1 Instruments - General

1.1 Introduction

The flight deck of a modern transport aeroplane can no longer be compared with the cockpit of early type aeroplanes. Display systems take over the function of individual indicators. The accuracy and reliability is significantly improved. Ergonomics has led to the various types of indicator including their location on the flight deck.

A comparison between the instrument panels of two versions of the same aeroplane manufacturer, will reveal the obvious enormity of the changes. *Fig. IN 1.1* shows the cockpit layout for an earlier version of the B737, the 100-series while *fig. IN 1.2* illustrates the flight deck for the latest version of the B737, the NG (Next Generation). The immediate visual impact is that the panel is cleaner, tidier and (with fewer dials) gives the illusion of being less confusing.

Fig. IN 1.1 Cockpit B737-100

Fig. IN 1.2 Flight deck B737-NG

1.2 Definition

An instrument consists of the following three parts, *see fig. IN 1.3*

1. a sensor,
2. a processor,
3. an indicator.

The sensor is that part of an instrument that is sensitive to the parameter to be measured. It converts the measured parameter into a quantity that is easy to process. The processor prepares the parameter for indication. This process may include fault correction, calibration and amplification. The indicator finally shows the measured parameter in the correct format.

In many small aeroplanes the three component parts are in one housing.

In large aeroplanes the sensor and processor are apart from the indicator. Sensor and processor are usually in one housing (analogue or digital computer) that is located in a central compartment near the flight deck with integral cooling. This compartment is called the avionics or E&E bay.

A recent development is to place the sensor directly at the ideal measuring spot. Its signals are sent via a digital data bus to the digital processor which is part of a computer network. From there the signals are sent to dedicated instruments systems which show the measured parameter on display units.

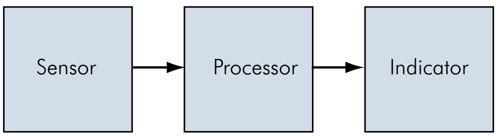

Fig. IN 1.3 Instrument

1.3 Instrument Panels

In front of the flight crew there are the left, centre and right main instrument panel, *see fig. IN 1.4*. The left and right main instrument panel are identical for both pilots. The left and right main instrument panels mainly hold the flight instruments. The centre main instrument panel holds the engine instruments.

On top of the main instrument panels there is a glareshield. The glareshield is a cover that shields the main instrument panels from direct sunlight. The glareshield holds, amongst others, a panel with the controls for the autoflight system.

Between the two seats the pedestal holds, amongst others, the various radio control panels.

The overhead panel holds the control panels for all aircraft systems (electric, hydraulic, pneumatic etc.).

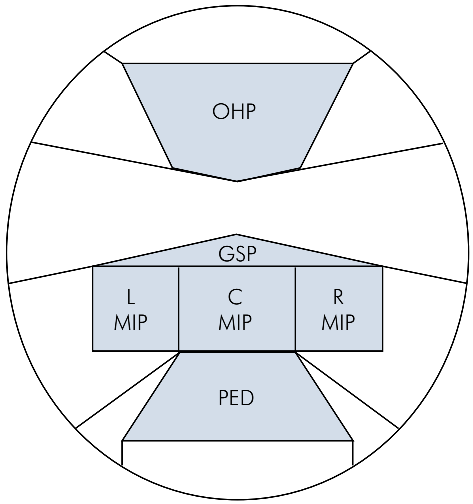

Fig. IN 1.4 Instrument panels

1.4 Ergonomics

In aviation it is important to design instruments according a few well-established ergonomic principles. The flight deck instruments are used to supply the flight crew with accurate data. In aviation, when safety is at stake, decisions have to be made in a very short time and often a quick scan must give an overall impression of the flight situation. Ergonomic thinking has therefore contributed considerably to the design of the cockpit and instrumental presentation systems.

1.4.1 Eye Reference Position

A very important concept for flight-deck design is the eye reference position. The flight deck designer has established a position where the eye of the pilot will be during flight. The flight deck will be designed around this position and cockpit seats are adjusted such that pilots of a range of body lengths are able to bring their eyes into this position. Glareshield height, the position of indicators, pushbuttons, switches and handles are chosen, accounting for the eye reference position. Even the outside shape of the aircraft nose, including the flight deck has been influenced by the eye reference position, because during approaches there are requirements concerning the pilot's outside view. There are examples of accident investigations, where important conclusions are drawn by assuming the pilot's eyes are in that position.

