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BRIEF REVIEW OF AIRCRAFT INSTRUMENTS & INTEGRATED SYSTEMS

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Abstract: The progress of all types of aviation has depended on providing the pilot with sufficient information to enable him or her to control the aircraft safely and to navigate it to its destination. From 1903 onwards each advance in speed, range, altitude and versatility has had to be matched by instruments which enable the crew to maximize an aircraft's potential. In the beginning, i.e. the Wright 'Flyer' of 1903, the instrumentation was rudimentary, consisting of only an anemometer for airspeed, a stop watch and an engine revolution counter. Perhaps the piece of string attached to the canard structure in front of the pilot, to indicate aircraft attitude relative to the airflow, can also be classed as an instrument. Limited instrumentation was a feature of the aircraft of the first decade of heavier-than-air powered flight. However, the demands of wartime flying accelerated the development of instrument;, and by 1918 a typical cockpit would have an airspeed indicator, an aiiimeter, inclinometer, fuel pressure gauge, oil pressure indicator, rpm indicator, compass and a clock. Not until the end of the 1920s were instruments available by which a pilot could maintain attitude and heading when flying in cloud, or whenever the horizon was obscured. In the 1930s and *40s, considerable progress was made toward 'blind flying' instruments. In the 1950s came the 'director'-type attitude indicators and in the '60s more and more electromechanical instruments became available. By 1970 solid-state displays were edging their way on to the flight deck. In the past ten years the electronic tide has swept in to an extent that the modem flight deck is awash from wall to wall with solid-state displays such as the electronic instrument systems (EIS) and engine indication and crew alert systems (EICAS)
Indexing terms: Flying instruments; avionics; displays; cockpit; control systems; aircraft;

I. INTRODUCTION

The flight, an aircraft and its operating crew form a 'man—machine' system loop which, depending on the size and type of aircraft, may be fairly simple or very complex. The function of the crew within th6 loop is that of controller, and the extent of the control function is governed by the simplicity or otherwise of the aircraft as an integrated whole. For example, in manually flying an aircraft, and manually initiating adjustments to essential systems, the controller's function is said to be a fully active one. If, on the other hand, the flight of an aircraft and system's adjustment is automatic in operation, then the controller's function becomes one of monitoring, with the possibility of reverting to the active function in the event of failure of systems. (Instruments, of course, play an extremely vital role in the control loop as they are the means of communicating data between systems and controller. Therefore, in order that a controller may obtain a maximum of control quality, and also to minimize the mental effort in interpreting data, it is necessary to pay the utmost regard to the content and format of the data displays.")

The most common forms of data display are (a) *quantitative,* in which the variable quantity being measured is presented in terms of a numerical value and by the relative position between a pointer or index and a graduated scale, and (b) *qualitative,* in which the data is presented in symbolic or pictorial format. Quantitative displays

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

(i) The circular scale, or more familiarly, the 'clock' type of scale,
(ii) Straight scale
(iii) Digital, or counter.

Circular scale

This may be considered as the classical method of displaying data in quantitative form and is illustrated in Fig. 1.1. The *scale base* refers to the graduated line, which may be actual or implied, running from end to end of the scale and from which die scale marks and line of travel of the pointer are defined.

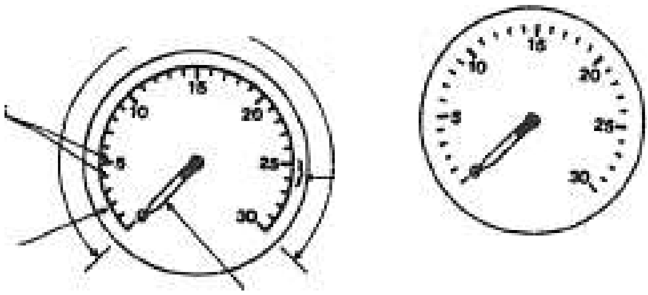


Figure 1.1 Circular scale quantitative display.

