Flight Management Systems (FMS)

Flight Management Systems (FMS)

FMS: Objectives

Important economical factor in the air transport

→ look for maximum efficiency of the aircraft

→ try to reduce costs

1. At the end of the 70s: piloting assistance (safety + regularity)
2. Very soon, technology applied to flight management problems (1984: 1st certified FMS)

2 advantages:

1. Decrease the crew's workload (otherwise more and more complex management tasks)
2. Minimization of the exploitation costs: to help the pilot in every flight stage to minimize the fuel consumption and the flight time

Example: Iberia: January 2008-September 2008:

Iberia: 1,201.4 million euros in fuel (29% of total operating expenses)

50 millions L of kerosene per week

Fuel: second cost in relevance (after staff)

1% of saving in fuel → 12 millions euros

→ How can you avoid 1% increase in fuel consumption?

→ Flight Management System optimizes

How can you reduce the consumption of 1%?

- choosing for a 500 nm route a more direct path of only 6 or 7 nm
- choosing a lower Flight Level if the wind is lower there

How can the consumption be increased of 1%?

- beginning the descent one minute too early
- flying one Mach point (0.01) too fast at the optimum altitude
- flying 1000 feet too low at cruise speed

FMS: Functions

- Flight plan design
- Flight plan sequence
- Development of forecasts and performance optimization
- Initialization of the inertial centrals
- Selection of the RNAV environment
- Emission of information for the crew
- **Emission of piloting order and guidance to the autopilot**

Composition

The Flight Management Computer (FMC), **interacts with**:

- A **database** (inside the system)
- The **crew** through the “Control Display Unit” - CDU,
  the “Navigation Display” - ND,
  and the “Primary Flight Display” - PFD
- The **navigation assistance systems** (VOR, DME, ILS, GPS…)
- The **measurements of the fuel consumed by the engines**

Flight Management System (FMS)

Purpose and Components

Control and Display Unit

Control and Display Unit

- Cost Index
- Route management
- Transition
- Approximation
- Management of the temporary flight plan

- Access to all vertical and lateral revision pages
- Instructions insertion

Control and Display Unit

Route change management

Radio Nav page:

Management of the radio

navigation systems

N.D: Navigation Display

Next to the PFD.

Visualization of the navigation information: horizontal or vertical flight plan.

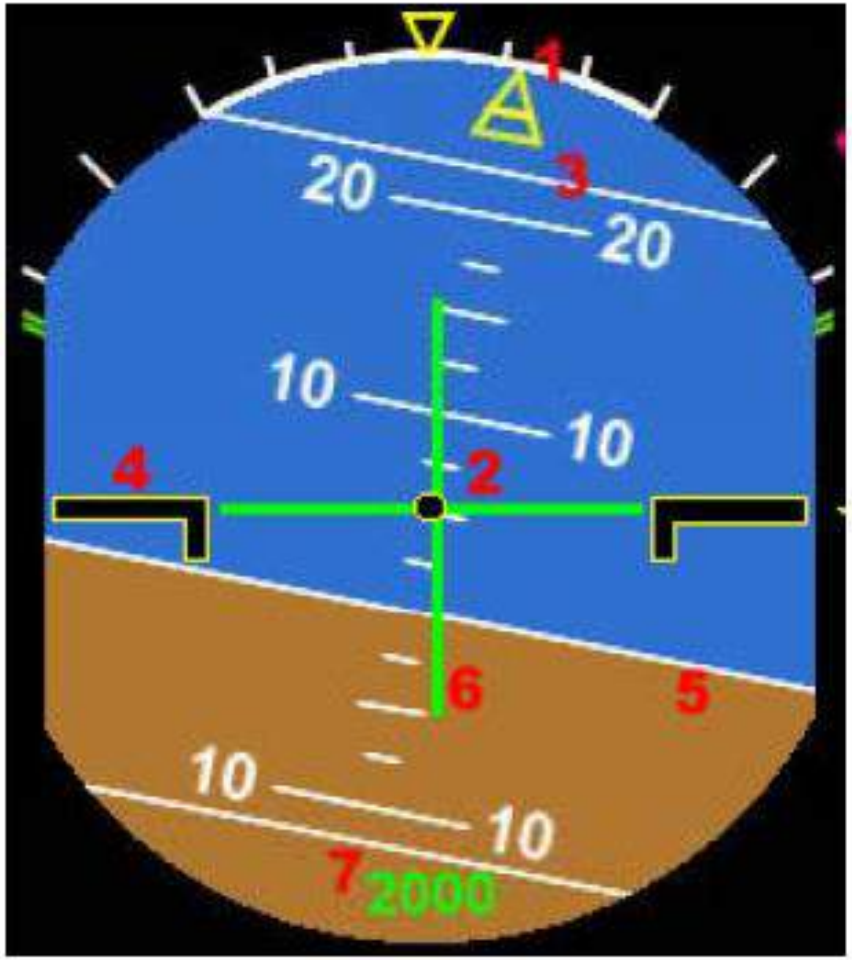
Visualization of the images from the meteo radar, the TCAS (traffic collision avoidance system) information with the position of the other airplanes, and the navigation instruments

N.D: Navigation Display

PFD: Primary Flight Display

On-board principal instrument used to pilot the airplane

PFD: Artificial horizon

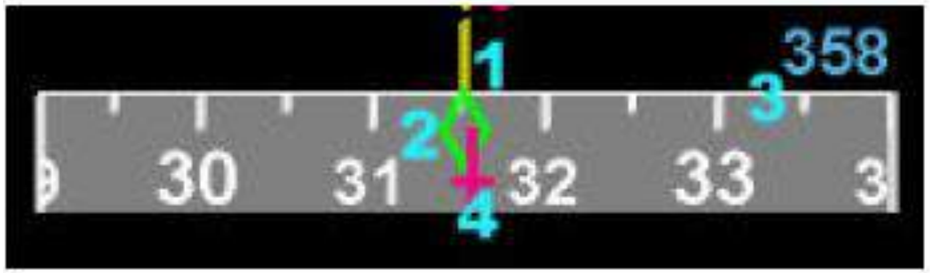


1. Roll (11° left turn)
2. Attitude (5°)
3. Ball
4. Airplane model
5. Horizon line
6. Flight director
7. Radar altimeter (2000ft)

PFD: Anemometer

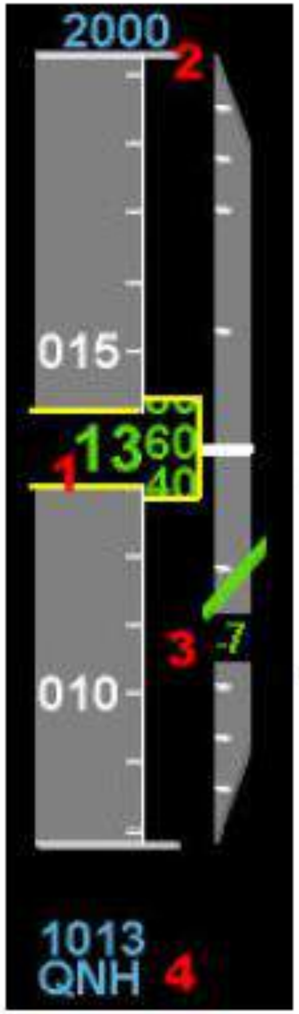
1. Indicated speed (154 kts)
2. Speed tendency in 10 sec (150kts)
3. Objective speed (145 kts)
5. Alpha Floor speed
6. Alpha Protection speed
7. Stall speed
8. Max speed

PFD: Compass



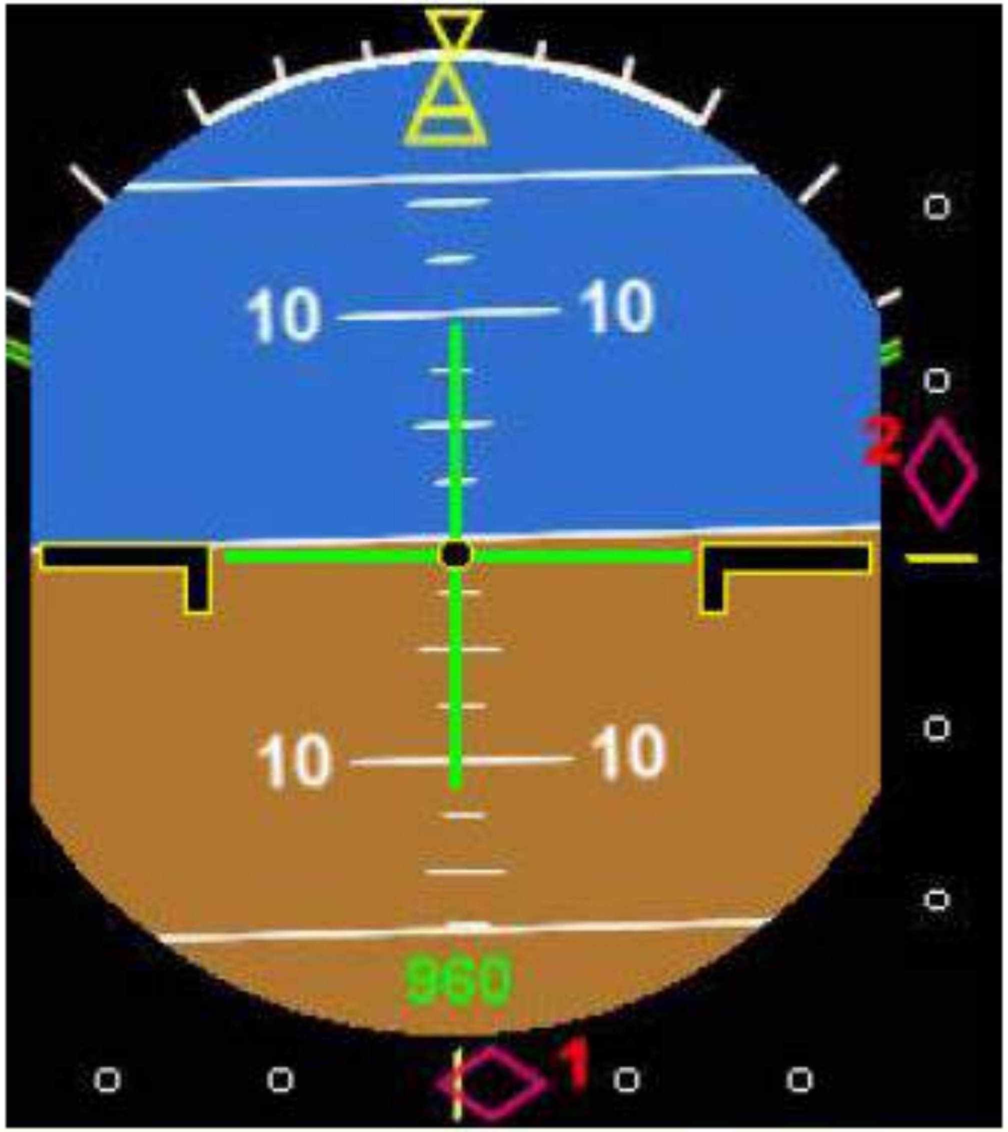
1. Heading(315°)
2. Route (315°)
3. Heading or route objective
4. ILS course