There are various ways to give an indication to the pilot where the eye reference position is located in the cockpit. One method is to mount an arrangement of three balls on the centre window post. Both pilots have to position their seats such (up-down, fore-aft) that they see two balls aligned. The only possible head position that makes this possible is the eye reference position, *see fig. IN 1.5.*

Fig. IN 1.5 Eye reference position

1.4.2 Parallax

One direct aspect of the eye reference position concerning instruments is parallax. If the pointer of an instrument is positioned a few millimetres from the scale and the observer looks at the instrument along a line that is not perpendicular to the scale plate, the pointer may seem to indicate another value than it in reality does. This effect is called parallax and it can be avoided by placing the most important instruments directly in front of the pilots face. If the instrument is placed at a certain distance sideward, it may be slightly tilted in order to offer the pilot a more perpendicular view.

Another way to account for parallax is to position the pointer as close to the scale as possible, but the best way to eliminate the problem completely is to draw the pointer on a computer presentation screen or by presenting data in the form of digital numbers.

1.4.3 Presentation

From the first day an instrument was installed into an aeroplane the essential role of the instrument has not changed. It is the means by which the information or data is conveyed from the source to the pilot that has been changed.

Effectively you can think of the operation of an aeroplane as being a control loop. In this the pilot is the controller, the aeroplane is the controlling body and the instruments are the means by which the pilot is kept informed as to how the body is functioning. In order that the controlling function can be carried out effectively it is of fundamental importance that mental effort of interpretation of the data should be minimised. This comes down to how the information is presented which in turn resolves in two issues:

- Design of the display,
- Location of the display.

Display design

Displays may be analogue, digital or pictorial.

In analogue display, the movement of the indicator is directly related to the change in value of the data being measured.

Most analogue indicators are (electro-mechanically driven but some are created electronically.

Analogue displays are applied to a wide variety of instruments but are of value when comparing one instrument against another and to show trends.

There are two basic forms of analogue display:

- Circular,
- Straight.

The scales are calibrated in accordance with the data to be shown. Generally as much of the available space is used as possible.

Typical circular and straight scales are shown in *figure IN 1.6*.

Fig. IN 1.6 Circular and straight scales

In some cases it is desirable to be able to read a particular portion of a scale with greater accuracy and greater definition than other parts of the same scale. This may be achieved by using a logarithmic scale in which the spacing of the numbers is set against the natural logarithm for these numbers.

Fig. IN 1.7 illustrates such a scale and it can readily be noted that the spacing from 0 to 1 is considerably greater than that from 1 to 2 etc.

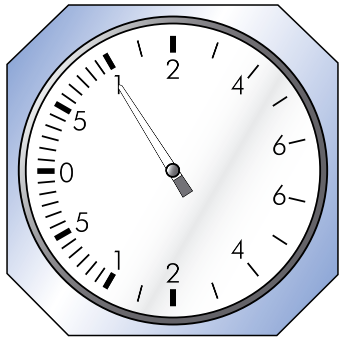

Fig. IN 1.7 Logarithmic scale

Digital displays, see *fig. IN 1.8*, are also applied to a variety of applications but are of most relevance when displaying quantitative values (in digits) e.g. altitude, distance, fuel, temperature, position and etc.

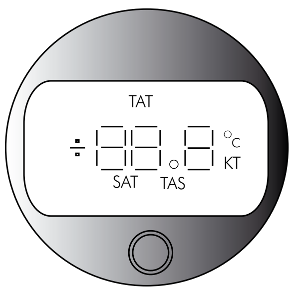

Fig. IN 1.8 Digital display

The way a certain variable is presented to the pilot has been given much thought. The ergonomic approach requires as much as possible a relationship between the presentation and the nature of the variable concerned. Where possible, the variable will be presented in a pictorial manner. For example in the past an altimeter was presented as an instrument with a round scale. The pointer moves sometimes up when the altitude increases, sometimes down. Ergonomically this is not a desirable property. On the modern EFIS displays the altitude is given as a straight vertical scale, such that the (fixed) pointer only rises relative to the (movable) scale when the altitude increases.

An advantage of a pictorial display is that a fast scan of the display immediately renders an internal picture in the pilot's mind, which enhances the situational recognition.