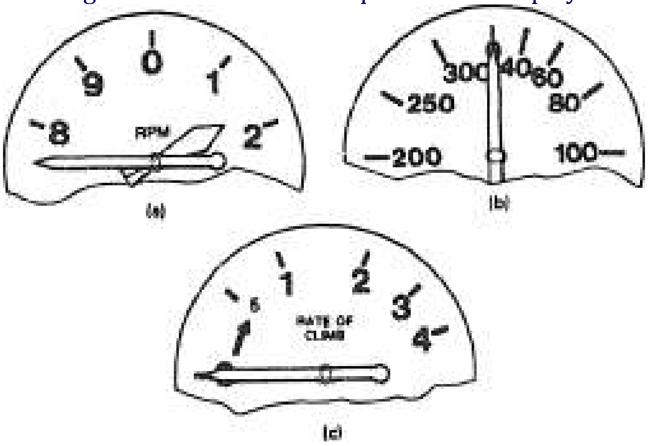


Figure 1.2 Linear and nonlinear scales, (a) Linear; (fo) square-law: (c) logarithmic.

Scale or graduation marks are those which constitute the scale of an instrument. For quantitative displays the number and size of marks are chosen in order to obtain quick and accurate interpretation of readings. In general, scales are divided so that the marks represent units of 1, 2 or 5, or decimal multiples thereof, and those marks which are to be numbered are longer than the remainder. Spacing of marks is also governed by physical laws related to the quantity to be measured, but in general they result in spacing that is either *linear* or *non-linear.* Typical examples are illustrated in Fig. 1.2, from which it will also be noted that non-linear 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. As 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 distance between the centres 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.* Governing factors in the choice of scale length for a particular range are the size of the instrument, the accuracy with which it needs to be read, and the conditions under which it is to be observed.

High-range long-scale displays

For the measurement of some quantities — for example, turbine engine speed, airspeed, and altitude — high measuring ranges are involved with the result that very long scales are required. This makes it difficult to display such quantities on single circular scales in standard-size cases, particularly in connection with the number and spacing of the marks. If a large number of marks are required their spacing might be too close to permit rapid reading, while, on the other hand, a reduction in the number of marks in order to 'open up' the spacing will also give rise to errors when interpreting values at points between scale marks.

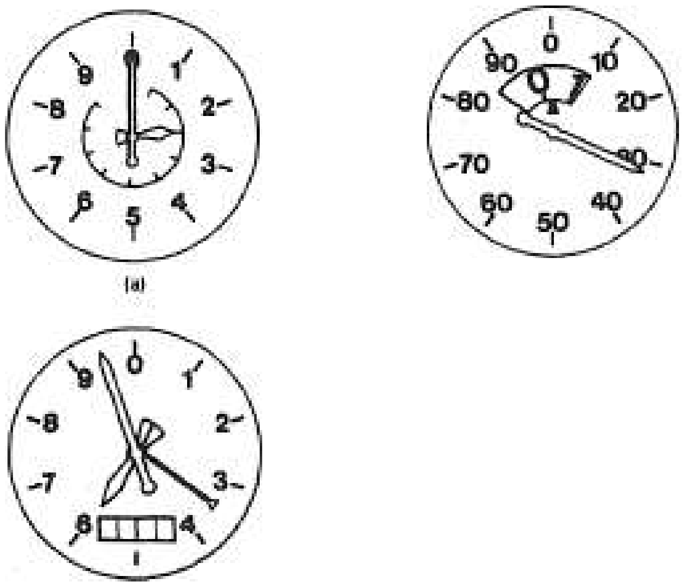


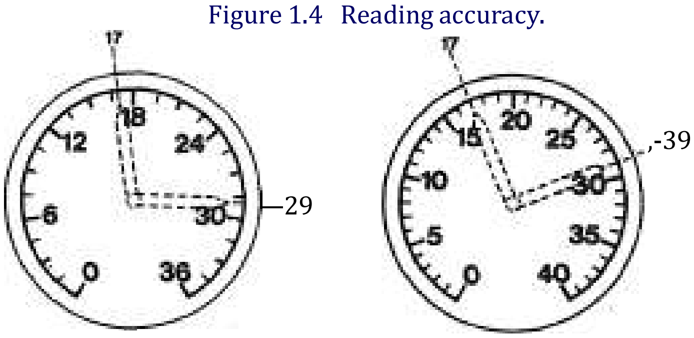
Figure 1.3 High-range long-scale displays, (a) Concentric scales; (6) fixed and rotating scales: (c) common scale and triple pointers.

A practical example of this is to be found in some types of engine speed indicator. In this instance, a large pointer rotates against an outer scale to indicate hundreds of rev/min, and at the same time it rotates a smaller pointer through appropriate ratio gearing, against an inner scale to indicate thousands of rev/min. The method shown at (b) is employed in a certain type of pneumatic airspeed indicator; in its basic concept it is similar to the one just described. In this case, however, a single pointer rotates against a circular scale and drives a second scale plate instead of a pointer. This rotating plate, which records hundreds of knots as the pointer rotates through complete revolutions, is visible through an aperture in the main dial of the indicator.

