Aircraft Systems

- Directional Systems
- Electronic Flight Instrument System
- Aircraft Navigation System
- Automatic Flight Control System
- Airborne Radars
- Flight Management systems
- Safety and Warning Systems

Aircraft Instruments

- Air Data Instruments
- Advanced Flight Instruments
- Engine Instruments
- Fuel Indicators

Aircraft Instruments- Types and Layout

The most important instruments which are used at all times and phases of flight are:

- Air Speed Indicator (ASI)
- Altitude Indicator (ALTI)

Attitude Indicator-can be anyone of the following

Gyro Horizon (GH)-Old

Attitude Director Indicator (ADI)-New

Electronic Attitude Director Indicator (EADI)-Latest

Direction Indicator (DI)-can be anyone of the following

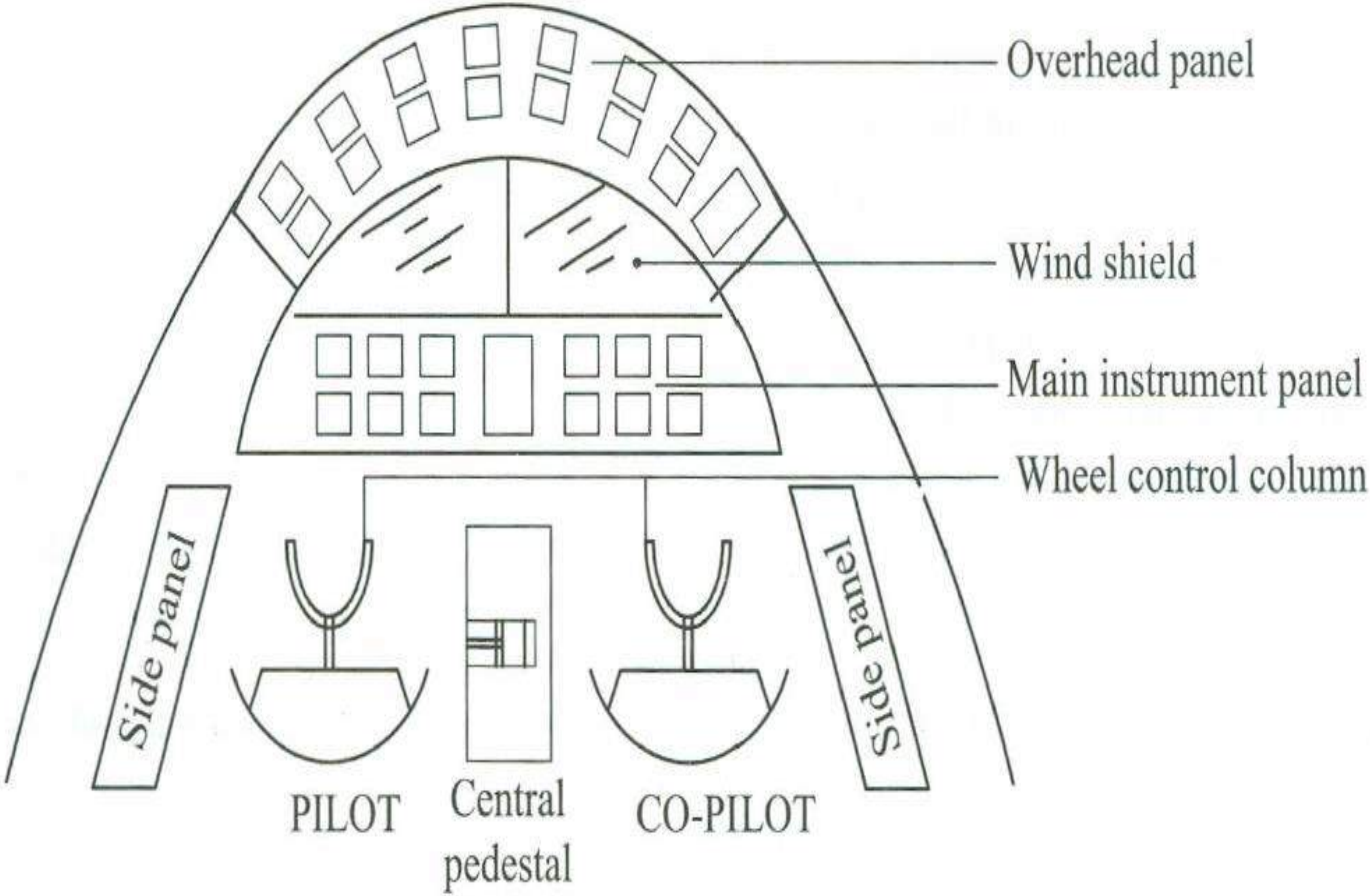
:

- Direct Reading Compass (DRC)
- Horizontal Situation Indicator (HSI)-New
- Electronic Horizontal Situation Indicator (EHSI)-Latest
- Vertical Speed Indicator (VSI)
- Turn and Bank Indicator (TBI).

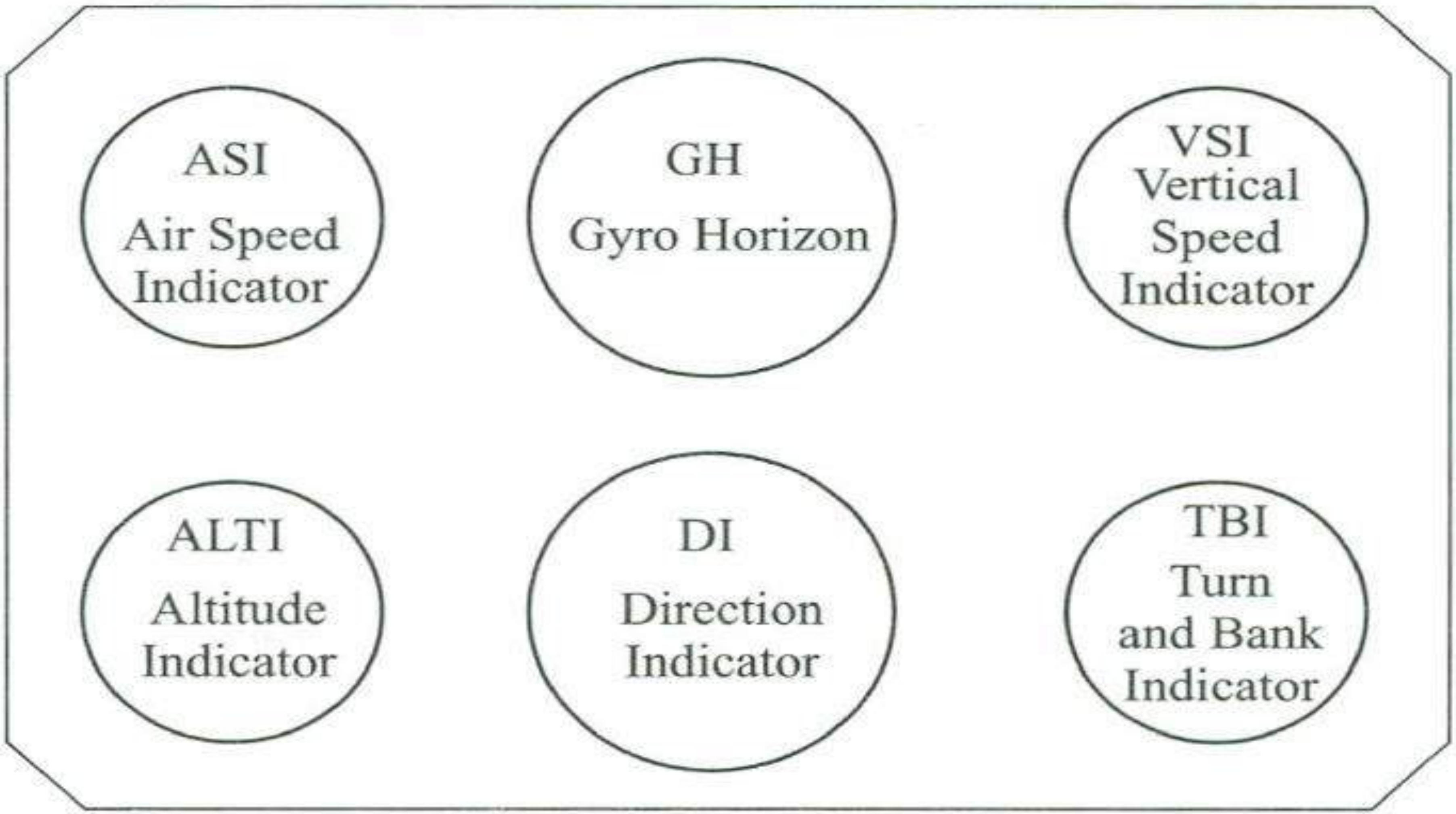
Instrument location in a cockpit.

The most important location, directly below the wind shield is called the Main Instrument Panel-

- MIP directly below the wind shield and will have duplicated instruments for the pilot (left seat) and the co-pilot (right seat).
- There are other locations such as side panels, overhead panel, and central pedestal


Overhead panel
Wind shield
Main instrument panel
Wheel control column
Side panel
Side panel
PILOT
Central
pedestal
CO-PILOT

In older aircraft the instruments were arranged in the so called "Basic Six" configuration, with aircraft instruments grouped as shown in Figure



Another important instrument is the Direction Indicator (DI) which gives to the pilot, in which direction, the aircraft is heading.

Directional changes are achieved by rolling (banking) and yawing (turning) the aircraft.

Hence very naturally, a Turn and Bank Indicator is positioned at the right side of DI.

To the left of DI is situated the Altitude Indicator (ALTI) giving information of flight level, usually in flight level units of 100 feet

Another grouping of instruments is known as "basic T", which is of more recent origin than the "basic six", and is shown in Figure

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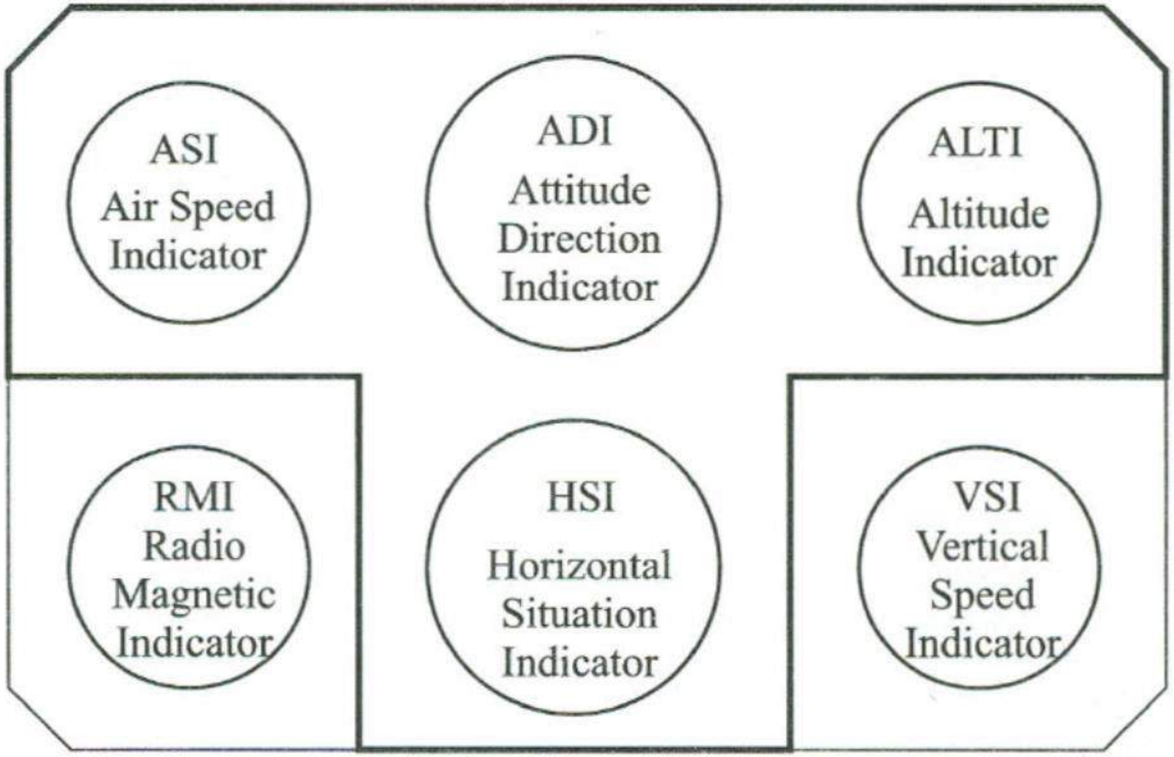


