. 2.9. Counter Pointer Pressure Altimeter

You make barometric corrections by turning the externally located knob. The knob engages the barometric dial and the main plate assembly that supports the entire mechanism. You make adjustments so the reading on the barometric dial corresponds to the area barometric conditions in which the aircraft is flying.

2.6 ACCELEROMETER INDICATORS

The pilot must limit aircraft maneuvers so various combinations of acceleration, airspeed, gross weight, and altitude remain within specified values. These operational limits cut out the possibility of damaging aircraft as a result of excessive stresses. The accelerometer shows the load on the aircraft structure in terms of gravitation (g) units. It presents information that lets the aircraft be maneuvered within its operational limits. The forces sensed by the accelerometer act along the vertical axis of the aircraft. The main hand moves clockwise as the aircraft accelerates upward and counterclockwise as the aircraft accelerates downward.

The accelerometer indications are in g units. The main indicating hand turns to +1 g when the lift of the aircraft wing equals the weight of the aircraft. Such a condition prevails in level flight. The hand turns to +3 g when the lift is three times the weight. The hand turns to minus readings when the forces acting on the aircraft surfaces cause the aircraft to accelerate downward.

The accelerometer operates independently of all other aircraft instruments and installations. The activating element of the mechanism is a mass that is movable in a vertical direction on a pair of shafts (**Fig. 2.10**). A spiral wound main spring dampens the vertical movement of the mass. The force of the mass travels by a string-and-pulley system to the main spring and aim shaft. From here, it goes to the plus and minus assemblies. The hand assemblies mount on the plus and minus assemblies. Changes in vertical acceleration cause movement of the mass on the shafts, which translates into a turning motion of the main shaft. The turning motion pivots the indicating hands around the dial. The hand travels a distance equivalent to the value, in g units, of the upward or downward acceleration of the aircraft.

The accelerometer operates on the principle of Newton's third Law of Motion. During level flight, no forces act to displace the mass from a position midway from the top and bottom of the shafts. Therefore, the accelerometer pulley system performs no work, and the indicating hands remain stationary at +1 g. When the aircraft changes from level flight, forces act on the mass. This action causes the mass to move either above or below its midway position. These movements cause the accelerometer indicating hands to change position. When the aircraft nose goes down, the hands move to the minus section of the dial. When the nose goes up, they move to the plus section.

The main hand continuously shows changes in loading. The two other hands on the accelerometer show the highest plus acceleration and highest minus acceleration of the aircraft during any maneuver. The indicator uses a ratchet mechanism to maintain these readings. A knob in the lower left of the instrument face is used to reset the maximum and minimum-reading hands to normal. Thus, the accelerometer keeps an indication of the highest accelerations during a particular flight phase or during a series of flights.

2.7. MAXIMUM ALLOWABLE AIRSPEED INDICATOR

Fig. 2.11 shows the face of a maximum allowable airspeed indicator. The dial face measurements are in knots from 50 to 450 with an expanded scale below 200 knots. The dial has an indicating pointer and a maximum safe airspeed pointer. The maximum safe airspeed pointer moves as the maximum safe airspeed changes because of static pressure changes at different altitudes.

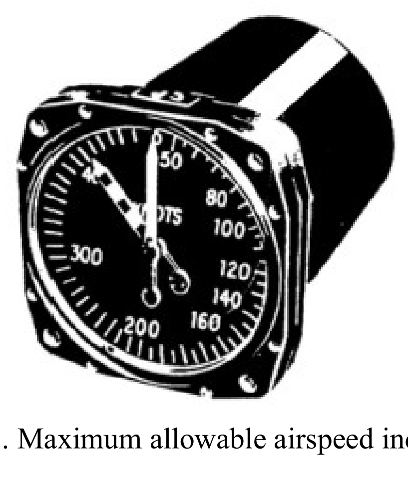


Fig.2.11. Maximum allowable airspeed indicator

No matter where the Pitot - static tube is located, it is impossible to keep it free from all air disturbances set up by the aircraft structure. It can be make allowances for this installation error when reading the indicator. Temperature is another cause of error. Also, imperfect scaling of the indicator dial with respect to the airspeed differential pressure relationship will cause an error in reading. It can be done simple adjustments to the instrument mechanism to correct the tendency to read fast or slow.

2.8. VERTICAL SPEED INDICATOR (VSI)

A VSI shows the rate at which an aircraft is climbing or descending. It is very important for night flying, flying through fog or clouds, or flying when the horizon is obscured. Another use is to determine the maximum rate of climb during performance tests or in actual service.

The rate of altitude change, as shown on the indicator dial, is positive in a climb and negative in a dive or glide. The dial pointer (Fig. 2-10) moves in either direction from the zero point. This action depends on whether the aircraft is going up or down. In level flight the pointer remains at zero.

The vertical speed indicator is contained in a sealed case, and it connects to the static pressure line through a calibrated leak. Refer to Fig 2.10. Changing pressures will result in expansion or contraction of the diaphragm, which in turn will move the indicating needle through the use of internal gears and levers. The instrument automatically compensates for changes in temperature. Although the vertical speed indicator operates from the static pressure source, it is a differential pressure instrument. The difference in pressure between the instantaneous static pressure in the diaphragm and the static pressure trapped within the case creates the differential pressure.

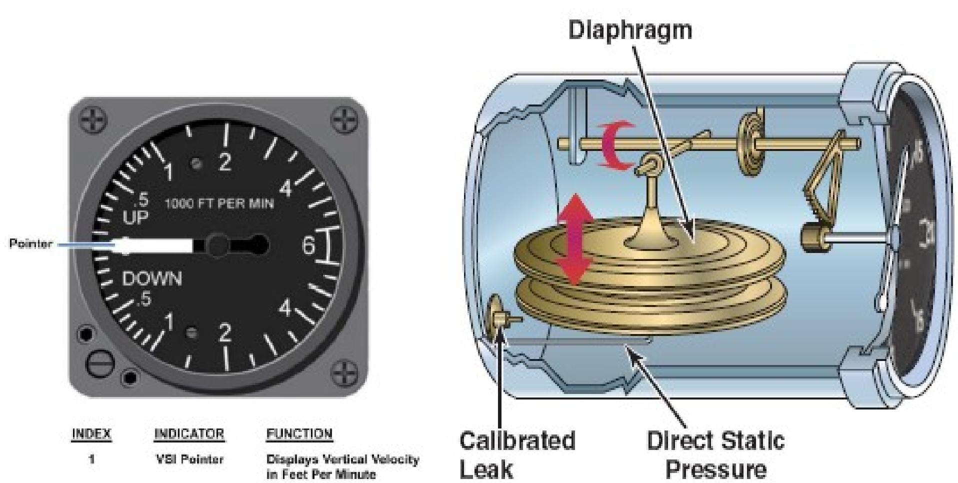


Fig. 2.10. Vertical Speed Indicator

When the pressures equalize in level flight, the needle reads zero. As static pressure in the diaphragm changes during a climb or descent, the needle immediately shows a change of vertical speed. However, until the differential pressure stabilizes at a definite ratio, indications are not reliable. Because of the restriction in airflow through the calibrated leak, the differential pressure requires a 6 to 9 second lag for the pressures to stabilize. The VSI has a zero adjustment on the front of the case. You use this adjustment with the aircraft on the ground to return the pointer to zero. While adjusting the instrument, tap it lightly to remove friction effects.

Measures how fast the static pressure increases or decreases as the airplane climbs or descends. It then displays this pressure change as a rate of climb or descent in feet per minute. Not affected by air temperature since it measures only changes in air pressure

Post MCQ Test

1. What are the standby instruments that are combined in a Solid state integrated standby instrument?
a) Altimeter, vertical speed indicator, artificial horizon
b) Altimeter, airspeed indicator
c) Altimeter, airspeed indicator, artificial horizon
d) Altimeter, turn coordinator, artificial horizon, heading/compass indicator & Mach meter
Answer: c Altimeter, airspeed indicator, artificial horizon

2. By correcting the indicated airspeed for nonstandard temperature and pressure, we obtain ___________ airspeed.
a) Actual
b) Virtual
c) True
d) Relative
Answer: c True

3. The VSI is also called as ___________
a) Vinometer
b) Radiometer
c) Barometer
d) Variometer
Answer: d Variometer

4. What is the full form of IAS?
a) Implied airspeed
b) Indicated airspeed
c) Incident airspeed

d) Immediate airspeed
Answer: b Indicated airspeed

5. TAS shows airspeed in ___________
a) Miles per hour
b) Knots
c) Nautical miles
d) Kilometer per hour
Answer: b Knots

6. Which of the following is not determined using the pitot-static system?
a) Altitude
b) Mach Number
c) Thrust
d) Airspeed
Answer: c Thrust

7. The Pitot tube is most commonly located on the wing assembly of an aircraft.
a) True
b) False
Answer: a True

8. What is the difference between the pitot pressure and the static pressure called?
a) Atmospheric Pressure
b) Dynamic Pressure
c) Air Pressure
d) Cabin Pressure
Answer: b Dynamic Pressure

9. When the aircraft is moving forward, air entering the Pitot tube is at a __________ pressure than the static line.
a) Equal
b) Lower
c) Greater
d) Infinite
Answer: c Greater

10. Ram air enters the system through the __________
a) Pitot tube
b) Static tube
c) Engines
d) APU Exhaust
Answer: a Pitot tube

11. TAS increases as altitude increases.

a) True

b) False

Answer: a True

12. Which of the following is not a unit of measurement for airspeed?

a) Kilometers per hour

b) Knots

c) Miles per hour

d) Pascal

Answer: d Pascal

13. What is the full form of CAS?

a) Constant airspeed

b) Continuous airspeed

c) Calibrated airspeed

d) Comparative airspeed

Answer: c Calibrated airspeed

14. What will the ASI pointer read, if both the Pitot tube and the static system are blocked?

a) Zero

b) Positive Infinite

c) No reading

d) Negative Infinite

Answer: a Zero

Assignment

1. Draw and explain with neat sketch the operation of Pitot-Static system and also describe the basic form of Pitot static Probe
2. Briefly explain the construction and operation of an altimeter. Explain any special feature which improves its accuracy

UNIT-III: Gyroscopic Instruments

Gyroscopic theory - directional gyro indicator, artificial horizon -turn and slip indicator.

Aim & objectives: Summarize the operating principles and characteristics of gyroscopic aircraft instrument systems, including directional gyro indicator and turn and slip indicator.

Pre MCQ Test

1. Which part of the insects acts as gyros?
   a) Wings
   b) Halteres
   c) Thorax
   d) Legs
   Answer: b Halteres
2. What is the purpose of a gyro in an inertial navigation system?
   a) Space-stabilize the accelerometer
   b) Angle of rotation
   c) Measure rotation rate
   d) Calculate velocity
   Answer: a Space-stabilize the accelerometer
3. Autopilot was first invented by ___________
   a) Lawrence Sperry
   b) William Boeing
   c) Nikola Tesla
   d) Wright Brothers
   Answer: a Lawrence Sperry

GYROSCOPIC THEORY

3.1. GYROSCOPIC INSTRUMENTS

Early aircraft were flown by visually aligning the aircraft with the horizon. With poor visibility, it was not possible to fly the aircraft safely. The need for flight instruments to correct this condition led to the development of gyroscopic instruments. The gyroscopic properties of a spinning wheel made precision instrument flying, precise navigation, and pinpoint bombing practical and reliable. Some of the instruments that use this principle are the turn-and-bank indicator, directional gyro, gyro horizon, and drift meter. Systems that use the gyroscopic principle include the Automatic Flight Control System (AFCS), gyro stabilized flux-gate compass, and inertial navigation system. The following paragraphs contain a brief review of gyroscopic principles.

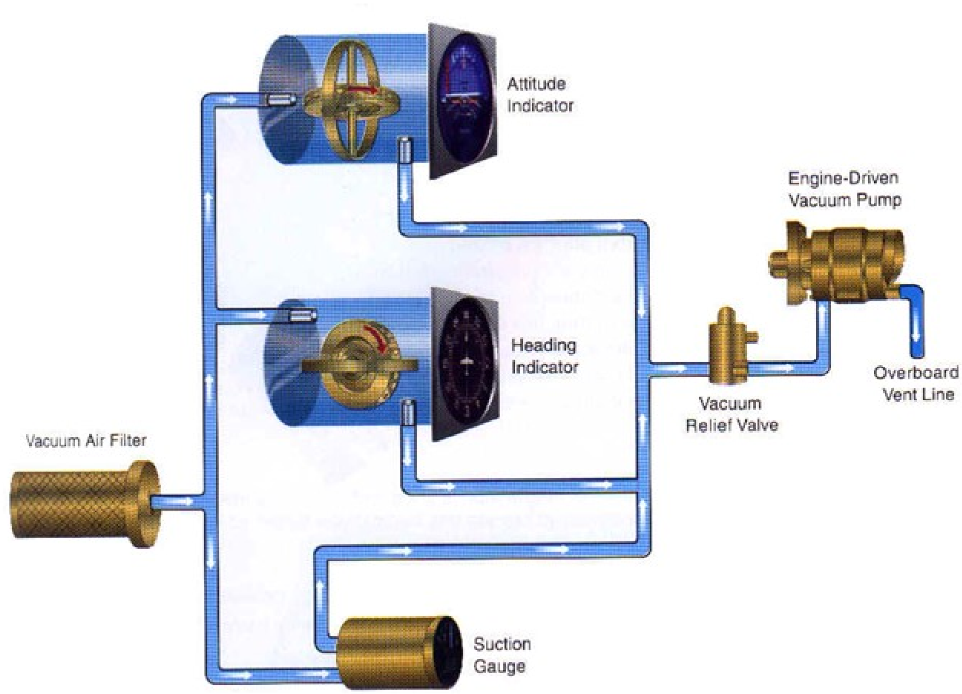


Fig 3.1 Gyroscopic instruments

Gyroscope

A gyroscope is a spinning wheel or rotor with universal mounting. This mounting allows the gyroscope to assume any position in space. Any spinning object exhibits gyroscopic properties. The wheel, with specific design and mounts to use these properties, is a gyroscope. The two important design characteristics for instrument gyros are:

1. High-density weight for small size
2. High-speed rotation with low friction

The mountings of the gyro wheels are gimbals. They can be circular rings or rectangular frames. However, some flight instruments use part of the instrument case itself as a gimbal. A simple gyroscope is shown in Fig. 3-2.

The two general types of mountings for gyros are the free or universal mounting and the restricted or semi-rigid mounting. The type of mounting the gyro uses depends on the gyro's purpose.

A gyro can have different degrees of freedom. The degree of freedom depends on the number of gimbals supporting the gyro and the arrangement of the gimbals. Do not confuse the term degrees of freedom, as used here, with an angular value as in degrees of a circle. The term degrees of freedom, as used here, with gyros, shows the number of directions in which the rotor is free to move. Some authorities consider the spin of the rotor as one degree of freedom, but most do not.