Scale and operating ranges

Instrument scale lengths and ranges usually exceed that actually required for the operating range of the system with which an instrument is associated, thus leaving part of the scale unused. This may appear somewhat wasteful, but an example will show that it helps in improving the accuracy with which readings may be observed. Let us consider a fluid system in which the operating pressure range is, say, 0—30 lbf/in^2. It would be no problem to design a scale for the required pressure indicator which would be of a length equivalent to the system's total operating range, also divided into a convenient number of parts as shown in Fig. 1.4(a).

Figure 1.4 Reading accuracy.



However, under certain operating conditions of the system concerned, it may be essential to monitor pressures having such values as 17 or 29 lbf/in^2 and to do this accurately in the shortest possible time is not very easy, as a second look at the diagram will show.

If the scale is now redesigned so that its length and range exceed the system's operating range and also graduated in the manner noted earlier, then as shown at (b) the result makes it much easier to interpret and to monitor specific operating values.

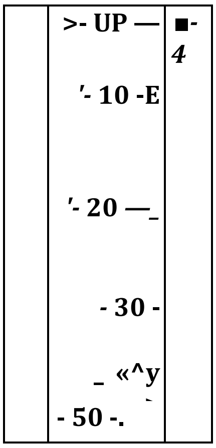
Straight scale

In addition to the circular scale presentation, a quantitative display may also be of the straight scale (vertical or horizontal) type. 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. It is pertinent to note at this juncture that in respect of electronic CRT displays (see Chapter 11) there are no mechanical restraints, and so straight scales can, therefore, be more widely applied.

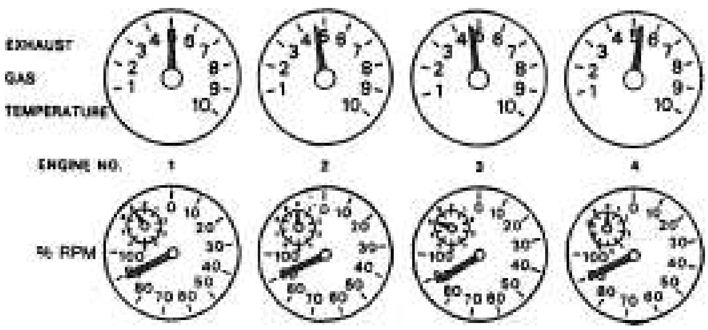
An example of a straight scale presentation of an indicator operating on the above-mentioned principles is illustrated in Fig. 1.5(a); it is used for indicating the position of an aircraft's landing flaps. The scales are graduated in degrees, and each pointer is operated by a synchro (see Chapter 5). The synchros are supplied with signals from transmitters actuated respectively by left and right outboard flap sections. Another variation of this type of display is shown at (b) of Fig. 1.5. It is known as the *moving-tape* or *thermometer* display and was originally developed for the measurement of parameters essential to the operation of engines of large transport aircraft.

Digital display

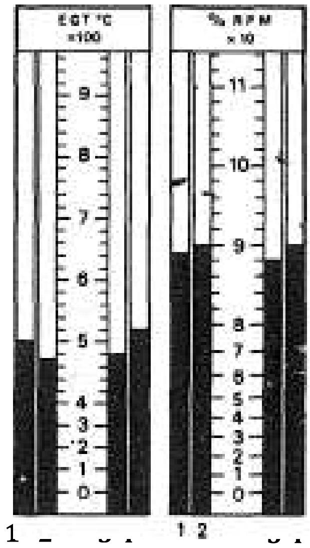
A digital, or counter, type of display is one that is generally to be found operating in conjunction with the circular type of display; two examples are shown in Fig. 1.6. Jin the application to an altimeter there are two counters: one presents a fixed pressure value which can be mechanically, set as and when required, and is known as aj5fgri£_ *counter* display; while the other is geared to the jiltimeter mechanism and automatically presents changes in altitude, and is therefore known as a *d^nanuc counter* display, It is of interest to note that the presentation of altitude data by means of a scale and counter is yet another method of solving the long-scale problem already referred to on page 3. The counter of the turbine gas temperature (TGT) indicator is also a dynamic display since, in addition to the main pointer, it is driven by a servo transmission system.