Most important indicators are:

- Air Speed Indicator (ASI)
- Attitude Director Indicator (ADI) and
- Altitude Indicator-ALTI
- Horizontal Situation Indicator (HSI)
- Vertical Speed Indicator (VSI)

HSI gives directional information to the pilots.On the right side of HSI is located a

Vertical Speed Indicator (VSI) gives rate of climb or descent of the aircraft

Aircraft Display Types

Aircraft displays form an important link between the pilots and the aircraft (man-machine loop).

Some of the more important requirements of the display system are:

1. They must be easy to interpret.
2. The display should be unambiguous.
3. Reliability should be very high.

4. Pilot effort should be minimum to read and absorb data content.

5. Accuracy of indication should be high.

6. Adequate sensitivity is required to sense small deviations.

9. Repeatability should be high to reduce repeated calibration efforts.

Display Types

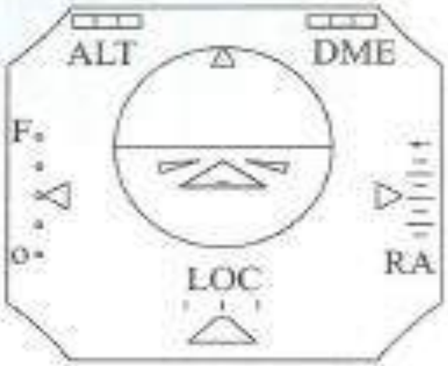
There are broadly two types of display:

1. Quantitative display, and
2. Qualitative display.

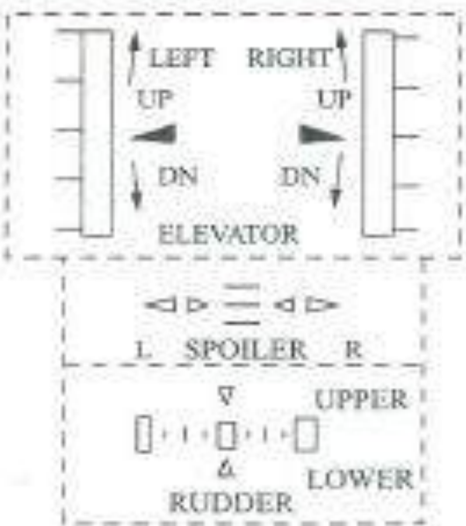
Classification of Aircraft Instruments

QUALITATIVE DISPLAYS

> Represents data as a symbol/moving bar/ command bar/horizon bar, etc.
> Examples: Electronic Attitude Director Indicator (EADI) as shown below:



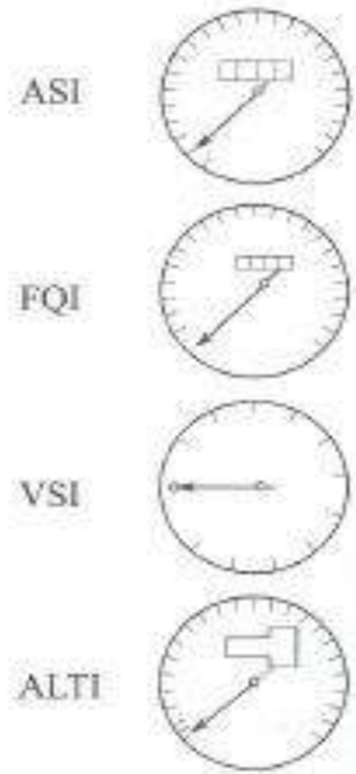
> Other qualitative displays include:
1) Flight Director (FD)
2) Attitude Director Indicator (ADI)
3) Horizontal Situation Indicator (HSI)
4) Electronic Horizontal Situation Indicator (EHSI)
5) Head Up Display (HUD)
6) Flight control surface positions as shown below



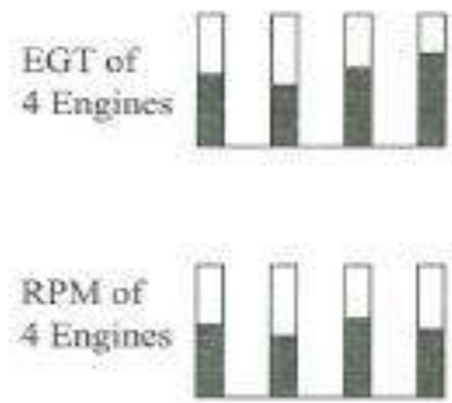
QUANTITATIVE DISPLAYS

> Represents quantitatively in numbers For example, dial reading on ALTI will give aircraft's altitude in feet
> Some examples are

Circular scales



Linear scales



Colour codes in circular displays

Red – Max limit

Yellow – Cautionary

Green – Normal

Red arc – Prohibited range

Quantitative Displays

In this type of displays, the data is displayed quantitatively as numbers either using a pointer-scale instrument or using an alphanumeric LED/LCD type numeric displays.

Examples of quantitative displays are: air speed indicator, altitude indicator, vertical speed indicator, etc.

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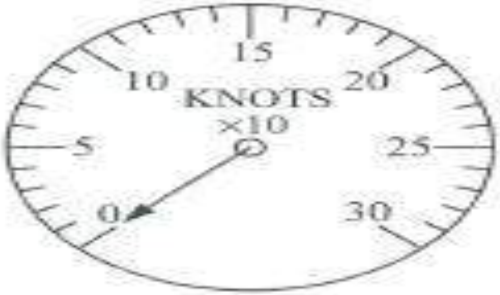
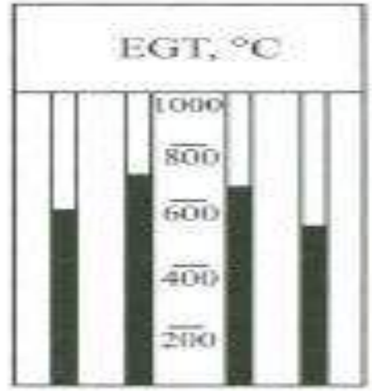
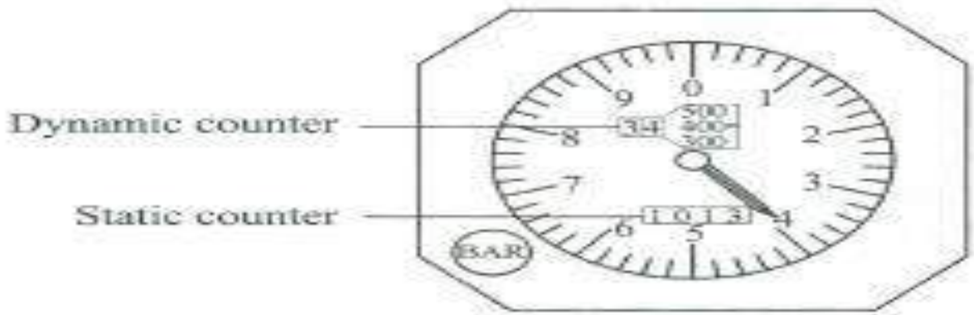


(a) Circular scale
(Air speed indicator)
(1 KNOT = 1.85 kmph)



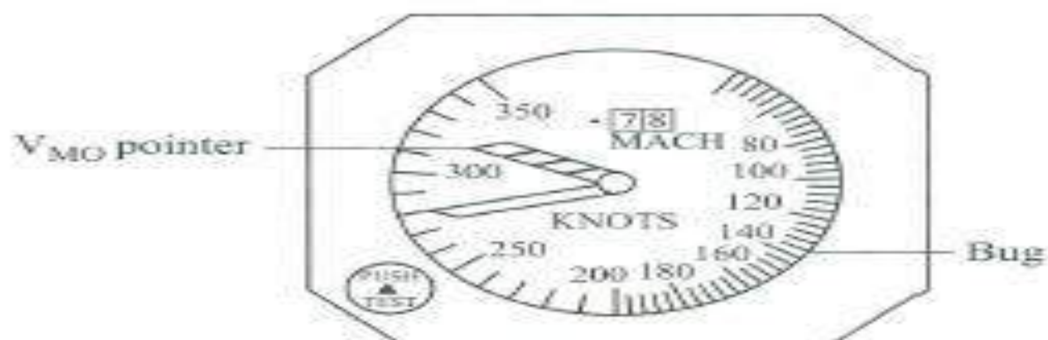
(b) Straight scale
(Exhaust gas temperature)

(c) Digital display
(Total air temperature)



(d) Digital counter display
(Altitude)

(e) Dual indicator
(to conserve space)