PFD: Altimeter



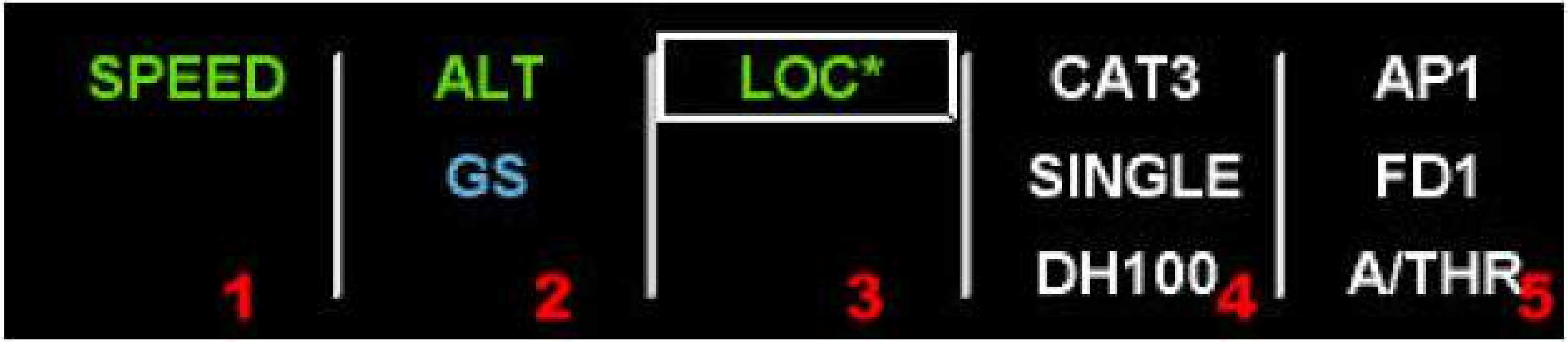
1. Altitude (1360ft)
2. Objective altitude(2000ft)
3. Variometer (-700 ft/mn)
4. Altitude reference

PFD: Localizer and Glide indicator

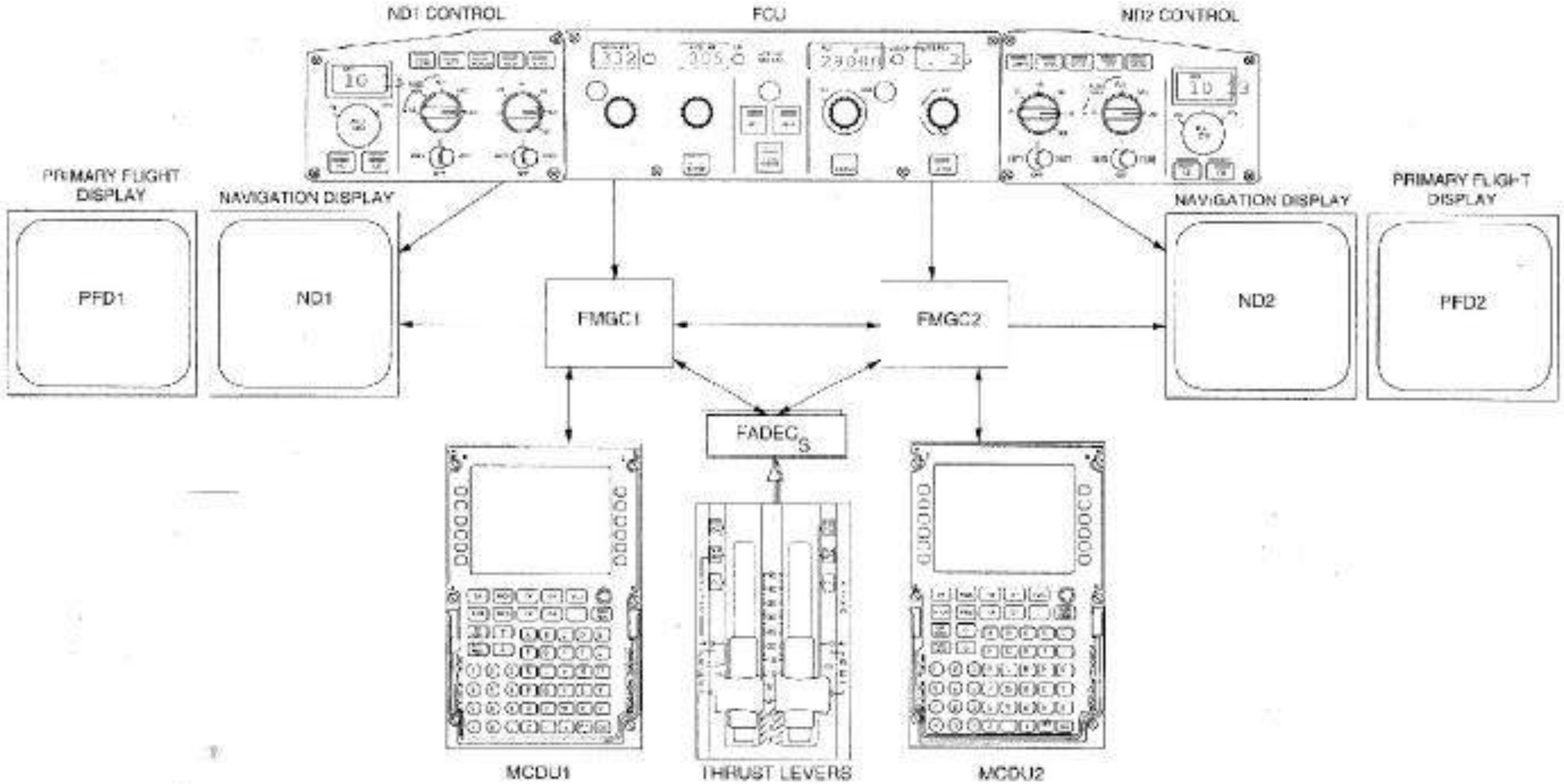


1. Localizer
2. Glide

PFD: Flight Mode Annunciator

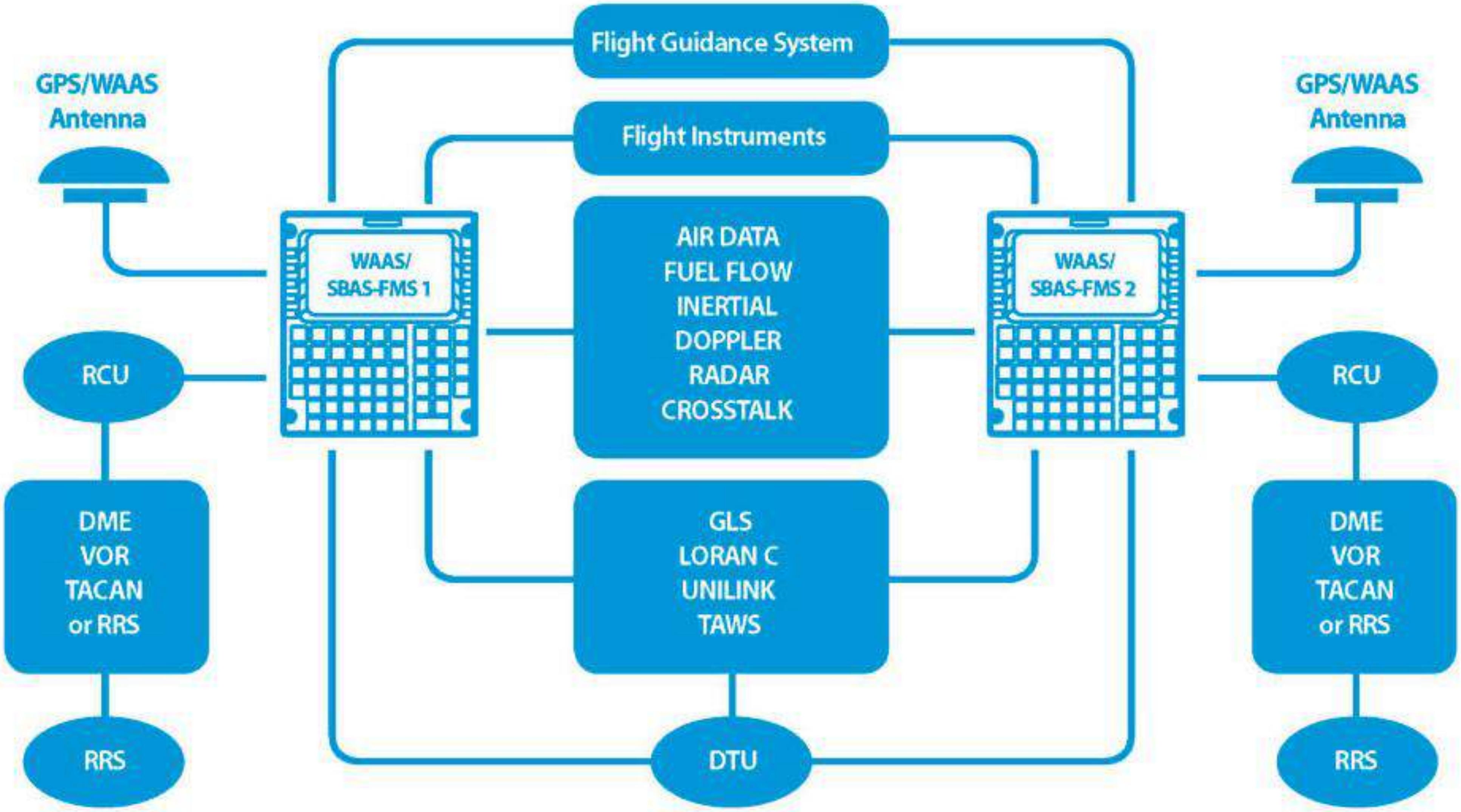


1. Mach hold mode (speed holding)
2. Longitudinal mode (altitude holding)
3. Lateral mode (LOC*: Localizer interception)
4. Approximation capacity
5. AP, FD, and A/THR state



INTERFACE EQUIPAGE/FMGS

System Architecture *WAAS/SBAS-FMS system architecture diagram*



Details Ideas of FMS

The flight management system provides the primary navigation, flight planning, and optimized route determination and en route guidance for the aircraft and is typically comprised of the following interrelated functions: *navigation, flight planning, trajectory prediction, performance computations, and guidance.*

To accomplish these functions the flight management system must interface with several other avionics systems.

Equipment need to FMS can be following generic categories.

- Navigation sensors and radios
  - Inertial/attitude reference systems
  - Navigation radios
  - Air data systems
- Displays
  - Primary flight and navigation
  - Multifunction
  - Engine
- Flight control system
- Engine and fuel system
- Data link system
- Surveillance systems

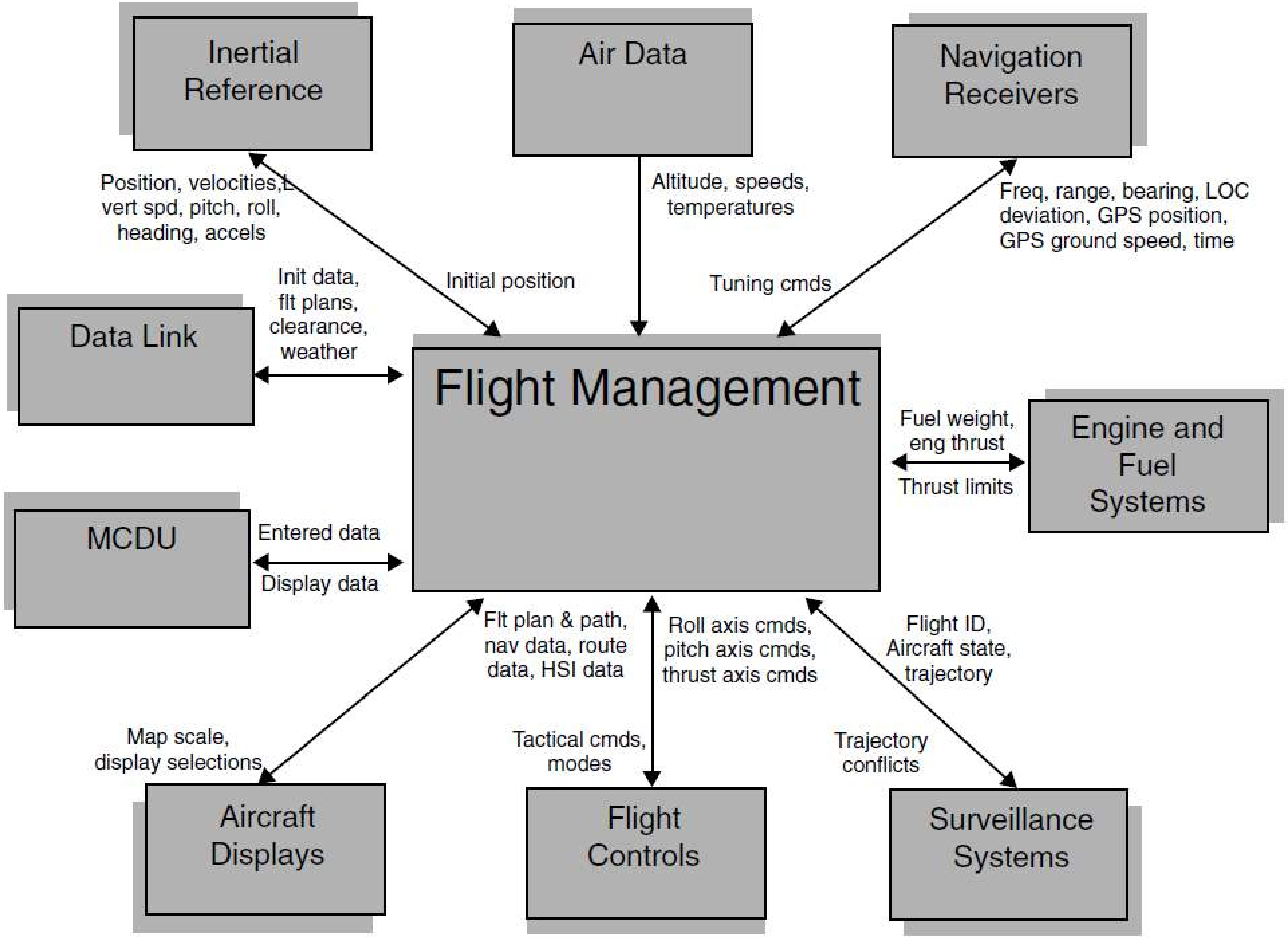


FIGURE 15.1 Typical interface block diagram.