(a)



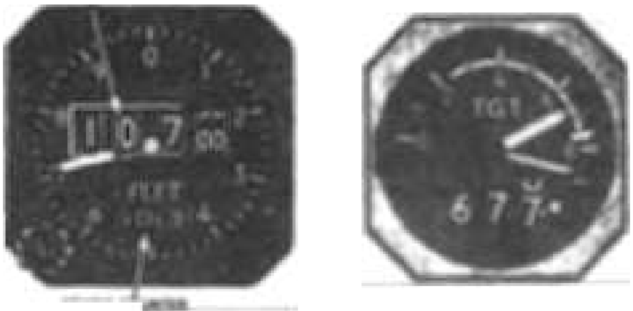
(b)



Engin No.	EGT °C	% RPM
1	500	89
■ 2	470	90
.-, 3-;	480	88
4	520	90

Figure 1.5 Straight scale displays. (£>) gives a comparison between moving-tape and circular scale displays

DYNAMIC COUNTER OtS PlAY



DISPLAY

Figure 1.6 Application of digital counter displays.

Dual-indicator displays

(These displays are designed principally as a means of conserving panel space, particularly where the measurement of the various quantities related to engines is concerned], IThey are normally of two basic forms: in one, two separate indicator mechanisms and scales are contained in one casej while in the other, which also has two mechanisms in one case, the pointers register against a common scale. Typical examples of display combinations are illustrated in Fig. 1.7.

Operational range markings

These markings take the form of coloured arcs, radial lines and sectors applied to the scales of instruments, their purpose being to highlight specific limits of operation of the systems with which the instruments are associated. The definitions of these marks are as follows:

f RED *radial line* Maximum and minimum limits
YELLOW *arc* Take-off and precautionary ranges \
1 I , GREEN *arc* Normal operating range
J ! RED *arc* Range in which operation is prohibited \

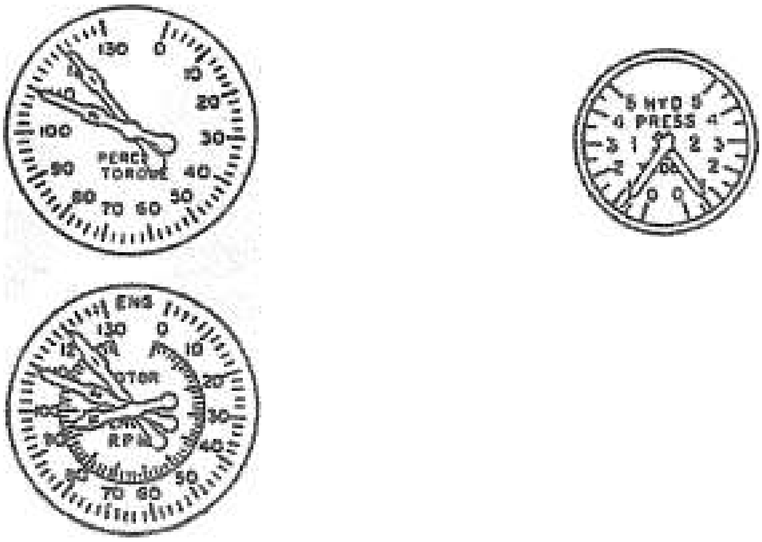
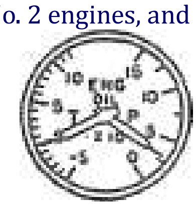


Figure 1.7 Dual-indicator displays. The display wish three pointers has a helicopter application: it shows the speed of No. 1 and No. 2 engines, and of the main rotor.



In the example shown in Fig. 1.8(a), an additional WHITE arc is provided which serves to indicate She appropriate airspeed range over which an aircraft's landing flaps may be extended in the take-off, approach and landing configurations. The application of sector-type markings is usually confined to those parts of an operating range in which it is sufficient to know that a certain condition has been reached rather than knowing actual quantitative values. For example, it may be necessary for an oxygen cylinder to be charged when the pressure has dropped to below, say, 500lbf/in^2. The cylinder pressure gauge would therefore have a red sector on its dial embracing the marks from 0 to 500 as at (b) of Fig. 1.8. Thus, if the pointer should register within this sector, this alone is sufficient indication that recharging is necessary, and it is only of secondary importance to know what the actual pressure is.

Another method of indicating operating ranges is one that uses what are termed 'memory bugs'. These take the form of small pointers which, by means of an adjusting device, can be rotated around the dial plate of an instrument to pre-set them at appropriate operating values on the scale. An example of their application to a Mach/airspeed indicator (see page 47) is shown at (c) of Fig. 1.8.

