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DOCUMENT TITLE
HUMAN PERFORMANCE AND LIMITATIONS

CHAPTER 19 – BASIC ERGONOMICS

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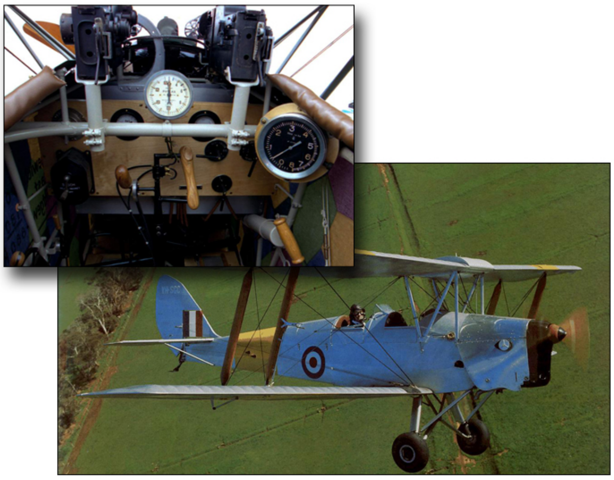
BASIC ERGONOMICS

19.1 Introduction



Cockpits of early aeroplanes were cold and windy (open to the air). They were cramped, often smelly and offered the pilot a poor view of where he was going. Where the cockpit was located often came as a second thought to designers – they were more concerned with the design of the rest of the aircraft than the comfort of the pilot. There was no standardisation of instrument layout – instruments were placed anywhere convenient with little consideration to how and when they might be used by the pilot.

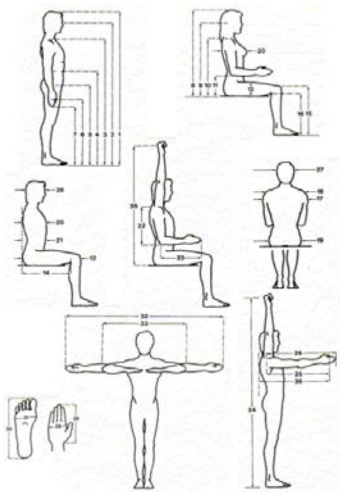
Over the decades it became increasingly obvious that the pilot was an important part in the aviation safety equation and a great deal of work has been done in making the interface between the aircraft and the pilot much more efficient. Aircraft cockpits are now designed around the pilot, with a great deal of emphasis being placed on ergonomics and standardisation of layout of instruments and controls.

Ergonomics is the study of humans in their working environment and the amount of physical and mental effort required for them to efficiently carry out their duties. The word comes from the Greek words ***ergon*** meaning work and ***nomos***, meaning natural law. In the cockpit, it takes consideration of the limited space available, the need to have crew sitting close enough to be able to react appropriately, to be able to reach the controls, see the instruments and displays and to be able to see forward sufficiently to take off and land safely.

The three domains of ergonomics are:

- Software
- Hardware
- Liveware.

19.2 Anthropometry



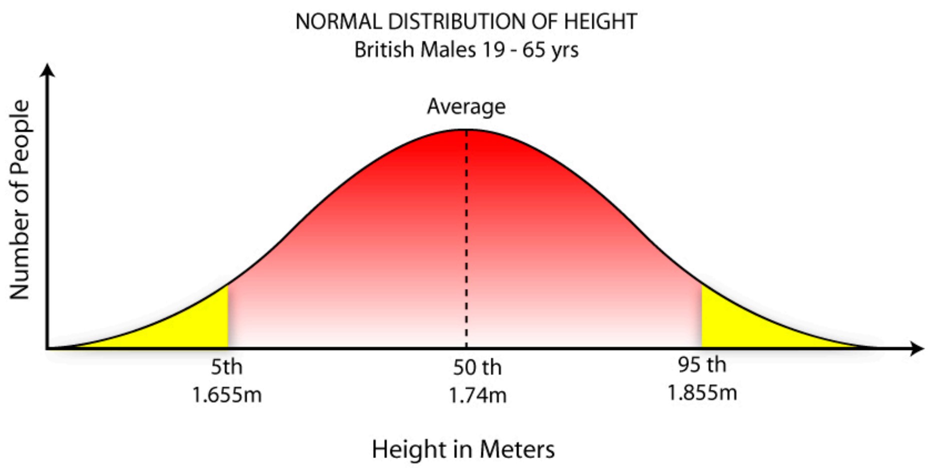
Anthropometry is the science of human measurement and is an essential component of ergonomics. Measurements can be:

- Static measurements. The measurement of non-moving subject. Height, length of thumb and size of foot are all static measures.
- Contour measurements, The surface measures made from the pivot points of joints; for example shoulder to elbow or knee to ankle.
- Dynamic measurements, The measures involves the study of the body in motion such as reach envelopes – can we reach the various controls.