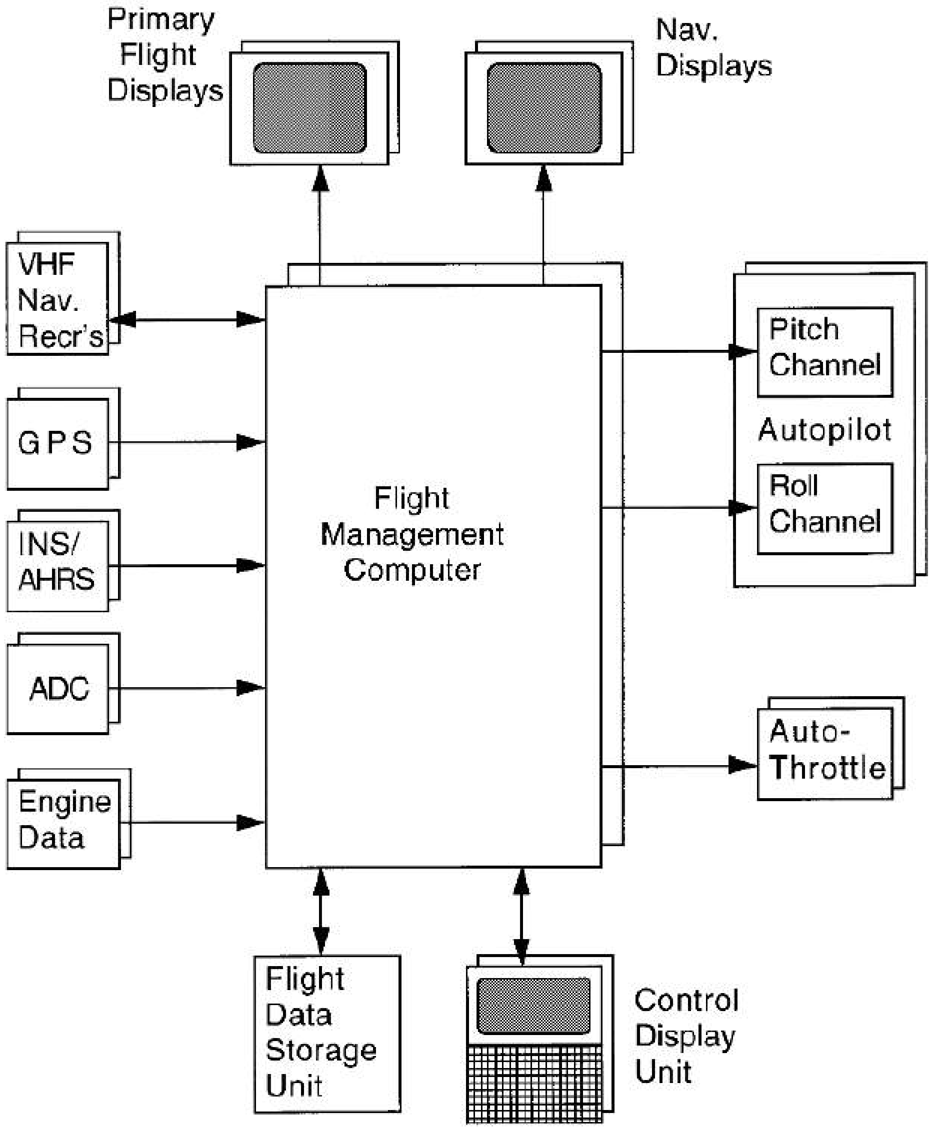


Fig. 8.15 Flight management system block diagram.

Block diagram of a typical flight management system.

The benefits they confer are briefly set out below:

- ***Quantifiable economic benefits*** – provision of automatic navigation and flight path guidance to optimise the aircraft's performance and hence minimise flight costs.

- ***Air traffic*** – growth of air traffic density and consequently more stringent ATC requirements, particularly the importance of 4D navigation.

- ***Accurate navigation sources*** – availability of accurate navigation sources. For example, INS /IRS, GPS, VOR, DME and ILS / MLS.

- ***Computing power*** – availability of very powerful, reliable, affordable computers.

- ***Data bus systems*** – ability to interconnect the various sub-systems.

The FMS carries out the following tasks:

1. Flight guidance and lateral and vertical control of the aircraft flight path.

2. Monitoring the aircraft flight envelope and computing the optimum speed for each phase of the flight and ensuring safe margins are maintained with respect to the minimum and maximum speeds over the flight envelope.

3. Automatic control of the engine thrust to control the aircraft speed.

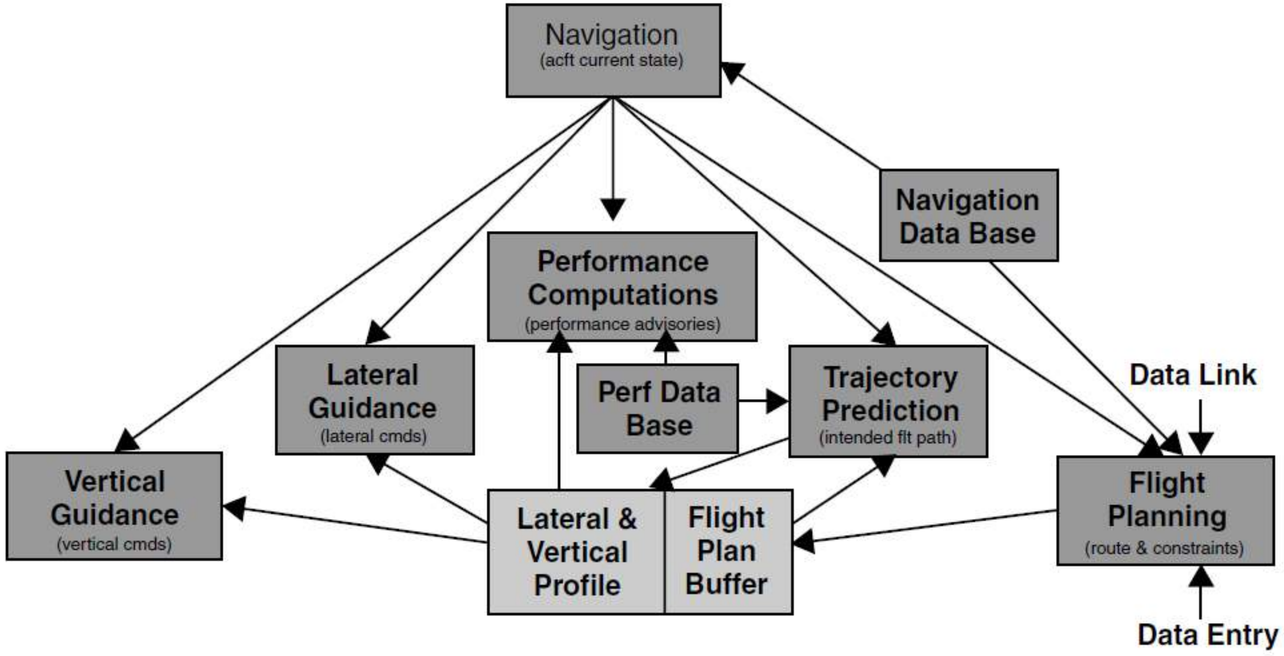
In addition the FMS plays a major role in the

flight planning task, provides a computerised flight planning aid to the pilot and enables major revisions to the flight plan to be made in flight, if necessary, to cope with changes in circumstances.

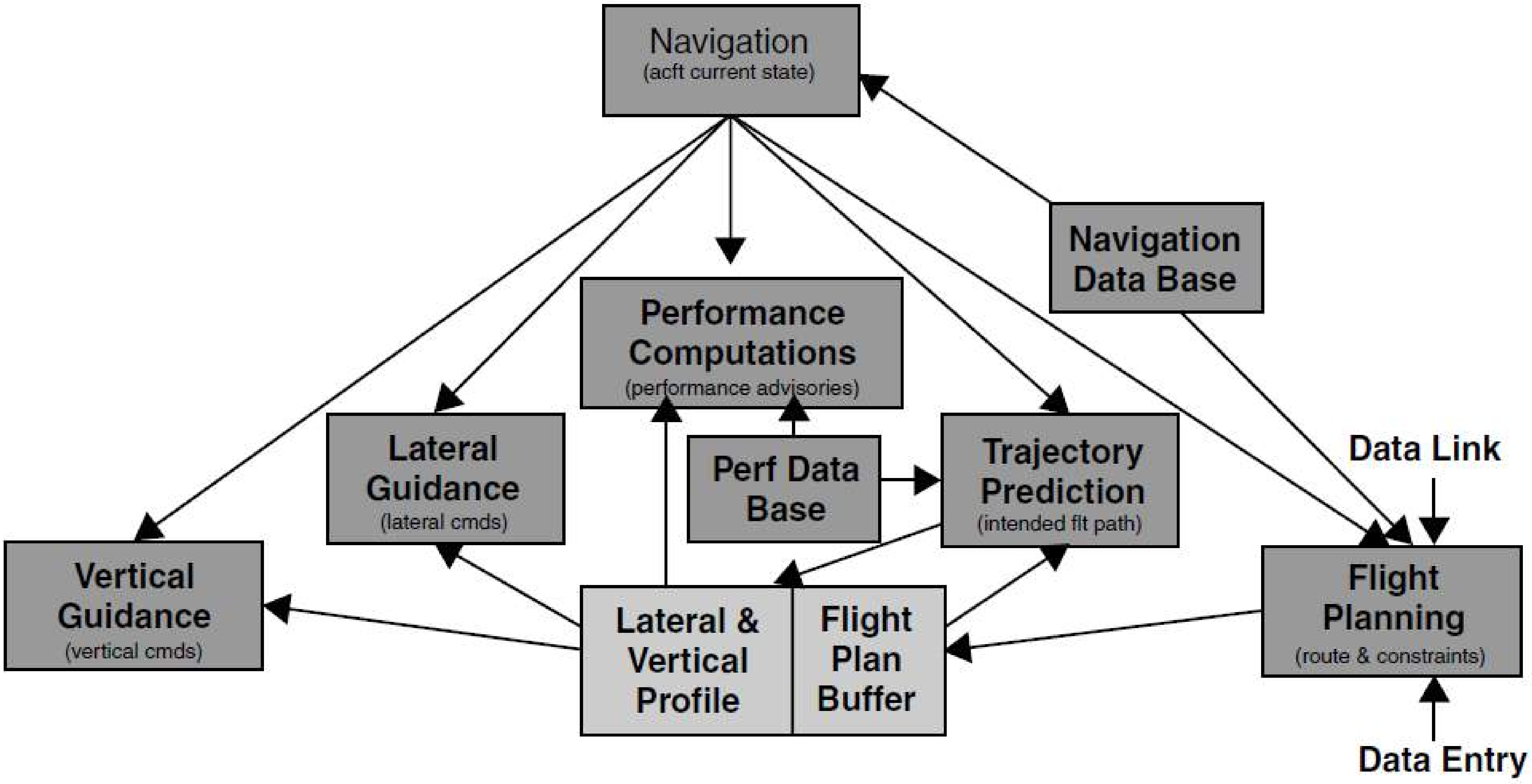
The vertical, lateral steering, and performance advisory functions use the current aircraft state from navigation and the information in the flight plan/profile buffer to provide guidance, reference, and advisory information relative to the defined trajectory and aircraft state.