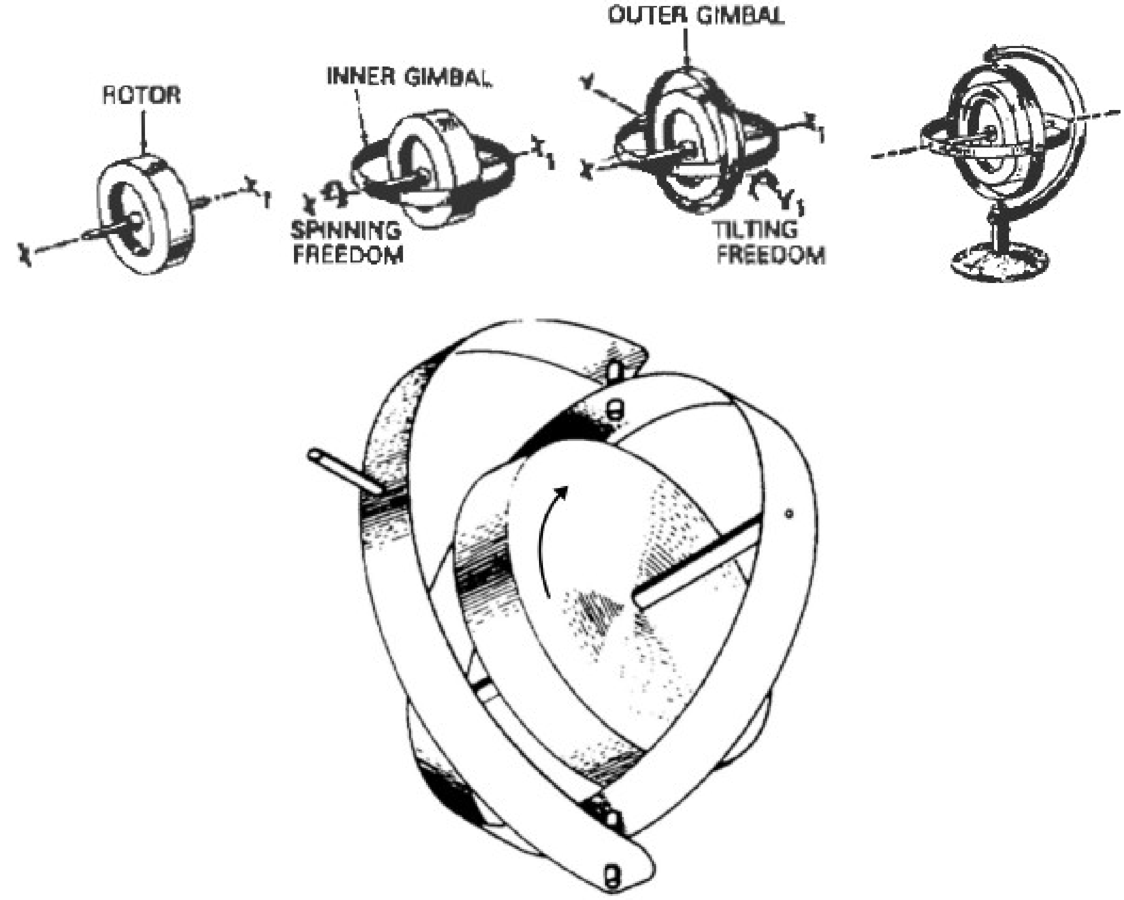


Fig 3.2 Simple Gyroscope

A gyro enclosed in one gimbal, such as the one shown in Fig. 3-2, has only one degree of freedom. This is a freedom of movement back and forth at a right angle to the axis of spin. When this gyro is mounted in an aircraft, with its spin axis parallel to the direction of travel and capable of swinging from left to right, it has one degree of freedom. The gyro has no other freedom of movement. Therefore, if the aircraft should nose up or down, the geometric plane containing the gyro spin axis would move exactly as the aircraft does in these directions. If the aircraft turns right or left, the gyro would not change position, since it has a degree of freedom in these directions.

A gyro mounted in two gimbals normally has two degrees of freedom. Such a gyro can assume and maintain any attitude in space. For illustrative purposes, consider a rubber ball in a bucket of water. Even though the water is supporting the ball, it does not restrict the ball's attitude. The ball can lie with its spin axis pointed in any direction. Such is the case with a two-degree-of-freedom gyro, often called a free gyro.

In a two-degree-of-freedom gyro, the base surface turns around the outer gimbal axis or around the inner gimbal axis, while the gyro spin axis remains fixed. The gimbal system isolates the rotor from the base rotation. The universally mounted gyro is an example of this type. Restricted or semi-rigid mounted gyros are those mounted so one plane of freedom is fixed in relation to the base.

Practical applications of the gyro are based upon two basic properties of gyroscopic action:

1. Rigidity in space
2. Precession

Newton's first law of motion states, "A body at rest will remain at rest, or if in motion will continue in motion in a straight line, unless acted upon by an outside force." An example of this law is the rotor in a universally mounted gyro. When the wheel is spinning, it stays in its original plane of rotation regardless of how the base moves.

The factors that determine how much rigidity a spinning wheel has are in Newton's second law of motion. This law states, "The deflection of a moving body is directly proportional to the deflective force applied and is inversely proportional to its mass and speed." To obtain as much rigidity as possible in the rotor, the rotor has great weight for size and rotates at high speeds. To keep the deflective force at a minimum, the rotor shaft mounts in low friction bearings. The basic flight instruments that use the gyroscopic property of rigidity are the gyro horizon, the directional gyro, and any gyro stabilized compass system. Therefore, their rotors must be freely or universally mounted.

Fig 3.3. Rigidity in space

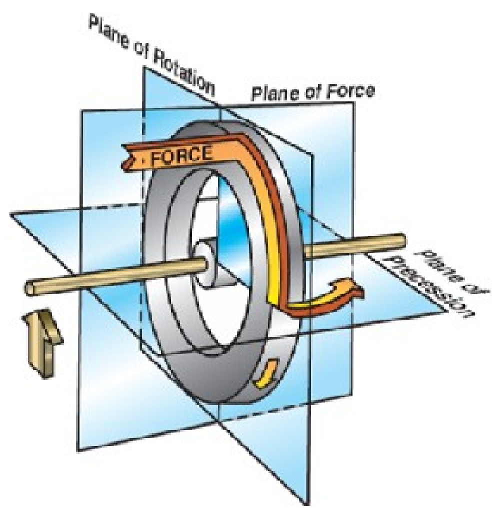


Fig 3.4. Precession

Precession (Fig. 3.4) is the resultant action or deflection of a spinning wheel when a deflective force is applied to its rim. When a deflective force is applied to the rim of a rotating wheel, the resultant force is 90 degrees ahead of the direction of rotation and in the direction of the applied force. The rate at which the wheel precesses is inversely proportional to rotor speed and directly proportional to the deflective force. The force with which a wheel precesses is the same as the deflective force applied minus the friction in the gimbal ring, pivots, and bearings. If too great a deflective force is applied for the amount of rigidity in the wheel, the wheel precesses and topples over at the same time.

Any spinning mass exhibits the gyroscopic properties of rigidity in space and precession. The rigidity of a spinning rotor is directly proportional to the weight and speed of the rotor, and inversely proportional to the deflective force.

3.3. Attitude Indicator

Pilots determine aircraft attitude by referring to the horizon when they can see it. Often, however, the horizon is not visible. When it is dark or when there are obstructions to visibility such as overcast skies, smoke, or dust, pilots cannot use the earth's horizon as a reference. When these conditions exist, they refer to an instrument called the attitude indicator. This instrument is also known as a Vertical Gyro Indicator (VGI), artificial horizon, Attitude Reference Indicator (ARI), or gyro horizon. From these instruments, pilots learn the relative position of the aircraft with reference to the earth's horizon.

Although attitude indicators differ in size and appearance, they all have the same basic components and present the same basic information. On the face of the indicator will always be a miniature aircraft that represents the nose (pitch) and wing (bank) attitude of the aircraft. The bank pointer on the indicator face shows the degree of bank (in 10-degree increments up to 30 degrees, then in 30-degree increments to 90 degrees). The sphere is always light on the upper half and dark on the lower half to show the difference between sky and ground. Calibration marks on the sphere show degrees of pitch in 5- or 10-degree increments. An OFF flag comes into view when the system has a loss of power or the pull-to-cage knob is pulled out (Fig. 3.5). Each indicator has a pitch trim adjustment or pull-to-cage knob for the pilot to center the horizon as necessary. When transporting the gyro, keep it in a locked and fixed position and use the pull-to-cage knob to protect the gimbals from damage. The knob must be pulled and turned clockwise.

There is also a miniature aircraft (orange line) and horizon bar representation.

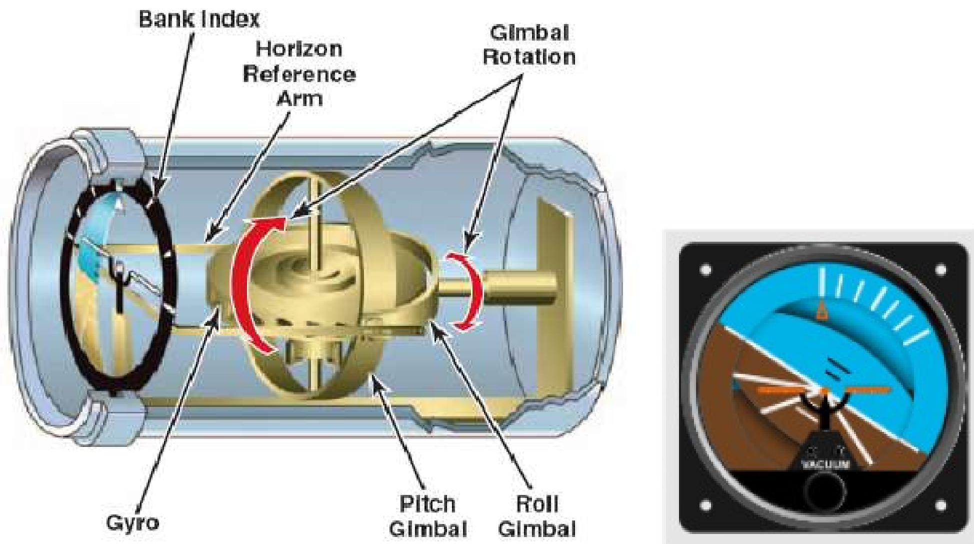


Fig 3.5 Attitude indicator

The horizon is displayed using a white line which separates the instrument in two parts:

- the blue one which represents the sky
- the brown one which represents the earth.

Some attitude indicators have a self-contained gyro. Other more modern indicators use pitch and roll information from the inertial system or the attitude heading reference system. These systems are accurate and reliable. They gain their reliability and accuracy from their larger size, which is not limited by the space of an instrument panel. Electrical signals from the remote gyro travel via synchros. The signal is amplified in the indicator to drive servomotors and position the indicator sphere. This positioning is the same as the vertical gyro position in the gyro case. In the newer attitude indicators, the sphere is gimbal-mounted and capable of 360-degree rotation. Also, a test function is provided to test the instrument landing system vertical and horizontal pointers. In contrast, the older gyros could only travel 60 degrees to 70 degrees of pitch and 100 degrees to 110 degrees of roll.

Fig. 3.6. Operation of Attitude indicator

Operation

The attitude reference indicator receives 115V ac 3-phase aircraft power through energized contacts of relay K1 located in the static power inverter. With 115V ac 3-phase power applied to the attitude reference indicator, the OFF flag goes out of view and the gyro will spin up and erect. Also, 115V ac phase A is applied to the dc power supply which develops dc voltages for the amplifiers and test circuits. The 115V ac phase C is used to excite the attitude pick-off synchros. If 115V ac 3-phase aircraft power is lost, relay K1, in the static power inverter, de-energizes and 28-V dc is applied to a dc-to-ac inverter and develops the 115V ac 3-phase power.

An electrically driven vertical gyro (Fig. 3.5) maintains vertical orientation through use of an electronic erection system and provides a continuous attitude display. Attitude pick-off synchros are mechanically coupled to the gyro and their output signals are applied to pitch and roll amplifiers. Amplified pitch and roll analog signals are then sent to control-converter. In the control-converter, pitch and roll analog signals are applied through Scott-T transformers and an A/D converter to produce attitude signals.

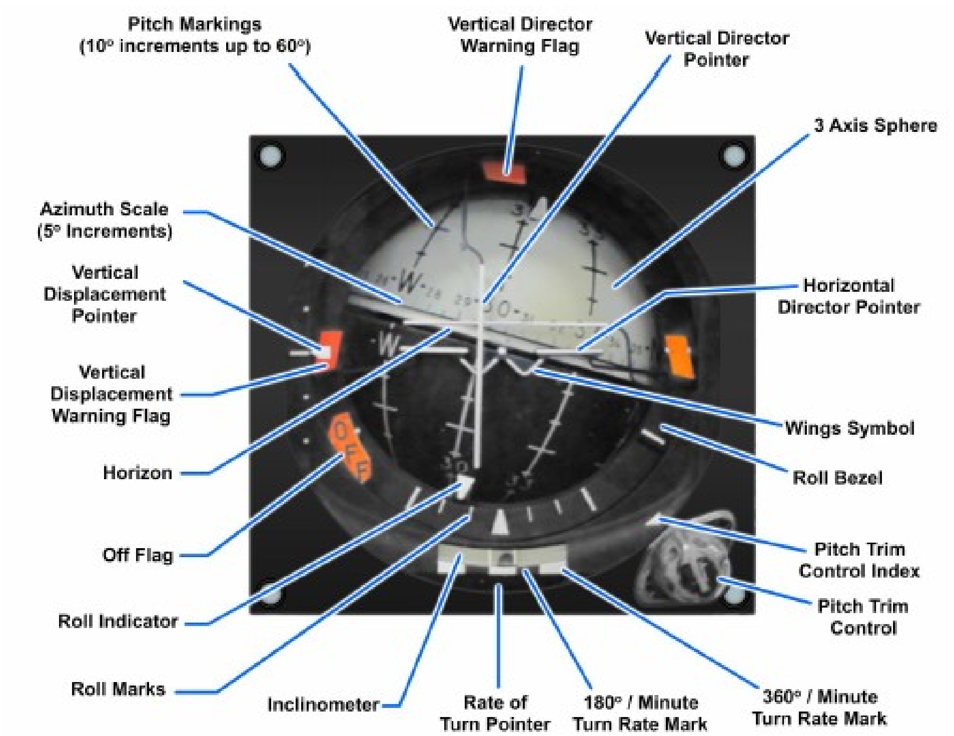


Fig. 3.7. All Attitude Indicators (AAI)

Software built in test BIT samples the attitude signals for reasonable content and a no-go produces not valid attitude pitch and roll output signals. The pitch and roll attitude and validity signals are then sent to the Mission Computer (MC) system and provide backup attitude signals for the various navigation routines and displays. Variations in aircraft angle-of-attack will cause differences in the caged position of the gyro spin axis relative to true vertical.