In a pictorial display there are two basic ways to present such a picture: the 'inside-out' presentation and the 'outside-in' presentation. In the inside-out presentation the observer sees the 'outside world' as the moving part of the presentation.

A good example is the artificial horizon. Using the 'inside-out' presentation the aircraft symbol would be the fixed part and the horizon is the moving part, *see fig. IN 1.9.*

Instrument position

A well-known ergonomic aircraft instrumentation principle is the 'basic-T' and 'basic-6' instrument arrangement. It concerns the six most basic flight instruments, notably the artificial horizon, the heading, the airspeed, the altitude (basic-T), the vertical speed and the rate of turn. The basic-T is an official requirement and is kept on modern

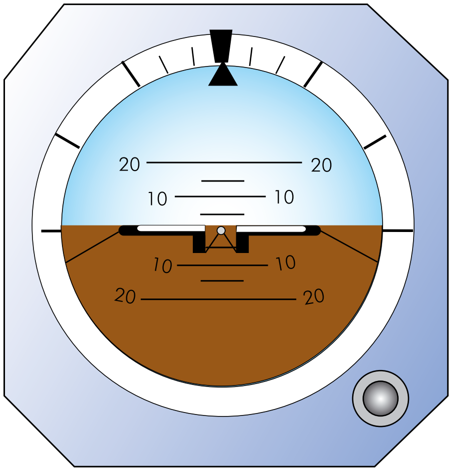

Fig. IN 1.9 Artificial horizon

large transport aircraft, whereas the basic-six is not always adhered to.

The basic-T requirement has an influence on the design of modern EFIS screens. The first designs placed the two computer screens vertically with respect to each other, while in later developments the bottom screen moved to a position next to the top screen. But the bottom presentation contained heading information, violating the basic-T requirement when placed next to the artificial horizon. Therefore these arrangements have a small part of the heading scale under the artificial horizon, restoring the basic-T, *see fig. IN 1.10.*

Fig. IN 1.10 Basic-6/T

1.5 Electronic Displays

There are several types of electronic displays:

- Incandescent
- Light Emitting Diode (LED)
- Cathode Ray tube (CRT)
- Liquid Crystal Display (LCD).

Incandescent

The first electronic displays were made of incandescent lamps. The illumination of individual filaments allowed the construction of seven segment displays that could show ten decimal digits, *see fig. IN 1.11.*

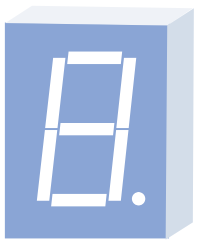

Fig. IN 1.11 Incandescent seven-segment display

Light Emitting Diode (LED)

This tiny semiconductor chip can also form a seven-segment arrangement but at the same time allows a more complex array such as the 5×7 display which could be used for alphanumeric characters, *see fig. IN 1.12.*

On the flight deck, the seven-segment or 5×7 display may be used in several instruments that show digits. Examples are the frequency displays, the DME display and the clock.

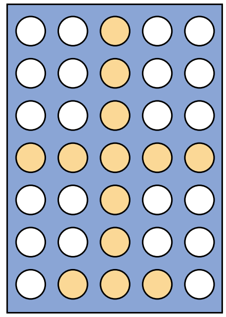

Fig. IN 1.12 5 x 7 LED display

Cathode Ray tube

A Cathode Ray Tube (CRT), *see fig. IN 1.13* consists of a vacuum glass tube with at the rear side a heated cathode (electron gun) that releases electrons. The electrons are attracted and accelerated by an anode with a very high positive voltage. The accelerated electron beam is focused and deflected such that it hits one narrow spot on the screen. The screen is covered with a phosphor layer that 'illuminates' when electrons strike the phosphor atoms. This type is called a monochromatic CRT.

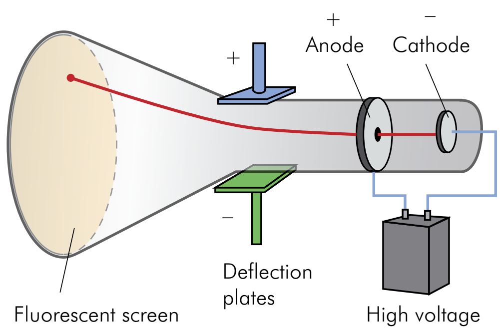

Fig. IN 1.13 Cathode Ray Tube

Modern full colour CRTs have three electron guns that each strike a coloured phosphor dot. The three colours are red, green and blue. The three dots are formed in a triangle and make one pixel, *see fig. IN 1.14*.