Not only does anthropometry concern types of measurement, but also who and what are to be measured.

90%

It is not practical to design an aircraft to suit every individual, so a distribution of statistics is taken and the aircraft designed to accommodate from the 5th to the 95th percentile of the population – that is, it does not include those below the 5th percentile or taller than the 95th percentile of the population. (Note that this is not necessarily the middle 90% of the population in number).



Selected Applications of Anthropometry for Aviation

All Body Dimensions	Clothing (including gloves, shoes, etc.) sizes for crew uniform.
Hand size	Size, location and layout of switches and small controls. Whether these can be on the control yoke or elsewhere. Maintenance access by engineers to hatches and doors.
Length of Arms, Legs	Reach envelope for control locations
Sitting Eye Height	Establishment of seat adjustment ranges to achieve the correct eye reference position.
Sitting Knee Height and Thigh Thickness	Control column-yoke clearance; desk and console design
Standing Height	Ceiling and door heights, overhead functional reach (eg. overhead baggage compartment)
Sitting Elbow Rest Height/Length	Location of arm rests
Body Width and Thickness	Passageways, seat dimensions, door or hatch widths, fuselage widths
Thigh Length	Length of seat
Foot length	Foot control(e.g. rudders) location and size
Range of motion and reach of body members	Control location, control design
Muscle strength	Control forces and direction of movement. Service and maintenance requirements. Allowable weight for portable equipment

19.3 Designing Eye Position or Eye Datum

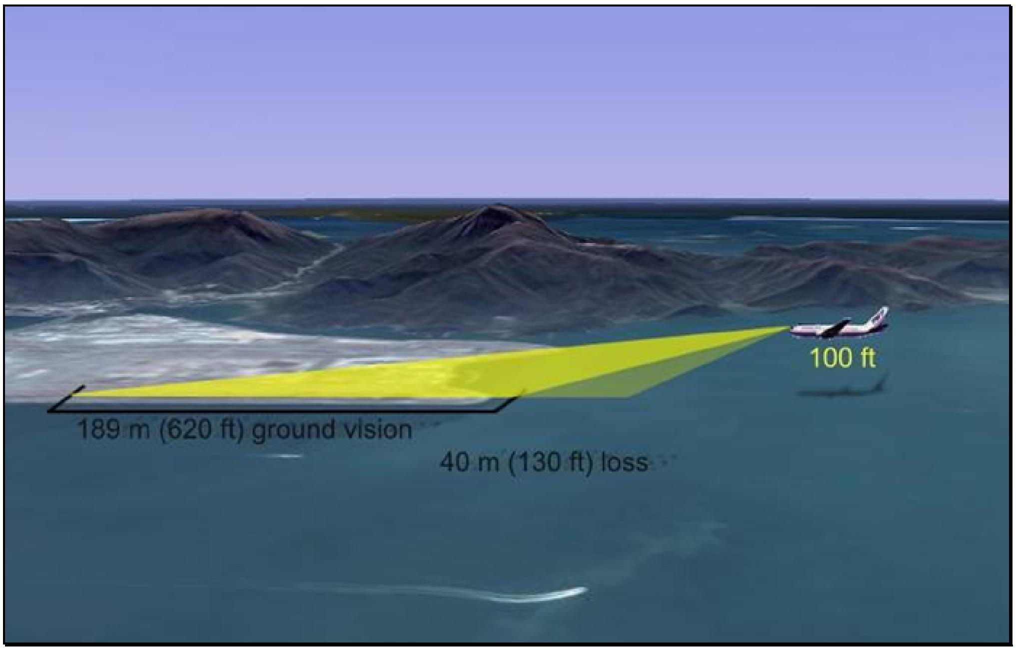
This is one of the most important aspects of cockpit design.

Pilots, with minimal head movement, should be able to view all-important instrument displays and be able to maintain an adequate view of the outside world. The pilot must be high enough to easily look over the top of the instrument panel and see enough of the runway ahead to be able to take off and land safely.

He must not be so high that he cannot see all of the instrument panel.

Aircraft manufacturers therefore, must design their cockpits around a standard pilot eye position called the **design eye position, eye datum, or reference point**.

All pilots operating that aircraft must adjust their seats so that their eyes are in this particular position. It is only here that the eyes in the optimum position to see the runway ahead, and be able to see all the instruments on the instrument panel.



Once the design eye position has been set, the size and layout of the cockpit will follow. The length of the limbs and the 'reach envelope' of the 5th to 95th percentiles pilots will then determine the positioning of the remained of the instruments, switches and controls.

The importance of the design eye position is illustrated on the next page. In the Boeing 767, for example, by sitting just 1" too low, 40 metres of the ground vision is lost on the final approach.