Some aircraft incorporate an all-attitude indicator (Fig. 3.7). In addition to pitch and roll, this indicator shows compass information along the horizon bar. It also shows turn and-bank information on the bottom. An even more sophisticated instrument, the flight director, displays the above information plus radio navigation information, all on one instrument.

3.4. Turn-and-Bank Indicator

The turn-and-bank indicator (Fig. 3.8) also called the turn-and-slip indicator, shows the lateral attitude of an aircraft in straight flight. It also provides a reference for the proper executions of a coordinated bank and turn. It shows when the aircraft is flying on a straight course and the direction and rate of a turn. It was one of the first modern instruments for controlling an aircraft without visual reference to the ground or horizon.

The indicator is a combination of two instruments, a ball and a turn pointer. The ball part of the instrument operates by natural forces (centrifugal and gravitational). The turn pointer depends on the gyroscopic property of precession for its indications. The power for the turn indicator gyro is either electrical or vacuum.

BALL – The ball portion of a turn-and-bank indicator (Fig 3.8) consists of a sealed, curved, glass tube. The tube contains water-white kerosene and a black or white agate or common steel ball bearing. The ball bearing is free to move inside the tube. The fluid provides a damping action and ensures smooth and easy movement of the ball. The curved tube allows the ball to seek the lowest point when in level flight. This point is the tube center. A small projection on the left end of the tube contains a bubble of air. The bubble lets the fluid expand during changes in temperature. There are two markings or wires around the center of the glass tube. They serve as reference markers to show the correct position of the ball in the tube. The plate that holds the tube and the references are painted with luminous paint.

The only force acting on the ball during straight flight (no turning) with the wings level is gravity. The ball seeks its lowest point and stays within the reference marks. In a turn, centrifugal force also acts on the ball in a horizontal plane opposite to the direction of the turn.

The ball assumes a position between the reference markers when the resultant of centrifugal force and gravity acts directly opposite to a point midway between the reference markers. When the force acting on the ball becomes unbalanced, the ball moves away from the center of the tube.

In a skid, the rate of turn is too great for the angle of bank. The excessive centrifugal force moves the ball to the outside of the turn. The resultant of centrifugal force and gravity is not opposite the midpoint between the reference markers. The ball moves in the direction of the force, toward the outside of the turn. Returning the ball to center (coordinated turn) is calls for increasing bank or decreasing rate of turn, or a combination of both.

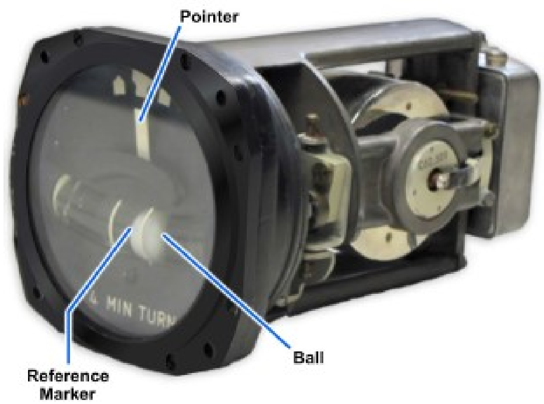


Fig 3.8. Turn and Bank Indicator

In a slip, the rate of turn is too slow for the angle of bank. The resultant of centrifugal force and gravity moves the ball to the inside of the turn. Returning the ball to the center (coordinated turn) requires decreasing the bank or increasing the rate of turn, or a combination of both.

The ball instrument is actually a balance indicator because it shows the relationship between angle of bank and rate of turn. It lets the pilot know when the aircraft has the correct rate of turn for its angle of bank.

3.5 TURN POINTER – The turn pointer operates on a gyro. The gimbal ring encircles the gyro in a horizontal plane and pivots fore and aft in the instrument case.

The major parts of the turn portion of a turn-and-bank indicator are as follows:

- A frame assembly used for assembling the instrument.
- A motor assembly consisting basically of the stator, rotor, and motor bearings. The electrical motor serves as the gyro for the turn indicator.
- A plate assembly for mounting the electrical receptacle, pivot assembly, choke coil, and capacitors for eliminating radio interference.
- A damping unit that absorbs vibrations and prevents excessive oscillations of the needle. The unit consists of a piston and cylinder mechanism. The

adjustment screw controls the amount of damping.

- An indicating assembly composed of a dial and pointer.
- The cover assembly.

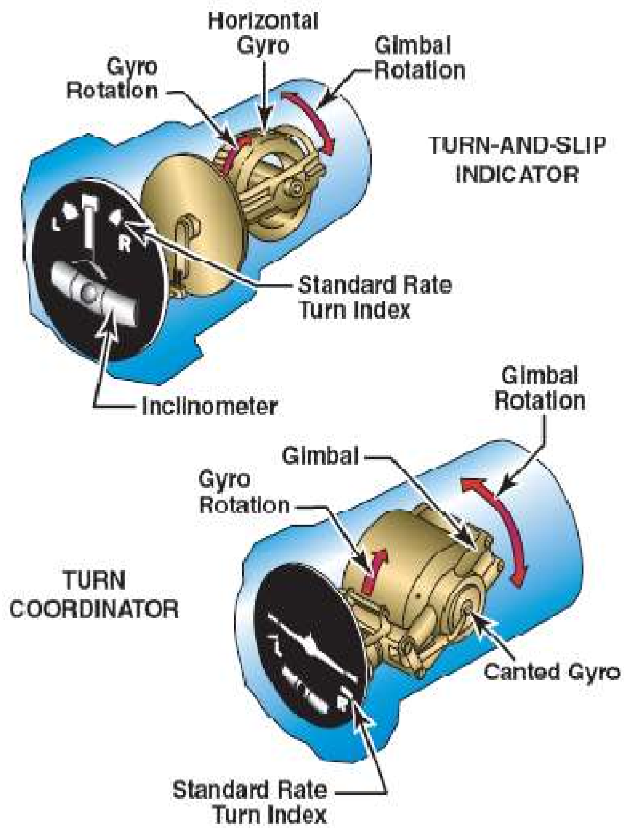


Fig 3.9.Turn Indicators

Fig 3.10. Turn Coordinator

The carefully balanced gyro rotates about the lateral axis of the aircraft in a frame that pivots about the longitudinal axis. When mounted in this way, the gyro responds only to motion around a vertical axis. It is unaffected by rolling or pitching.

The turn indicator takes advantage of one of the basic principles of gyroscopes—precession. Precession, as already explained, is a gyroscope's natural reaction 90 degrees in the direction of rotation from an applied force. It is visible as resistance of the spinning gyro to a change in direction when a force is applied. As a result, when the aircraft makes a turn, the gyro position remains constant. However, the frame in which the gyro hangs, dips to the side opposite the direction of turn. Because of the design of the linkage between the gyro frame and the pointer, the pointer shows the correct direction of turn. The pointer displacement is proportional to the aircraft rate of turn. If the pointer remains on center, it shows the aircraft is flying straight. If it moves off center, it shows the aircraft is turning in the direction of the pointer deflection. The turn needle shows the rate (number of degrees per minute) at which the aircraft is turning.

By using the turn-and-bank indicator, the pilot checks for coordination and balance in straight flight and in turns. By cross-checking this instrument against the airspeed indicator, the pilot can determine the relation between the aircraft lateral axis and the horizon. For any given airspeed, there is a definite angle of bank necessary to maintain a coordinated turn at a given rate.

3.6. Primary Flight Display (PFD)

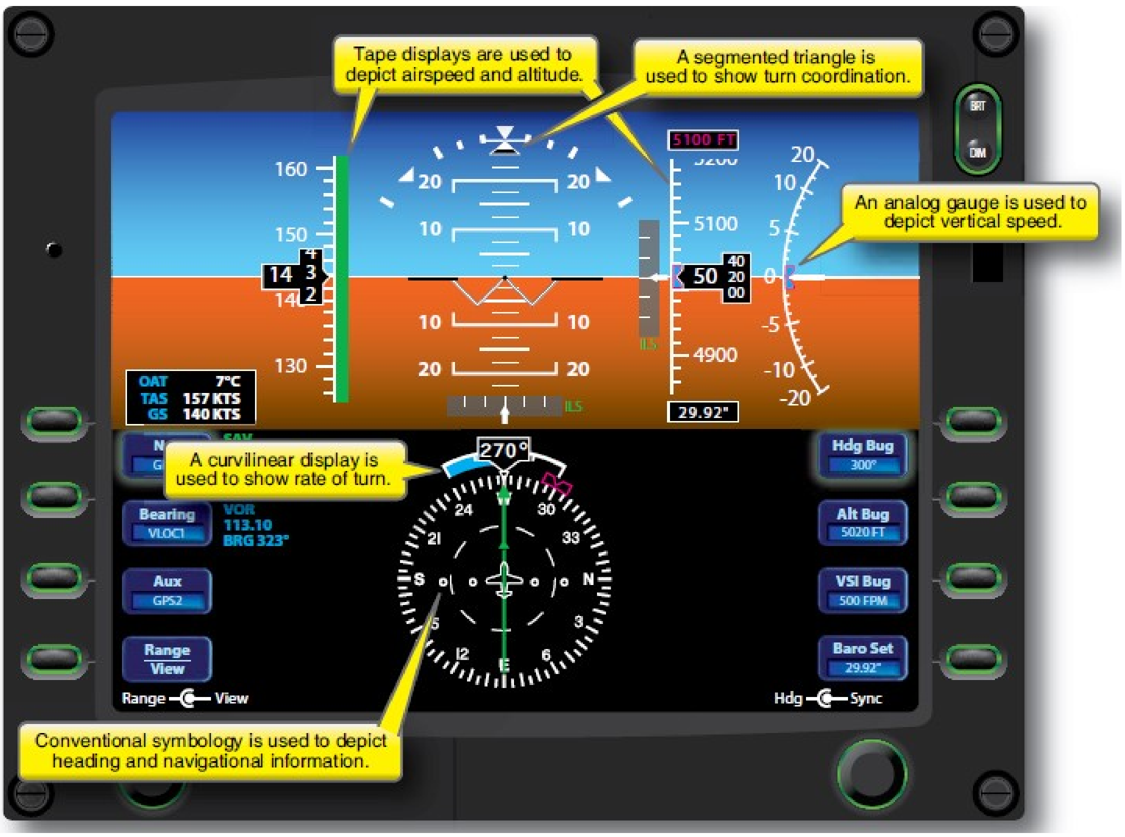


Fig. 3.11. Primary Flight Display (PFD)

A PFD presents information about primary flight instruments, navigation instruments, and the status of the flight in one integrated display. Some systems include power plant information and other systems information in the same display. A typical primary flight display is shown in Fig. 3.11.

The attitude indicator on the PFD in Fig 3.11 is larger than conventional round-dial presentations of an artificial horizon. Airspeed and altitude indications are presented on vertical tape displays that appear on the left and right sides of the primary flight display. The vertical speed indicator is depicted using conventional analog presentation. Turn coordination is shown using a segmented triangle near the top of the attitude indicator. The rate-of-turn indicator appears as a curved line display at the top of the heading/navigation instrument in the lower half of the PFD.

The primary flight instruments that appear on a PFD are driven by instrument sensor systems that are more sophisticated than conventional instrument systems. The attitude of the aircraft may be measured using microelectronic sensors that are more sensitive and reliable than traditional gyroscopic instruments. These sensors measure pitch, roll, and yaw movements away from a known reference attitude. Aircraft heading may be determined using a magnetic direction-sensing device such as a magnetometer or a magnetic flux valve.

Post MCQ Test

1. Turning of rotor about a third axis when a torque transverse to spin axis is known as -------------
    a) Transverse stress
    b) Precession
    c) Transverse shear
    d) Face shear

    Answer b) Precession
2. Which of the following represents condition for ideal gyroscope?
    a) Very low drift of spin axis
    b) Infinite drift of spin axis
    c) Infinite speed for gyro meter
    d) None of the answers

    Answer a) Very low drift of spin axis
3. Increase in angular momentum decreases error.
    a) True
    b) False

    Answer a) True
4. Axis of rotation of wheel in gyroscope is called --------
    a) Vertical axis
    b) Spin axis
    c) Horizontal axis
    d) Angular axis

    Answer b) Spin axis

5. Gimbels are used for -------------

    a) Improving rotational speed

    b) Supporting gyro wheel

    c) As damping agent

    d) None of the answers

    Answer b) Supporting gyro wheel

6. Rate gyroscope is a _____________

    a) Zero order system

    b) First order system

    c) Second order system

    d) Third order system

    Answer: c) Second order system

7. The input, output and spin axes of a gyro are always perpendicular to each other.

    a) True

    b) False

    Answer: a) True

8. A turn coordinator provides an indication of the -------

    a) Aircraft in the ground

    b) Movement of the aircraft about the yaw and roll axes.

    c) Ascending speed

    d) None of the above

    Answer b) Movement of the aircraft about the yaw and roll axes.

9. How should a pilot determine the direction of bank from an attitude indicator

    a) Aircraft speed

    b) Movement of the aircraft about the yaw and roll axes.

    c) By the relationship of the miniature airplane (in the display) to the deflected horizon bar.

    d) None of the above

    Answer c) By the relationship of the miniature airplane (in the display) to the deflected horizon bar.

10. The proper adjustment to make on the attitude indicator during level flight is to align the -----

    a) Miniature airplane to the horizon bar.

    b) Aircraft speed

c) Miniature airplane to compass.

d) None of the above

Answer a) miniature airplane to the horizon bar.

Assignment

1. Briefly explain the principle of working of Attitude indicator with neat diagrams
2. Write short notes on turn and bank indicator with relevant diagrams.

UNIT-IV: Aircraft Computer Systems

Terrestrial magnetism, aircraft magnetism, Direct reading magnetic components- Compass errors gyro magnetic compass.

Aim & objectives: Describe the operating principles of direct reading magnetic components including heading indicator in aircraft instrument system.. Also differentiate terrestrial and artificial magnetism and can able to correct the compass errors.

Pre MCQ Test

1. Deviation in a magnetic compass is caused by the
   a) Turning left
   b) Turning right
   c) Magnetic fields within the aircraft distorting the lines of magnetic force.
   d) Descending
   Answer c)
2. Does the Directional Gyro depend on earth's magnetic field to operate?
   a) Yes
   b) No
   Answer b)
3. How many gimbals do the Directional Gyro has?
   a) 2
   b) 4
   c) 6
   d) 5
   Answer a)

THEORY

4.1. Magnetic Fundamentals

The three principal properties of a permanent magnet:

(i) it will attract other pieces of iron and steel,

(ii) its power of attraction is concentrated at each end, and

(iii) when suspended so as to move horizontally, it always comes to rest in an approximately North-South direction.

The second and third properties are related to what are termed the poles of a magnet, the end of the magnet which seeks, North being called the North Pole and the end which seeks South the South pole.