(f) Air speed indicator

Display Colour and Markings

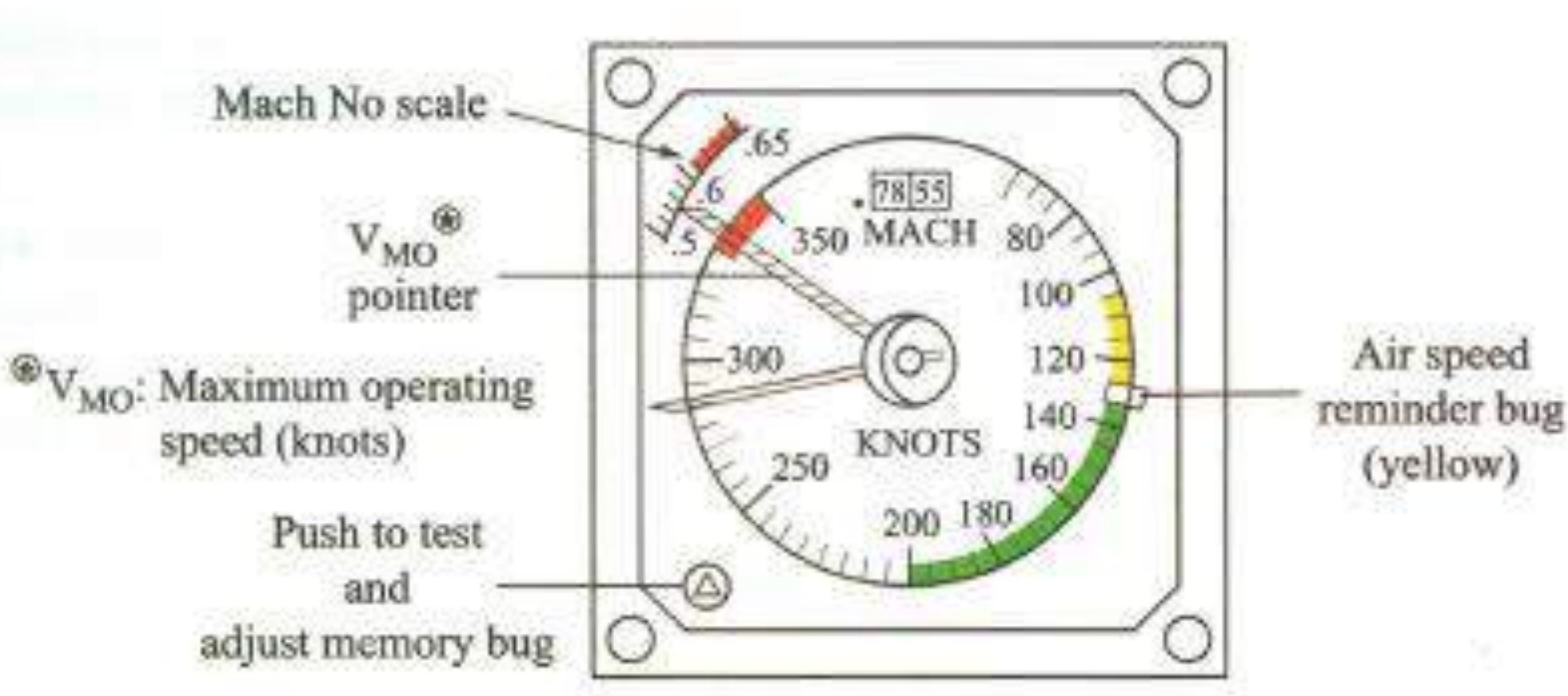
Pilots should be able to easily interpret, comprehend and be alerted about certain parameters exceeding maximum limits.

In order to achieve this, there are coloured arcs, radial lines and sectors, in order to highlight the limits of operation.

The markings use the following standard colour conventions:

Markings	Purpose
Red markings on scale	Maximum and minimum limits
Yellow arc	Take-off/precautionary sectors
Green arc	Safe and normal operational zone
Red arc	Prohibited zone

Figure shows some of the colour markings in an air speed indicator.



Qualitative Displays

Here pilot is presented with symbolic or pictorial representations; for example:

(i) a particular parameter-whether it is increasing or decreasing or

(ii) if a flap is deployed or not deployed,

(iii) whether the landing gear is up or down

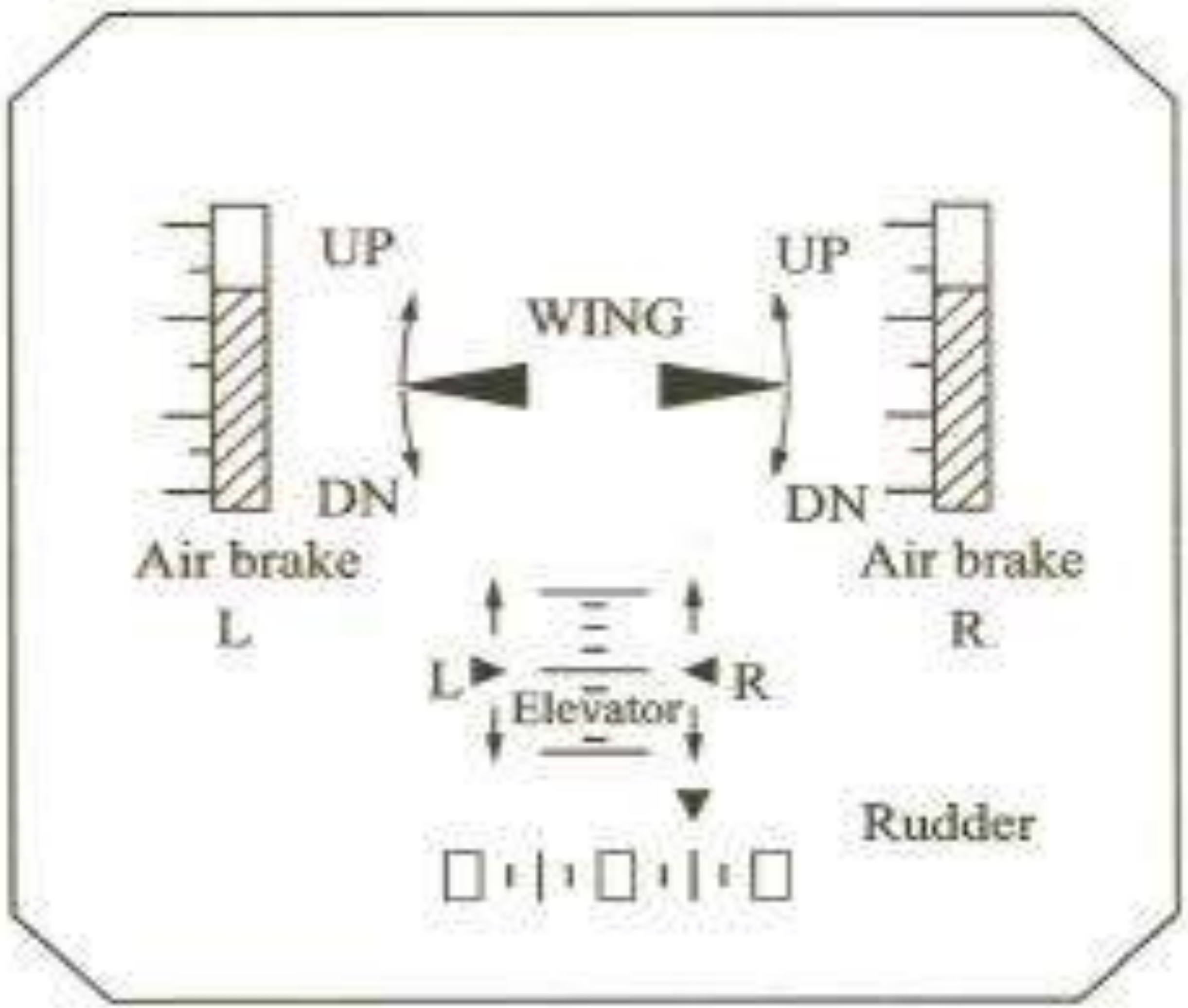
(iv) whether the aircraft wings are level or have moved to left or right,

(v) whether the elevator (left or right) has moved or not

(vi) whether the rudder has moved or not

(vii) air break surface up or down.

Figure shows some of these qualitative displays. There are no quantitative numbers associated with the markings.



Basic flight instruments:

Altimeter:

Giving the aircraft's height above some reference level by measuring the local air pressure. The altimeter has a provision to adjust to local barometric pressure which must be correctly set to obtain accurate altitude data, (BARO adjustment).

Attitude Indicator:

Shows the pitch, and roll and angles relative to the horizon.

By reading this instrument, pilot will be able to know whether the wings are level and if the aircraft nose is pointing above or below the horizon.

In modem aircraft Electronic Attitude Director Indicator EADI replaces this altitude indicator.

Air Speed Indicator (ASI):

This instrument displays the aircraft's speed in knots relative to the surrounding air.

The indicated speed should be corrected for air density in order to get the True Air Speed- TAS.

Magnetic Compass:

The magnetic compass is used to indicate the aircraft's heading relative to the earth's magnetic north, to know which direction the aircraft is flying with respect to the magnetic north.

While the compass shows reliable readings in steady and level flight, it gives faulty indications when turning, climbing, descending or accelerating.

Heading Indicator: (also known as Directional Gyro-DG).

It is based on the gyro stability and precession, and is therefore subject to errors, which must be periodically corrected by calibrating it with respect to the magnetic compass.

In modem aircraft, the DG is replaced by a Horizontal Situation Indicator (HSI), which provides the same heading information, but also helps in navigation

Turn and Bank Indicator (TBI):

The TBI is a gyroscopic instrument, displaying direction and the rate of turn, (in degrees per minute).

Turn Coordinator:

Typically displays the rate and direction of roll while the aircraft is rolling, displays rate and direction of turn, while the aircraft is not rolling. Internally housed inclinometer also displays the turn quality..

Vertical Speed Indicator (VSI):

Displays the rate of climb or descent, usually in feet per minute.

Vertical speed is indicated by sensing the changing air pressure during ascent or descent.

10-20400

Glass Cockpits of Modern Aircraft

- Features electronic instrument displays similar to PC glass monitor displays (hence the name glass cockpit), rather than old and unreliable electromechanical instruments.
- Utilizes computer-controlled displays that can be configured and adjusted to display flight information as required by flight phase and as needed by the pilots.

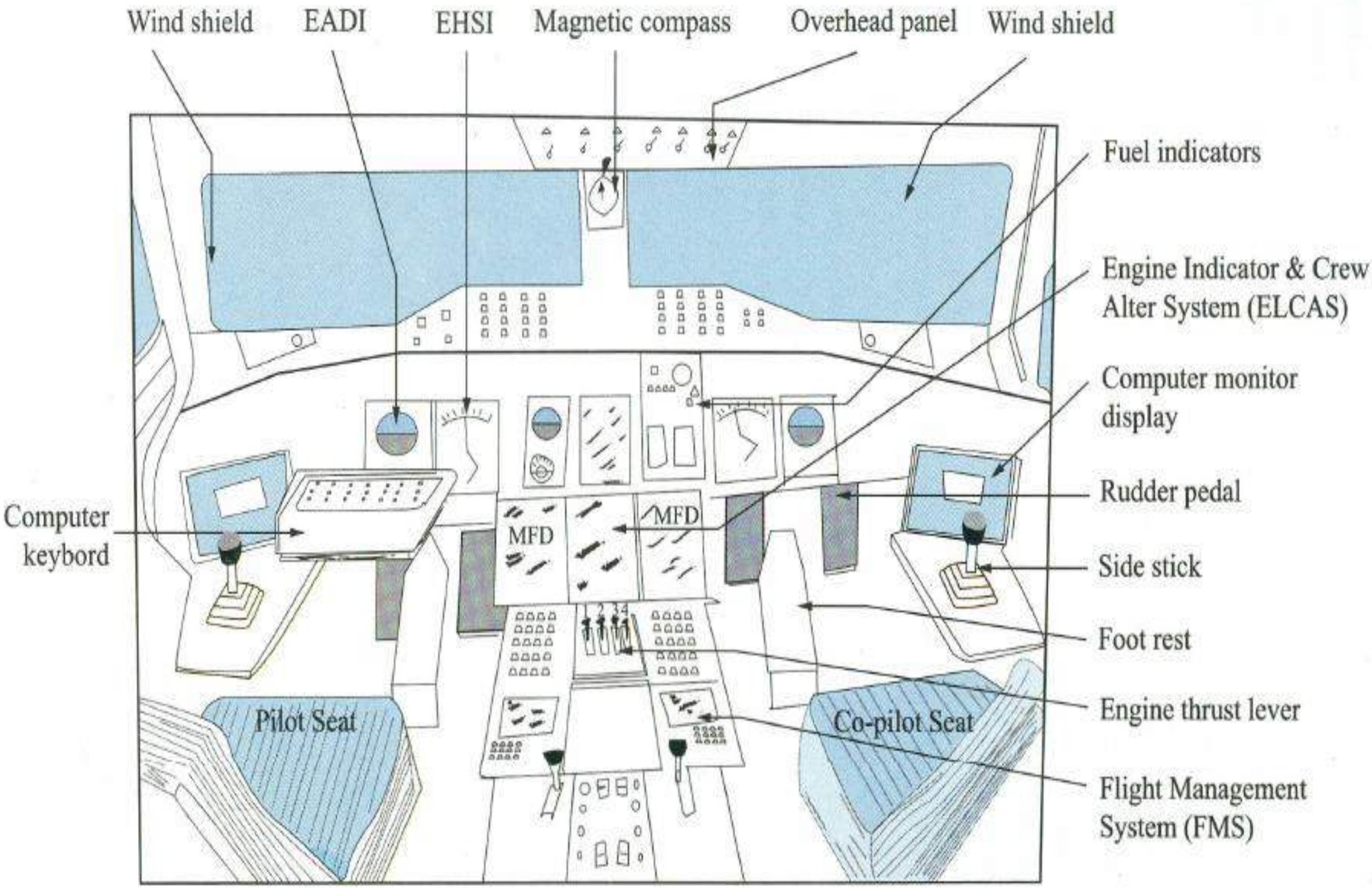


Fig. 2.13 All-glass cockpit of a modern aircraft.