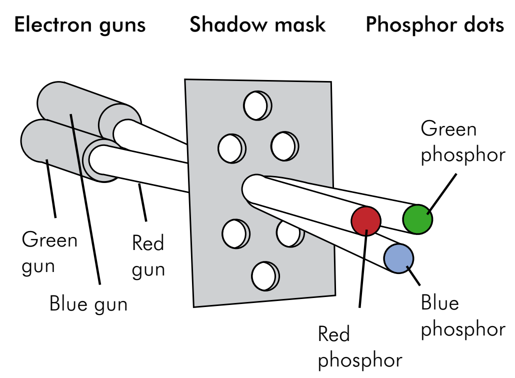

Fig. IN 1.14 Shadow mask colour CRT

There are two ways of creating an image. The first is raster scan. Like in a TV the image is created by drawing lines on top of each other. This method is used to fill up large areas such as the blue sky and the brown ground at the artificial horizon. The second method is stroke writing. In here an image is created by scanning the whole screen and turning the beam on and off for each symbol, *see fig. IN 1.15.*

A combination of raster scan and stroke writing is called hybrid scan.

A CRT produces heat that must be removed by an active cooling system (eg a cooling fan). If the cooling system fails the CRT might 'black-out'.

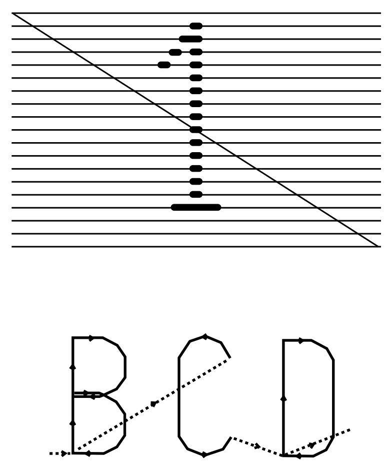

Fig. IN 1.15 Raster scan and stroke writing

Liquid Crystal Display

A liquid crystal is kept between two clear glass plates. The rear glass is coated with a thin transparent metallic film while the front glass is coated at specific areas with a transparent metallic material. These specific areas can be a seven-segment configuration or a customized pattern.

Outside the front and rear glass plates is a polarizing film. A polarizing film creates plane polarized light out of random polarized light. Polarization occurs when the electric field of the light is parallel to a plane. A polarizing film is like a microscopic window blind. When light strikes the polarizing film where the electric field can pass through the blind, the light passes. Light of other polarization is blocked. When two polarizing films are aligned, so polarization is the same, we see through the two films. On the other hand when the polarization is different, the result is darkness.

When an electric field is applied to the liquid crystals, they change the polarization of light. Assume the polarizing films are aligned to let light pass through. Selective application of electric fields causes the polarity of the light to rotate and causes areas to become opaque.

Very simple type LCDs have a mirror behind but more sophisticated displays have a fluorescent-type backlight.

If the polarizing filters are oriented 90º to each other the display appears dark. In this case the electric field causes a bright area as the additional 90º rotation allows light to pass through the LCD.

So by orientation of front and back polarizing films the LCD can be configured as a white on black display or black on white display, *see fig. IN 1.16*..

Another development is the full-colour TFT Active Matrix LCD (AMLCD)

A major advantage of a LCD is its low power consumption. Many segments can be placed on a relative small surface. Modern computer monitors make use of a raster of 1024 x 1024 pixels. The pixels are created by depositing Thin Film Transistors (TFT) on the glass plate and connect them to the segments. The display drivers are also mounted directly on the glass. These drivers make use of multiplexing techniques to drive the individual segment.