Qualitative display®

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, or to show the movement of flight control surfaces as in the example shown in Fig. 1.9.

(b)

Figure 1.8 Operational range markings.

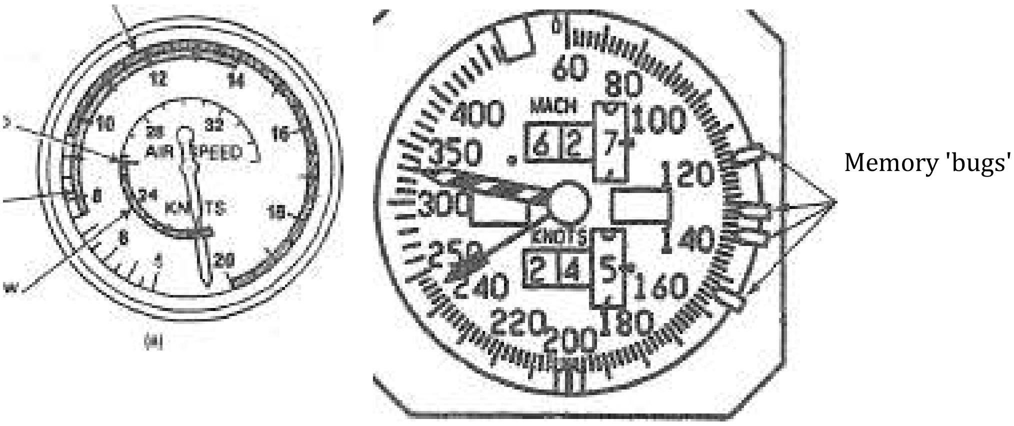


Figure 1.8 Operational range markings

These displays are associated principally with the mgnitQrjng_pXflightaMitudj^andjnajagationaLdaJa^ and present it in a manner that indicates to the flight crew what control movements must be made, either to correct any departure from a desired flight path, or to cause an aircraft to perform a specific manoeuvre^ It is thus apparent that in the development of such a display there must be a close ("relationship between the direction of control movements and the instrument pointer, or symbolic-type indicating element]! in other words, movements should be irf the 'natural' sense in order that the 'directives' or 'commands' of the display may be obeyed.

Displays of this nature are specifically applied to the two primary instruments which comprise conventional flight director systems and electronic flight instrument systems (see Chapters 9 and 12). One of the instruments (referred to as an Attitude Director Indicator) has its display origins in one of the oldest of flight attitude instruments, namely the gyro horizon (see Chapter 4), and so it serves as a basis for understanding the concept of director displays. As will be noted from Fig. 1.10, three elements make up the display of the instrument: a pointer registering against a bank-angle scale, an element symbolizing an aircraft, and an element symbolizing the natural horizon. Both the bank pointer and natural horizon element are stabilised 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 an aircraft, and that of the moving element.
Assuming that in level flight an aircraft's pitch attitude changes such as to bring the nose up, then the movement of the horizon element relative to the fixed aircraft symbol will be displayed as in diagram (a). This indicates that the pilot must 'get the nose down'. Similarly, if an aircraft's bank attitude should change whereby the left wing, say, goes down, then the display as at (b) would direct the pilot to 'bank the aircraft to the right'.

MINIATURE AIRCRAFT

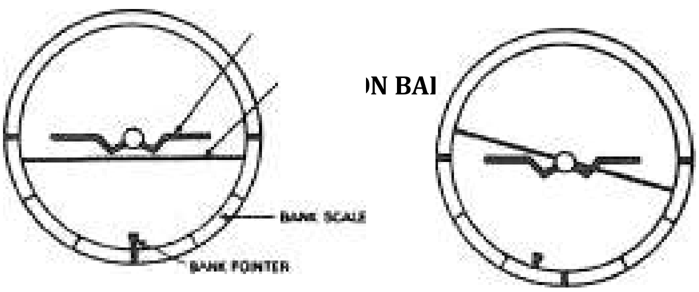


Figure 1.10 Director display (gyro horizon).

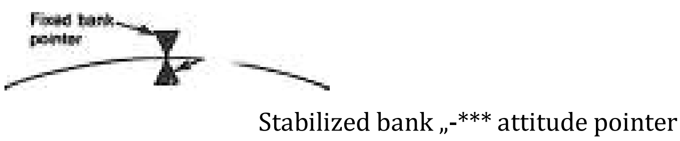


Figure I. II Attitude director display, (a) Aircraft straight and level; (4>) aircraft nose up; (c) aircraft banked left; {d) 'fly up" command; (e) "fly left" command.