Modern glass cockpit has an Electronic Flight Information System-(EFIS) as the primary component.

EFIS displays all information relating to aircraft's situation, position and progress. There are basically two display units-

- Electronic Attitude Director Indicator-EADI and
- Electronic Horizontal Situation Indicator-EHSI,

EADI is the Primary Flight Display (PFD), and EHSI contains the Navigation Display (ND).

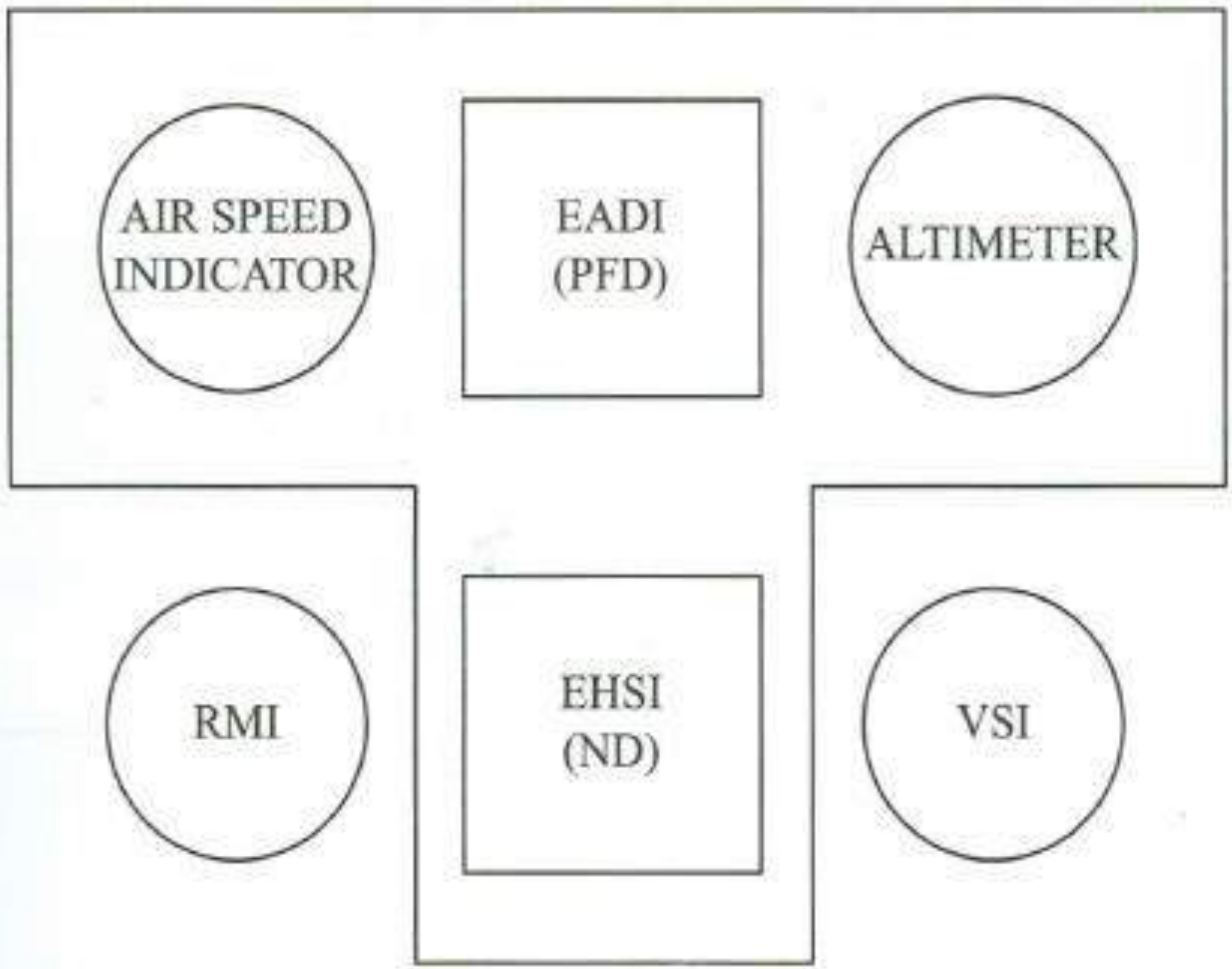


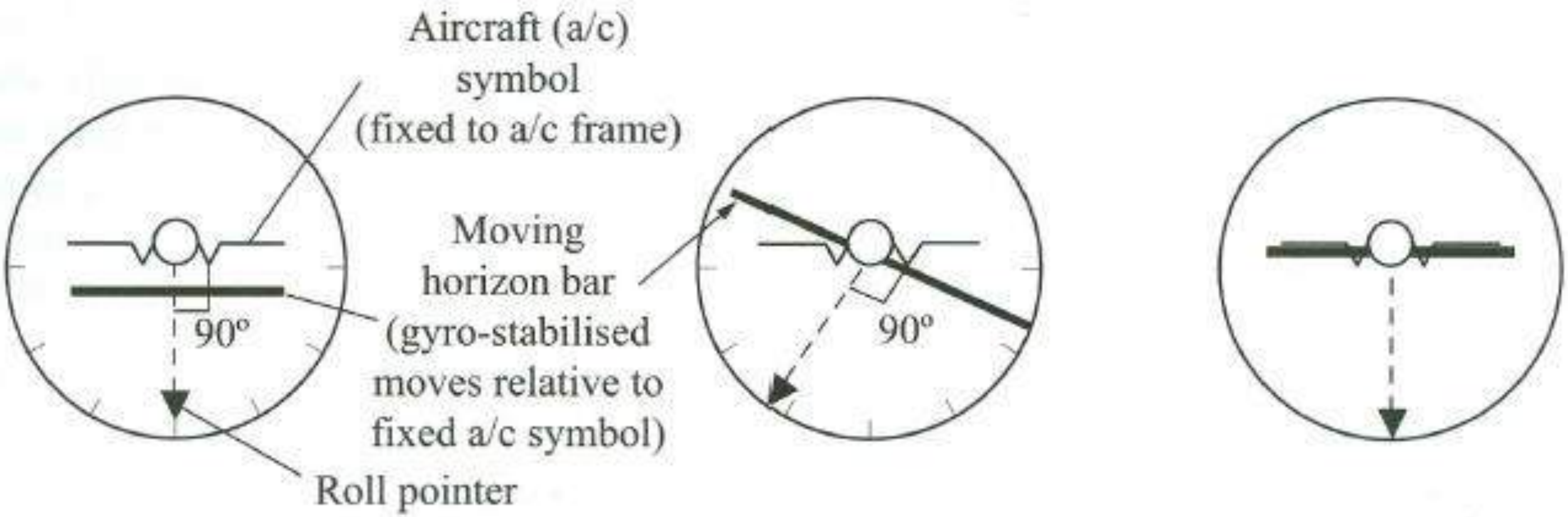
Fig. 2.12 Modern "glass cockpit" configuration with EADI and EHSI. This is duplicated for the co-pilot also.

The second part of the glass cockpit shows the aircraft's systems conditions and engine performance; this is either known as EICAS (Engine Indicator and Crew Alert System) by Boeing USA or as ECAM (Electronic Centralized Aircraft Monitor) by the Airbus France.

Attitude Director Indicator (ADI)

ADI is a Primary Flight Display (PFD), displaying all information critical to flight.

It indicates pitch (nose up/down) and roll (wings not level) of the aircraft .



(a) Aircraft flying, nose up, and wings level. Pilot must make the nose down to fly straight and level

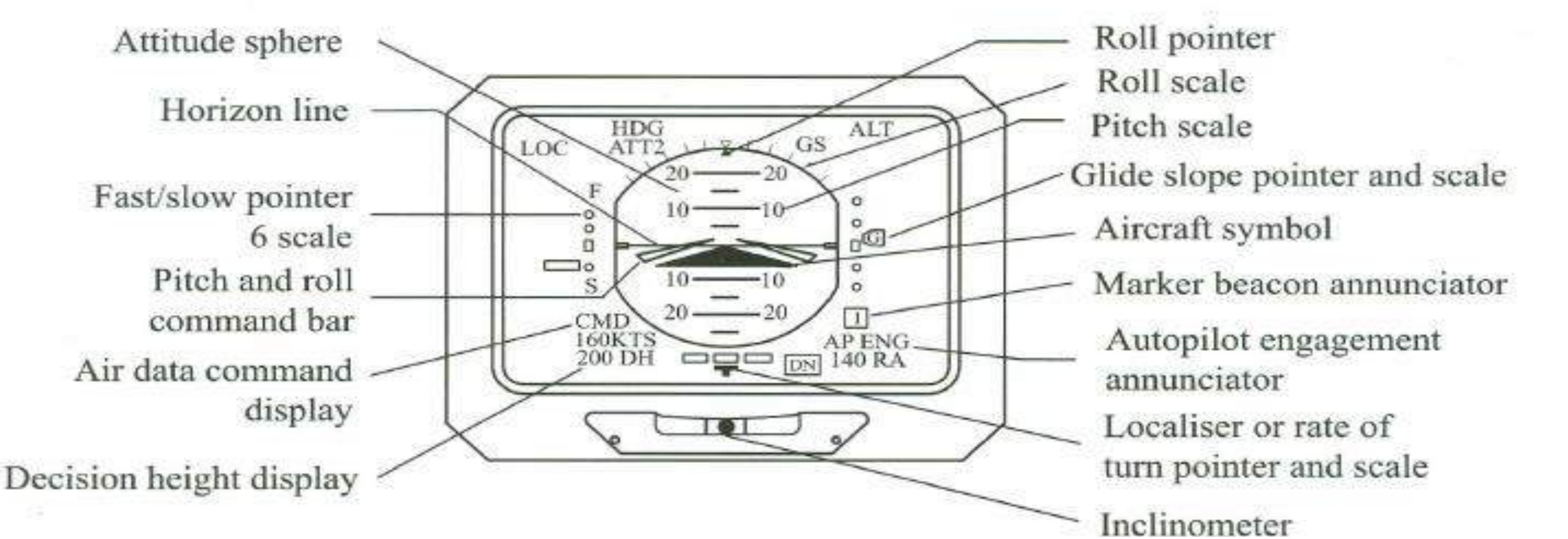
(b) Aircraft flying, with left wing below horizon (left banked). Pilot should roll right to fly straight and level