19.4 Work Space Constraints

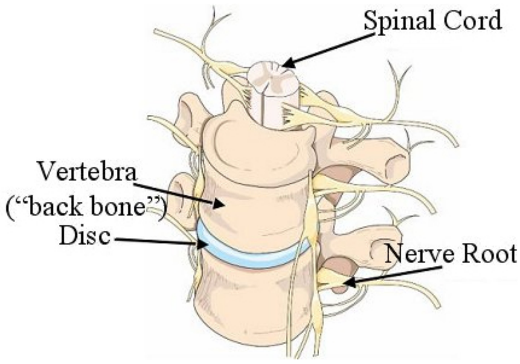
Workspace design has to be a compromise involving ergonomics, anthropometry, function, aerodynamics and aircraft strength.

Controls, displays and warnings will be looked at in detail in subsequent paragraphs. However their locations will be determined by requirements such as shared use, compared to duplication, reach envelopes, frequency of use and relative importance.

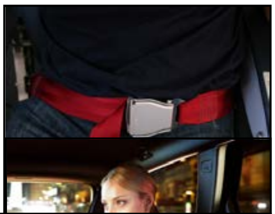
19.4.1 Pilot Comfort

It is important that the pilot be able to sit comfortably for considerable periods of time and a great deal of work has been done on the design of pilots' seats. Many studies have shown that there is a prevalence of lower back problems in pilots, caused by sitting for long periods. Therefore the seat must be designed and adjusted properly to achieve an optimum degree of lumbar support.

Correct lumbar support helps to hold the spine into a shape that allows compression to be shared by all of the shock-absorbing discs in the spine. Inadequate lumbar support will result in back-aches and in the long-term, debilitating back injuries.



19.5 Safety Harness



There are four main types of safety harness:

- **Lap:** Not an acceptable harness in aircraft. In an accident, the upper body will be thrown forward.
- **Lap/Sash:** Common in cars. Better than lap only harnesses, but still not ideal for aircraft operations. Lap/sash harnesses are more comfortable for the female form. In any accident imparting lateral movement of the body, the body may slip out of the harness.
- **Four point harness:** The most acceptable solution. Almost universally used in airline class aeroplanes.
- **Five point harness:** commonly used in aerobatic aircraft, but also in some RPT aircraft. They are usually considered too cumbersome for airline operations, although some five-point harnesses have been used in earlier aircraft.

19.5.1 Inertia Reel

- Used on the lap/sash and the four and five-point harness.
- Centrifugally-operated internal mechanism permits slow intentional forward movement of the body, but will lock with fast forward thrust. This allows the pilot to lean fully forward during normal operations, but will restrain him in an accident.
- Designed to tolerate up to 20 'g' decelerations for short periods.
- Should lock at 1'g' deceleration.

19.5.2 Adjustment

- Belt must be firm over the hips.
- On lap/sash harnesses, the buckle should be at the side of hip away from the abdomen. Shoulder strap should run from the hip to the middle of the shoulder.
- Check for fraying.
- Check recoil.
- Must be replaced after an accident, as the design of the system requires the belt to stretch slightly and so take up part of the deceleration shock.

19.6 Displays

A display is the presentation of information and may be visual (see), aural (hear) or tactile (you feel it). Most flight deck displays are visual, but audible warnings (Master Caution, GPWS, stall, fire) and tactile warnings (stick shaker) are also used. The position of the visual displays will be determined by the Design Eye Position. Important and frequently used instruments will be placed where they can be seen most easily. Interpretation and legibility of displays will be affected by factors such as size, illumination, colour and design.

Visual displays must be large enough and well lit, and they must be easily read and legible. The size of the display will be dictated mainly by relative importance, but also by panel space available. Essential flight instruments will be in the most prominent position with less essential instruments situated elsewhere in the cockpit.

Standardisation is an important consideration in display and control design. This allows a pilot to transfer more easily between aircraft types without confusion and ‘negative transfer’.

A digitised voice is often used, an example being the radar altitude call-out during the flare. Head up displays are useful, particularly on military aircraft, but are now being introduced to RPT aircraft for the transition from instrument to visual mode on approach, or for taxying in low-visibility conditions.

19.6.1 Display Design

Analogue scale: The circular or semi-circular analogue scale is still preferred for many aircraft applications. It has the advantage that the position of the pointer can be interpreted instantly and the associated scale used only when more precise readings are required. For example, a quick glance would tell us we were cruising at exactly our assigned altitude if the altimeter hand is vertical (up for whole 000’s or down for 000’s + 500).