Thus, assuming as before a nose-up displacement of an aircraft, the signals transmitted by the gyroscope unit will cause the horizon symbolic element to be driven to a position below the fixed eiement symbolizing the aircraft, as shown at (b). The pilot is therefore directed to 'fly down' to the level flight situation as at (a). If a change in the aircraft's attitude produces, say, a left bank, then in response to signals from the gyroscope unit the horizon symbolic element and bank pointer will be driven to the right as shown at (c). The pilot is therefore directed to 'fly right' to the level flight situation.

In addition to displaying the foregoing primary attitude changes, an indicator also includes what is termed a command bar display that enables a pilot to establish a desired change in aircraft attitude. If, for example, a climb attitude is to be maintained after take-off, then by setting a control knob the command bars are motor-driven to a 'fly up' position as shown at (d) of Fig. 1.11. During the climb the horizon symbolic element will be driven in the manner explained earlier, and the command bars will be re centred over the fixed element so that the display will be as shown in diagram (b).

Roll attitude, or turn commands, are established in a similar manner, the command bars in this case being rotated in the required direction; diagram (e) of Fig. 1.11 illustrates a 'fly left' command. As the aircraft's attitude changes the aircraft symbolic element moves with the aircraft, while the horizon symbolic element and bank pointer are driven in the opposite direction. When the command has been satisfied, the display will then be as shown in diagram (c). The scales and pointers shown to the left and bottom of the indicator also form a director display that is utilized during the approach and landing sequence under the guidance of an Instrument Landing System. Details of the operation of this display and of the second indicator involved in a Flight Director System will be given in Chapter 9. Electronic displays With the introduction of digital signal-processing technology into the field colloquially known as 'avionics', and its application of microelectronic circuit techniques, it became possible to make drastic changes to both quantitative and qualitative data display methods. In fact, the stage has already been reached whereby many of the conventional 'clock' type instruments which, for so long, have performed a primary role in data display, can be replaced entirely by a microprocessing method of 'painting' equivalent data displays on the screens of cathode ray tube (CRT) display units.

Table *I.* i Applications of electronic displays

Display technology	Operating mode	Typical applications
Light-emitting diode	Active	Digital counter displays of engine performance.
Liquid crystal	Passive	monitoring indicators; radio frequency selector indicators; distance measuring indicators; control display units of "menial navigation systems.
Electron CRT beam	Active	Weather radar indicators; display of navigational data; engine performance data: systems status; check lists-

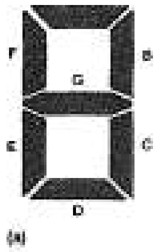
Active: a display using phenomena potentially capable of producing light when the display elements are electrically activated.
Passive: a display which either transmits light from an auxiliary light source after modulation by the device, or which produces a pattern viewed by reflected ambient light.

Display configurations

Displays of the light-emitting diode and liquid crystal type are usually limited to applications in which a single register of alphanumeric values is required, and are based on what is termed a seven-segment matrix configuration or, in some cases, a dot matrix configuration. Figure 1.12(a) illustrates the seven-segment configuration, the letters which conventionally designate each of the segments, and the patterns generated for displaying each of the decimal numbers 0—9. A segmented configuration may also be used for displaying alphabetic characters as well as numbers, but this requires that the number of segments be increased, typically from seven up to 13 and/or 16. Examples of these alphanumeric displays are illustrated at (b) of Fig. 1.12. In a dot matrix display the patterns generated for each individual character are made up of a specific number of illuminated dots arranged in columns and rows. In the example shown at (c) of Fig. 1.12, the matrix is designated as a 4 X 7 configuration, i.e. it comprises four columns and seven rows.

Light-emitting diodes (LEDs)

An LED is a solid-state device comprising a forward-biased p-n junction transistor formed from a slice or chip of gallium arsenide



No. of segments 6 2 5

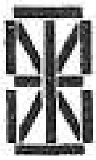


Figure 1.12 Electronic alphanumeric displays, (a) Seven-segment; (i>) 13- and 16-segment; (c) a 4 x 7 matrix.