(c) Aircraft flying, straight and level

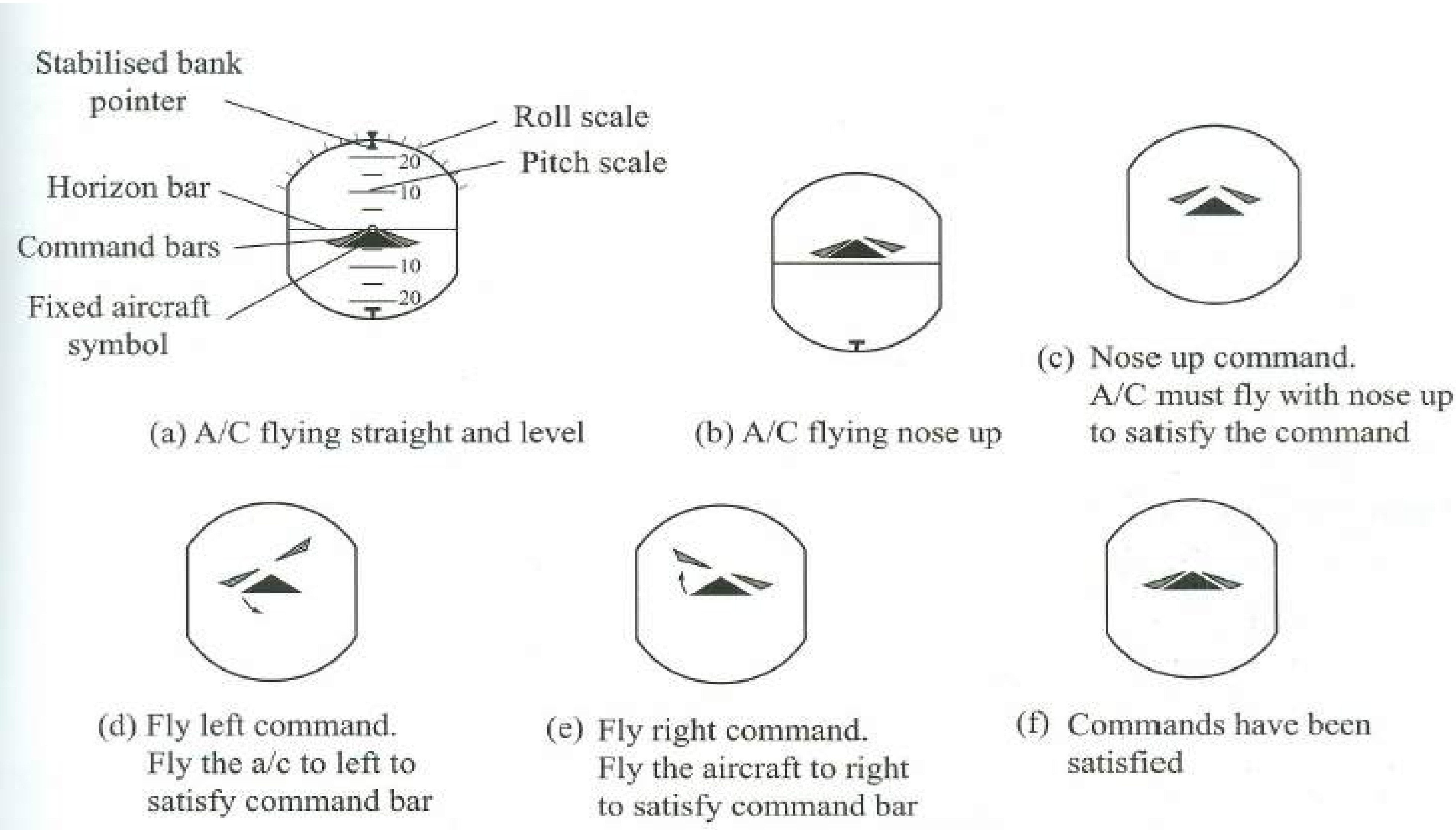
Fig. 2.14 Attitude Indicator (gyro horizon) with different aircraft attitudes (a) Pitch up (b) Left roll and (c) Straight and level flight.

Electronic Attitude Director Indicator

An improvement was made in EADI (Electronic Attitude Director Indicator), which in addition to displaying the attitude, issues commands using movable command bars.



The command bars can be preset by the pilot. Different command bar presentations are



(a) A/C flying straight and level

(b) A/C flying nose up

(c) Nose up command. A/C must fly with nose up to satisfy the command

(d) Fly left command. Fly the a/c to left to satisfy command bar

(e) Fly right command. Fly the aircraft to right to satisfy command bar

(f) Commands have been satisfied

Horizontal Situation Indicator (HSI)

The HSI is primarily a Navigation Display (ND), and it is an aircraft instrument located in Main Instrument Panel (MIP) , just below the ADI(Attitude Director Indicator).

In the electronic flight instrumentation system, it is known as EHSI (Electronic Horizontal Situation Indicator). HSI provides the plan view (map view) of aircraft motion which is important to navigate to the desired airport.

Thus, HSI provides a basic horizontal view of the aircraft's navigation around the earth. It provides an excellent picture for precise navigation.

EHSI displays: (i) magnetic heading, (ii) bearing and distance to navigation aid (VOR or ADF) and (iii) CDI (course deviation indicator).

An HSI is a combination of two familiar cockpit instruments:

- the directional gyro (DG)· with a heading memory bug and
- a VOR (VHF Omni directional Receiver) / ILS (Instrument Landing System) indicator.

EHSI reduces pilot's effort--otherwise the pilot has to eye scan many instruments individually.

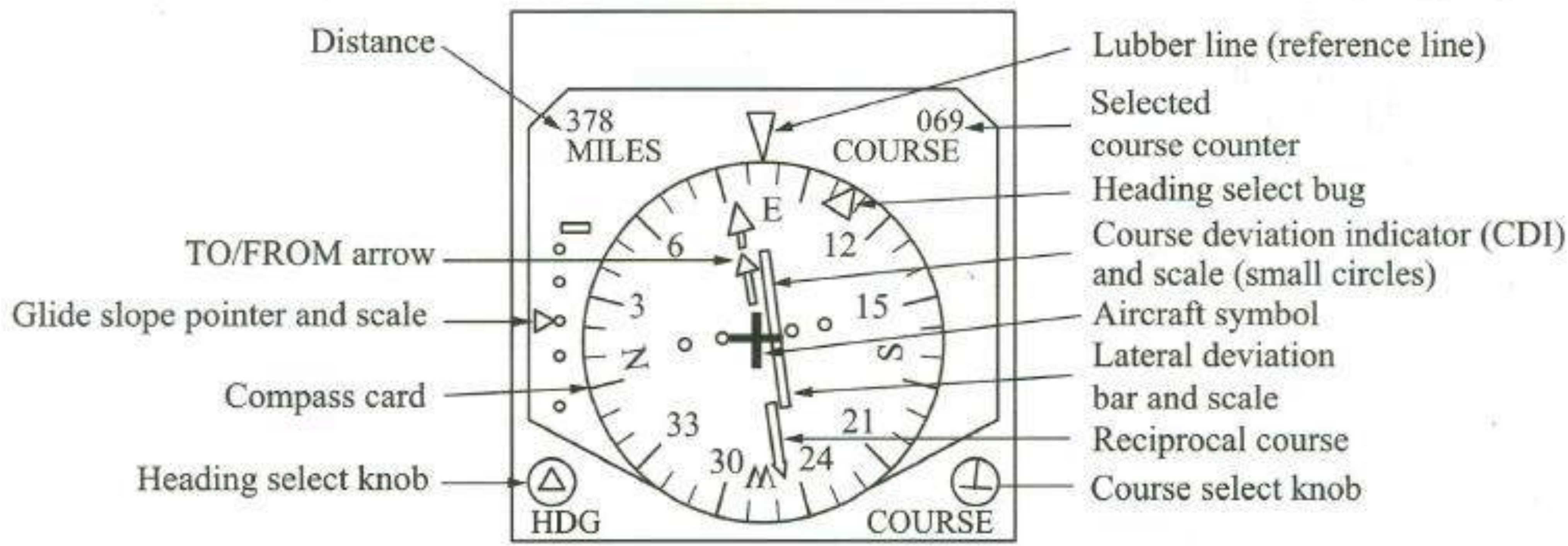
EHSI, which incorporates the following:

1. Glide slope needle for guiding the aircraft into the airport runway, in a vertical direction.

2. Course Deviation Indicator (CDI) is shown relative to airplane symbol, in azimuth (plan) direction.

3. Interlinked to autopilot to hold altitude and while approaching follow glide slope all the way to decision height (DH) and beyond.

4. Course deviation indicator (CDI) and scale.
5. Compass card operated by DG (directional gyro)
7. Heading select memory bug to aid the pilot to navigate to destination



Combining the DG and NAV indicator into a single instrument, reduces the pilot workload by providing the following vital information:

- heading-which direction the aircraft is going,
- course reference,which direction the aircraft has to go
- course deviation,
- glide slope information; while landing.

Electronic Flight Instrument System (EFIS)

An EFIS is an instrument display system in MIP (Main Instrument Panel). EFIS basically comprises:

1. Primary Flight Display (PFD)

2. Multi Function Display (MFD)

3. Engine Indicating and Crew Alert System (EICAS)

4. Control Panels

5. Data Processors including Symbol Generator Unit (SGU).

In 1970s aircraft used CRT displays. Present, newer generation EFIS incorporates, twisted matrix active-matrix-liquid crystal displays, which consume less power and the display is of exceptionally high quality.

1.Primary Flight Display (PFD)

PFD in a modem aircraft replaces ADI.

If a separate display replaces HSI, then it is known as ND(Navigation Display)

PFD displays all vital information critical to flight like: air speed, altitude,heading, attitude (pitch and roll), vertical speed and yaw.


FMC SPD
LNAV
VNAV PTH
175
427 M
1400
DME ----
LNAV/VNAV
CMD
5.2
220
3000
200
10
10
821 M
175
31
32
33
2600
160
10
10
140
2400
VREF
120
30/152
152
GS 181
29.92 IN.
30
31
32
33
34
35
120 H

PFD also alerts pilots to unusual or potentially hazardous conditions: like low aircraft speed, high descent rate, etc. This warning is accomplished by changing the colour and shape of the display plus providing synthesized voice alerts like "Whoops Whoops, pull up" or "Terrain, Terrain", etc.

PFD is configured to enhance pilot's situational awareness, by fusing this information into a single display, instead of a number of analog instruments, this minimizes the time to monitor the instruments, which becomes critical particularly during emergency situations.

PFD and ND are identical display units, which can be cross-connected to function either as PFD or ND. The information displayed depends on the system interface.