- *The navigation function* — responsible for determining the best estimate of the current state of the aircraft.
- *The flight planning function* — allows the crew to establish a specific routing for the aircraft.
- *The trajectory prediction function* — responsible for computing the predicted aircraft profile along the entire specified routing.

- *The performance function* — provides the crew with aircraft unique performance information such as takeoff speeds, altitude capability, and profile optimization advisories.
- *The guidance functions* — responsible for producing commands to guide the aircraft along both the lateral and vertical computed profiles.



Flight management functional block diagram.



Flight management functional block diagram.

FMS Architecture

- flight management system architecture of a modern airliner, in this case the Airbus A380.

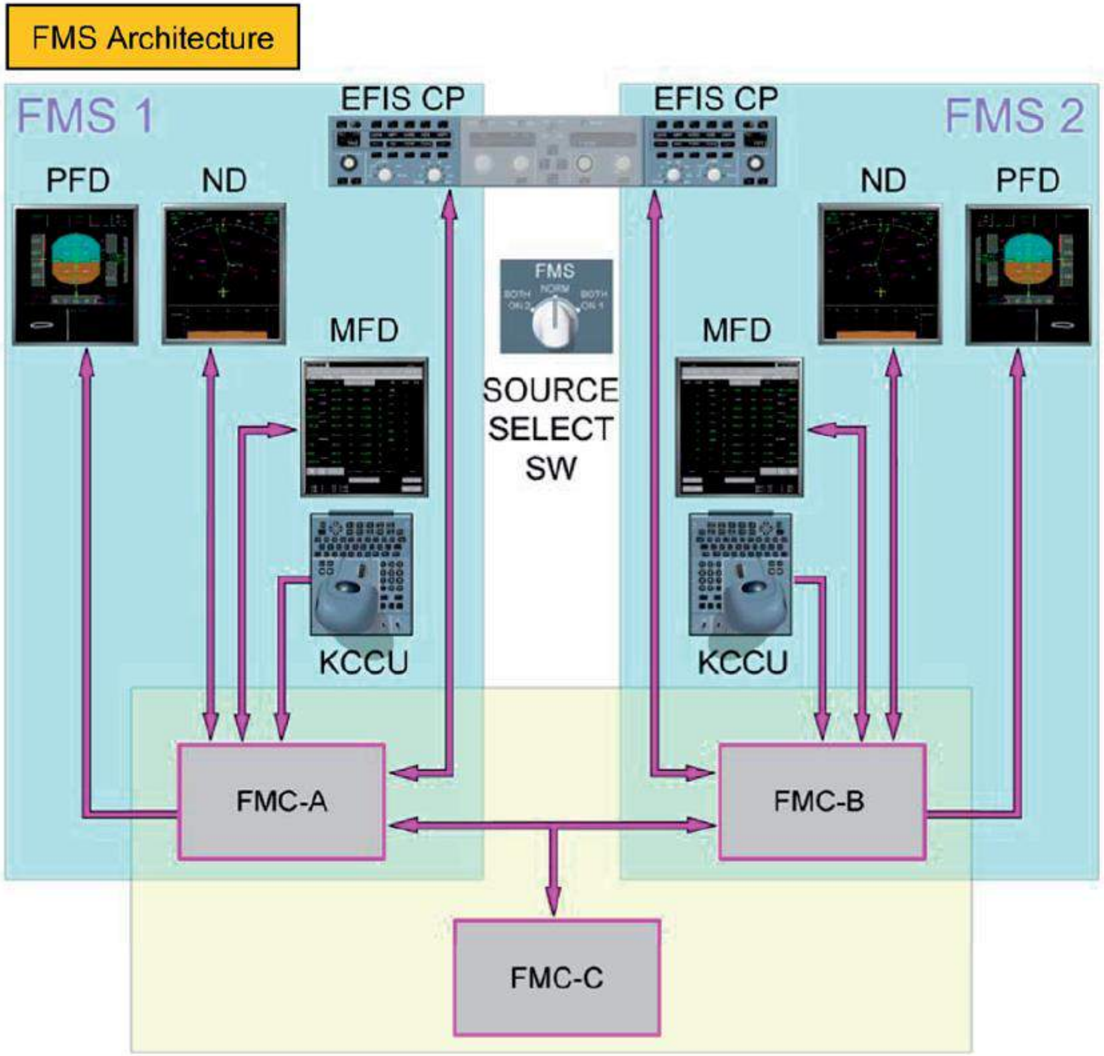


Fig. 8.16 FMS architecture (by courtesy of Airbus).

- Two independent Flight Management Systems; FMS-1 on the Captain’s side and FMS-2 on the First Officer’s side carry out the flight management function.

- The cockpit interfaces to the flight crew provided by each FMS comprise a Navigation Display (ND), a Primary Flight Display (PFD), a Multi-Function Display (MFD), a Keyboard and Cursor Control Unit (KCCU) and an Electronic Flight Instrument System (EFIS) Control Panel (EFIS CP).

- The *Multi-Function Display* (MFD) displays textual data; over 50 FMS pages provide information on the flight plan, aircraft position and flight performance.

- The MFD is interactive; the flight crew can navigate through the pages and can consult, enter or modify the data via the Keyboard and Cursor Control Unit (KCCU).

- The *Keyboard and Cursor Control Unit* (KCCU) enables the flight crew to navigate through the FMS pages on the MFD and enter and modify data on the MFD, and can also perform some flight plan revisions on the lateral Navigation Display (ND).

- The *EFIS Control Panel* (EFIS CP) provides the means for the flight crew to control the graphical and textual FMS data that appear on the ND and PFD.

- There are three *Flight Management Computers*;

FMC-A, FMC-B and FMC-C to carry out the functional computations, which can be reconfigured to maintain the system operation in the event of failures.

Three different FMS operating modes;

Dual Mode,

Independent Mode and

Single Mode dependent

Dual Mode

Both flight management systems, FMS-1 and FMS-2, are healthy.

Shown below figure is the configuration in normal operation in the left side illustration and the configuration after a single flight management computer failure in the right side illustration.

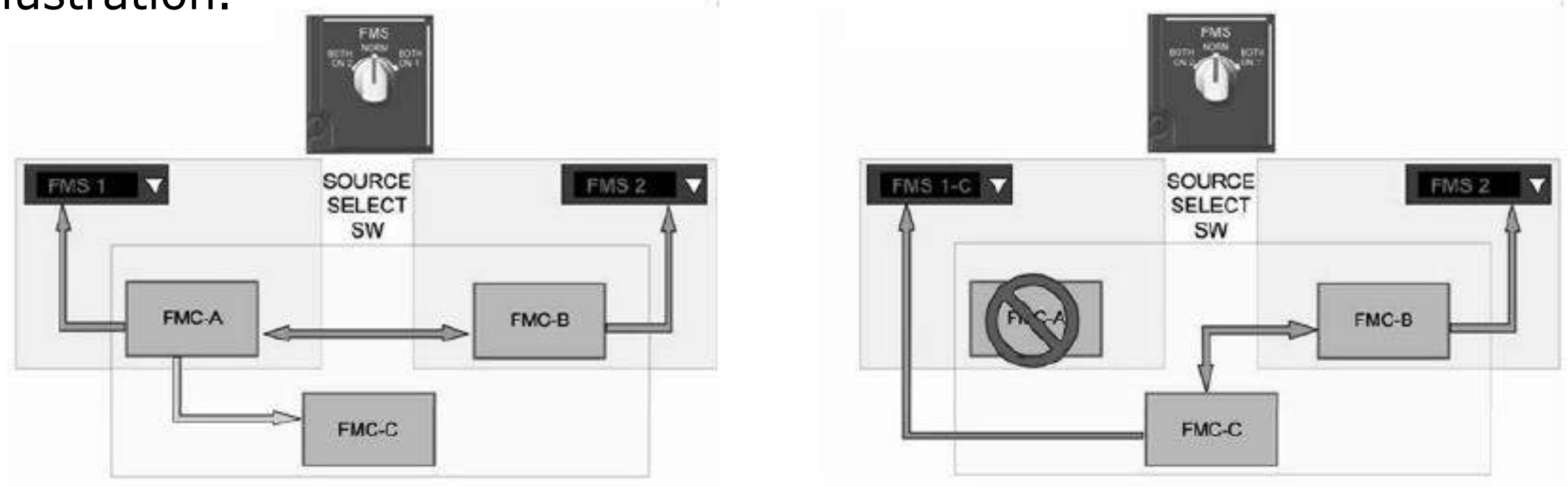


Fig. 8.17 Dual Mode operation (by courtesy of Airbus).

In normal operation,

FMC-A provides data to FMS-1, FMC-B provides data to FMC-2 and FMC-C is the standby computer.

Out of the two active computers, one FMC is the ‘master’ and the other is the ‘slave’, depending on which autopilot is active and the selected position of the FMS Source Select Switch.

The two active FMCs independently calculate data, and exchange, compare and synchronise these data.

The standby computer does not perform any calculations, but is regularly updated by the master FMC.

In the case of a single FMC failure, for example FMC-A, FMC-C provides data to FMS-1.

Independent Mode

In the Independent Mode, FMS-1 and FMS-2 are both operative, but there is no data exchange between them because they disagree on one or more items such as aircraft position, gross weight, etc.

Single Mode

The loss of two FMC’s causes the loss of either FMS-1 or FMS-2. The data from the operative FMS is displayed to the flight crew by operating the Source Select Switch.

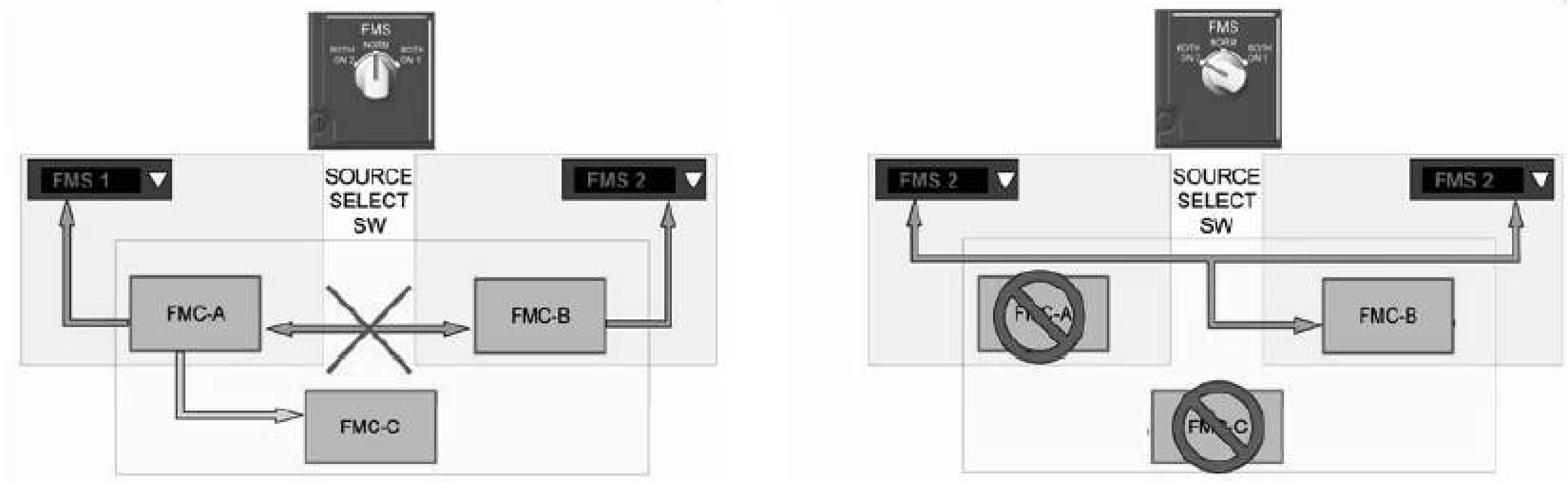


Fig. 8.18 Independent Mode and Single Mode configurations (by courtesy of Airbus).