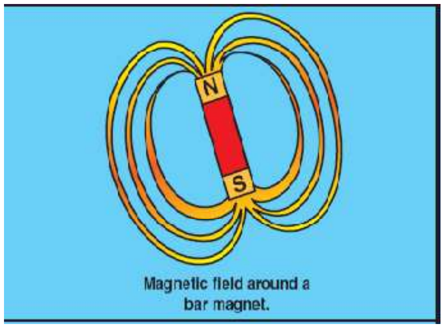


Fig 4.1 Bar Magnet

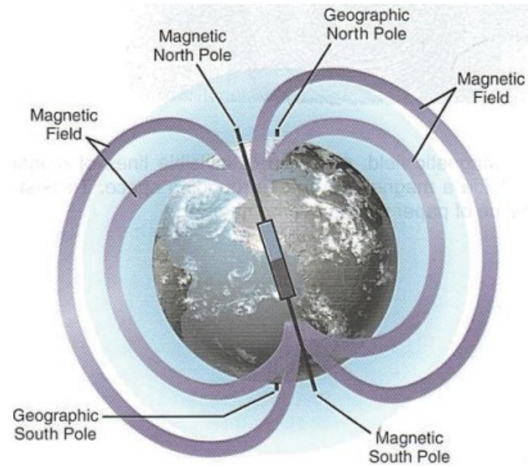


Fig 4.2 Earth's Magnetic field

When two such magnets are brought together, *like poles repel and unlike poles attract*; this is one of the fundamental laws of magnetism. The force of attraction or repulsion between two poles *varies inversely as the square of the distance between them*.

The region in which the force exerted by a magnet can be detected is known as a *magnetic field*. Such a field contains *magnetic flux*, which can be represented in direction and density by *lines of flux*.

The symbol for magnetic flux is Φ, and its unit is the weber (Wb). The amount of flux through unit area, indicated by the spacing of the lines of flux, is known as magnetic flux density (B); its unit is the weber per square metre, or tesla (T).

All materials, whether magnetic or not, have a property called reluctance which resists the establishment of magnetic flux and is equivalent to the resistance of an electric circuit. It follows that, if a material of low reluctance is placed in a magnetic field, the flux density in the material will be greater than that in the surrounding air.

Magnetic field strength, H, or the strength of a magnetic field at any point is measured by the force, F, exerted on a magnetic pole at that point. The force depends on the pole strength, i.e. the flux Φ 'emanating' from the pole* as well as on the field strength. In symbols,

$$H = F/\Phi \text{ newtons per weber.}$$

Thus the unit of H is the newton per weber (N/Wb). A unit that is more familiar to electrical engineers is the ampere per metre (A/m).

Magnetic Moment

The magnetic moment of a magnet is the tendency for it to turn or be turned by another magnet. It is a requirement in aircraft compass design that the strength of this moment be such that the magnetic detecting system will quickly respond to the directive force of a magnetic field, and in calculating it the length and pole strength of a magnet must be considered

Hard Iron and Soft Iron

'Hard' and 'soft' are terms used to qualify varieties of magnetic materials according to the ease with which they can be magnetized. Metals such as cobalt and tungsten steels are of the hard type since they are difficult to magnetize but once in the magnetized state they retain the property for a considerable length of time; hence the ten permanent magnetism. Metals which are easy to magnetize (silicon iron for example), and generally lose their magnetic state once the magnetizing force is removed, are classified as soft.

4.2. Terrestrial Magnetism

The surface of the earth is surrounded by a weak magnetic field which culminates in two internal magnetic poles, situated near the North and South true or geographic poles. That this is so is obvious from the fact that a magnet freely suspended at various parts of the earth's surface will be found to settle in a definite direction, -which varies with locality. A plane passing through the magnet and the centre of the earth would trace on the earth's surface an imaginary line called the ***magnetic meridian*** as shown in Fig 4.2.

The earth's magnetic field differs from that of an ordinary magnet in several respects. Its points of maximum intensity, or strength, are not at the magnetic poles (theoretically they should be) but occur at four other positions, two near each pole, known as magnetic foci. Moreover, the poles themselves are continually changing their positions, and at any point on the earth's surface the field is not symmetrical and is subject to changes both periodic and irregular.

4.3 Artificial Magnetism

The magnetic field in the aircraft due to electric current flowing in wires or metal parts that are magnetized is called Artificial Magnetism

Challenge to designers:

Direct Reading Compass (DRC) must be located where pilot can readily see it. DRC in the cockpit is surrounded by magnetic material and electrical circuits. Such magnetic influence provides a deviation force to the Earth’s magnetic field: compass needle will not point to the local meridian

Such magnetic influences may originate from: - components of the airplanes structure, items of the traffic load, cargo and passengers’ baggage- items placed near to the compass. Deviation caused by a/c magnetism can be analyzed and errors can be minimized

Deviation is the angle measured at a point between the direction indicated by a compass needle and the direction of Magnetic North It is termed East or West according to whether the Compass North lies to the East or West of Magnetic North.

Hard magnetism in aircraft:-

- Is permanent in nature
- Caused by steel components used in its construction
- Such components are difficult to magnetize but once magnetized, hold their magnetic field for a long time.
- This magnetism has its origin in components permanently installed in the aircraft
- So: Direction and force of hard magnetism relative to the compass position will be the same for all attitudes and headings Hardened steel materials used in the engines, the fuselage and in bolts and nuts all over the a/c
- Distance between magnetic steel component and sensitive part of the compass is important The force of the field is reduced by the square of the distance from the magnetic source
- To study their influence on the sensitive part of the compass, all hard iron sources are considered simultaneously, based on the direction and force of the magnetic field they produce in the position where the sensitive unit of the compass is installed.

Soft magnetism in aircraft:-

- Soft iron magnetism is referred to metal easily magnetized but that will lose its magnetism with same facility.
- It is temporal induced magnetism due to the Earth´s magnetic field, acting as a focus for it and causing a localized intensifying of that field.
- It is due to the Earth´s field which gives the components of the soft metal a variable magnetic value which depends on the forces H and Z
- Effects and strength of their magnetic field around the compass are easy to calculate but difficult to compensate for in isolation.
- They are most often only recorded as a part of the total deviation registered during a compass swing.

4.4. Direct-Reading Magnetic Compasses

During the early days of aviation, direction of flight was determined chiefly by direct reading magnetic compasses. Today, the direct-reading magnetic compass (Fig.4-3) is used as a standby compass. Direct-reading magnetic compasses used in Navy aircraft mount on or near the instrument panel for use by the pilot. They are read like the dial of a gauge.

A nonmagnetic metal bowl, filled with liquid, contains the compass indicating card. The card provides the means of reading compass indications. The card mounts on a float assembly and is actually a disk with numbers painted on its edge. A set of small magnetized bars or needles fasten to this card. The card-magnet assembly sits on a jeweled pivot, which lets the magnets, align themselves freely with the north-south component of the earth's magnetic field. The compass card and a fixed-position reference marker (lubber's line) are visible through a glass window on the side of the bowl.

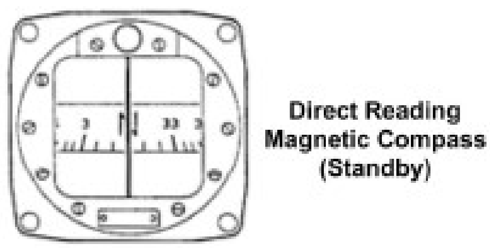


Fig. 4.3.Direct reading Magnetic Compass

An expansion chamber in the compass provides for expansion and contraction of the liquid caused by altitude and temperature changes. The liquid dampens, or slows down, the oscillation of the card. Aircraft vibration and changes in heading cause oscillation. If suspended in air, the card would keep swinging back and forth and be difficult to read.

The liquid also buoys up the float assembly, reducing the weight and friction on the pivot bearing.

Instrument-panel compasses for naval aircraft are available with cards marked in steps of either 2 degrees or 5 degrees. Such a compass indicates continuously without electrical or information inputs. You can read the aircraft heading by looking at the card in reference to the lubber line through the bowl window.

4.5. ERRORS IN THE DIRECT INDICATING COMPASS (COMPASS ERRORS)

4.5.1. Magnetic Variation

The horizontal angle contained between the true and magnetic meridian at any place is known as the magnetic variation or declination. Magnetic variation is affected by geographical location; different locations on Earth have different amount of variation error.

When the direction of the magnetic meridian inclines to the left of the true meridian at any place, the variation is said to be westerly. When the inclination is to the right of the true meridian the variation is said to be easterly. It varies in amount from 0° along those lines where the magnetic and true meridians run together to 180° in places between the true and magnetic poles. At some places on the earth where the ferrous nature of the rock disturbs the earth's main magnetic field, local attraction exists and abnormal variation occurs

Information regarding magnetic variation and its changes is given on special charts of the world which are issued every few years. Lines are drawn on the charts, and those which join places having equal variation are called ***isogonal lines***, while those drawn through places where the variation is zero are called ***agonic lines***.

Correction for Variation

• East of Agonic line:

Magnetic Heading = True Heading – Variation

• West of Agonic line:

Magnetic Heading = True Heading + Variation

• Memory Aid: West is Best, East is Least;

Means when variation is west, add to true heading

4.5.2. Magnetic Dip: Bar magnet contained in compass is pulled by the earth's magnetic field; it tends to point north and somewhat downward. It is greatest near the poles.

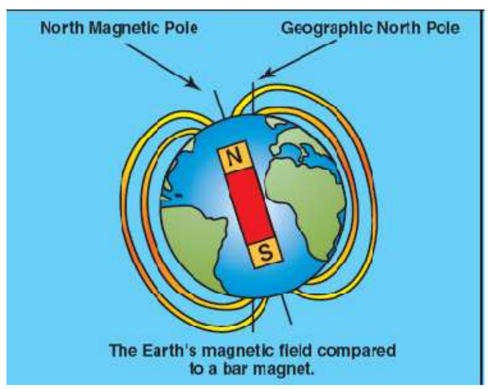


Fig.4.4. Magnetic Dip

– Magnetic field lines are not parallel to Earth's surface except at Equator

– Thus a freely-suspended magnet will not be horizontal

– Float is weighted at one end to correct for dip

The Magnetic North Pole is the position on the surface of the Earth where the dip (or inclination) is plus 90 degrees.

The Magnetic South Pole is the position on the surface of the Earth where the dip (or inclination) is minus 90 degrees

The Angle of Dip is the angle in the vertical plane between the horizontal and the Earth's magnetic field at a point

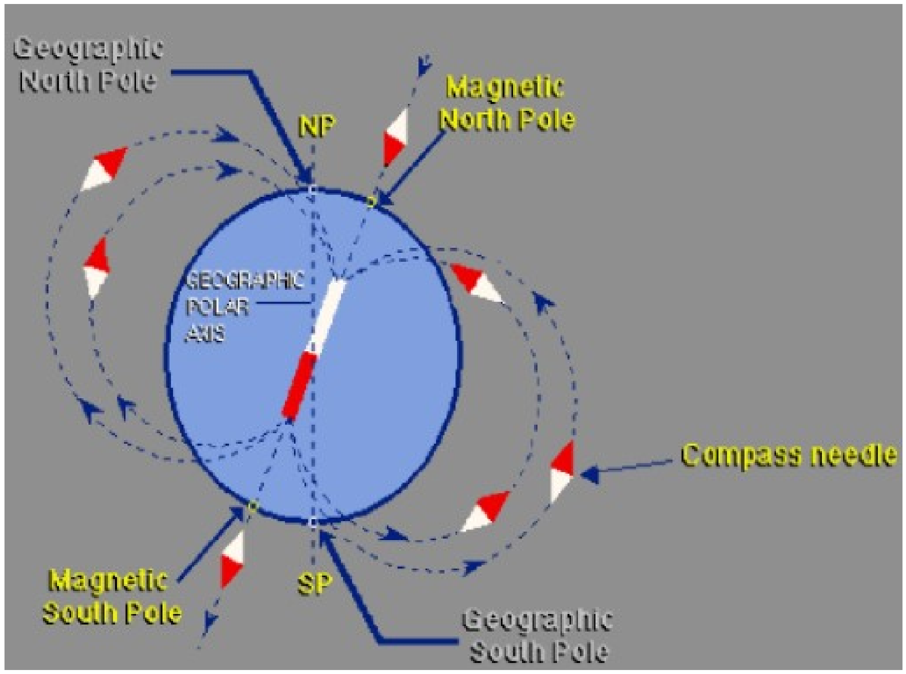
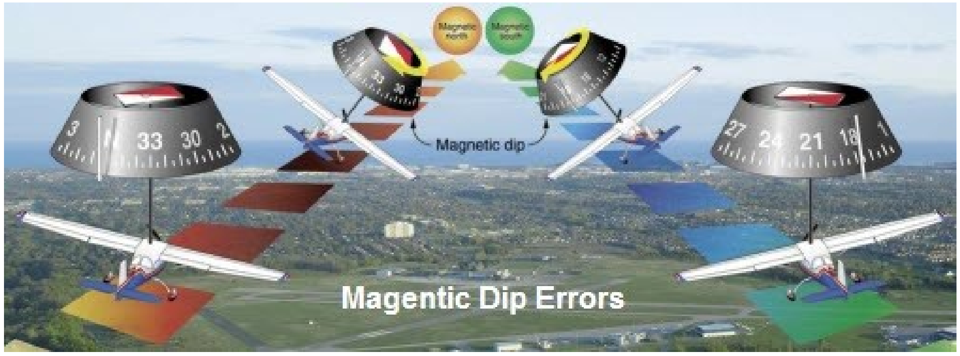


Fig.4.5. Angle of Dip

1. Compass tends to dip toward the magnetic pole, most dominate as latitude increases
    - The lines of magnetic flux are considered to leave the Earth at the magnetic north pole and enter at the magnetic South Pole
    - At both locations, the lines are perpendicular to the Earth's surface
    - At the magnetic equator, which is roughly halfway between the poles, the lines are parallel with the surface
    - Within 300 miles of the poles, the instrument is unreliable due to extreme errors
2. The south end of the compass is therefore weighted to minimize this error
3. The magnets in a compass align with this field; near the poles they dip or tilt the float and card
4. The float is balanced with a small dip-compensating weight, so it stays relatively level when operating in the middle latitudes of the northern hemisphere
5. To counter this the pivot point on which the bar magnet swings is deliberately placed at a position other than the magnets center of gravity (CG)
    - This counters magnetic dip up to a point, but introduces turning and acceleration errors
6. When the aircraft is flying at a constant speed on a heading of east or west, the float and card is level and the effects of magnetic dip and the weight are approximately equal



4.5.3. Magnetic Deviation

• Difference between compass north and magnetic north

• Caused by aircraft magnetism (i.e. magnetic field in the aircraft due to electric current flowing in wires or metal parts that are magnetized)

• Compass swing is done to minimize deviation

• Affected by heading - different headings produce different deviation error

• Any remaining error will be recorded on a compass deviation card

Deviation: Compass error due to disturbances in magnetic field de to metals and electrical accessories in the airplane. Use deviation card in airplane to correct.