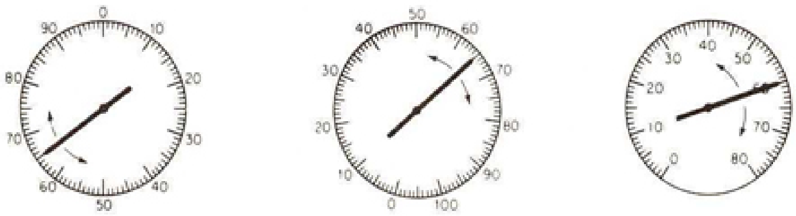
This is of particular value with engine instruments on a multi-engine aircraft. A known position indicates correct cruise power settings—all pointers would be in the same relative position. The circular analogue scale also indicates direction and rate of change—very useful in altimeters.

Readability is a high priority in the design. It takes about three times longer to read a ‘three point’ altimeter than it does to read a digital one, and about 20% of the readings taken from the three-pointer altimeter are likely to be misinterpreted, as against none in the case of the digital altimeter. Three point altimeters are common in higher performance general aviation aircraft, but are gradually being phased out of use.

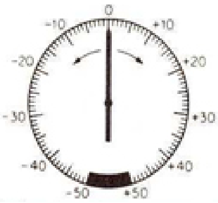
Analogue displays may be linear, with a pointer moving against a fixed horizontal or vertical scale, or a moving scale against a fixed pointer. These displays are useful for comparing information (e.g. engine parameters of all four engines) since the scales can be positioned in parallel to each other and occupy limited space.

EXAMPLES OF CERTAIN TYPES OF DISPLAYS USED IN PRESENTING QUALITATIVE INFORMATION ON AN ANALOGUE SCALE (McCormick *ET AL* 1983)

Fixed scale, moving pointer



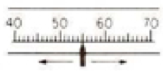
Circular



Circular scale with positive and negative values

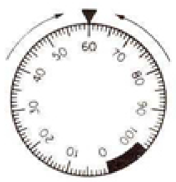
Semicircular or curred scale

Vertical

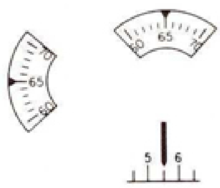


Horizontal scale

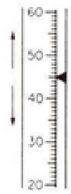
Moving Scale, fixed pointer



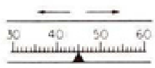
Circular



Open-window

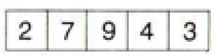


Vertical



Horizontal

Digital display



Digital scale: These are displays that present information in numerical form. They are particularly useful where exact numerical values are important (e.g. altimeter subscale setting, DME distance). They are not as intuitive in displaying direction and rate of change.

To achieve the 'best of both worlds', digital scales may be combined with analogue displays. The pressure altimeter is a common example. Instead of the potentially confusing three-pointer sensitive altimeter display, a digital readout of height in thousands of feet, supplemented by an analogue pointer showing height in hundreds of feet offers the best of both types of scale.

19.6.2 Analogue Vs Digital Summary

- Digital displays are best for displaying quantitative, or exact numerical values.
- Analogue displays are not good at displaying exact numerical values, but are best for qualitative (approximate data) as well as rate and trend of movement.

Misread the Altimeter

A British European Airways Viscount had departed London Heathrow at 8:40 P.M. to collect a group of passengers at Prestwick in Scotland and return to Heathrow. The pilot commenced a descent from 18,500 feet and was cleared to 8,000 feet. Shortly after the report "passing 11,000 feet" the aircraft struck the ground at Tarbolton, Ayrshire. The cause of this controlled-flight-into-terrain accident was that the captain had misread the altimeter's shortest pointer by 10,000 feet, and the co-pilot had made the same error - or realised they had passed through 8,000 feet and was afraid to speak up!

The Standard 'T' Instrument Layout

19.6.3 Illumination and Colour

The illumination of displays to make them visible in a dimly lit cockpit must be such that they are visible (where appropriate) to both of the pilots and light sources must be positioned so as to cause neither shadows nor glare.

Illumination may be from floodlighting or internal, or a combination of both. In either case the brilliance must be adjustable to cover the range of requirements from daylight to night-time.

CRT (glass cockpit) displays may well require automatic brightness control to compensate for sudden changes in cockpit light levels, such as occur during an aircraft turn in day-time.

Colour coding can be useful as an 'attention getter', but should be limited to as few different colours as possible to avoid confusion. Red is the conventional colour for an alert or emergency situation; yellow for a caution or advisory indication and green indicates a normal parameter.

19.7 Control Layout and Design

Aircraft controls should be placed so that they are easy to reach and use, and in positions that are appropriate to their use. Furthermore, the direction of movement of a control should be compatible with its effect.

19.7.1 Standardisation

This is of major importance. Directions of operation, (eg. for power changes), shapes of levers, layout of levers and gauges should be standardised wherever possible.

19.7.2 Simultaneous operation

Some controls need to be operated almost simultaneously, e.g. engine manifold pressure and RPM. Where this is so, the controls should be located closely.