Radio Navigation Tuning

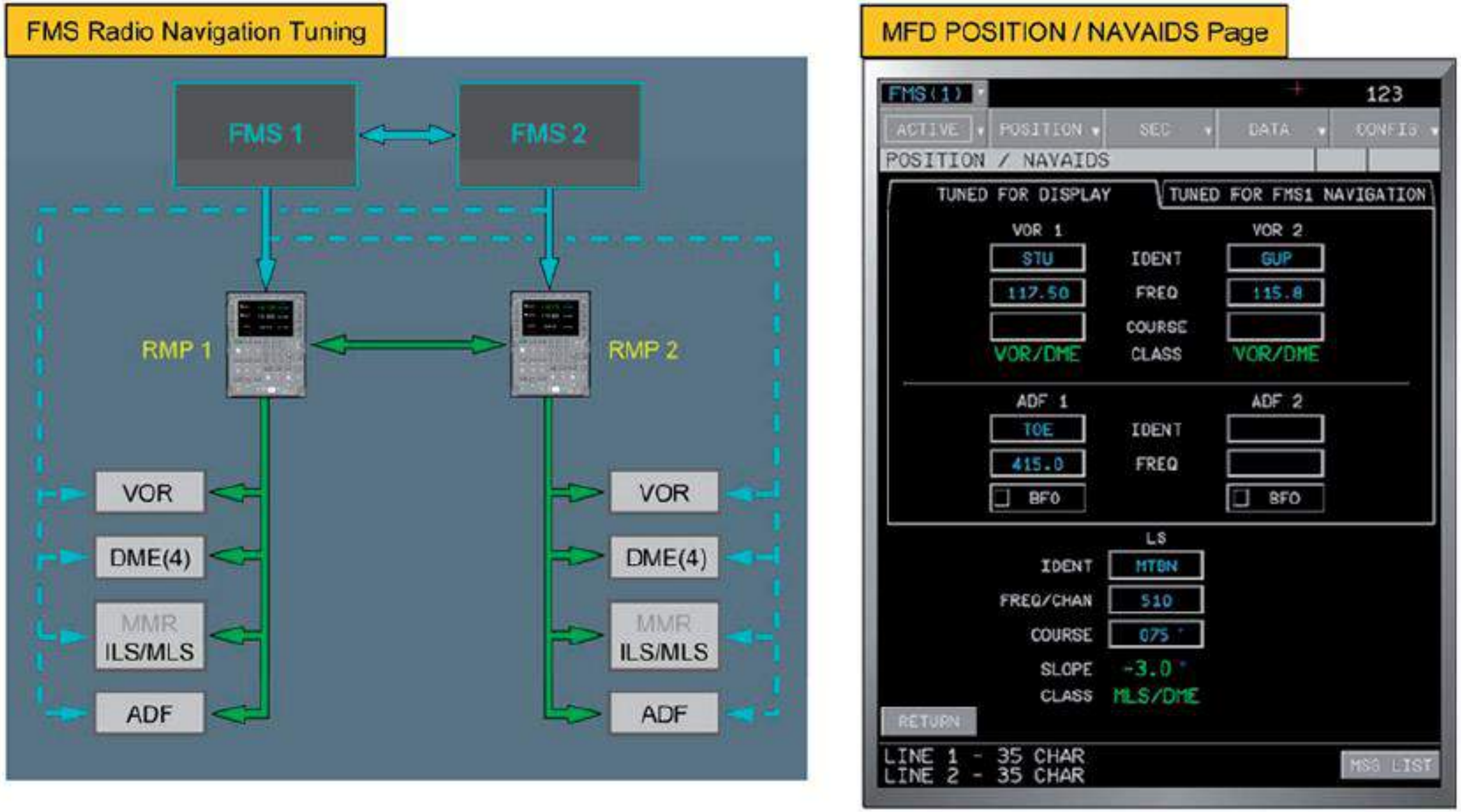


Fig. 8.19 NAVAIDS tuning and POSITION/NAVAIDS Page displays on MFD (by courtesy of Airbus).

- The FMS automatically tunes the radio navigation aids, (NAVAIDs), used for the radio position computation, the NAVAIDS for display on the Navigation Displays and the landing system NAVAIDS.
- In 'Dual' and 'Independent' modes each FMS tunes its onside NAVAIDS.
- These comprise, in the case of the A380, one VOR, four DMEs, one ILS (MLS/GLS optional), one ADF (optional).
- In 'Single' FMS mode, or in the case of a communications failure between an FMS and its onside Radio Management Panel (RMP), the available FMS will tune the NAVAIDS on both sides.

- The tuning of the onside NAVAIDS passes through the onside RMP, to synchronize the NAVAIDS tuning between the FMS and the RMP.

- The A380 FMS radio navigation tuning system together with the ‘POSITION/ NAVAIDS Page’ display on the Multi-Function Display.

- The NAVAIDS displayed on the Navigation Displays and the landing system NAVAIDS can also be tuned manually on the ‘POSITION/NAVAIDS’ Page of the MFD, or on the Radio Management Panel.

- Manual tuning always has priority over automatic tuning.

Navigation

The navigation function within the FMS computes the aircraft current state based on a statistical blending of multisensor position and velocity data.

The aircraft current state data usually consists of:

- *Three-dimensional position (latitude, longitude, altitude)*
- *Velocity vector*
- *Altitude rate*
- *Track angle, heading, and drift angle*
- *Wind vector*
- *Estimated Position Uncertainty (EPU)*
- *Time*

A typical navigation sensor complement consist of:

- *Autonomous sensors*
  - *Inertial reference*
  - *Air data*
- *Navigation receivers*
  - *DME receivers*
  - *VOR/LOC receivers*
  - *GPS receivers*

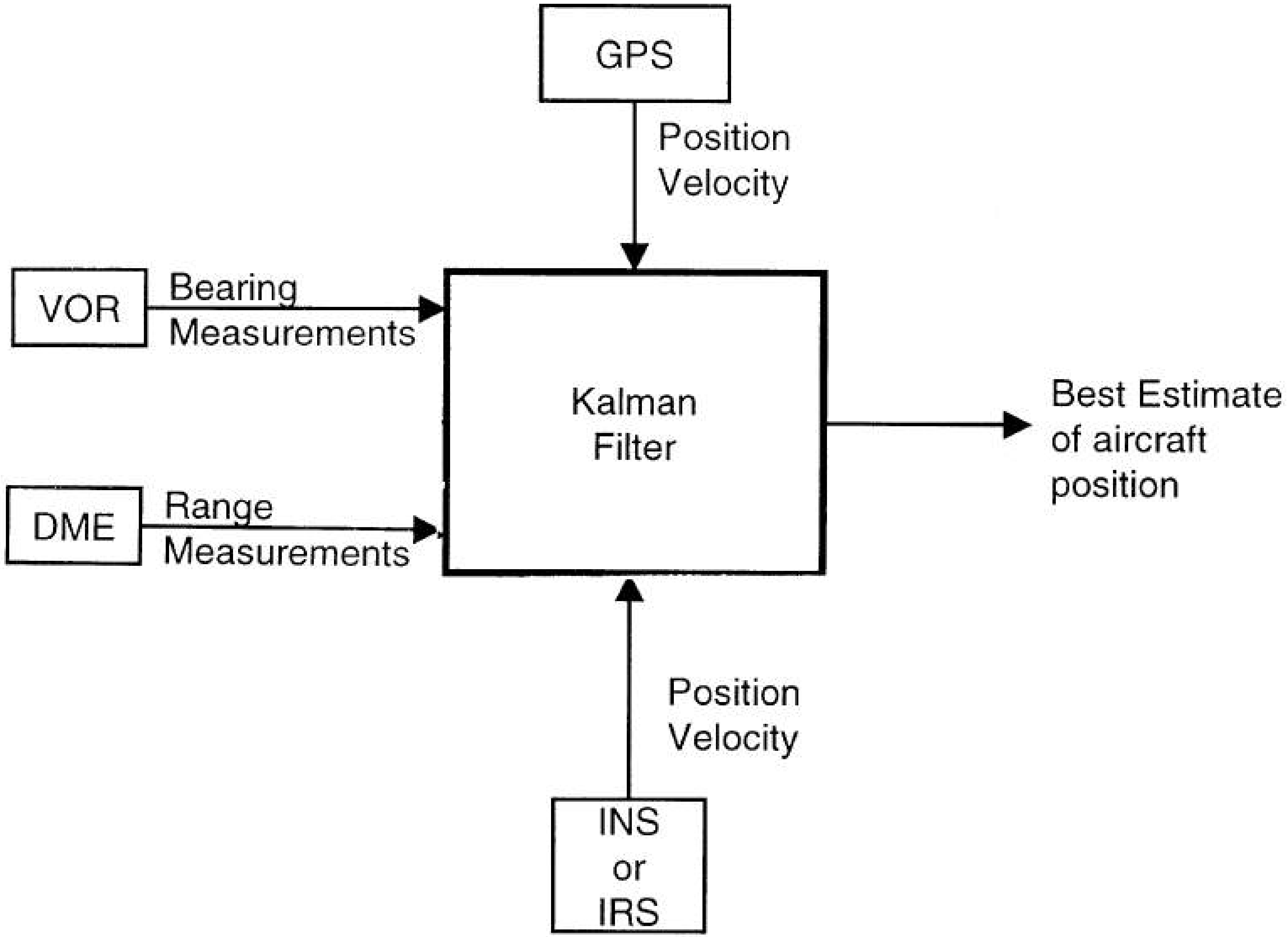


Fig. 8.20 Kalman filtering of navigational data sources.

- The FMS combines the data from the navigational sources, comprising the inertial systems, GPS and the radio navigation systems, in a Kalman filter to derive the best estimate of the aircraft position.

- The accuracy of this estimate is also evaluated.

- Each FMS computes the aircraft position and the position accuracy.

- The FMS computed position is an optimum combination of the inertial position and the GPS or radio position, depending on which equipment provides the most accurate data.

- This results in four navigation modes in decreasing order of priority:
    - Inertial (IRS) – GPS.
    - Inertial (IRS) – DME/DME.
    - Inertial (IRS) – VOR/DME.
    - Inertial (IRS) only.

- The FMS aircraft position always uses the inertial position.
- This computation is not possible if the inertial position is not valid, and in this case all the FMS navigation and flight planning functions are no longer available.
- The FMS continually computes the Estimated Position Uncertainty (EPU), and the EPU is used, together with the Required Navigation Performance (RNP,) to define the aircraft navigation accuracy.
- The FMS continuously compares the actual EPU with the current RNP, and defines the navigation class as:
    - HIGH, if the EPU is less than, or equal to the RNP.
    - LOW, if the EPU is greater than the RNP.
- The navigation class has to satisfy the Airworthiness Authorities Accuracy Requirements(AAAR).

- The FMS computes ground speed, track, wind direction and velocity.
- The FMS provides both lateral and vertical guidance signals to the autopilot to control the aircraft flight path.
- In the lateral case, the FMS computes the aircraft position relative to the flight plan and the lateral guidance signals to capture and track the flight path specified by the flight plan.
- Three-dimensional vertical guidance is provided to control the vertical flight profile including the time.
- This is of particular benefit during the descent and approach.