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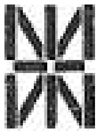

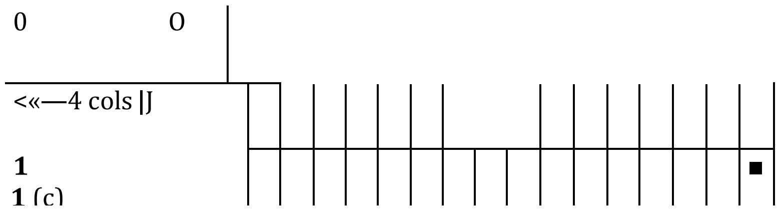

phosphide (GaAsP) moulded into a transparent covering as shown in Fig. 1.13. When current flows through the chip it emits light which is in direct proportion to the current flow. Light emission in different colours of the spectrum can, where required, be obtained by varying the proportions of the elements comprising the chip, and also by a technique of 'doping' with other elements, e.g. nitrogen. In a typical seven-segment display format it is usual to employ one LED per segment and mount it within a reflective cavity with a

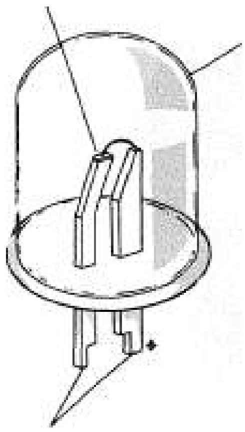

Figure 1.13 Light-emitting diode.

The segments are formed as a sealed integrated circuit pack, the connecting pins of which are soldered to an associated printed circuit board. Depending on the application and the number of digits comprising the appropriate quantitative display, independent digit packs may be used, or combined in a multiple digit display unit. LEDs can also be used in a dot-matrix configuration, and an example of this as applied to a type of engine speed indicator is shown in Fig. 1.14. Each dot making up the decimal numbers is an individual LED and they are arranged in a 9 x 5 matrix. The counter is of unique design in that its signal drive circuit causes an apparent 'rolling' of the digits which simulates the action of a mechanical drum-type counter as it responds to changes in engine speed. Liquid crystal display (LCD). The basic structure of a seven-segment LCD is shown in Fig. 1.15. It consists of two glass plates coated on their inner surfaces with a thin film of transparent conducting material (referred to as polarizing film) such as indium oxide. The material on the front plate is etched to form the seven segments, each of which forms an electrode. A mirror image is also etched into the oxide coating of the back glass plate, but this is not segmented since it constitutes a common return for all segments. The space between the plates is filled with a liquid crystal

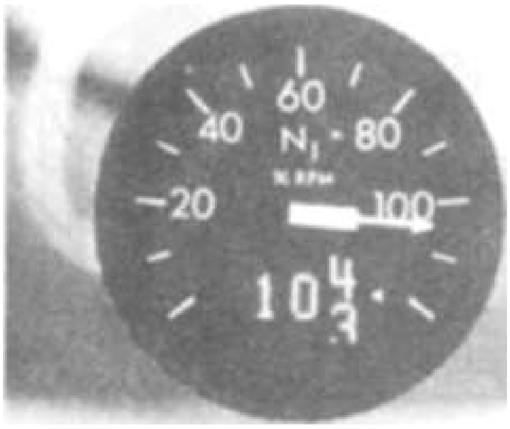

Figure 1.14 Engine speed indicator with a dot matrix LED. (Courtesy of Smith's Industries Ltd.)

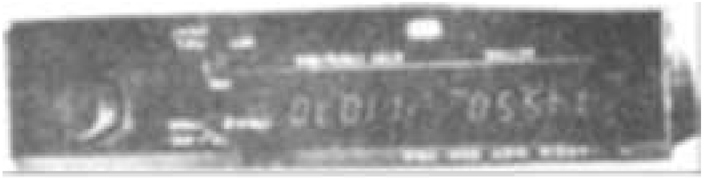

Figure 1,16

Application of (LCD.

Magnitude of the optical change is basically a measure of the light reflected from, or transmitted through, the segment area to the light reflected from the background area. Thus, unlike an LED, it does not emit light, but merely acts on light passing through it. Depending on polarizing film orientation, and also on whether the display is reflective or transmissive, the segments may appear dark on a light background (as in the case of digital watches and pocket calculators) or light on a dark background. An example of LCD application is shown in .Fig. 1.16.