19.7.3 Shape

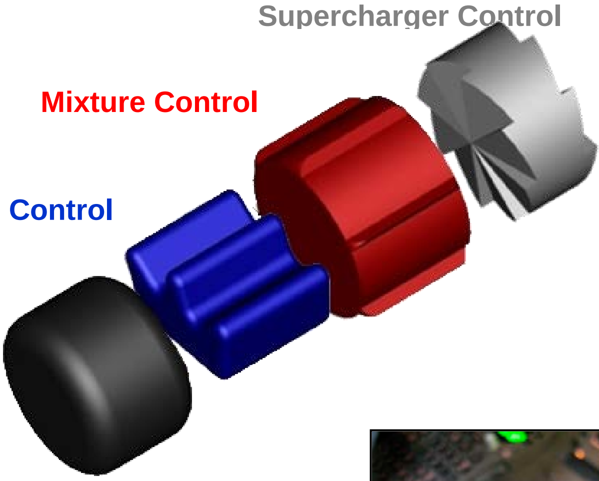
The shape of a control lever or switch may be made distinctive, to reduce the possibility of inadvertent operation. In some cases the handle shape represents the function of the lever; some examples of this are shown.

Supercharger Control

Mixture Control

RPM Control

Throttle Control



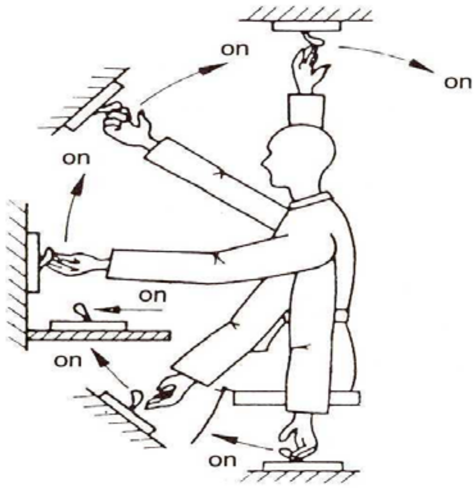
Landing Gear Control

Flap Control

FEDERAL AVIATION ADMINISTRATION REQUIREMENTS FOR COCKPIT CONTROL KNOBS IN GA AIRCRAFT

19.7.4 Direction

There is a certain instinctive way in which most people will operate a given control - clockwise to increase, down to decrease etc. These instinctive patters are studied and applied by cockpit designers, since in a crisis most people will revert to a previously-learned habit. On the flight deck, however, control switches are located in a 180° arc from floor to ceiling and a common approach is to adopt the 'sweep on' philosophy as illustrated. Boeing uses the 'sweep forward' approach where moving a switch towards the windscreen turns it on.



19.7.5 Sequence

If a number of switches or controls are frequently used in a given sequence, they should be laid out in that sequence on the control panel.

19.7.6 Frequency of Use

The more frequently a particular control is used, the more convenient it should be to the user and laid out in a way that prevents an awkward and fatiguing posture in the pilot.

19.7.7 Importance

Important, but irregularly used controls like flap levers and landing gear selector should be positioned in easily reached and unobstructed positions. Commonly used controls (undercarriage, flaps, throttles) will be located within easy reach of either pilot, typically on or near a central console.

19.7.8 Related Controls

Controls with related functions such as throttle lever and propeller controls should be grouped together and may be arranged sequentially.

19.7.9 Control Loading

This refers to the amount of muscle force required to operate flight controls.

In older aircraft, this implied that the force required to operate the control was within the capabilities of the average pilot. With modern aircraft, control surfaces (ailerons, elevators) are hydraulically operated and it is necessary to provide artificial feel in the controls, firstly to give appreciation that it is in fact operating and sensitivity so that a degree of input required for a given amount of control response can be achieved.

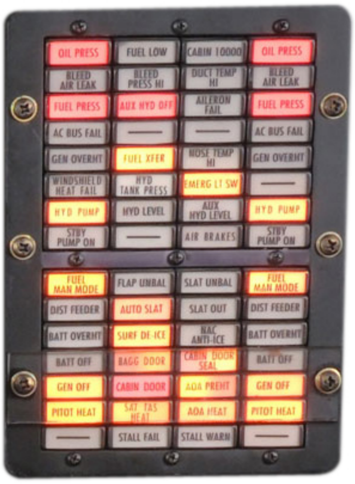
The force required to operate controls should be similar for all the associated controls, such as elevators and ailerons. For example, a control column will be difficult to use if it requires large forces to control roll but only light forces for pitch.

19.7.10 Protection against Inadvertent Operation

Guards may be needed, e.g. for alternate static source control, etc.

19.8 Warnings

The three main functions of a warning are: to attract attention; inform or report the nature of the problem; and to guide appropriate actions. Warnings should be attention getting, but not startling. They should also be reliable, in that they respond to all genuine problems but do not generate false alarms.