4.5.4. Turning Error:

Most pronounced when turning to or from headings of north or south.

When a turn from a heading of north begins, the compass initially indicates a turn to the opposite direction. When the turn is established, the compass begins to turn in the correct direction, but it lags behind the actual heading.

Turning errors do not occur when turning from an east or west heading.

4.5.5. Acceleration Error:

Magnetic dip causes the acceleration and deceleration errors, which are fluctuations in the compass during changes in speed. In the northern hemisphere, the compass swing toward the north during acceleration and toward the south during deceleration occurs when accelerating or decelerating on an easterly or westerly heading. If it is accelerated, inertia causes the compass weight on the south end of magnetic to lag and turn the compass toward north. If it is decelerated, inertia causes weight to move ahead, moves the compass toward a southerly heading.

The memory aid: ANDS (Accelerate North, Decelerate South). In the southern hemisphere, the error occurs in the opposite direction (accelerate south, decelerate north) Acceleration/deceleration errors do not occur when on a north or south heading.

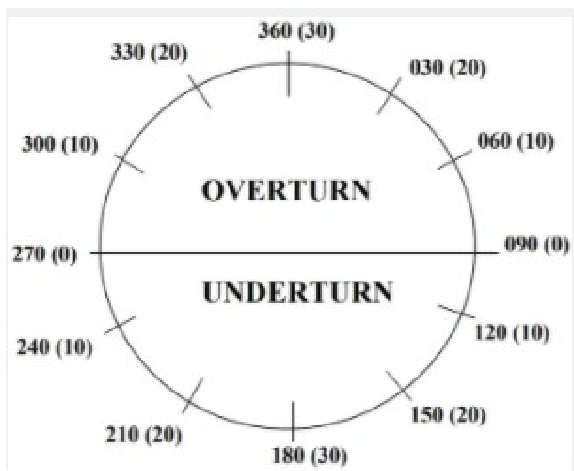


Fig.4.6.Turning Error

4.5.6. Turbulence

Turbulence is not a real error. It makes the compass unstable and it has therefore more or less unreliable indication. Gyro compasses give a much stable reading in turbulence problem with these gyro's is that their indication changes due to drift in the instrument and the rotation of the earth, 15^{o} per hour (as they are fixed to one point in space). Earth's rotation can be compensated.

4.6. Directional Gyro and Gyro compass (Heading Indicator)

The heading indicator (also known as the directional gyro, or DG; sometimes also called the gyrocompass, though usually not in aviation applications) displays the aircraft's heading with respect to magnetic north. The heading indicator is used to inform the pilot of the aircraft's heading. The pilot will periodically reset the heading indicator to the heading shown on the magnetic compass

The magnetic compass, for its construction, is sensitive to inertia forces. This means that a compass is a reliable heading instrument in the long term, but in manoeuvre conditions it may swing and be hardly readable. To provide a more precise heading instrument in these conditions, a directional gyro is used. Like the horizontal gyro, it is a 3-degree-of-freedom system, but with horizontal axis; due to gyroscopic rigidity, it will keep its orientation during manoeuvres, but is affected by drift errors that again can be compensated by erection devices.

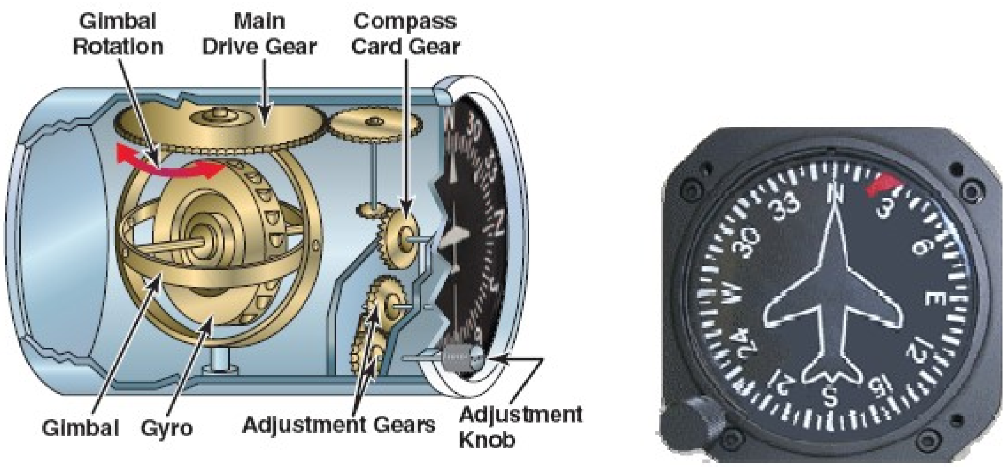


Fig. 4.7. Directional gyro display

The display of the directional gyro is similar to a compass display, as shown in fig. 4.7. In general the indication of the directional gyro is reliable in the short term (10 to 20 minutes); for this reason the crew must reset it to the compass reading during levelled flight conditions, when the compass is reliable, and most of all before starting a manoeuvre.

More modern systems have a gyrocompass, or a directional gyro connected or slaved to a remote compass, that cancel the long-term drift automatically. In these systems the compass is typically an electronic compass, or flux valve, made of a series of coils that sense the direction of the magnetic field, located near the wing tips in order to minimize the disturbances from magnetic and electric fields.

Heading Indicator Errors:-

Precession caused by the mechanical friction of the gimbals will cause the heading indicator to become inaccurate. Hence, must be reset every 15 minutes through checking the heading indicator with the magnetic compass.

Post MCQ Test

1. What is another name for the Direction Gyro?

    a) Heading Indicator

    b) Compass

    c) Aircraft Gyro

    d) VSI

    Answer a)

2. How many errors do the Directional Gyro has?

    a) 6

    b) 5

    c) 4

    d) 3

    Answer c)

3. To receive accurate indications during flight from a heading indicator, the instrument must be

    a) Periodically realigned with the magnetic compass as the gyro precesses.

    b) Kept in vertical position

    c) No need of re alignment

    d) All the above

    Answer a)

4. During flight, when are the indications of a magnetic compass accurate?

    a) Turning left

    b) Turning right

    c) Decending

    d)Only in straight-and-level unaccelerated flight.

    Answer d)

5. In the Northern Hemisphere, a magnetic compass will normally indicate a turn toward the north if

    a) An aircraft is accelerated while on an east or west heading.

    b) Moving straight

    c) The aircraft is decelerated while on a west heading.

    d) None of the above

    Answer a)

6. In the Northern Hemisphere, if an aircraft is accelerated or decelerated, the magnetic compass will normally indicate

a) Correctly when on a north or south heading.

b) Correctly when on a east or west heading.

c) Ascending

d) Descending

Answer a)

7. In the Northern Hemisphere, a magnetic compass will normally indicate initially a turn toward the west if

a) a left turn is entered from a north heading.

b) a right turn is entered from a north heading.

c) Ascending

d) Descending

Answer b)

8. In the Northern Hemisphere, the magnetic compass will normally indicate a turn toward the south when

a) Ascending

b) Descending

c) The aircraft is decelerated while on a west heading.

d) All the above

Answer c)

9. In the Northern Hemisphere, a magnetic compass will normally indicate initially a turn toward the east if

a) Ascending

b) Descending

c) The aircraft is decelerated while on a west heading.

d) a left turn is entered from a north heading.

Answer d)

Assignment

1. Explain the principle of operation of gyro magnetic compass with diagram.
2. Briefly explain Compass errors
3. Discuss in detail about the magnetic system of a typical aircraft compass and how is the effect of dip overcome.

UNIT- V: POWER PLANT INSTRUMENTS

Fuel flow -Fuel quantity measurement, exhaust gas temperature measurement and pressure measurement.

Aim & objectives: Explain the operating principles and characteristics of engine instrument systems, including temperature indicating, fuel flow, oil pressure, fuel pressure, oil temperature, exhaust gas temperature measurement and pressure measurement systems. Also, identify the various procedures used to maintain, and test aircraft instruments

Pre MCQ Test

1. The calorific value of gaseous fuels is expressed in terms of ___________

   a) Kcal

   b) Kcal/kg

   c) Kcal/m2

   d) Kcal/m3

   Answer: d

2. To assist in reducing the temperature of the engine----

   a) The air / fuel mixture can be richened

   b) The airspeed can be reduced

   c) The cowl flaps can be closed

   d) The air / fuel mixture can be weakened

   Answer: a)

3. The normal method for shutting down an aircraft engine is -----

   a) Closing the throttle

   b) Moving the mixture to Idle Cut off

   c) Switching the starter switch to off

   d) Closing the throttle and moving the mixture to ICO.

   Answer: d)

THEORY

5.1. TEMPERATURE INDICATING SYSTEMS

To properly monitor the operation of an aircraft engine, you must know various temperature indications. Some of the more important indications include the temperatures of the engine oil, free air, and exhaust systems of jet engines. Various types of thermometers, such as the bimetal and resistance types, collect and present this information. The main parts of resistance thermometers are the indicating instrument, the temperature sensitive element (resistance bulb), and the connecting wires leading from the bulb.

5.1.1. Wheatstone bridge System

A schematic diagram of a Wheatstone bridge thermometer circuit is shown in Fig.5.1. The resistance bulb element is one side of the Wheatstone bridge circuit. The other three sides are resistors in the indicating meter. The circuit receives voltage from the aircraft dc power supply.

When the temperature bulb senses a temperature of 0 °C, its resistance is 100 ohms. The resistance of arms X, Y, and Z are also 100 ohms each. At this temperature the Wheatstone bridge is in balance. This means the sum resistance of X and Y equals the sum resistance of the bulb and Z. Therefore, the same amount of current flows in both sides of this parallel circuit. Since all four sides are equal in resistance, the voltage drop across side X equals the drop across the bulb. Since these voltages are equal, the voltage from A to B is zero, and the indicator reads zero.

When the temperature of the bulb increases, its resistance also increases. This unbalances the bridge circuit causing the needle to deflect to the right. When the temperature of the bulb decreases, its resistance decreases. Again, the bridge circuit goes out of balance. However, this time the needle swings to the left.

The galvanometer is calibrated so the amount of deflection causes the needle to point to the number of the meter scale. This number corresponds to the temperature at the location of the resistance bulb.

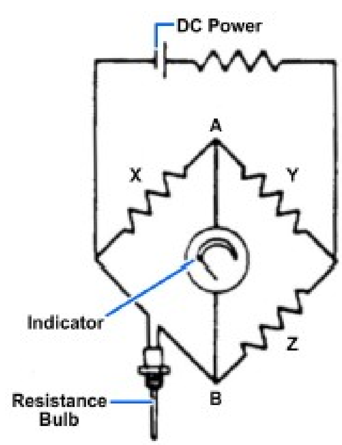


Fig. 5.1. Wheatstone bridge thermometer

This instrument requires a constant and steady supply of dc voltage. Fluctuations in the power supply affect total bridge current, which can cause an unbalanced bridge. Unless excessive heat damages the bulb, it will give accurate service indefinitely. When a thermometer does not operate properly, check carefully for loose wiring connections before replacing the bulb.

5.1.2. Thermocouple System

Thermocouple temperature indicators show the air temperatures in the heater duct of anti-icing systems and in the exhaust systems of jet engines.

A thermocouple is a junction or connection of two unlike metals; such a circuit has two junctions. When one of the junctions becomes hotter than the other, an electromotive force is produced in the circuit. By including a galvanometer in the circuit, this electromotive force can be measured. The hotter the high temperature junction (hot junction) becomes, the greater the electromotive force. By calibrating the galvanometer's dial, in degrees of temperature, the galvanometer becomes a thermometer. The galvanometer contains the cold junction.

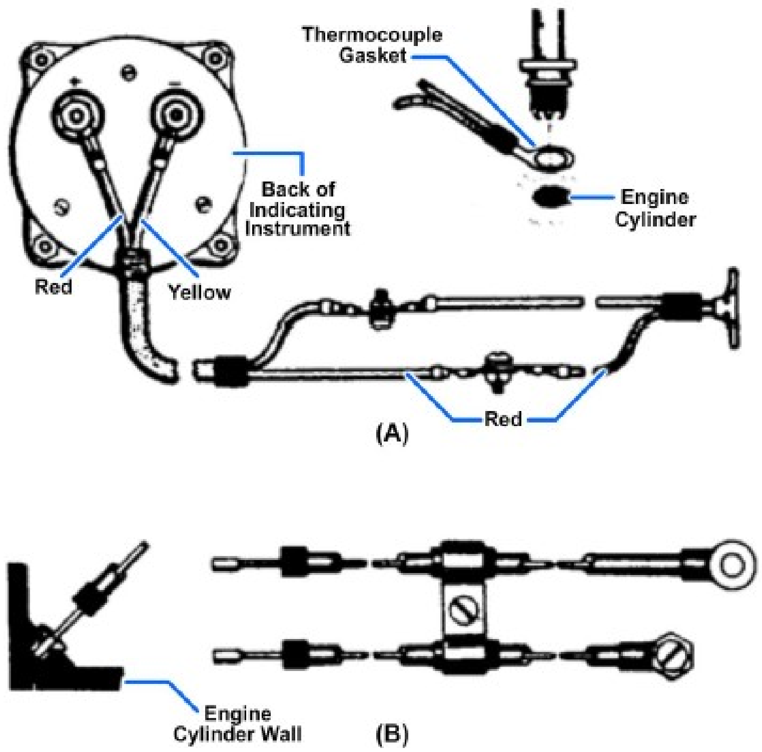


Fig. 5.2. – Thermocouples: A) gasket type B) rivet type

The thermocouple thermometer systems used in naval aircraft consist of a galvanometers indicator, a thermocouple or thermocouples, and thermocouple leads. Some thermocouples consist of a strip of copper and a strip of constantan pressed tightly together. Constantan is an alloy of copper and nickel. Other thermocouples consist of a strip of iron and a strip of constantan. Others may consist of a strip of Chromel and a strip of Alumel.

The hot junction of the thermocouple varies in shape, depending on its application. Two common types, gasket and rivet, are shown in Fig. 5.2. In the gasket thermocouple, the rings of two dissimilar metals are pressed together, forming a spark plug gasket. Each lead that connects back to the galvanometers must be of the same metal as the thermocouple part to which it connects. For example, a copper wire connects to the copper ring, and a constantan wire connects to the constantan ring. Thermocouple leads are critical in makeup and length because the galvanometers are calibrated for a specific set of leads in the circuits.

5.2. EXHAUST GAS TEMPERATURE INDICATING SYSTEM

The Exhaust Gas Temperature (EGT) indicating systems provide a visual temperature indication in the cockpit of the engine exhaust gases. The following is a discussion of a typical EGT indicating system.

The aircraft contains two separate but identical EGT indicating systems (Fig. 5.3), one for each engine. Each system has 12 dual thermocouples, a combination indicator and transistorized amplifier, and the interconnecting Chromel and Alumel leads. Power for the indicator-amplifier is from the essential 115-volt ac bus.