Flight Planning

A major function of an FMS is to help the flight crew with flight planning and it contains a database of:

- *Radio NAVAIDS* – VOR, DME, VORTAC, TACAN, NDB, comprising identification, latitude/longitude, altitude, frequency, magnetic variation, class, airline figure of merit.
- *Waypoints* – usually beacons.
- *Airways* – identifier, sequence number, waypoints, magnetic course.
- *Airports* – identifier, latitude, longitude, elevation, alternative airport.
- *Runways* – length, heading, elevation, latitude, longitude.
- *Airport procedures* – ICAO code, type, SID, STAR, ILS, profile descent.
- *Company routes* – original airport, destination airport, route number, type, cruise altitudes, cost index.

- *The navigation data base is updated every 28 days, according to the ICAO AiRAC cycle, and is held in non-volatile memory.*

- *It is clearly essential to maintain the recency and quality of the data base and the operator is responsible for the detail contents of the data base which is to ARINC 424 format.*

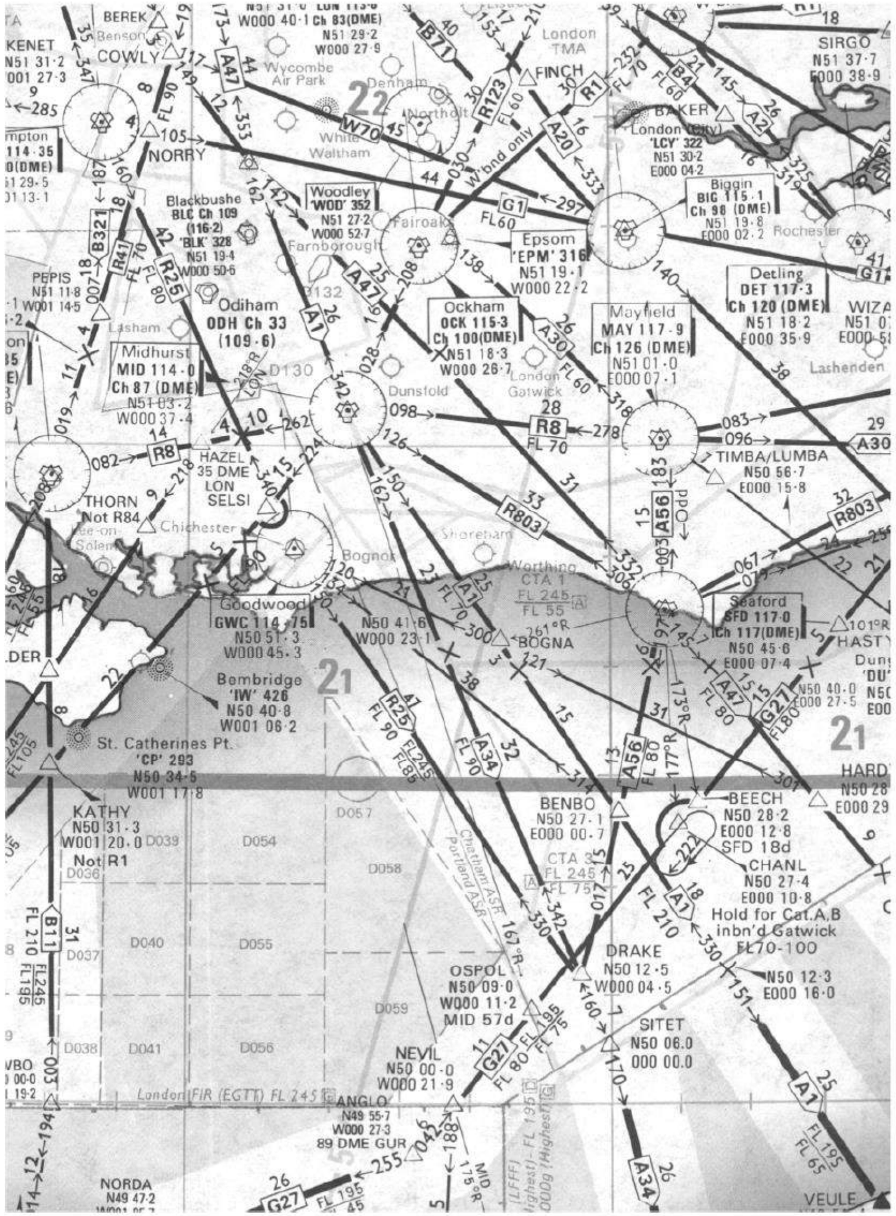


Fig. 8.21 Section of radio navigation chart (by courtesy of British Airways AERAD).

- *The flight crew can enter the flight plan in the FMS including all the necessary data for the intended lateral and vertical trajectory.*

- *When all the necessary data is entered, the FMS computes and displays the speed, altitude, time, and fuel predictions that are associated with the flight plan.*

- *The flight crew can change the flight plan at any time; a change to the lateral plan is called a 'lateral revision' and a change to the vertical plan a 'vertical revision'.*

The FMS can simultaneously memorise four flight plans:

- One *active* flight plan for lateral and vertical long term guidance and for radio navigation auto-tuning.

- Three *secondary* flight plans with drafts to compare predictions, to anticipate a diversion or to store company, ATC and Onboard Information System flight plans.

- The lateral flight plan includes the departure, cruise and arrival and is composed of waypoints that are linked with flight plan legs and transitions between legs.

- Below figure(8.22) shows on the MFD of the ‘Active Initialisation’ Page (ACTIVE INIT) and the ‘Active Fuel’ Page (ACTIVE FUEL).

- The ease and visibility of the data entry process can be appreciated.

- A flight plan can be created in three ways:

1. By inserting an origin/destination pair and then manually selecting the departure, waypoints, airways and arrival.

2. By inserting a company route stored in the database.

3. By sending a company request to the ground for an active Flight Plan (F-PLN) uplink.

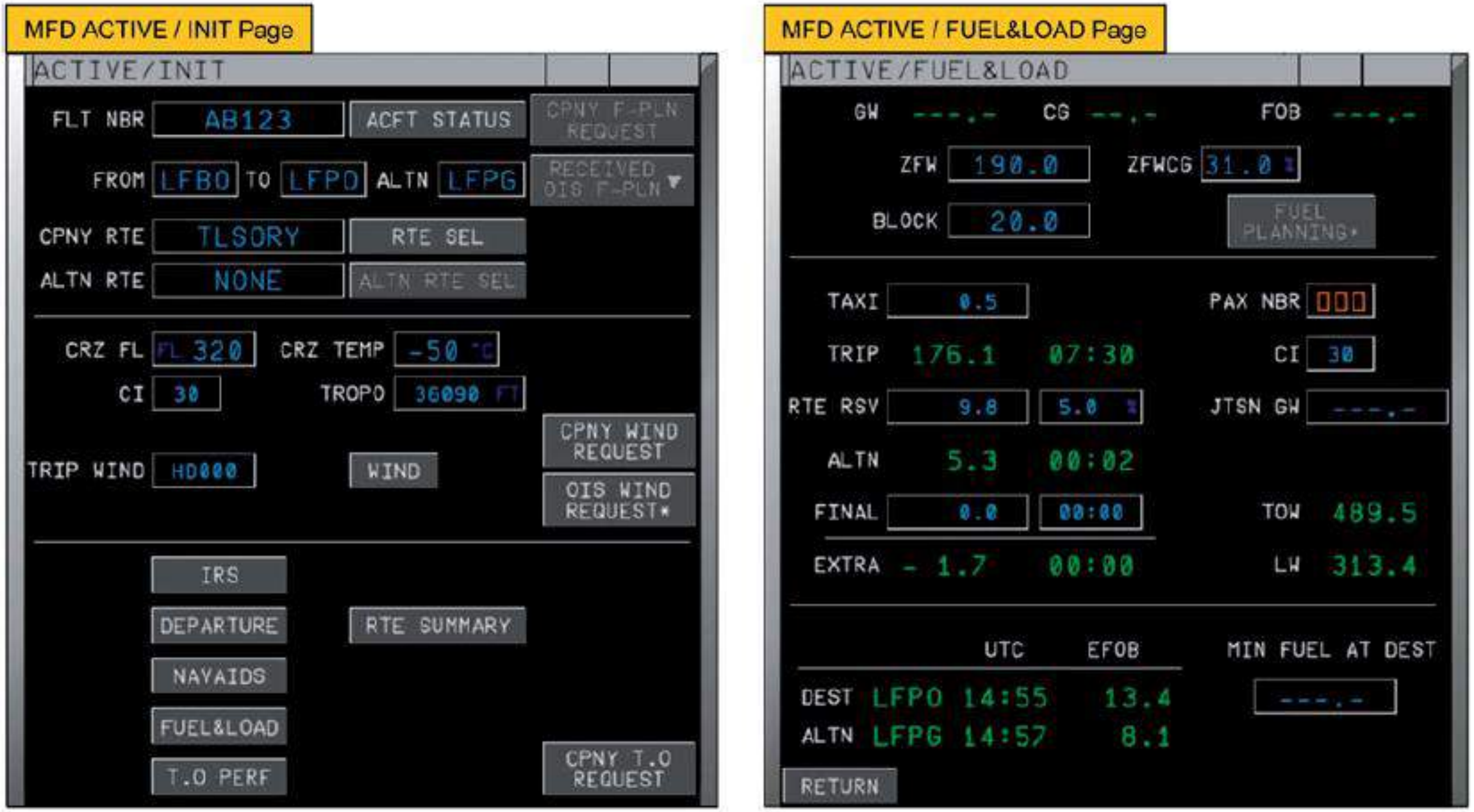


Fig. 8.22 'Active Initialisation' Page and 'Active Fuel' Page displays on MFD (by courtesy of Airbus).

The flight crew can perform the following lateral revisions:

- Delete and insert waypoints.
- Departure procedures: Takeoff runway, Standard Instrument Departure (SID) and transition.
- Arrival procedures: Runway, type of approach, Standard Terminal Arrival Route (STAR), via, transition.
- Airways segments.

The flight crew can also perform the following vertical revisions:

- Time constraints.
- Speed constraints.
- Constant Mach segments.
- Altitude constraints.
- Step altitudes.
- Wind.

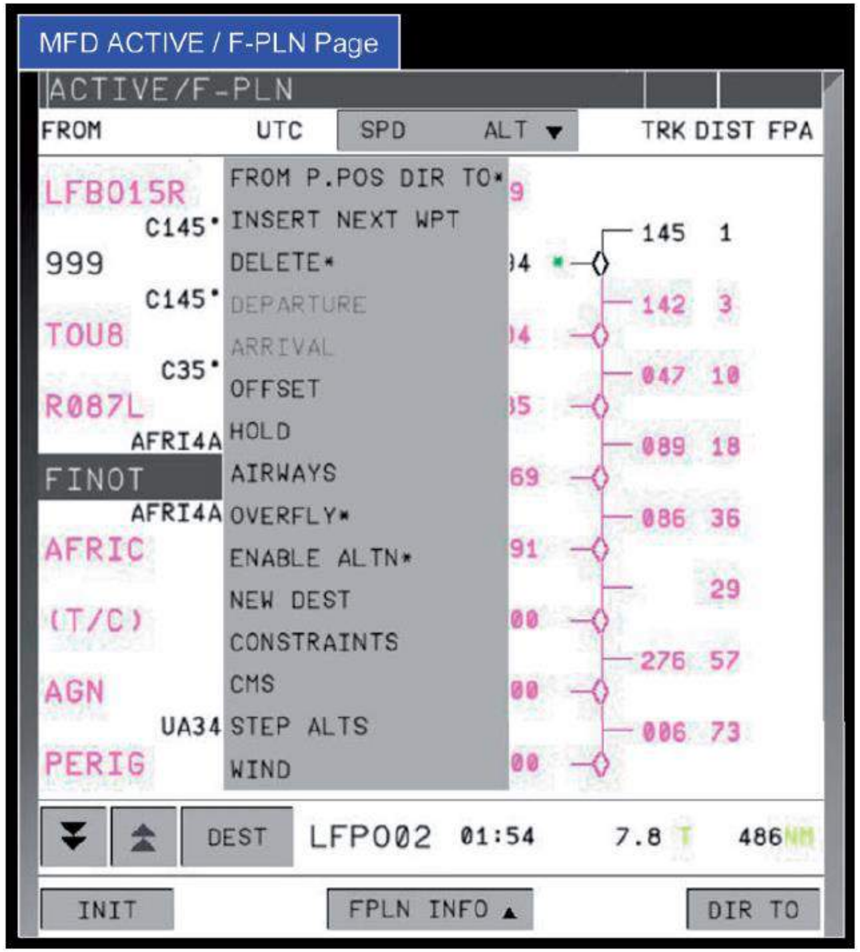


Fig. 8.23 'Active Flight Plan' Page display on MFD (by courtesy of Airbus).