Annunciator Panel

In practice this could involve:

- <u>Alerting</u> the pilot to the existence of a problem by means of a sound or flashing light.
- <u>Describing</u> the problem by means of an illuminated caption.
- <u>Directing</u> the pilot's response where appropriate (e.g. an illuminated fire 'T' handle guides the pilot to the appropriate response mechanism).
- Warnings are usually presented as visual and/or aural information and may be accompanied by tactile information (stick shakers/pushers).

19.8.1 Visual Warnings

Usually in the form of flashing or continuous lights, coloured in accordance with the level of urgency and accompanied in many cases by text captions. Coloured flags partially obscuring a display (e.g. Radio Altimeter, VOR, ILS) are also used to warn of system failures.

Warning lights are often placed close to the limits of peripheral vision for the simple reason that the main instrument panel is too cluttered to accept them all. It is now common to have a master caution warning light on the glare shield to direct the pilot's attention to a warning somewhere. He must then detect the failure or the source of the warning.

19.8.2 Audible Warnings

These have the advantage of being omni-directional attention-getters and they are usually used in conjunction with visual warnings (engine fire, TCAS). The sound made should be quite distinct from any other and should indicate urgency (eg aircraft over-speed). Sounds graduated to the level of urgency can be used.

Voice (spoken) warnings have become popular in relatively recent years, such as in the GPWS. The voice warning must be completely unambiguous and must be quite different from any normal flight deck dialogue. All audio warning systems suffer from a serious disadvantage in that two or more operating at the same time can be extremely confusing.

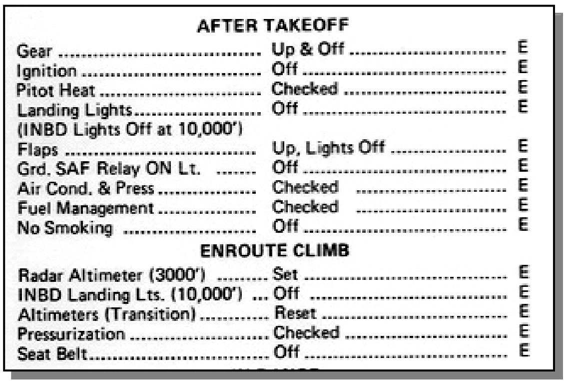
Misinterpretation of warnings has lead to accidents. People tend to see what they expect to see, especially in an emergency. If number 3 engine EGT had previously been causing problems, and an engine fire warning illuminates, there is an immediate tendency to assume it is number 3 again. Alternatively, there is the danger of ignoring warnings through over familiarity.

The best general advice that can be given to pilots is that all warnings must be taken seriously, but not acted upon until the pilot is certain of the nature of the problem.

19.9 Checklists and Manuals

19.9.1 Checklists

Checklists are a guide to pre-set sequences of essential actions - pre and post take-off checks are an example, but there are several other checklists in heavier aircraft. There is a compelling requirement for good accessibility of information in manuals and checklists.



AFTER TAKEOFF

Gear	Up & Off	E
Ignition	Off	E
Pitot Heat	Checked	E
Landing Lights (INBD Lights Off at 10,000')	Off	E
Flaps	Up, Lights Off	E
Grd. SAF Relay ON Lt.	Off	E
Air Cond. & Press	Checked	E
Fuel Management	Checked	E
No Smoking	Off	E

ENROUTE CLIMB

Radar Altimeter (3000')	Set	E
INBD Landing Lts. (10,000')	Off	E
Altimeters (Transition)	Reset	E
Pressurization	Checked	E
Seat Belt	Off	E

Legibility is obviously essential, to achieve this, a clear typeface, black on white should be used with **normal lower case lettering**. It has been found that word shape (not found in UPPER CASE ONLY TEXT) is an aid to comprehension and speeds up reading. Upper case text or italics should only be used for emphasis. The checklist should be resistant to wear from repetitive use.

Different checklists or parts of checklists may be categorised or emphasised by the use of colour. For example, emergency checklists might be printed in red. The QRH may be printed on yellow paper.

It is important that the pilot disciplines himself to adhere to the designed procedure of the checklist. If the checklist calls for a challenge and response, then that is the way it should be used.

A major source of error in using routine checklists is that they may be responded to in an automatic, unthinking way rather than diligently.

Abbreviations should be avoided.

Compliance checks are desirable, such as a means for 'ticking off' items that have been checked. Modern glass cockpit displays usually now incorporate electronic checklists with electronic 'tagging' as items are completed.

19.9.2 Manuals

Manuals should provide information in a clear, understandable form and include relevant diagrams.