A head-up display (HUD) is one in which vital in-flight data are presented at the same level as a pilot's line of sight when he is viewing external references ahead of the aircraft, i.e. when he is maintaining a 'head-up' position. This display technique is one that has been in use for many years in military aviation, and in particular it has been essential for those aircraft designed for carrying out very high-speed low-level sorties over all kinds of terrain. As far as civil aviation is concerned, HUD systems have been designed specifically for use in public transport category aircraft during the approach and landing phase of flight, but thus far it has been a matter of choice on the operators' part whether or not to install systems in their aircraft. This has resulted principally from the differing views held by operators, pilot representative groups, and aviation authorities on the benefits to be gained, notably in respect of a system's contribution to the landing of an aircraft, either automatically or manually, in low-visibility conditions. The principle adopted in a HUD system is to display the required data on the face of a CRT and to project them through a collimating lens as a symbolic image on to a transparent reflector plate, such that the image is superimposed on a pilot's normal view, through the windscreen, of the terrain ahead. The display is a combined alphanumeric and symbolic one, and since it is focused at infinity it permits simultaneous scanning of the 'outside world' and the display without refocusing the eyes. The components of a typical system are shown in Fig. 1.17. The first real attempt at establishing a standard method of grouping was the 'blind flying panel' or 'basic six' layout shown in Fig. 1.19(a). if 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

Figure1.18 Flight deck layout: Boeing 737-300 series aircraft.

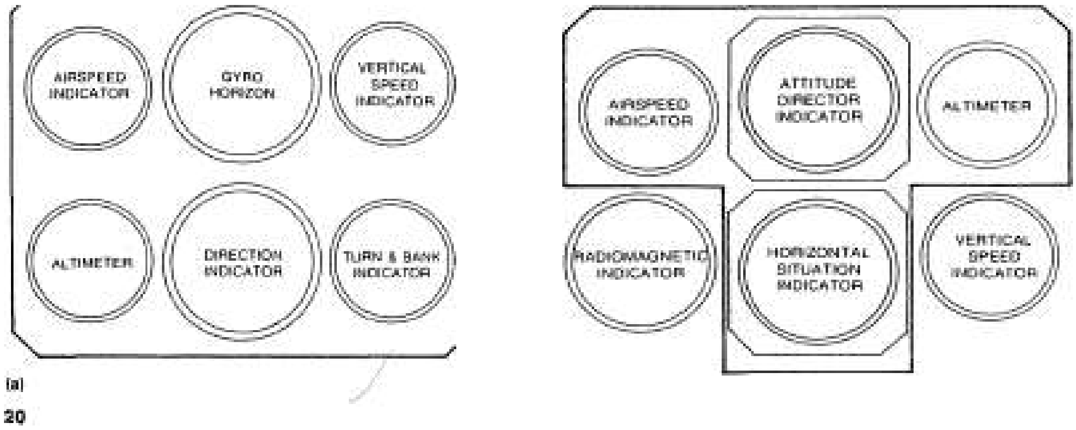

Figure 1.19 Flight instrument grouping, (a) Basic six; (b) basic T (with night director system indicators).

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, and of more comprehensive display presentations afforded by the indicators of flight director systems, a review of the functions of certain of the instruments and their relative positions within the group resulted in the adoption of the 'basic T arrangement as the current standard) As will be noted from diagram (b) of Fig. 1.19, there are now four 'key[1] indicators: jdrsrjged, pitch and roll attitude, an altitude indicator forming the horizontal bar of the T\ and a horizontal situation (direction) indicator forming the vertical bar. As far as the positions flanking the latter indicator are concerned, they are taken up by other less specifically essential flight instruments which, in the example shown, are the vertical speed indicator and a radio magnetic indicator (RMI). In some cases a turn-and-bank indicator, or an indicator known as a turn co-ordinator, may take the place shown occupied by the RMI. In many instances involving the use of flight director system indicators and/or electronic flight instrument system display units, a turn-and-bank indicator is no longer used.

In the case of electronic flight instrument systems, the two CRT display units (EADI and EHSI) are also used in conjunction with four conventional-type indicators to form the basic 'T', as shown in Fig. l.20(a). In displays of more recent origin, and now in use in such aircraft as the Boeing 747-400 (see also Fig. 12.11), the CRT screens are much larger in size, thus making it possible for the EADI to display airspeed, altitude and vertical speed data instead of conventional indicators. The presentation, which also corresponds to the basic 'T' arrangement is illustrated at (b) of Fig. 1.20.

Power plant instruments

|The specific grouping of instruments required for the monitoring of power plant operation is governed primarily by the type of power plant, the size of aircraft, and therefore the space available for location of instruments, jf |n a single-engined aircraft this does not present too much of a problem since the small number of instruments required may flank the flight instruments y thus keeping them within a small 'scanning ranged