Performance Prediction and Flight Path Optimisation

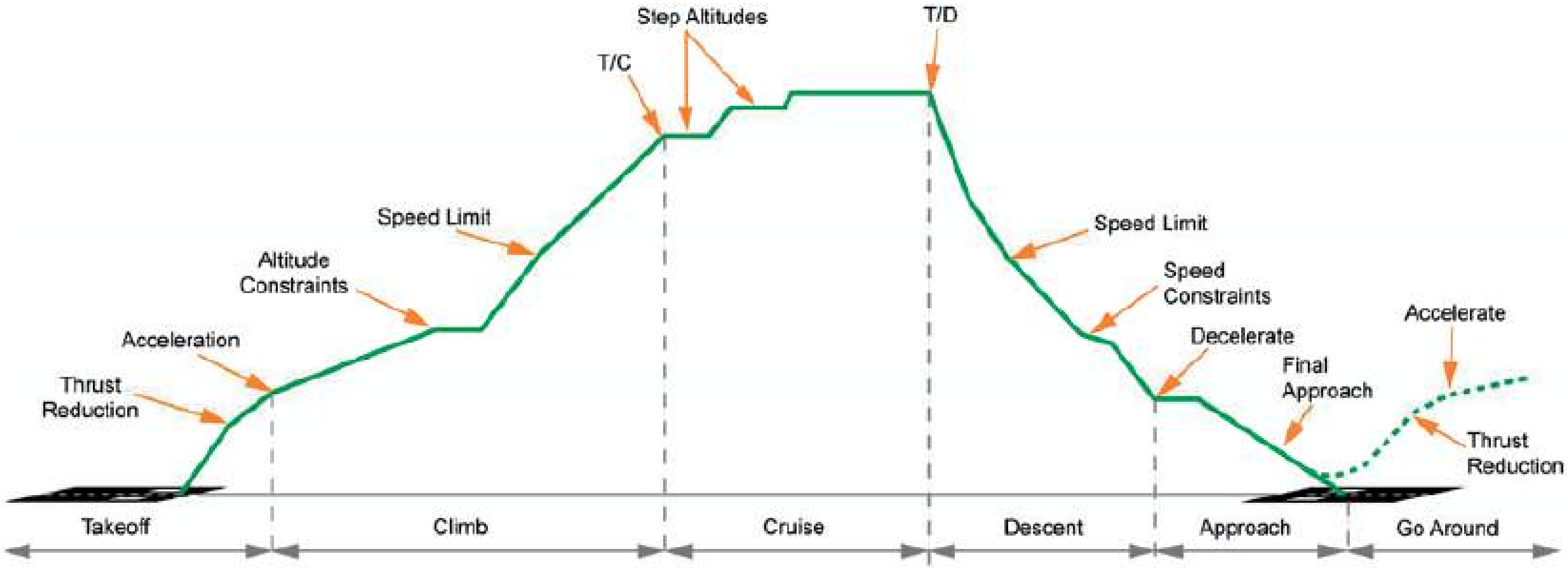
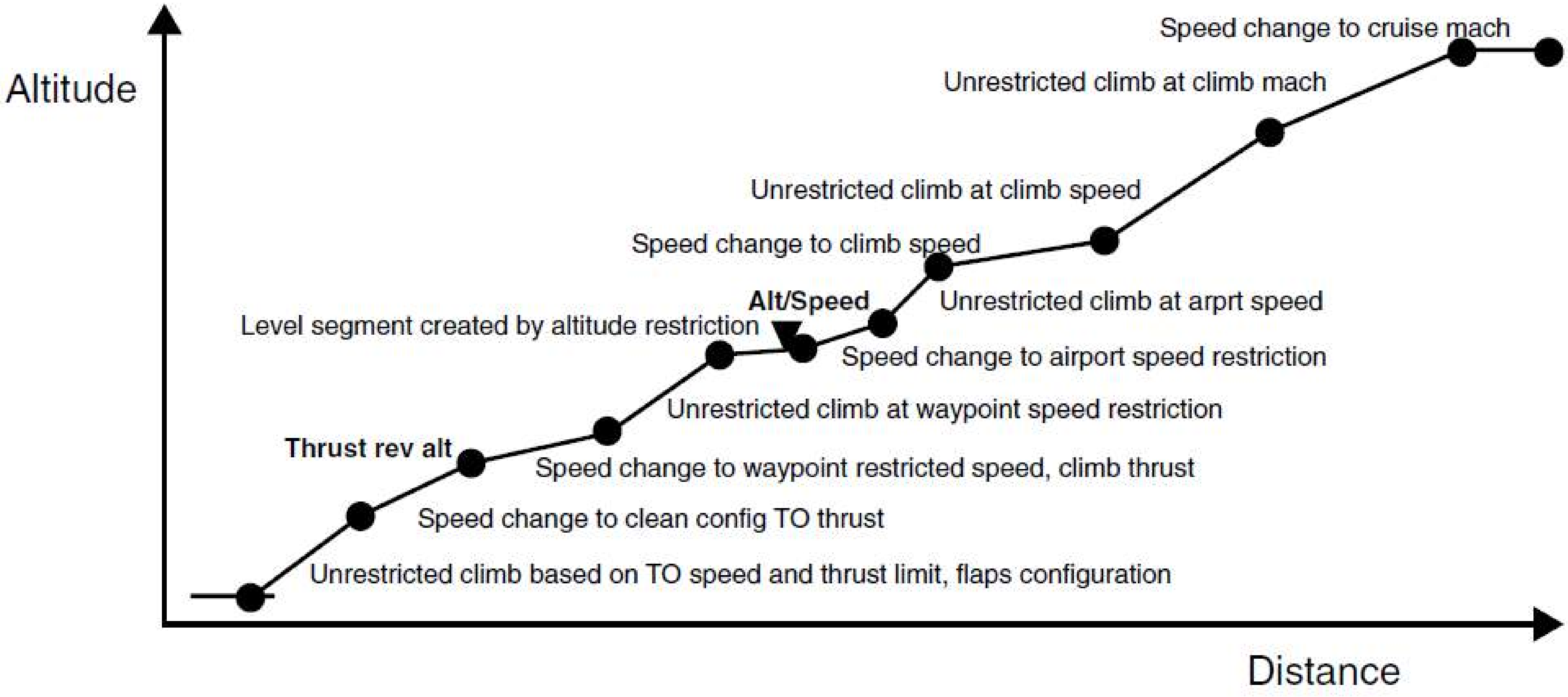


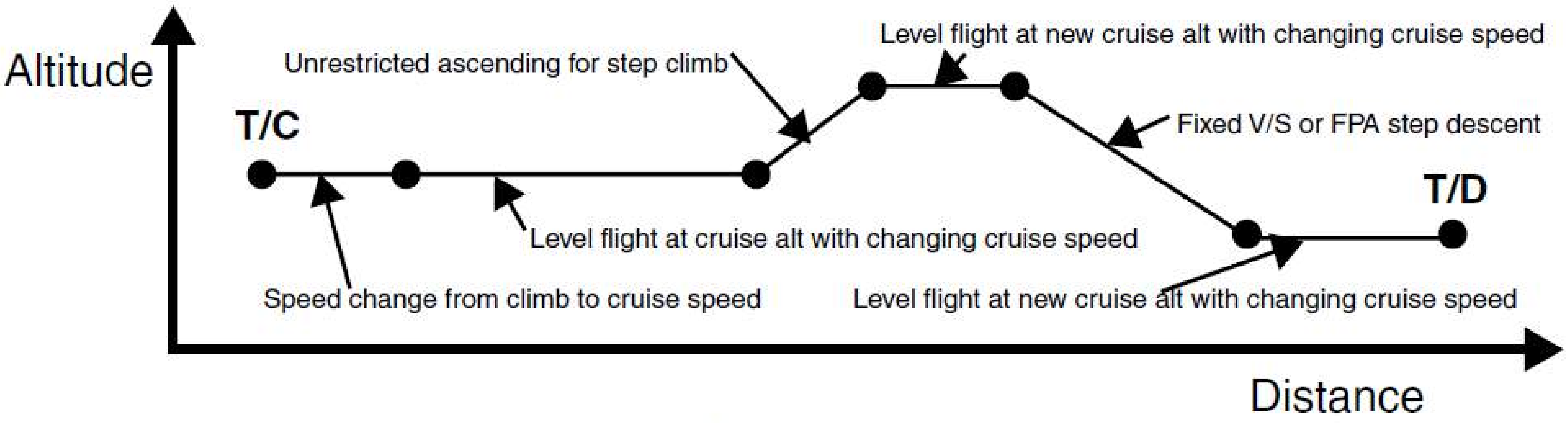
Fig. 8.26 Flight plan – vertical definition (by courtesy of Airbus).

- The FMS is able to optimise specific aspects of the flight plan from a knowledge of the aircraft type, weight, engines and performance characteristics, information on the wind and air temperature and the aircraft state – airspeed,Mach number, height, etc.

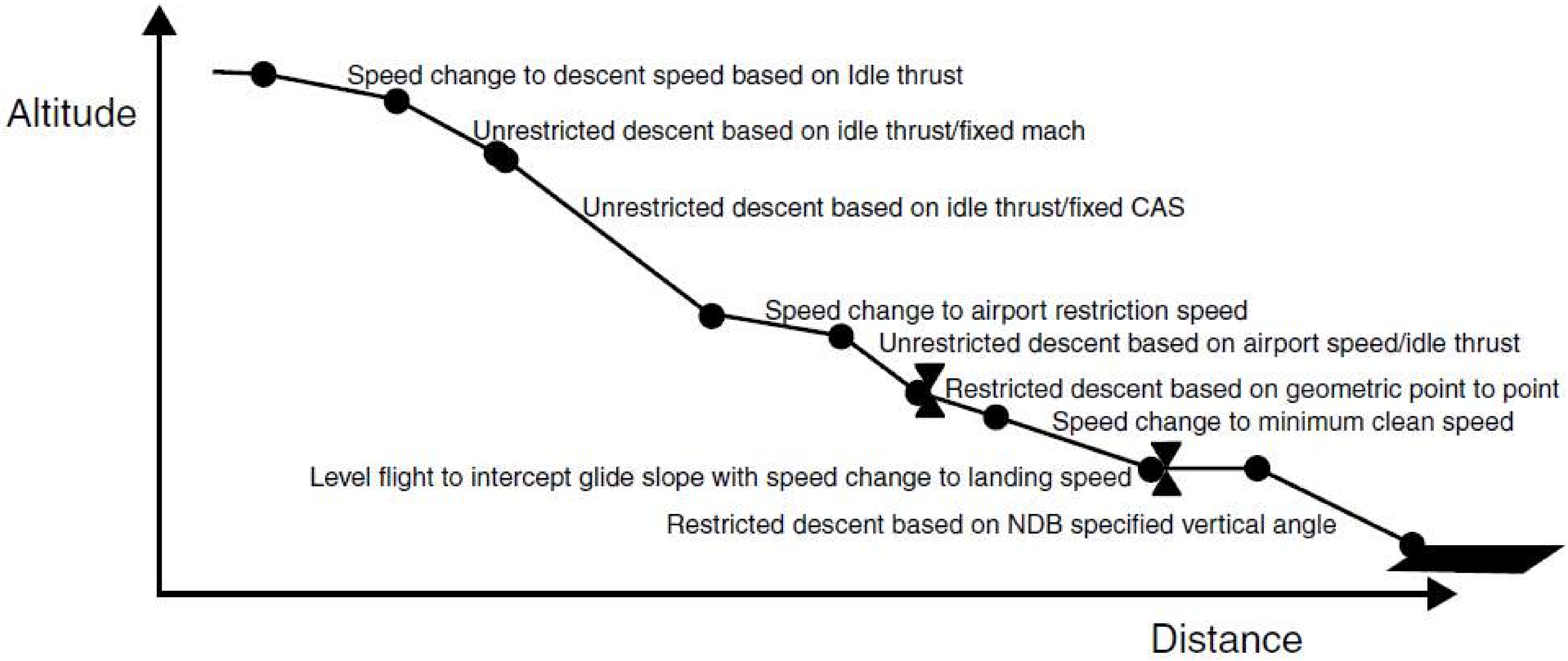
- The FMS continually monitors the aircraft envelope and ensures that the speed envelope restrictions are not breached. It also computes the optimum speeds for the various phases of the flight profile.