They should be indexed for easy location of subject, and should remain open at a chosen page. Data tables should be kept as straightforward as possible, with large quantities of data broken down into easy to follow sections. System diagrams should be colour coded for ease of understanding.

Manuals should be designed to be easily read and understood in conditions of poor lighting, in possibly emergency situations, or by presbyopic pilots.

Legibility will depend upon size and layout of letters and numerals; **4 millimetres** is the accepted **minimum** for character height and a mixture of upper and lower case has been found preferable to all upper case letters.

19.9.3 Summary of Checklists and Manuals

Checklists and manuals must:

- Have good legibility
- Print must be to a minimum size
- Be relevant
- Use clear language
- Use upper case or italics for emphasis only
- **It must be adhered to.**

19.10 Automation and the Glass Cockpit

In light aircraft cockpits, and in the early days of airliners, each instrument in the cockpit was connected to its own sensor. This gave us a continuous reading of that piece of information (e.g. airspeed). As aircraft became larger and more complex, the number of instruments required to keep the pilot fully advised exceeded his ability to read and interpret them fully

With the introduction of computers, it became possible for much of the routine information (e.g. track, groundspeed, drift etc.) to be calculated automatically, so leaving the pilot free for the more important higher-level decisions. Computers also allowed pilots to select the type of information to be displayed on a single, comprehensive display (e.g. navigation data, checklists, engine data, etc)

CRT and 'flat screen' computer displays also allowed a greater use of colour, with colours being used to categorise information (e.g. whether an emergency, an alert, or a normal operation) according to certain accepted conventions.

Facilities were introduced where the aircraft's data computers were linked to the autopilot systems. This allowed certain operations such as not allowing the aircraft to exceed a certain angle of attack, and so not ever stall. While this sounds nice, such automation cannot absolve the pilot from the responsibility of operating the aircraft in a way that follows the basic requirement for safe flight.

A second problem perceived in 'glass cockpit' aircraft is that the displays are so easy to use that they make it difficult when they fail for the pilot to use his traditional skills at basic instrument flight. This is particularly the case if the pilot is relatively young and inexperienced. (A similar problem is becoming evident in light aircraft, with a growing over-emphasis on the use of GPS for navigation. Pilots are beginning to lose their basic 'dead reckoning' skills and the number of VCAs is increasing.)

A further concern is that the complexity of the systems that are now driving the modern pilot/aeroplane interface, is such that pilots cannot understand them to the same degree they would understand more basic systems.

However, the problem that has caused most concern in recent years is that of 'mode awareness'. Since the autopilot can now be set up in so many modes (e.g. should the descent be at a certain angle, a certain number of feet/minute, certain airspeed, or to achieve a certain distance), it is possible for the pilot to think the aircraft is carrying out a particular function when it is really doing something else. This problem has caused accidents in the past.

19.10.1 The Glass Cockpit

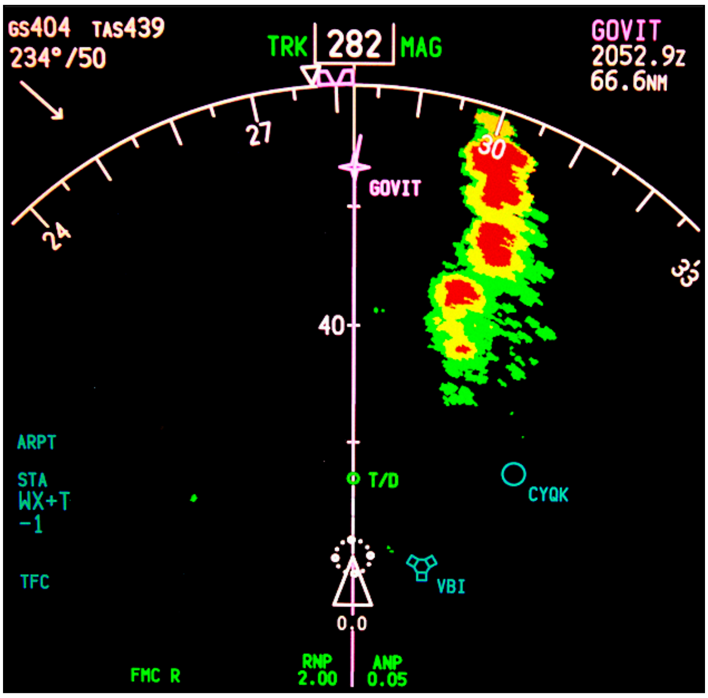
The term 'glass cockpit' is derived from the use of electronic displays; the earlier form being cathode ray tubes (CRTs, similar to the old style TV screens) but more recently the use of flat screen displays (plasma or LCD)

While the layout of the display will vary between aircraft, a format now commonly adopted is the use of three screens:

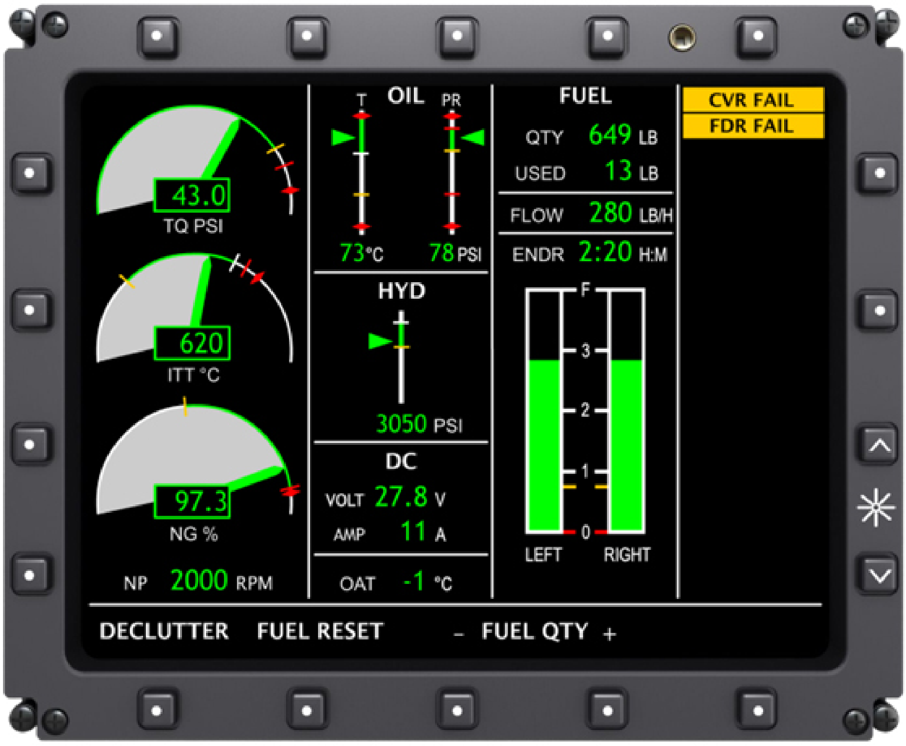
- **Primary flight displays:** AI, ASI, VSI, DI and other data.

- **N**

- **Navigational displays:** Flight planned route. Navaids, often overlaid with weather radar data.



- **Multi-function display:** In summary, everything else, such as checklists, engine data, electrics, hydraulics, air conditioning data, etc.



- **Head-up Display (HUD:** Being developed for airlines. Data is projected on to a transparent screen above the glare shield. The pilot can see through the screen to the runway ahead.

19.10.2 Conventional vs. Glass Cockpit Summary

19.10.2.1 <u>Conventional Cockpit</u>

- Every sensor has own display
- The instrument panel can be very complex and cluttered in large aircraft

19.10.2.2 <u>Glass Cockpit</u>

- All data selectively sampled and only relevant data displayed to the pilots.
- Usually three comprehensive, special purpose displays; the Primary Flight Display (PFD), the Navigation Display, or the Electronic Horizontal Situation Indicator (EHSI) and the Multi-function Display (MFD – used to display various information such as checklists, engine data, electrics, hydraulics, fuel, etc).

- The pilot no longer needs to do basic calculation—the computers do it for him, releasing the pilot for the more important tasks relating to safe operation of the aircraft.
- More capability for higher level decisions.
- Reduced pilot workload.

19.11 Automation and the Pilot

19.11.1 For:

- Much more data is readily available to the pilot
- Computers can carry out repetitive, routine tasks, monitoring and data storage and recall infinitely more efficiently than the human pilot.
- Reduced pilot workload improves safety.
- Reduced crew size—reduced operating costs.
- High level of operating efficiency—the computers do the repetitive work and the crew can concentrate on the more relevant tasks.

19.11.2 Against:

- New tasks of reprogramming often required in congested airspace.
- Unconventional manoeuvres can be difficult to program into the FMS.
- A possible lack of mode awareness.
- Complacency and reduced situational awareness.
- Transfer of some aircraft control to PNF. (The PNF has the ability to enter data into the FMS—so taking control away from the PF).
- Comfort differences in the use of automation, e.g. the older person who may not be as comfortable using computer devices as might a younger person.
- Appearance of less standardisation (the flexibility available creates the appearance of less standardisation in cockpit procedures).
- Transfer of workload amongst phases of flight, e.g. the pre-takeoff phase (already busy) is made busier, while the cruise phase (already quiet) is made even less busy.
- Change in timing of errors (errors are now made at the time of data entry, not at the particular time in flight).
- Tendency to use extremes of automation (some pilots prefer to use automation to the maximum, others prefer to 'hands-fly' whenever possible).
- Difficulty in detecting automation failures.