Both exhaust gas temperature indicators are on the pilot's main instrument panel. They provide a visual indication of the engine exhaust temperatures. Each instrument is a hermetically sealed unit with a single receptacle for a mating plug electrical connection. The instrument scale ranges from 0 °C to 1,200 °C. There is a vernier dial in the upper right corner of the instrument face. A power-off warning flag is in the lower portion of the dial.

Internally, the indicator contains a simulated thermocouple cold junction with compensating resistors, a reference voltage source, and a dc-to-ac modulator. It also contains a transistor power output stage, miniature ac servomotor, and the power-off warning flag. The temperature indicator contains range markings on the instrument face.

The thermocouples convert engine exhaust gas temperature into millivolts. The voltage from the thermocouples goes directly to the indicator amplifier through the Chromel and Alumel leads. The voltage is amplified and drives a small servomotor. The motor, in turn, drives the indicator pointer. The thermocouple harness consists of two halves, each containing six dual-loop thermocouples. The assembled halves make up two independent thermocouple systems, each consisting of 12 thermocouples connected in parallel. The harness mounts on the turbine frame aft of the turbine rotor.

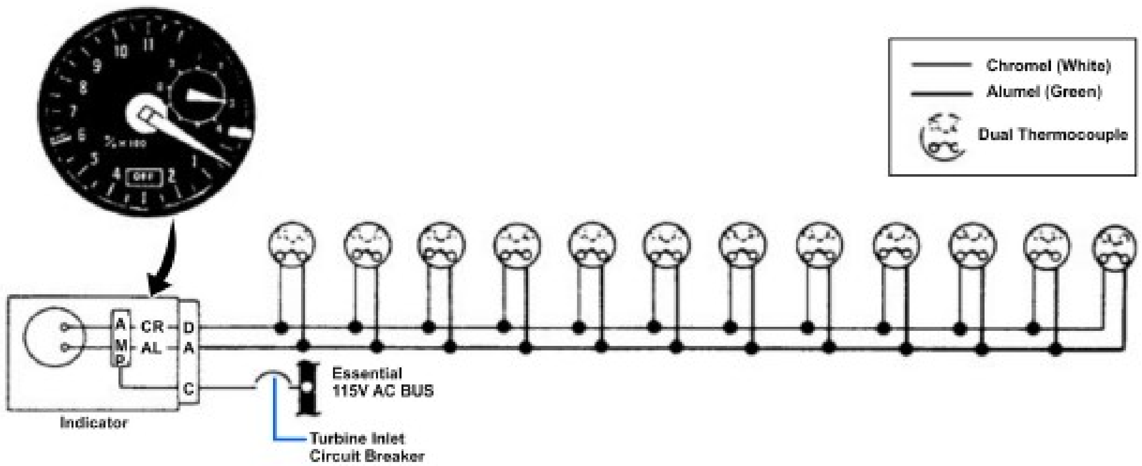


Fig. 5.3. — Exhaust gas temperature indicating system.

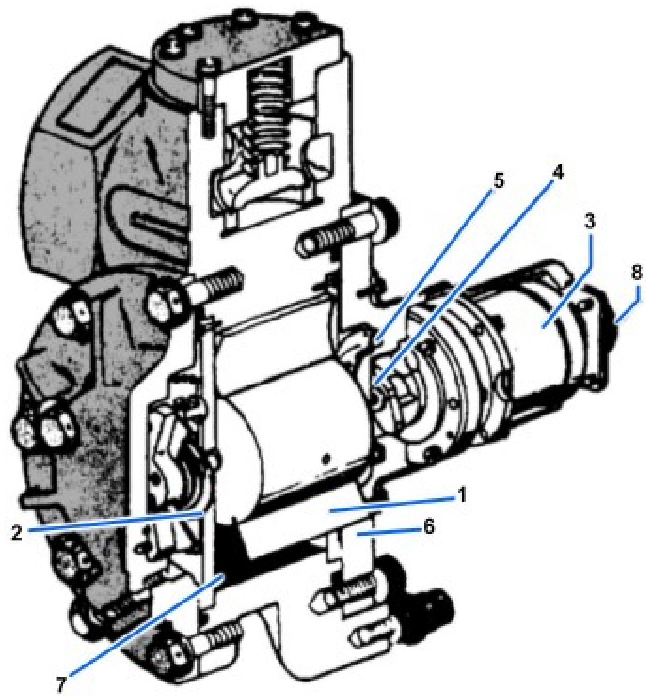
5.3 FUEL FLOW SYSTEMS

Fuel flow indicating systems provide a continuous indication of the rate of fuel delivery to the engine. The rate of flow is in pounds per hour. In some systems, the indicator also shows the amount of fuel remaining in the tanks. A typical flow meter consists of two units, a transmitter and an indicator. The measurements are transmitted electrically to the panel-mounted indicator. Thus, use of electrical transmission ends the need for a direct fuel-filled line from the engine to the instrument panel. Removing the fuel line minimizes the chance of fire and reduces mechanical failure rate.

5.3.1. Fuel Flow Transmitter

Fig.5.4 shows a cutaway view of a fuel flow transmitter. It is a two-in-one unit, a fuel-measuring mechanism (or meter) and a synchro transmitter. It can be separated from one another for maintenance purposes, but they join as a single assembly for installation.

The fuel enters the inlet port of the transmitter and flows against the vane (callout 1), causing the vane to swing. The spiral fuel chamber design allows the distance between the vane and chamber wall to become increasingly larger as fuel flow increases. A calibrated hairspring (callout 2) retards the motion of the vane. The vane ceases motion when the forces exerted on it by the hairspring and by the fuel are equal. The rotor shaft of the synchro transmitter (callout 3) connects to a bar magnet (callout 4). Attached to the vane shaft is a ring magnet (callout 5). The ring magnet moves as the vane shaft moves.



1. Vane
2. Hairspring
3. Synchro transmitter
4. Bar Magnet assembly
5. Ring magnet assembly
6. Transmitter mountin frame
7. Fuel chamber
8. Electrical connector

Fig 5.4. Cutaway view of a fuel flow transmitter.

The transmitter mounting frame is between the bar magnet and the ring magnet, forming a liquid-tight seal. This is the seal between the fuel-metering section of the mechanism and the synchro. However, the bar magnet moves in unison with the ring magnet because the two magnets are magnetically coupled. The south pole of the ring magnet is opposite the north pole of the bar magnet. The two magnets send vane movement, caused by the fuel flow, to the synchro rotor. This action results in a corresponding movement of the rotor. Therefore, the angular displacement of the vane in relation to the fuel chamber housing determines the synchro rotor movement with respect to the stator.

The fuel flow transmitter has a relief valve, which automatically opens and bypasses the instrument when the fuel flow exceeds the capacity of the instrument. At such time, only part of the fuel flows through the metering portion. As the pressure across the instrument falls below the value at which the relief valve opens, the valve closes. This lets the flowmeter again operate normally. The transmitter unit location is in the fuel line between the fuel pump and fuel nozzle.

5.3.2. Fuel Flow Indicator

The fuel flow meter indicator is located on the instrument panel. It is a remote-indicating instrument. This indicator consists of a synchro receiver, a step-up gear train, a magnetic drag cup, and a calibrated spring. When fuel flows through the fuel flow transmitter, an electrical signal goes to the indicator receiver. This signal drives the synchro rotor to the proper position. Thus, the indicator pointer shows the rate of fuel flow.

Fig.5.5. Fuel Flow Indicator

Fig 5.5 shows the face of the single flow indicator. To determine the amount of fuel consummation per hour, multiply the scale reading by 1,000. Fig.5.6. shows a schematic diagram of the single fuel flow indicator.

The fuel flow transmitter consists of a synchronous motor, drum assembly, impeller assembly, spiral spring, and pickup coils. The transmitter housing has fuel inlet and outlet attachment flanges. The drum and impeller assemblies have two miniature permanent magnets, 180 degrees apart. The motor runs at a constant 120 RPM. The motor connects through a shaft to the drum assembly.

The impeller assembly rotates over the motor drum shaft and mechanically couples to the drum with the spiral spring. The pickup coils, one for each assembly, are in line with the drum and impeller assembly magnets. As the motor rotates the drum, the impeller also rotates. When there is no fuel flow, the magnets of the drum and impeller assemblies align. As they pass their respective coil, they generate simultaneous output signals.

As fuel flow starts and increases through the transmitter housing, it goes through straightening vanes. These vanes eliminate the swirling motion of fuel. The fuel then passes through straight drilled passages of the rotating impeller. As fuel flow increases through the impeller, a proportional drag factor, or resistance to rotation, is imposed on the impeller assembly. This resistance causes the spring to deflect, equalizing the loading. The impeller magnets then deflect out of alignment. This action produces a later signal than that of the drum magnets and coil. Thus, an increased time span between signals of the rotating assemblies becomes relative to increased fuel flow.

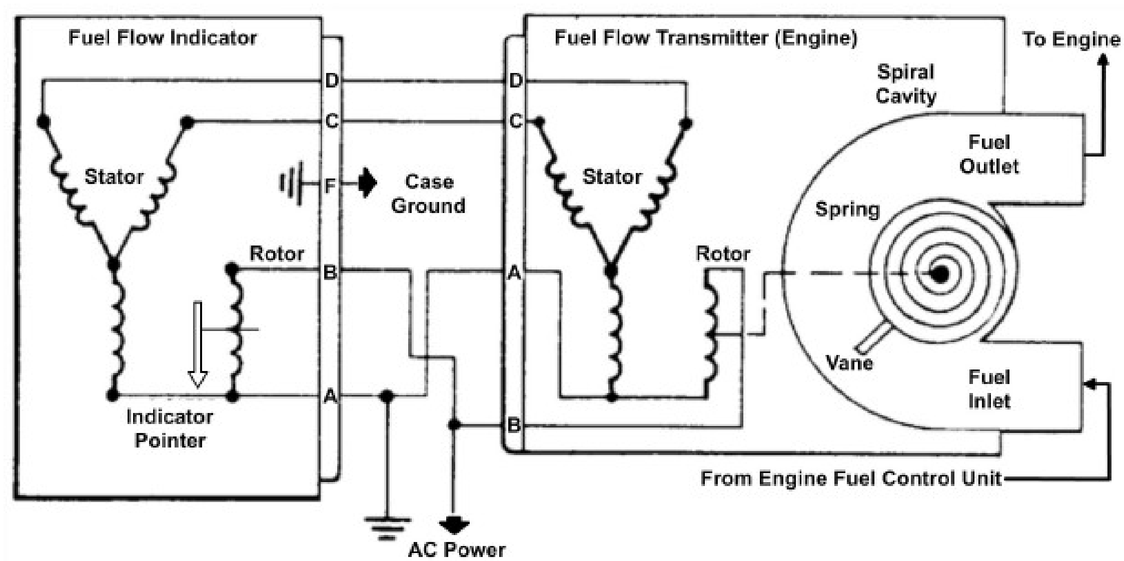


Fig 5.6. Single fuel flow indicating system.

The fuel rate-of-flow power supply consists of a power transformer and power supply, two signal-conditioning channels, and a motor driver. The transformer receives 115 volts ac, 400 Hertz, and it feeds the power supply. The power supply provides low dc voltage to operate the motor-driven logic and signal-conditioning channels. Using a stepping signal to drive control logic, the motor driver controls positive and negative 8- Hertz ac signals between phases of both fuel rate-of-flow transmitter motors.

The signal-conditioning channel for each engine system receives pulses from the coils of its transmitter. For each channel, a pulse shaper converts the time between transmitter drum and impeller coil pulses into a rectangular pulse width signal. An averaging filter processes this converted signal, which provides a low-ripple dc signal input to the fuel rate-of-flow indicator. The size (0 to 5 volts dc) of this signal is proportional to flow rate. A test circuit permits testing the power supply. A tap-off motor, phases A and B from the motor driver, routes an 8-Hertz signal through an external test switch to the signal-conditioning channels for processing. The results of the processed signal are displayed on the indicator.

The fuel rate-of-flow indicator, a vertical scale indicator, displays rate of fuel flow for each engine on parallel scales. The scales are from 0 to 13. The scale reading, multiplied by 1,000, shows the rate (pounds per hour) at which the engine is consuming fuel. The upper left and right OFF failure flags show a loss of power, or signal to the indicator. The indicator has two separate channels, one for each engine. The channels include a control transformer servo amplifier, servomotor, gears, and sprockets. The indicator channels receive 115 volts of ac for signal processing. An input of 0 to 5 volts dc from the fuel rate-of-flow power supply produces an output. This output is from the control transformer rotor winding to the servo amplifier.

The servo amplifier modifies the signal to the proper impedance and power level to drive the channel servomotor. Shaft rotation controls transformer output, and the rotation reduces transformer output voltage. When the output is null, the motor, gear train, and sprockets come to rest at a rate equivalent to the input.

The test selector switch on the MASTER TEST panel tests the indicators. The self-test circuit in the indicators disconnects the fuel rate-of-flow transmitter input circuits. It then connects to an appropriate test signal within the two indicator channels. The channel circuitry processes the test signal and drives the indicator tapes to indicate 4,200 to 4,400 pounds per hour.

5.4. OIL PRESSURE SYSTEM

Oil pressure instruments show whether oil is circulating under proper pressure. An oil pressure drop warns of impending engine failure due to lack of oil, oil pump failure, or broken lines. Oil pressure shows on an engine gauge unit (Fig.5.7). This unit consists of three separate gauges in a single case, oil pressure, fuel pressure, and oil temperature. The gauge has a Bourdon tube mechanism for measuring fluid under pressure (Fig.5.8). The instrument’s oil pressure range is from 0 to 200 pounds per square inch (psi) and can read the scale in graduations of 10 psi. There is a single connection on the back of the case leading directly into the Bourdon tube.