Present-day display units use colour AMLCD technology which consume less power, generate less heat, lighter and occupy a lower volume. The initial problems of reliability and viewing angle have been successfully resolved.

Modem aircraft use Twisted Active Matrix Liquid Crystal Displays (TAMLCD), which replaces earlier CRT displays.

2.Multi Function Display (MFD)

MFD is primarily a Navigation Display (ND) unit. It combines data superimposed on the map.

3.Engine Indications and Crew Alert Systems (EICAS)

EICAS shows information regarding the aircraft's systems such as fuel, electrical, engines, etc.

EICAS also alerts pilots of unusual or hazardous situations like low engine lubricating oil pressure, engine overheat, autopilot malfunction, loss of emergency/utility power, etc.


TO
TAT +19 c
64.4
68.9
N1
629
646
EGT
74.0
75.9
N2
1.64
2.07
FF/FU
KG x 1000
OIL P
OIL T
100
OIL Q %
100
VIB
A
B
HYD P
98
HYD Q %
99
2386
CTR
11536
FUEL KG
1510
IMBAL

4.Mode Control Panels

Pilots can select display range and mode as well he can enter data, using the control panel.

For example, command bars mentioned earlier are set using knobs in Mode Control Panels.

5.Display Data Processors

The visual display of an EFIS is made possible through the SGU (Symbol Generator Unit), which gets data from the pilot, sensors and format selected. SGU is also called display processor, or display electronics unit.

First generation flight decks

- Avionics developments in the mid-1970s allowed significant digitalization of flight deck systems, leading to the consolidation of a number of legacy interfaces into combined electronic displays.
- Fig. illustrates the historical evolution of first, second and third generation electro-optical deck displays, which included
- Electronic Attitude Director Indicator (EADI) and
- Electronic Horizontal Situation Indicator (EHSI);
- Electronic Centralised Aircraft Monitor (ECAM) or Engine-Indicating and Crew-Alerting System (EICAS); as well as
- Multipurpose Control and Display Unit (MCDU) of the Flight Management System (FMS).

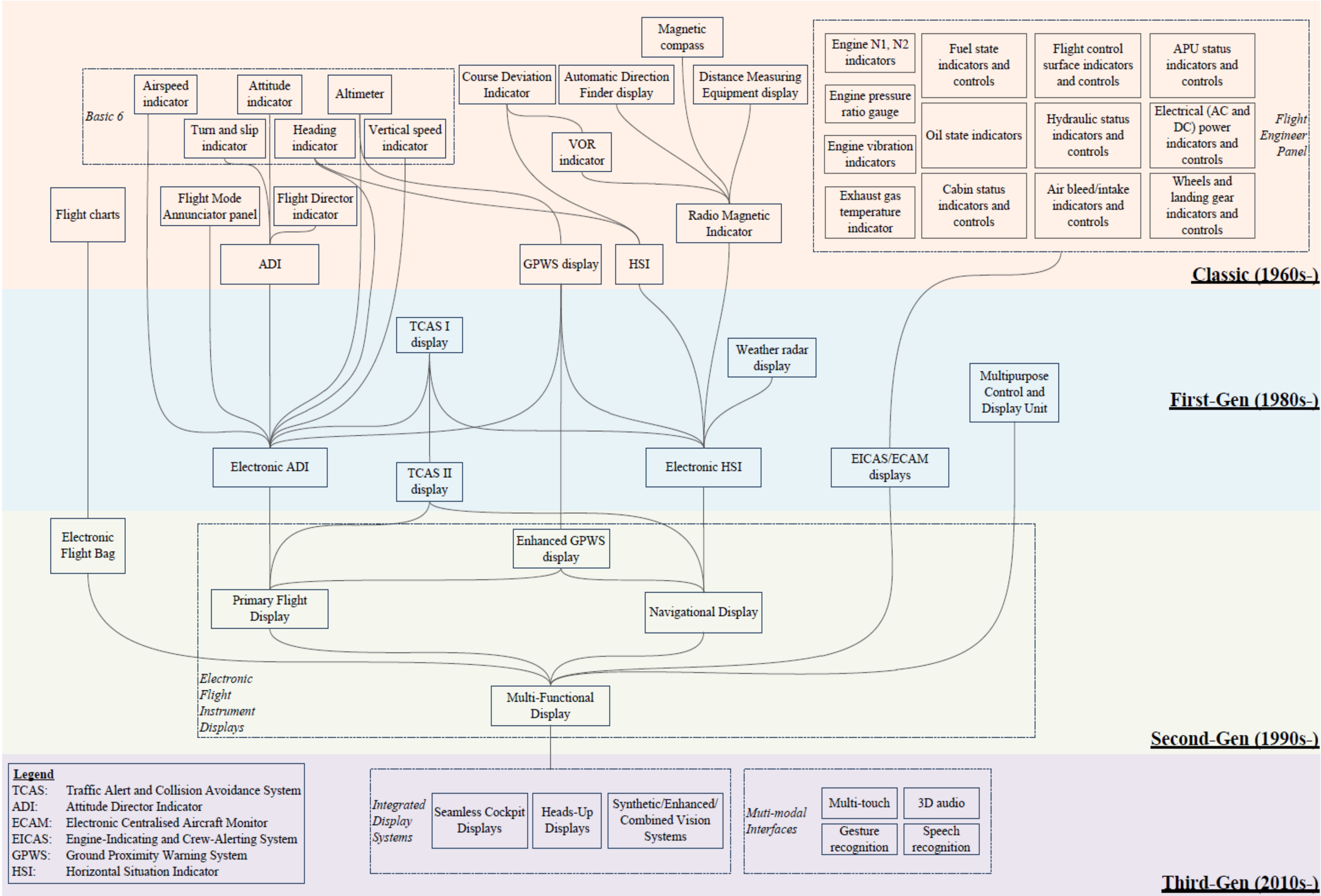


Fig. 6. Evolution of flight deck displays.

- The Boeing 757 and Airbus A310 were among the first aircraft to feature these electronic displays.

Fig. 7. Boeing 757, first generation flight deck, [12].

Traffic Collision Avoidance Systems

- Traffic Collision Avoidance Systems (TCAS) belong to a family of airborne systems providing traffic advisories and collision avoidance protection independently from ground-based ATC.
- A TCAS display shows the location of proximate traffic.
- TA (Traffic advisories) provide cautions and warnings to indicate possible conflicts with proximate aircraft, while (Resolution advisories) RA recommend vertical manoeuvers (either a climb or descent) to the pilot for avoiding the conflict, coordinated between the two TCAS-equipped aircraft when possible.

The major components of TCAS are:

- TCAS computer unit
- Mode S Transponder
- TCAS control panel
- Cockpit display .

Fig. shows a typical TCAS display containing both TA and RA information.

- A number of changes to the TCAS system over time has been done. The changes include:
- Improved TCAS logic Additional TCA advisories
- Modifications to the presentation of information
- Proposed downlinking or sharing TCAS information.

Electronic ADI and Electronic HSI

- The Electronic Attitude Directional Indicator (EADI) and Electronic Horizontal Situation Indicator (EHSI) serve as electronic replacements of the ADI and HSI.
- The EADI and EHSI integrate salient flight information on a central display, thereby reducing the need for the flight crew to cross scan between multiple instruments.
- The EADI and EHSI also interface with other avionic systems, such as the Mode Control Panel/Flight Control Unit (MCP/FCU) or the FMS to provide navigation and guidance information in addition to basic control information.

- Depending on the information required by the pilot, the EHSI can be switched between different modes.
- The main modes include:
- MAP (or NAV): used for most phases of flight, different toggles can be used to display NAVAID, route, airport or waypoint information, as well as VNAV path deviation;
- ILS : used for approaches, display depends on the type of approach being performed
- VOR: used for VOR navigation, displays the VOR indicator on top of a compass rose.

Flight Management System

- The Flight Management System (FMS) was first introduced on the Airbus A310 and Boeing 767 in the 1980s and has become a key avionic system on-board modern airliners.
- The FMS has been described as the heart of an airplane's flight planning and navigation function , integrating data from a number of subsystems including guidance, navigation, control, aircraft performance, systems management as well as air-ground communication.

- A typical FMS consists of one or more Flight Management Guidance Computers (FMGC) and Control Display Units (CDU).
- The tasks performed by the FMS include performance calculations, trajectory prediction, flight planning and optimization, as well as vertical/lateral guidance.
- While early functionality was limited to lateral navigation and vertical guidance, later versions of the FMS have incorporated additional functionalities including flight planning, wind and temperature modelling, performance prediction, integration with Global Navigation Satellite System (GNSS) data as well as Controller Pilot Data Link Communications (CPDLC) capabilities.

- Fig. illustrates a Boeing-style Multifunction Control Display Unit (MCDU).

- The MCDU contains multiple pages, which allow the flight crew to access different FMS functions.
- Pages are selected by pressing the page keys.
- Line select and skew keys allow the user to navigate within and between pages.

The main pages on the Airbus MCDU are:

- **DIR**: used to initiate a direct flight to a waypoint not in the programmed flight plan;
- **PROG:** provides flight information (e.g., optimum and maximum cruise flight levels) corresponding to the flight phase that is currently in progress;
- **PERF**: provides performance data associated with the active flight phase;
- **INIT:** used for pre-flight initialisation of the flight plan;
- **DATA:** aircraft and navigation sensor status, as well as FMGC data bases and stored data;
- **F-PLN**: used to view and make revisions to the lateral and vertical elements of the flight plan;
- **RAD NAV**: displays the NAVAIDs tuned by the FMGC or selected by the pilot;
- **FUEL PRED**: used for fuel prediction and management;
- **SEC F-PLN**: used to access the secondary flight plan;
- **ATC COMM:** used for text-based communications between the flight crew and ATC.

Crew Alerting Systems

- The 1980s also saw the introduction of Crew Alerting Systems (CAS) such as the Electronic Centralised Aircraft Monitor (ECAM), and the Engine-Indicating and Crew-Alerting System (EICAS).
- The ECAM was developed by Airbus and first used on the A310 while the EICAS was developed by Boeing and first used on-board the 767.
- While there are slight differences between the two displays, both the EICAS and ECAM essentially serve the same purpose of monitoring multiple aircraft systems, consolidating monitoring data into integrated displays, alerting the flight crew of any abnormal conditions, as well as providing relevant advisories.

- Indications are classified in increasing importance: as memos (used to recall normal or automatic selection of functions), advisories (used when a monitored parameter drifts out of its normal operational range), cautions (used for events requiring crew awareness but not immediate action) or warnings (used for events requiring immediate crew action).
- In the event of multiple faults or failures, the relevant indications are prioritized according to their level of importance.

- Typically, EICAS/ECAM displays are situated in the middle of the flight deck and are composed of an upper and lower display.