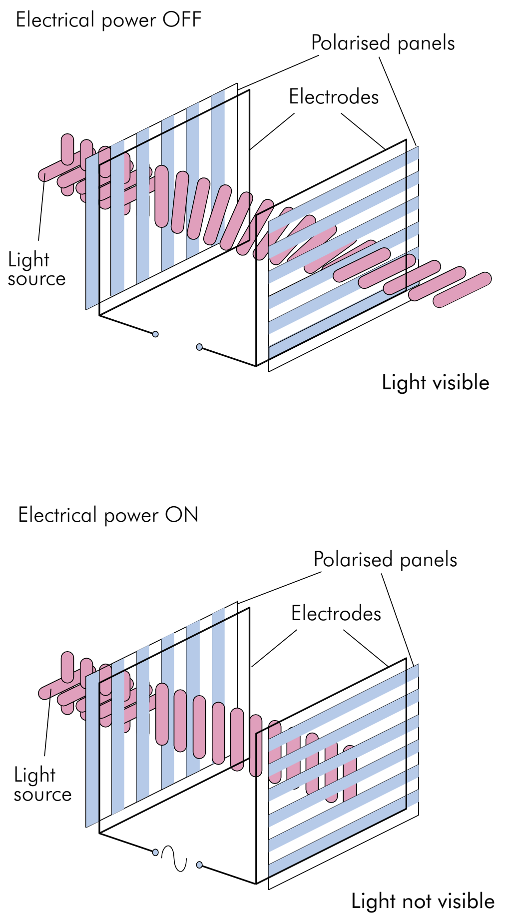

Fig. IN 1.16 LCD

The full-colour AMLCD generates colour graphics by providing three light valves, one for each additive primary colour at each pixel. Every shutter has a microscopic light filter: red, green or blue.

The main disadvantages of a LCD is its temperature range. Too high and too low temperatures may damage the LCD. The lower the temperature, the slower the display; below -20°C the display freezes and below -40°C permanent damage occurs.

Summarising, when comparing with a CRT an LCD does not produce radiation, is less heavy and consumes less power.

A CRT produces a lot of heat that must be removed with forced cooling. An LCD must not be exposed to extreme (high and low) temperatures. Another important factor that must be taken in account is glare.

1.6 Transmission Systems

Transmission systems fall in three categories:
- Mechanical,
- Electro-mechanical,
- Digital.

1.6.1 Mechanical transmission

This is the traditional form of transmitting data that has been in use for hundreds of years.

Fig IN 1.17 illustrates a typical mechanical system, which consists of gears and shafts that are designed to process the movement of the sensor and transmit it to the indicator.

Although such systems are simple and reliable, they do suffer from some major problems:
- The sensor and indicator must be located close together,
- Friction in the bearing will cause wear and this will reduce the time between overhauls,
- Friction in the bearings will cause mechanical forces that will result in a time

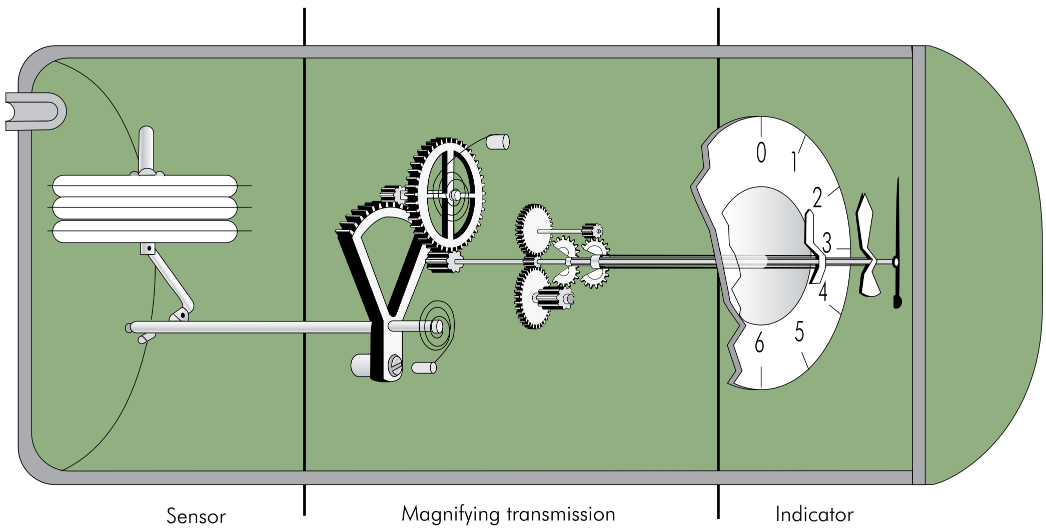

Fig. IN 1.17 Mechanical transmission