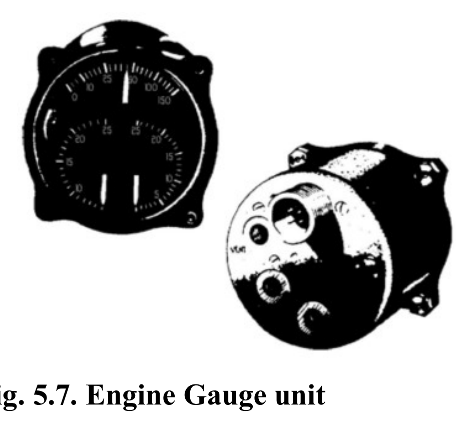


Fig. 5.7. Engine Gauge unit

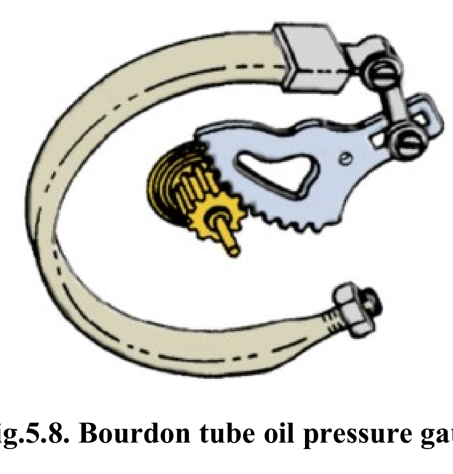


Fig.5.8. Bourdon tube oil pressure gauge

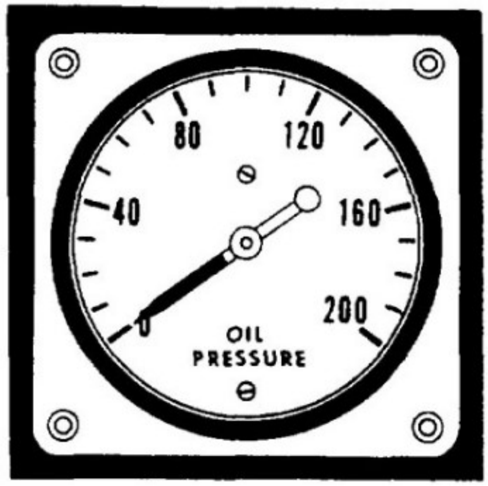


Fig. 5.9. Bourdon tube oil pressure instrument.

In some aircraft, the oil pressure gauge is a separate instrument (Fig.5.9). This instrument operates on the Bourdon tube principle.

The synchro system is another method of measuring oil under pressure. This type of oil pressure system is used on most modern aircraft. Essentially, it is a method of directly measuring engine oil pressure. After the measurements are taken, they go electrically from the point of measurement to the synchro indicator on the instrument panel. The synchro system ends the need for direct pressure lines from the engine to the instrument panel. It also reduces the chances of fire, loss of oil or fuel, and mechanical difficulties.

The synchro system consists of a synchro indicator and transmitter. The synchro transmitter consists of a permanent magnet moving within a stator. The stator is a circular core of magnetic material wrapped with a single, continuous toroidal winding. Taps divide the winding into three sections. Voltages in each of the sections vary with the position of the permanent magnet. As the magnet moves, the ratio between the three signal voltages varies accordingly.

5.5. OIL PRESSURE INDICATING SYSTEM

In Fig.5.10, the transmitter and indicator connect in parallel. When excited by the same fundamental source, the signal voltages in corresponding sections of the two stators are equal and balanced. The signal voltages remain equal and balanced as long as the magnets are in the same relative positions.

However, if the transmitter magnet moves to a new position, the voltages in the three sections of the transmitter are no longer the same. They now differ from the voltages in the corresponding sections of the indicator

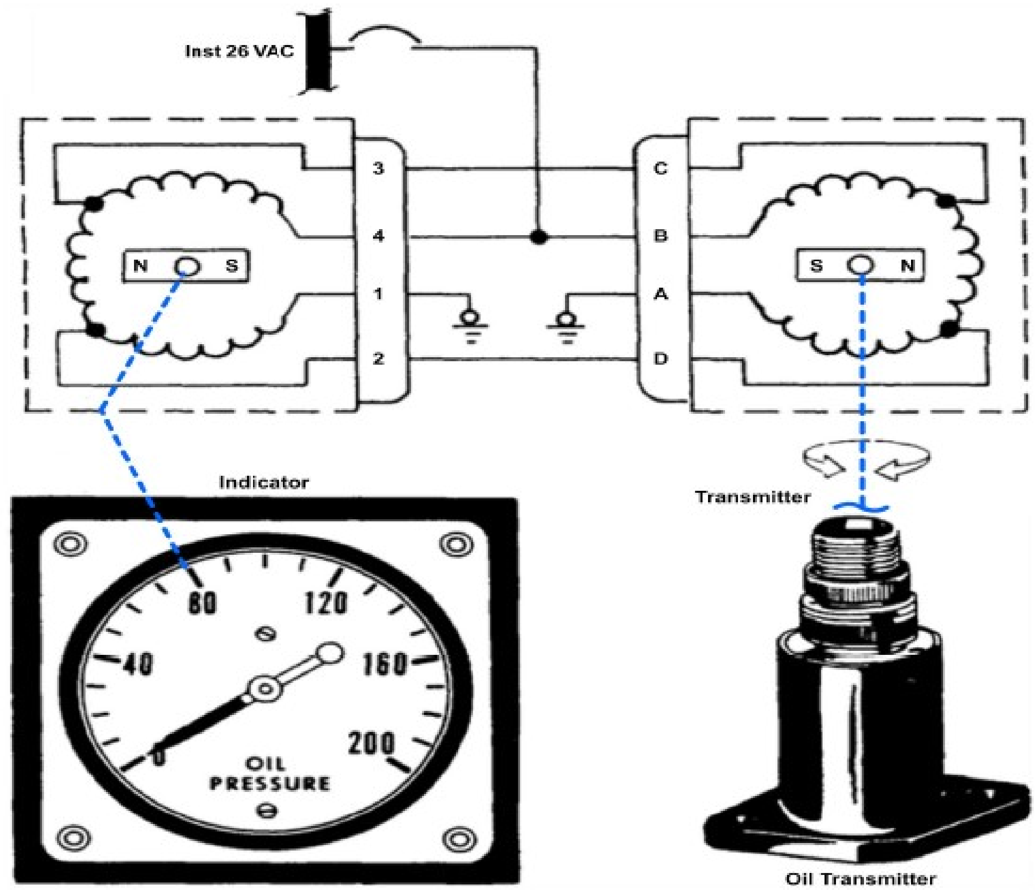


Fig. 5.10. Schematic of a synchro oil pressure indicating system

. Because of this imbalance, current flows between the two units. This circulating current sets up additional magnetic lines of force in each stator, which establishes a magnetic force between the stator and the magnet of each unit. Since the indicator magnet is free to turn, it moves to a position corresponding to the position of the transmitter magnet. The indicator magnet connects to the indicator pointer by a shaft to provide a visual indication. The electrical leads between the transmitter and the indicator may be any reasonable length without noticeable effect on the indication.

5.6. FUEL PRESSURE SYSTEM

The fuel pressure gauge provides a check on the operation of the fuel pump and fuel pressure relief valve. The pilot must check the gauges often to ensure that the fuel pressure is correct. With the fuel pressure correct, the engines have a full range of power at all altitudes. The fuel pressure gauge operates on the same principle as the oil pressure gauge.

Fuel pressure indicators may be located in the cockpit by means of synchro systems. This type of system is the same for both fuel and oil pressure indications. However, the oil system transmitter is NOT interchangeable with the fuel system transmitter.

From the fig.5.11, the synchro system is used to show fuel pressure. A change in fuel pressure introduced into the synchro transmitter causes an electrical signal to go through the interconnecting wiring to the synchro receiver. This signal moves the receiver rotor and the indicator pointer a distance proportional to the amount of pressure exerted by the fuel.

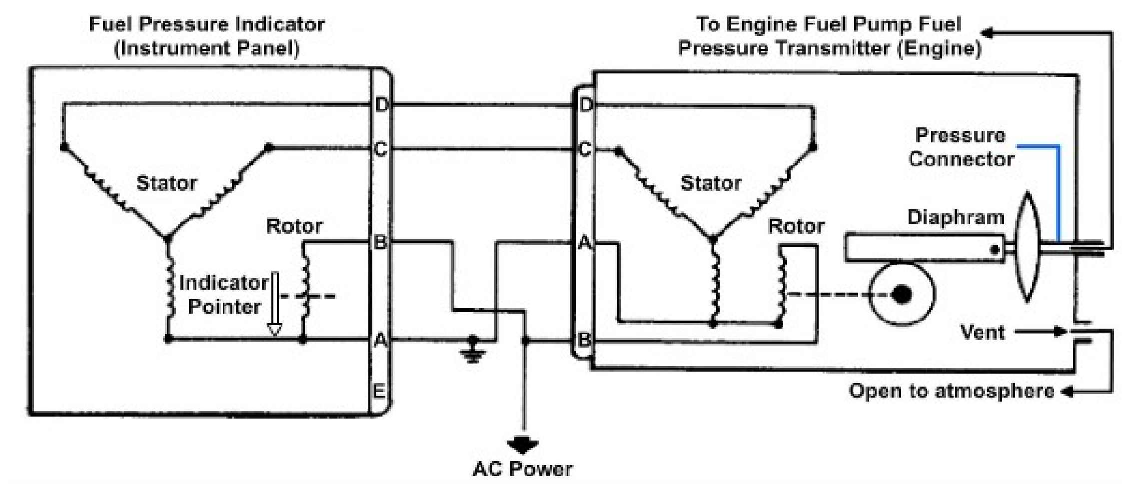


Fig 5.11. Fuel pressure synchro system

5.7. OIL TEMPERATURE SYSTEM

Two types of oil temperature gauges are available for use in the engine gauge unit. One unit consists of an electrical resistance type of oil thermometer, supplied with electrical current by the aircraft dc power system. The other unit, the capillary oil thermometer, is a vapor pressure thermometer. It consists of a bulb connected by a capillary tube to a Bourdon tube and a multiplying mechanism connected to a pointer. The pointer shows the oil temperature on a dial.

5.8. EXAUST NOZZLE INDICATING SYSTEM

The exhaust nozzle position indicating system shows the pilot engine variable exhaust nozzle position. This indication, in turn, provides a measure of percentage of afterburning, since constant temperatures are indicated throughout the afterburner range.

Each engine has a separate but identical nozzle position indicating system. Each system consists of a transmitter potentiometer in the nozzle area control unit and an indicator on the main instrument panel. Power for the system is from the essential 28 volt dc bus.

Each indicator is a hermetically sealed unit containing a single receptacle for a mating plug electrical connection. The instrument scale ranges from OPEN to CLOSE, with markings at the ¼, ½, and ¾ positions (Fig. 5.12).

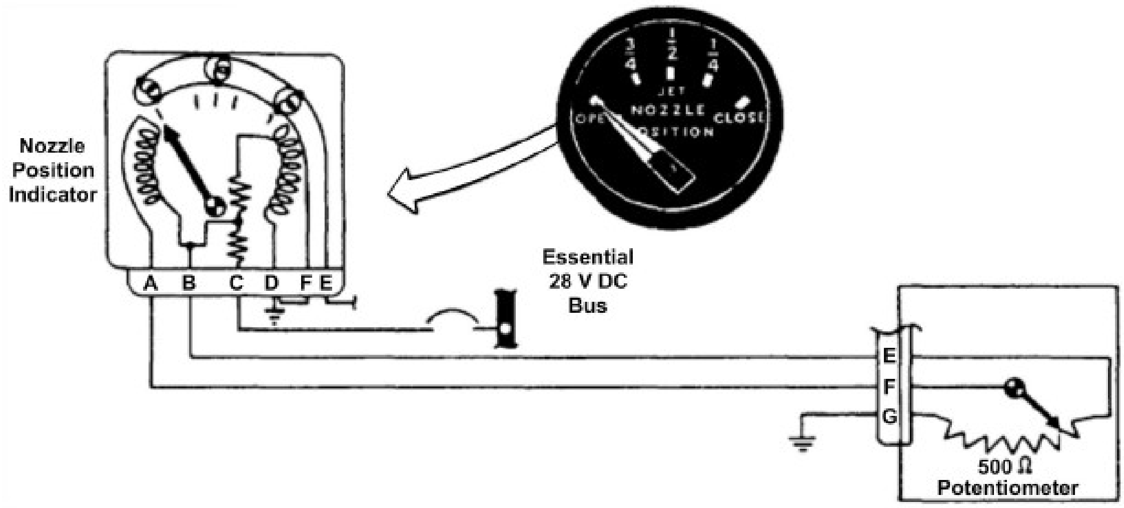


Fig. 5.12.Exhaust nozzle position indicating system.

The transmitter potentiometer consists of a resistance winding with a movable brush. This brush connects to a linkage within the nozzle area control and moves in relation to the variable exhaust nozzle. Current in the resistance winding is picked up by the movable rush, and it varies according to the location of the brush. Then, this signal current goes to one of the indicator field coils. The indicator contains two field coils and a rotor.

The polarized rotor mounts on a free-moving shaft. The shaft is located in the center of the magnetic field created by the two coils. One coil connects to the transmitter potentiometer in the nozzle area control. The second receives a constant current to give smooth indicator operation. The rotor aligns itself with the magnetic field. The magnetic field varies as the signal received from the potentiometer varies. A pointer mounted on the rotor shaft shows rotor position in relation to nozzle position.

5.9. CAPACITIVE-TYPE FUEL QUANTITY INDICATING SYSTEM

The capacitive-type fuel quantity system electronically measures fuel weight (not gallons) of the fuel in the tanks of an aircraft. The main units of the system are an indicator, tank probes, a bridge unit, and an amplifier. In some systems, the bridge unit and amplifier are one unit mounted in the same box. In the design of newer systems, the bridge and a transistorized amplifier are contained in the indicator.

Fuel Quantity Indicator

The fuel quantity indicator (Fig. 5.13) is a hermetically sealed, self-balancing, motor driven instrument. It contains a motor, pointer assembly, transistorized amplifier, bridge circuit, and adjustment potentiometers. As the quantity of fuel in the tank changes, the capacitance value of the tank probe changes proportionately. The tank probe is one arm of a capacitance bridge circuit. The change of capacitance of the probe unbalances the bridge circuit of the amplifier power unit. The unbalance in the circuit causes an error voltage.

Fig.5.13.Fuel quantity Indicator.

The amplified error voltage goes to the motor. The motor drives the pointer mechanism and the rebalancing potentiometers to restore the bridge to a balanced condition. The direction of change in the capacitance of the probe unit determines the phase of the error voltage. The phase determines the direction of motor rotation and, therefore, the direction of pointer movement.

Tank Probe

A tank probe and a simplified version of a tank circuit are shown in Fig.5.14. The capacitance of a capacitor depends upon three factors, the area of the plates (A), the distance between the plates (d), and the dielectric constant (K) of the material between the plates, or

$$C = KA / d$$

Where A = the area of the plates

d = the distance between the plates

K = the dielectric constant of the materials between the plates

The only variable factor in the tank probe is the dielectric of the material between the plates. When the tank is full, the dielectric material is all fuel. Its dielectric constant is about 2.07 at 0 °C, compared to a dielectric constant of 1 for air. When the tank is empty, there is only air between the plates, and capacitance is less. Any change in fuel quantity between full and empty produces a corresponding change in capacitance.