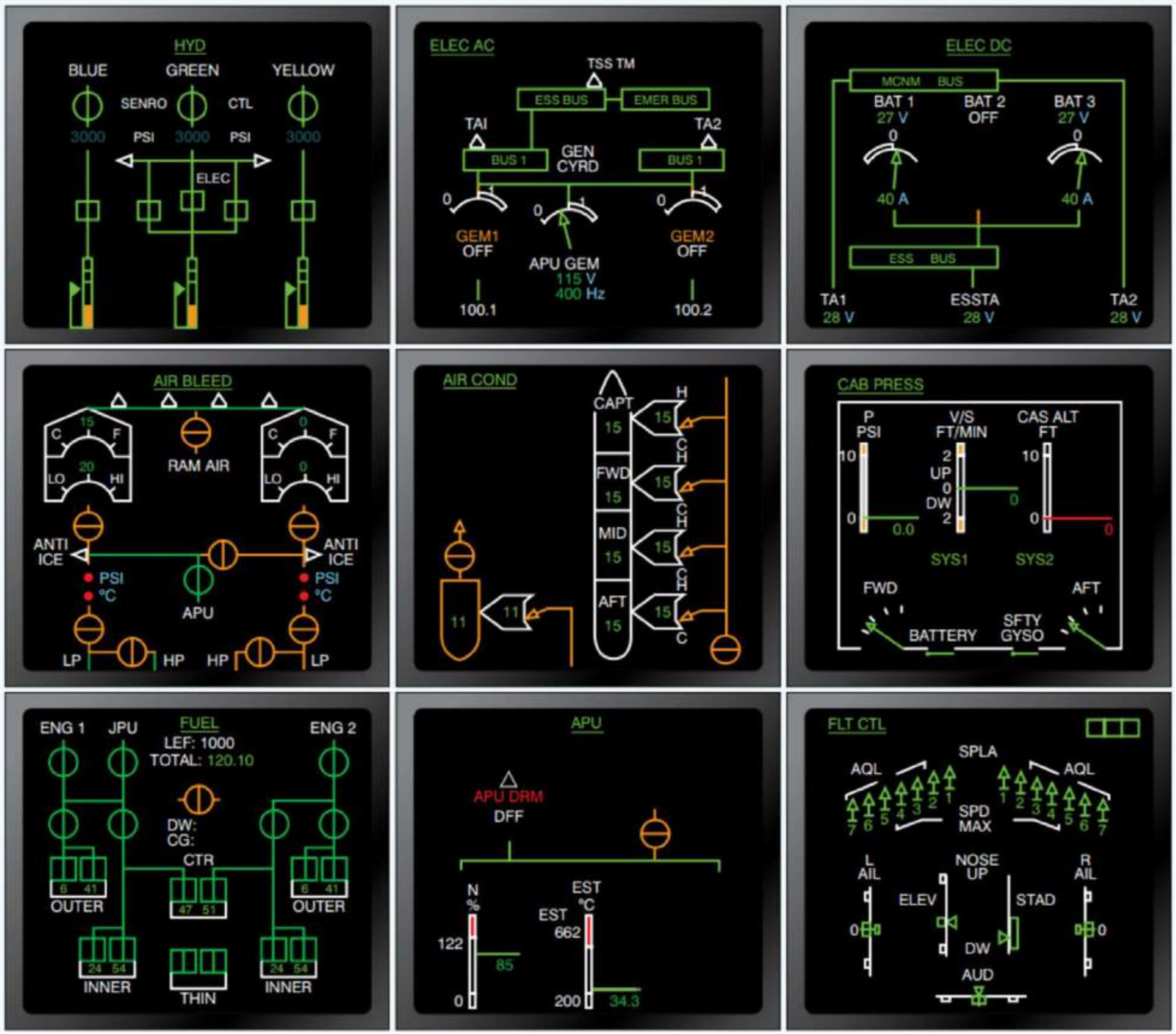
The top display provides information relevant to primary systems (mainly engine parameters), such as:

- Primary engine parameters (thrust limit mode, N1, exhaust gas temperature,N2, fuel flow, etc.);
- Total and static air temperature;
- Quantity of fuel-on-board;
- Slat and flap position;
- Landing gear position;
- Summary messages or remedial instructions.

- The lower unit typically contains secondary engine data, the status of secondary systems in the aircraft, or remedial procedures in the event of system malfunctions or failures.

Information is displayed on multiple pages, which can include:

- Secondary engine parameters (fuel used, oil quantity, oil pressure, oil température, engine vibration, engine bleed pressure, etc.);


HYD
BLUE
GREEN
YELLOW
SENRO
CTL
3000
PSI
3000
PSI
3000
ELEC
ELEC AC
TSS TM
ESS BUS
EMER BUS
TAI
TA2
BUS 1
GEN
CYRD
BUS 1
GEM1
OFF
APU GEM
115 V
400 Hz
GEM2
OFF
100.1
100.2
ELEC DC
MCNM BUS
BAT 1
27 V
BAT 2
OFF
BAT 3
27 V
40 A
40 A
ESS BUS
TA1
28 V
ESSTA
28 V
TA2
28 V
AIR BLEED
RAM AIR
ANTI
ICE
ANTI
ICE
PSI
°C
PSI
°C
APU
LP
HP
HP
LP
AIR COND
CAPT
FWD
MID
AFT
CAB PRESS
P
PSI
V/S
FT/MIN
CAS ALT
FT
UP
DW
SYS1
SYS2
FWD
AFT
BATTERY
SFTY
GYSO
ENG 1
JPU
FUEL
LEF: 1000
TOTAL: 120.10
ENG 2
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Second generation flight decks

- Second generation flight decks, such as the A320 and Boeing 747-400 are characterised by additional integration of avionics systems, allowing further consolidation of the displays used in first generation decks.
- The Electronic Flight Instrument System (EFIS) is a general term referring to the set of all electronic display systems used on-board second generation flight decks.
- EFIS displays typically include the Primary Flight Display (PFD) and Navigation Display (ND).

Advantages of EFIS are:

I. The same display can be made to function as PFD, ND, offering versatility.

2. Software upgradable to latest versions without changing hardware.

3. Should one of the display fail, the other can take over and thus act as a redundant system.

4. Any LRU can be plugged in anyone of the five slots

- As the EFIS uses standard display units, each display unit is inherently reconfigurable and interchangeable between different display modes.
- Such displays can perform multiple functions and are therefore known as Multi-Functional Displays (MFD).

Boeing 747-400, second generation flight deck.

Enhanced GPWS

- The Enhanced GPWS (EGPWS) was introduced in 1996.
- The EGPWS augments the classic GPWS with an internal database comprising terrain, obstacle and airport runways as well as the capability to relate the aircraft position to these databases, thereby providing predictive alerting and display functionalities.
- The added functionalities of the EGPWS includes two additional operating modes as well as a number of enhanced functions (e.g., envelope modulation, terrain display, terrain look ahead alerting, terrain clearance floor) .

- Terrain display is an enhanced function for depicting surrounding terrain on compatible and enabled displays (e.g., EFIS displays). In the plan view display, relative terrain elevation is represented by various colours and intensities (primarily black, green, yellow and red).

- Terrain look ahead alerting is an enhanced function, which provides more time for the flight crew to react to alerts, which are issued typically 60 s (cautions) or 30 s (warnings) prior to a predicted terrain conflict.

- The EGPWS compares the aircraft's position, flight path angle, track and speed against an internal terrain database to determine possible conflicts.

- Terrain clearance floor is an enhanced function, which alerts pilots of possible premature descent during non-precision approaches. Using runway position data, a protective envelope is first defined around all runways.
- During approach, if the aircraft descends below these envelopes, the voice alert “Too low terrain” is triggered.

Display Systems

- It provides the visual interface between the pilot and the aircraft systems – HUD, HMD, HDD.

- HUD and HMD can project the display information into the pilot's field of view so that the pilot can be head up and can concentrate on the outside world. HUD can also display a **FLIR** (Forward Looking Infrared) video picture.

- The HMD enables the pilot to be presented with information while looking in any direction, as opposed to the limited forward field of view of the HUD.

- Multi-function colour displays (HDD) provide the primary flight displays (PFDs) of height, airspeed, Mach number, vertical speed, artificial horizon, pitch angle, bank angle and heading, velocity vector and also engine data.

Display Systems – HUD Images

Display Systems – HMD Images

Display Systems – Primary Flight Display

Display Systems – HDD

HDD monitor

HDD color CRT

Cockpit Display of Traffic Information

- The Cockpit Display of Traffic Information (CDTI) is an evolution of the TCAS and navigational displays for providing flight crew with greater situational awareness of surrounding traffic.

CDTI displays are designed to integrate and display traffic information from a range of different sources, such as

- Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Service – Broadcast (TIS-B), and can also depict terrain or weather information.

- CDTI information can be displayed using two views – a plan-view Traffic Situation Display (TSD) and a side-view Vertical Situation Display (VSD) – improving flight crew awareness of proximate traffic and facilitating the execution of more complex lateral/vertical avoidance manoeuvers.

Multi-Functional Displays

- Multi-Functional Displays (MFD) feature multiple pages, with each page typically serving a specific function.
- MFD allow pages to be switched either automatically or manually and for information to be layered on a single page, thus allowing the presentation of data from many sources.
- Emerging MFD in the business jet market also provide multi-touch capabilities and can also serve as Combined Vision Systems (CVS) by overlaying Enhanced Vision Systems (EVS) images onto synthetically generated terrain

The considerations for designing MFD briefly include:

- Accessibility and sensitivity of control and input elements (e.g., push buttons and touch screens);
- Colour and symbology usage;
- Organization of information elements (e.g., menus, windows, overlays);
- Clutter management;
- Sharing and switching between different functions

Third generation flight decks

- Advances in display technology will pave the way for larger MFD, providing fully integrated and interchangeable displays.
- Synthetic Vision Systems (SVS) are already in use in some business jets such as the Bombardier Challenger 650 and are likely to be integrated into the displays of third generation civil flight decks.
- EVS (Enhanced Vision Systems) such as Heads-Up Displays (HUD) are being offered on some civil aircraft such as the Boeing 787 and the Airbus A320.
- Both SVS and EVS provide increased safety for flight in low visibility conditions such as darkness, smoke, fog or rain.

- The quality of SVS images depends on the accuracy and precision of navigation data as well as the validity of the database.
- EVS uses imaging sensors (such as forward looking infrared, millimeter wave radar and/or low light level image intensifying) to provide the flight crew with a sensor-derived or enhanced image of the external scene.
- As such, the quality of EVS images very much depends on the type of sensors used.
- CVS (Combined Vision Systems) combines information from synthetic and enhanced vision systems in a single integrated display.

The human factors considerations associated with these vision systems include:

- Image quality (e.g., field-of-view, display size, clutter, symbology, brightness, contrast, data inaccuracy, noise, lag, jitter, etc.);
- Information integration (e.g., information presentation, information organization, systems and display integration, operator-related cognitive demand, workload demand, skill retention, etc.);
- Operational concepts (e.g., display transitions, crew interaction, procedural changes, failure modes, depiction of essential information, crew trust, resource management, etc.).

Airborne Collision Avoidance System X

- Airborne Collision Avoidance System (ACAS) X is a proposed concept that has already undergone a number of flight tests .
- The decision logic of ACAS X is based on a probabilistic approach, different from the rule-based logic of legacy TCAS systems.
- The approach allows for uncertainties in aircraft state, as well as pilot response to be taken into account in the collision avoidance decision logic, offering greater operational flexibility and pilot acceptance in addition to enhanced safety.

There are four variants of ACAS X:

- ACAS Xa (active), the general purpose ACAS X that will replace TCAS II;
- ACAS Xo (operation), designed for particular operations where ACAS Xa is unsuitable;
- ACAS Xp (passive), intended for low performance general aircraft lacking certified collision avoidance protection;
- ACAS Xu (unmanned).