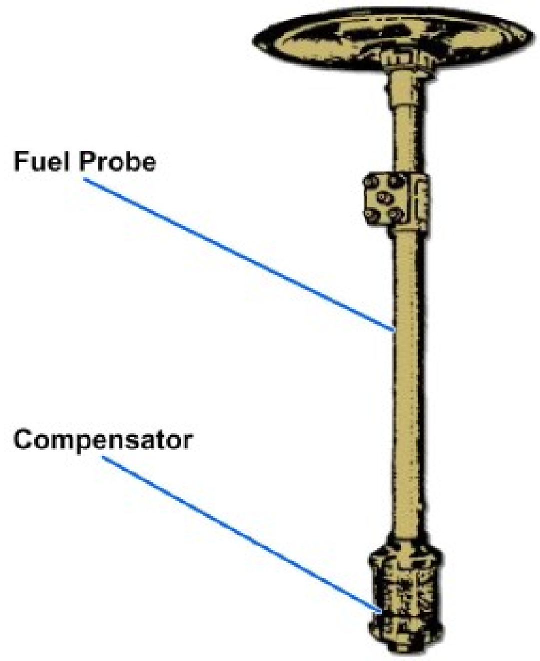


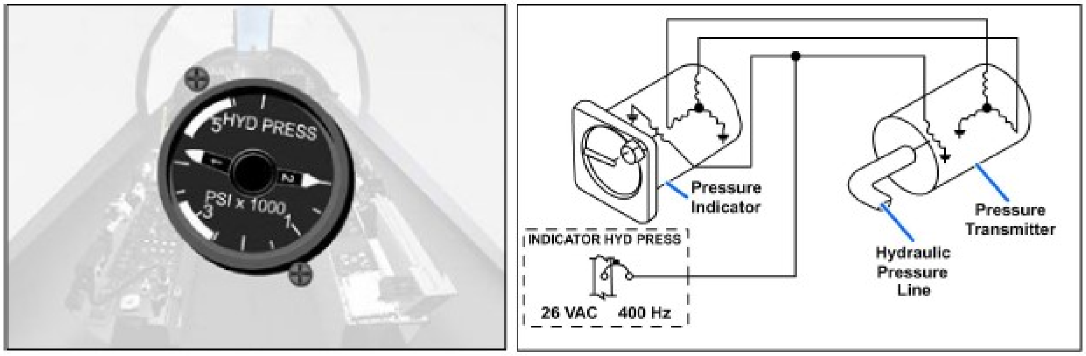
Fig. 5.14. Fuel Quantity Transmitter

5.10. HYDRAULIC PRESSURE INDICATORS

In most naval aircraft, the hydraulic system operates the landing gear, flaps, speed brakes, bomb bay doors, and certain other units. Aircraft hydraulic pressure gauges show either the pressure of the complete system or the pressure of an individual unit in the system. A typical direct reading gauge contains a Bourdon tube and a gear-and pinion mechanism. The mechanism amplifies and transfers the tube's motion to the pointer. The position of the pointer on the calibrated dial shows the pressure in pounds per square inch.

The pumps supplying pressure for operating the aircraft's hydraulic units are driven by an aircraft engine, an electric motor, or both. Some installations employ a pressure tank or accumulator to maintain a reserve of fluid under hydraulic pressure. In such cases, the pressure gauge registers continuously. With other installations, operating pressure builds up only when needed, and pressure registers on the gauge only during these periods.

The pressures of hydraulic systems vary for different models of aircraft. In older pressure systems, the gauges registered from 0 to 2,000 psi. With later model aircraft, the pressure ranges have increased. Some aircraft have systems with pressure ranges as high as 4,000 psi. The trend is away from the direct reading pressure gauge and towards the synchro (electric) type of gauge.



(A) (B)

Fig. 5.15.(A) Hydraulic pressure indicator; (B) hydraulic pressure indicating schematic.

Fig. 5.15 A), shows the hydraulic pressure indicator of a late model naval aircraft. This aircraft has two hydraulic systems. The indicating system shows the hydraulic system (HS) No. 1 and HS No. 2 system pressures. The hydraulic pressure indicator pointers, driven by signals from the hydraulic pressure transmitters, respond to signals from matching synchronous motors in the pressure transmitters. The indicating system consists of two remote hydraulic pressure transmitters and a dual pointer indicator. The system uses 26-volt, 400-Hertz, single-phase alternating current from the 26-volt, single-phase bus.

Each hydraulic pressure system line contains a Bourdon tube type of pressure transmitter. Expansion and contraction of the Bourdon tube travels by mechanical linkage to the rotor of the transmitter synchro. The pressure transmitter synchro sends an electrical signal to the receiving synchro within the indicator. The receiving synchro's rotor links mechanically to the indicator pointer. The pressure indicator contains two synchros that attach mechanically to two separate pointers.

5.11. PNEUMATIC PRESSURE SYSTEMS

Fig. 5.16 cabin pressure altitude indicator

The cabin pressure altitude indicator (Fig. 5.16) is a sensitive altimeter that measures cabin pressure. The instrument contains a sensitive diaphragm that expands or contracts with changes in cabin pressure. The altitude equivalent of cabin pressure shows on the dial, in increments of 1,000 feet. The range is from 0 to 50,000 feet. An opening in the back of the instrument case allows it to sense cabin pressure. It can also be used, this instrument to reflect pressure suit altitude rather than cabin altitude when wearing a pressure suit.

Post MCQ Test

1. An aircraft engine generates __________ power.
   a) Electrical
   b) Mechanical
   c) Thermal
   d) Hydraulic
   Answer: b)
2. Onboard communications on an aircraft are done through public address systems and aircraft intercoms.
   a) False
   b) True
   Answer: b)
3. The normal method for shutting down an aircraft engine is -----
   a) Closing the throttle
   b) Moving the mixture to Idle Cut off
   c) Switching the starter switch to off
   d) Closing the throttle and moving the mixture to ICO.
   Answer: d)
4. The temperature of the gases within the cylinder of a four stroke engine during the power stroke will ----
   a) Increases
   b) Decreases
   c) Follow Charle's Law
   d) Remain constant
   Answer a)
5. Detonation is -----
   a) An explosion that occurs before the normal ignition point
   b) Unstable combustion

c) Usually associated with a rich mixture and high cylinder head temperature

d) Usually associated with a rich mixture and low cylinder head temperature

Answer b)

6. In the aircraft tanks, fuel is most likely to be contaminated by water from

a) Poorly fitting fuel caps

b) Contamination during re-fuelling

c) Atmospheric air remaining in the tanks

d) Leaks in the tanks that have let in rain

Answer c)

Assignment

1. Draw the circuit of a typical capacitance – type fuel quantity indicating system. Explain the operating principle.
2. Describe the construction and operation of the fuel flow meter indicator.

CONCLUSIONS

The first aircraft instruments were fuel and oil pressure instruments. These instruments warned the pilot of engine trouble so the aircraft could be landed before the engine failed. Later, when the aircraft could fly over considerable distances, weather became a problem. This led to the development of instruments that helped pilots fly through snowstorms, thunderstorms, and other bad weather conditions

Instrumentation is basically the science of measurement. Measurements that are common on all aircraft are position, direction, speed, altitude, engine condition, fuel on board, and fuel consumption. In addition, jet aircraft instruments include Mach speed, angle of attack, and Exhaust Gas Temperature (EGT) indicators.

With the natural progression and development in these areas continue to be of the utmost importance, paralleling as it does the increasing complexity of aircraft and their systems. As the controller of a 'man-machine loop' and in developing and operating the machine, man has been continually reminded of the limitations of his natural means of sensing and processing control information.

However, in the scientific and technical evolutionary processes, instrument layout design and data presentation methods have become a specialized part of ergonomics, or the study of man in his working environment; this, together with the rapid strides made in avionics, culminates in the provision of electronic display instruments, computerized measuring elements, integrated instrument and flight control systems for fully automatic control, enabling man to deal with an expanding task within the normal range of human performance.

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1. Pallett, E.B.J “Aircraft Instruments Principles and applications”, Pitman and sons, 1981.
2. “Aircraft Instrumentation and systems”, S.Nagabhushana, L.K.Sudha. I.K. International Publishing House Pvt., Ltd., S-25, Green Park Extensions, Uphaar Cinema Market, New Delhi – 110016(India)

QUESTION BANK

EI8E3 / MH8EB - Aircraft Instrumentation
(Common to EIE/Mechatronics)

PART - A

UNIT 1 - Introduction

PART A

1. Define Plasma Panel.
2. Classify the types of displays.
3. What is quantitative Display?
4. What is qualitative Display?
5. Explain Circular scale?
6. Distinguish between linear and non linear scale.
7. What type of display is associated with the following instruments?
   i) Synchroscope ii) Altimeter iii) Gyro horizon
8. What is the purpose of using Dual indicator display? Give examples.
9. What do you mean by director display?
10. What is blind flying Panel?
11. What are the most common forms of data display applied to aircraft instruments?
12. Name some of the Aircraft Instruments to which digital counter display is applied.
13. Draw the block diagram of Flight Data Recorder.
14. Draw the block diagram of Cockpit Voice Recorder.
15. What is a magnetic indicator?

UNIT 2 - Flight Instrumentation

PART A

1. Name the components present in the aircraft pitot-static system.
2. What are the two pressures compared in Air speed indicator?
3. What corrections must be applied to indicated Air speed to produce True Airspeed?
4. What does each coloured arc mean in the Air speed Indicator?
5. Name and define four different types of air speed.
6. What is meant by Mach meter?
7. Define Mach number and critical Mach number
8. What are the three primary instruments?
9. What is CAS,TAS and IAS

10. Define Pitot Pressure.
11. Name five different types of altitudes.
12. What is the difference between the ‘pressure altitude’ and ‘indicated altitude’?
13. What does a VSI shows?

UNIT 3 - Gyroscopic Instruments

PART A

1. What do you mean by Gyroscope/Gimbal system?
2. Name the three degrees of freedom.
3. What do you understand by the terms ‘gimbal lock’ and gimbal error’?
4. What are the three gyroscopic instruments?
5. What is the purpose of gyro horizon/artificial horizon?
6. List the two main principles of gyroscopic instruments.
7. Which gyroscopic principle does the attitude indicator use?
8. What gyroscopic principle does the heading indicator use?
9. What is Rigidity in space?
10. What is Precession?
11. Which instruments are powered by the vacuum system?
12. Which instruments are powered by the electrical system? Why?
13. What do you mean by turn coordinator?
14. What is Slip and skid?

UNIT 4 - Aircraft Computer Systems

PART A

1. What is hard iron magnetism?
2. What is soft iron magnetism?
3. Explain the principal of magnetic compass.
4. List the compass errors.
5. Define Magnetic dip.
6. Explain magnetic Dip errors.
7. Define Magnetic variation.
8. What are the types of error due to magnetisation?
9. Define Acceleration error.
10. Define Turning errors.

UNIT 5 - Power Plant Instruments

PART A

1. Mention aircraft pressure gauges.
2. What is absolute pressure?
3. What is gauge pressure?
4. What is the principle of a thermocouple?
5. What are the factors that affect the capacitance of a capacitor?
6. How do airplane fuel gauges work?
7. Why is temparature compensation done in thermocouple circuit?
8. What is a Ratiometer?
9. What are pressure switches?
10. What is VTO?

PART B

UNIT 1 - Introduction

1. What do you understand by the term head up display system? With the aid of diagram describe how basic flight data is displayed to a pilot.
2. Describe the methods adopted for the display of indications related to high range measurements.
3. What is the significance of coloured markings applied to the dials of certain instruments?
4. Describe the basic T method of grouping flight instruments.
5. Explain various panels used in Aircraft.
6. What is the purpose of a Platform scale? Describe its arrangement.
7. Describe Cockpit layout.
8. Draw and explain the block diagram of Flight Data Recorder.
9. Draw and explain the block diagram of Cockpit Voice Recorder.
10. Explain various types of displays used in Aircraft.

UNIT 2 - Flight Instrumentation

1. What are the principle component and instruments which comprise an aircraft pitot-static system? Explain.
2. Draw and explain with neat sketch the operation of Pitot-Static system and also describe the basic form of Pitot static Probe.
3. Explain briefly about Vertical Airspeed Indicator with neat diagram.

4. Briefly explain the construction and operation of an altimeter. Explain any special feature which improves its accuracy.
5. Describe how the function of a Mach meter and an Air speed indicator can be combined to give an indication of maximum safe Air speed.
6. Describe the construction and operation of an Air speed indicator.
7. Describe the construction and operation of an Accelerometer.

UNIT 3 - Gyroscopic Instruments

1. Explain briefly about gyroscopic theory and artificial horizon.
2. How is the gyroscopic principle applied to a gyro horizon? Describe the construction and operation of an electrically drive gyro horizon including any special design features.
3. Briefly explain the principle of working of Attitude indicator with neat diagrams.
4. Write short notes on Heading indicator with relevant diagrams.
5. Explain in detail a) turn and bank indicators b) turn co-coordinator.
6. With the aid of diagrams, describe how a ball type of bank indicator indicates a) a correctly banked turn. b) a turn to starboard in which the aircraft is overbanked
7. Explain clearly about the concepts a) Rigidity in space
   b) Precession with diagrams

UNIT 4 - Aircraft Computer Systems

1. Explain in detail Terrestrial Magnetism.
2. Discuss in detail about the magnetic system of a typical aircraft compass and how is the effect of dip overcome.
3. With the aid of diagrams, explain how a deviation compensating device neutralizes the fields due to aircraft magnetic components.
4. Explain the relationship between aircraft magnetism and deviation coefficients.
5. Explain the principle of operation of gyro magnetic compass with diagram.
6. Briefly explain Compass errors.
7. Explain electromagnetic compensation in compass.

UNIT 5 - Power Plant Instruments

1. Explain the construction and operation of float type fuel quantity gauge.
2. Describe measurement of fuel quantity by weight with relevant diagrams.
3. Draw the circuit of a typical capacitance – type fuel quantity indicating system. Explain the operating principle.

4. Describe the construction and operation of the fuel flow meter indicator.
5. Explain Integrated flow meter system with neat diagram.
6. Explain in detail about Radiation pyrometer systems used to measure exhaust gas temperature.
7. Write short notes on various temperature measurement techniques.
8. a) Explain how Wheatstone bridge circuit may be utilized for measurement of temperature.

   b) Would the circuit be in balance at each temperature?
9. Describe the construction and working of turbine-engine exhaust-gas temperature measurement.
10. Describe the operating principle of a U-tube manometer.
11. Explain the fundamental operating principle of the Bourdon tube for pressure measurement.

Video links

1. https://www.youtube.com/watch?v=7JowiXwzBvk – Basics, PFD
2. https://www.youtube.com/watch?v=F077WDnB8P8 – Construction & take off
3. https://www.youtube.com/watch?v=u3z2qZex1gg – Instruments in the Cockpit
4. https://www.youtube.com/watch?v=SVkUXsRVf98 –Flight instruments (1)
5. https://www.youtube.com/watch?v=wjTZsHU3T5g – Flight instruments (2)
6. https://www.youtube.com/watch?v=hVsx4XWafXg – Gyroscopic instruments
7. https://www.youtube.com/watch?v=u3z2qZex1gg – Attitude instrument flying
8. https://www.youtube.com/watch?v=FeELh0kMSIA – Landing (ILS)
9. https://www.youtube.com/watch?v=OykXhUK2S04 –Top 10 most dangerous airports in the world 2019