Speech recognition

- Speech recognition is an emerging concept that is being considered for implementation in third generation flight decks.

Potential applications of speech technology include :

- Voice-based FMS inputs;
- Voice-based tuning of radio frequencies;
- Calling up and interacting with voice-based checklists;
- Synthesis of multi-modal interactions (e.g., touch screen, gesture recognition, eye tracking) to support context-aware inputs;
- Using voice authentication to augment cyber-security;
- Reduction of cultural bias or language misunderstanding through language-neutral cockpits;
- Emotion, stress and workload identification.

However, a number of challenges include:

- Accidental/inadvertent triggering of the system leading to unintended inputs;
- Accuracy of the speech recognition system, which is affected by a number of factors, including aircraft background noise, user differences (e.g., tone, pitch, accents) as well as the type of system used;
- Changes in a user's voice under different operational (e.g., high/low workload) conditions, which might affect system accuracy;
- Reductions in system vocabulary, which might improve system accuracy at the cost of limiting the number of possible applications of the system;
- Training time required for speaker-adaptive systems to adapt to the user
- User acceptance – some pilots prefer a sterile cockpit without small talk.

Enhanced audio

- In current flight decks, audio is used to provide secondary warnings, or in critical cases, to issue instructions for evasive action (as in the case of TCAS and GPWS advisories).
- Enhanced auditory displays can potentially reduce operator head down time on visual displays, while providing an additional channel to convey information to operators.

Research in enhanced audio are focused on a number of key areas:

- 3D audio for conveying spatial information (e.g., traffic proximity and location);
- Spatial separation of different auditory sources to facilitate user localization.
- Synthetic speech for voice narration of data link messages.
- Enhanced audio concepts have also been explored in military applications, primarily for representing spatial information, augmenting situational awareness and improve overall operator performance.

Military cockpits

- It is observed that advances in military aviation technology are generally ten to fifteen years ahead of their civil counterparts. Some examples include:
- The first fighter jets were introduced about a decade before the start of the civil jet age in 1952.
- Glass displays were used in third and fourth generation military cockpits in the 1970s, approximately a decade before the technology became available on civil flight decks of the 1980s.
- Fly-by-wire was first implemented in fourth generation fighter aircraft such as the F-16 (introduced to service in 1978) before being adopted in civil aircraft such as the Airbus A320 (introduced to service in 1988).

- While first and second generations of fighter jets were designed to maximise aircraft performance (e.g., speed, range, payload capacity, manoeuvrability, etc.), the third generation of fighter aircraft had enhanced capabilities which were brought about by advances in mission and avionics systems (e.g., stealth, surveillance, weapons, etc.).
- These third generation fighters incorporated precision-guided munitions systems, which supported the transition to engagements beyond the visual range and led to the development of increasingly advanced systems for detection, acquisition, engagement and evasion of enemy aircraft.

- The transition to the fourth generation of fighters saw further advances in mission systems, allowing swing and multi-role fighters capable of operating in air-to-air or air-to-ground roles, or performing airborne reconnaissance, surveillance and support.
- Currently, fifth generation fighters are being developed to support network-centric warfare.
- Fifth generation fighter aircraft are characterized by their inherent capability to network with other aircraft and manage large amounts of data by intelligent data fusion algorithms, thereby enhancing the fighter pilot's situational awareness and tactical decision-making in increasingly complex scenarios.

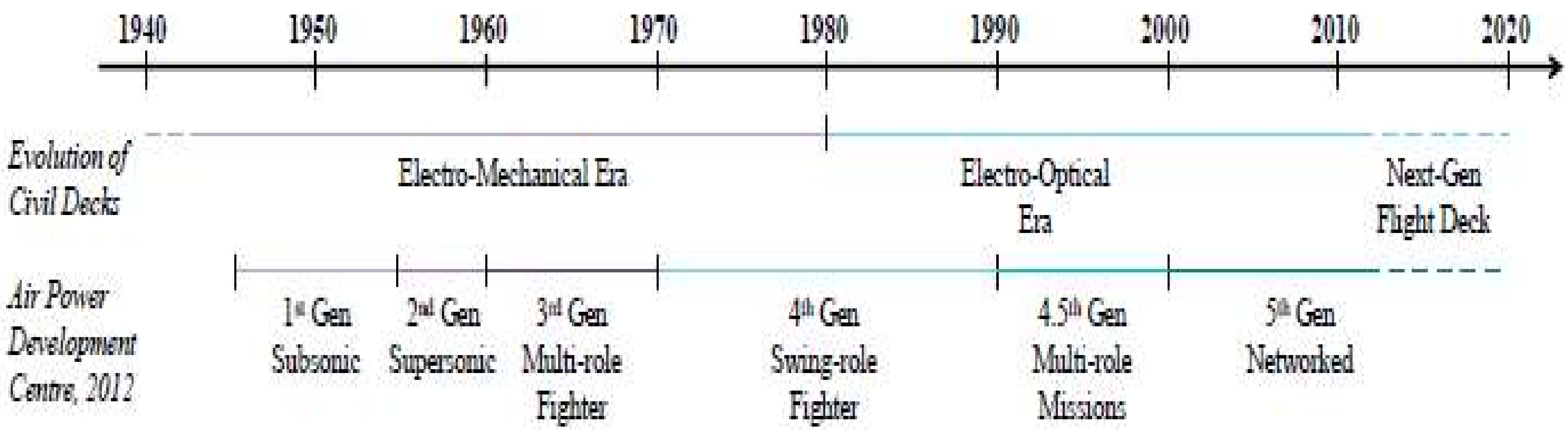

Fig. 15. Evolution of military fighter aircraft.

First to third generation military cockpits

- Similar to flight decks of the electro-mechanical era, first to third generation cockpits featured dedicated analogue displays and instrumentation.
- Guided missiles were used on second and third generation fighters with the support of radar and infrared technologies.
- Late-second generation and third generation cockpits also saw the use of the electro-optical radar scope.
- Third generation fighters such as the F-4, featured more advanced radar systems such as the Doppler radars, which supported “look-down, shoot-down” capabilities. The F-4 was manned by two crew members, with the pilot sitting in the front seat and the Radar Intercept Officer (RIO) managing the advanced radar system in the back.

F-4 Phantom II, a third generation fighter.

Fourth generation military cockpits

- Fourth generation aircraft such as the F-15A saw the introduction of advanced flight control systems. Fighters such as the F-16 and Mirage 2000 were designed with increased responsiveness and manoeuvrability but were inherently unstable.

F-15A Eagle, a fourth generation fighter, image courtesy of the National Museum of the U.S. Air Force.

- Fly-by-wire systems were designed to compensate for this lack of stability by providing artificial stability.
- The head-down analogue instruments used in first to third generation fighters were gradually replaced with electro-optical displays in fourth generation cockpits.
- MFD-style displays, which were used by second generation civil flight decks of the 1990s, were already found in F-16 cockpits since the late 1970s.
- Similar to civil flight decks, MFD on fighter cockpits consolidated the displays of numerous standalone instruments into single glass displays, allowing fighter pilots and Weapon Systems Officers (WSO) to switch between different display configurations and functions.

MFD supported the transition of fighter aircraft with dedicated roles, to multi-role and swing-role fighters.

Typical MFD pages include:

- Horizontal Situation Display (HSD);
- Fire Control Radar (FCR);
- Stores Management System (SMS);
- Terrain Following Radar (TFR);
- Forward Looking Infrared (FLIR);
- Targeting Pod (TGP);
- Flight Control System (FLCS);
- Data Terminal Entry (DTE);
- Weapon Systems (WPN).

- In addition to the head down MFD, fourth generation cockpits also feature HUD that are now beginning to appear in modern flight decks.
- The HUD is considered to be the aircraft's PFD and displays primary flight data.
- Additionally, fighter HUD typically include G readouts as well as weapon targeting information.
- The HUD allows fighter pilots to maintain situational awareness by providing pilots with crucial flight and combat information that they would otherwise have to obtain by shifting their gaze down toward the heads down displays.

- Another feature introduced in fourth generation fighters is the Hands on Throttle-and-Stick (HOTAS) controls.
- Buttons and switches are located on the HOTAS, allowing pilots to perform some tasks without taking their hands off the controls.
- The throttle contains switches for managing communications, weapons and sensors.
- Some civil aircraft manufacturers favour the use of the side-stick over the yoke.
- The use of sidesticks in civil airliners frees up the space in front of the pilot, improving display visibility and allows for other for other uses in the area (such as incorporating alternative control devices like keyboards, trackballs, etc.).
- The Gulfstream G500 is the first civil aircraft to use an active inceptor system to provide pilots with tactile feedback.

Four-and-a-half generation military cockpits

- Reduced aircraft development due to forced reductions in military spending led to a half generation increment from fourth generation fighter jets.
- Four-and-a-half generation fighters such as the Eurofighter
- Typhoon included avionic improvements such as the Active Electronic Scanned Array (AESA) radar, integrated Infrared Search and Track (IRST) systems and high capacity data-link, allowing for network centric warfare.
- Four-and-a-half generation cockpits also feature alternative input technologies such as Direct Voice Input (DVI) and touchscreen displays.

Eurofighter Typhoon, a four-and-a-half generation fighter.

RAFALE

Fifth generation military cockpits

- Fifth generation fighters are designed around the concept of network centric warfare, with ability to exchange and store information between other battlespace elements.
- Such aircrafts are characterized by advanced avionics systems capable of multi-sensor data fusion, which integrate data from multispectral and/or networked sensors to provide fighter pilots with a consolidated view of the battlespace.

- Helmet Mounted Displays (HMD) have been used since fourth generation fighters and are an ongoing area of development in fifth generation jets.
- Standard HMD provide a holographic display of aircraft data and target information within the helmet's visor.
- Images from on-board sensors such as the Forward Looking Infrared (FLIR) and Night Vision Imaging Systems (NVIS) can be fused to maintain pilot situational awareness in degraded visual conditions.
- HMD cueing systems allow pilots to designate and acquire targets as well as aim sensors and weapons via head motion.
- Eye tracking technology is not featured on current HMD but offer the potential for even more accurate HMD.

- Fifth generation fighters such as the F-35 have completely replaced the HUD with HMD as the primary flight display.
- The F-35's HMD uses a distributed aperture system to provide a 360-degree view of the aircraft's surroundings, supporting even greater situational awareness.
- The F-35 also features a panoramic touchscreen MFD, similar to the type of displays that will be featured in next generation of civil flight decks.
- Fifth generation fighters are also typically singleseated, with the role of the Weapon Systems Officer (WSO) in the back seat being replaced by a combination of other networked battlespace support elements as well as by higher levels of on-board automation.

F-35 Lightning II, a fifth generation fighter.

Single-pilot operations

- SPO flight decks are currently used in the military, General Aviation (GA) and business jet domain, but given developments in flight deck autonomy and HMI2 evolutions, SPO is expected to become a viable concept of operations for future commercial airliners.
- SPO flight decks contain HMI2 elements of second and third generation two-pilot civil flight decks – business jets such as the Embraer Phenom 300 are certified for SPO and feature streamlined interfaces containing widescreen and high resolution MFD.
- The MFD functionalities can contain SVS, touchscreen and satellite weather capabilities that are typical of third generation civil flight decks.

Thank You