Typical climb profile



Typical cruise profile.



Typical descent profile.

Performance Computations

The performance function provides the crew information to help optimize the flight or provide performance information that would otherwise have to be ascertained from the aircraft performance manual.

Speed Schedule Computation

Climb

- Economy (based on Cost Index) — speed that optimizes overall cost of operation (lowest cost).

- Maximum angle of climb — speed that produces maximum climb rate with respect to distance.

- Maximum rate of climb — speed that produces maximum climb rate with respect to time.

- Required time of arrival speed (RTA) — speed that optimizes overall cost of operation, while still achieving a required time of arrival at a specific waypoint.

Cruise

- Economy (based on Cost Index) — speed that optimizes overall cost of operation (lowest cost).

- Maximum endurance — speed that produces lowest fuel burn rate, maximizing endurance time.

- Long range cruise — speed that produces best fuel mileage, maximizing range.

- Required time of arrival (RTA) — speed that optimizes overall cost of operation, while still achieving a required time of arrival at a specific waypoint.

Descent

- Economy (based on Cost Index) — speed that optimizes overall cost of operation (lowest cost).

- Maximum descent rate — speed that produces maximum descent rate with respect to time.

- Required time of arrival (RTA) — speed that optimizes overall cost of operation, while still achieving a required time of arrival at a specific waypoint.

Cost Index (CI)=flight time-related cost/fuel cost

This is carried out taking into account factors such as:

- Aircraft weight – computed from a knowledge of the take-off weight and the fuel consumed (measured by the engine flow meters).
- It should be noted that fuel can account for over 50% of the aircraft weight at take off.
- CG position – computed from known aircraft loading and fuel consumed.
- Flight level and flight plan constraints.
- Wind and temperature models.
- Company route cost index.

- The recommended cruise altitude and the maximum altitude are also computed from the above information.

- The flight crew enter the following data to enable the performance computations and flight plan predictions to be made.
    - Zero Fuel Weight (ZFW) and Zero Fuel Centre of Gravity (ZFCG).
    - Block fuel.
    - Airline Cost Index (CI).
    - Flight conditions (Cruise Flight Level (CRZ FL), temperature, wind).

The FMS computes the following predictions from the flight plan and the flight crew data entries:

- Wind and temperature.
- Speed changes.
- Pseudo waypoint computation: T/C, T/D, LVL OFF.
- For each waypoint or pseudo waypoint:
  - Distance
  - Estimated Time of Arrival (ETA)
  - Speed
  - Altitude
  - Estimated Fuel on Board (EFOB)
  - Wind for each waypoint or pseudo waypoint
- For primary and alternate destination
  - ETA
  - Distance to destination
  - EFOB at destination

- These predictions are continually updated depending on:
  - Revisions to the lateral and vertical flight plans.
  - Current winds and temperature.
  - Actual position versus lateral and vertical flight plans.
  - Current guidance modes.

- The predictions and the lateral flight plan combine to form a vertical profile that has six flight phases.

- The Multi Function Display Page display used to carry out the performance calculation and optimization (Figure 8.24).

- Flight envelope protection is achieved by computing maximum and minimum selectable speed, stall warning, low energy threshold, alpha floor signal and reactive wind shear detection.

Fig. 8.24 'Active Performance' Page display on MFD (by courtesy of Airbus).

➢ The FMS also computes maneuvering speed and flap and slat retraction speeds.

➢ Below figure shows these limits displayed on the Primary Flight Displays.

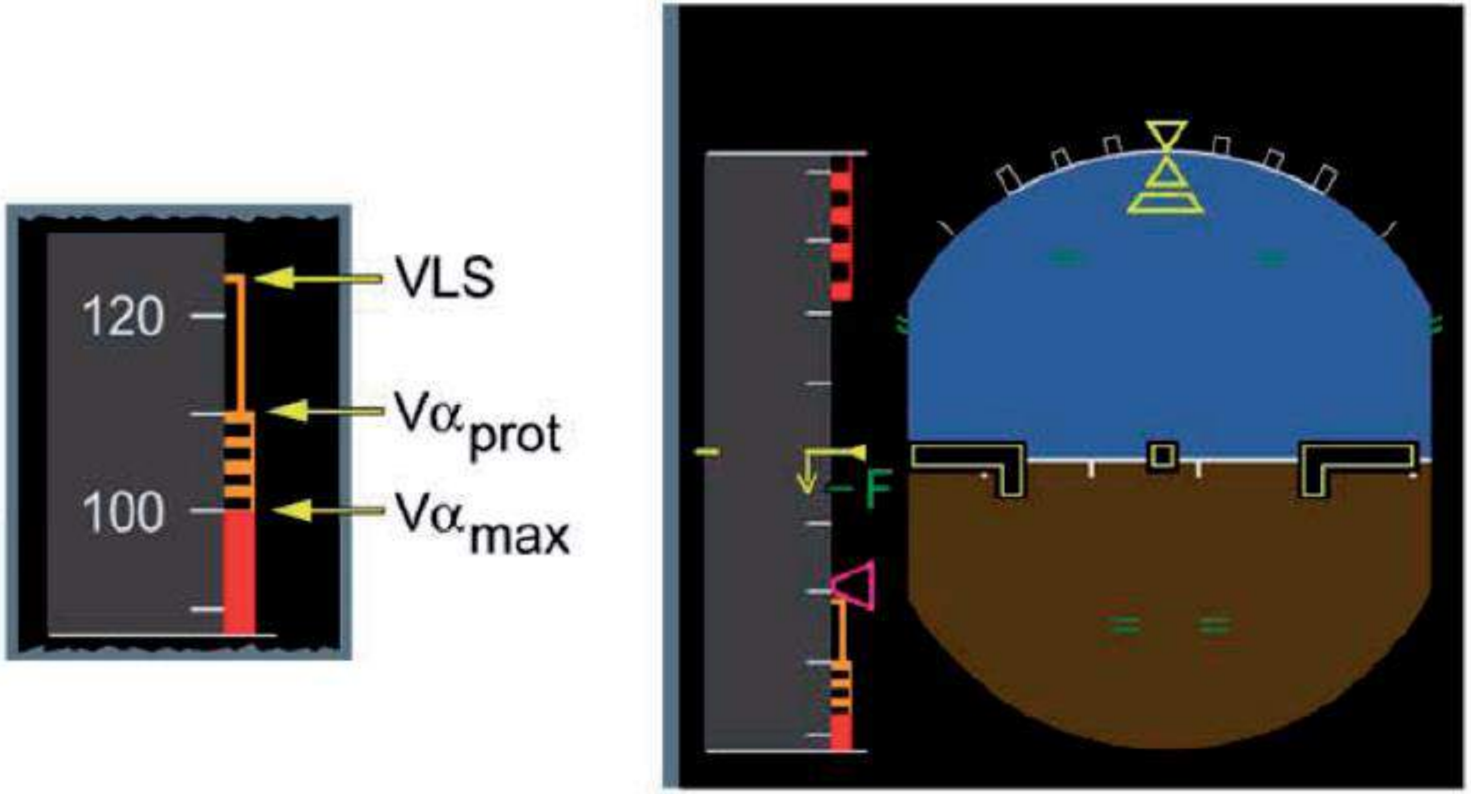


Fig. 8.25 Speed scale showing safe limiting values on PFD (by courtesy of Airbus).

Control of the Vertical Flight Path Profile

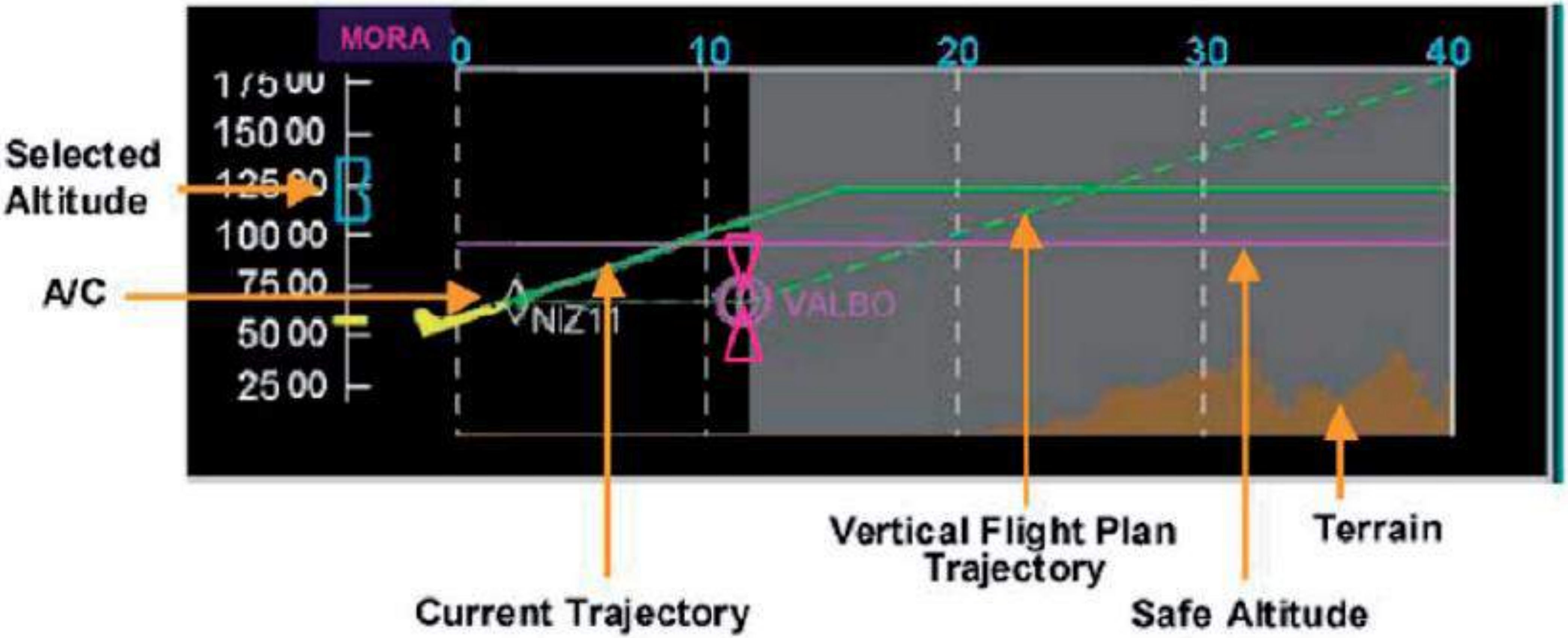


Fig. 8.27 Aircraft trajectory in vertical plane displayed on lower section of Navigation Display (by courtesy of Airbus).

- The FMS selects the speeds, altitudes and engine power settings during climbs, cruises and descents taking into account the flight plan, the prevailing conditions and the optimisation of the operation of the aircraft.

- The tasks which can be carried out and the facilities provided by the FMS during the various phases of the flight are briefly summarised below:

    - TAKE OFF – The critical speeds V1, VR, and V2 are inserted by the crew and displayed on the primary flight displays.

    - CLIMB – The FMS uses the manually input speed, the ATC constraint speed or the economical speed. It determines the start of the climb during take-off and predicts the end of the climb and the optimum cruising flight level.

- CRUISE – Five flight levels can be defined manually in the FMS.
- Two flight levels can be stored for every route in the navigation data base.

- During the cruise, ATC or the crew may change the cruise altitude and the FMS can perform a ‘step’ climb at economical speed or a ‘step’ descent at 1000 ft/min at an economical speed.

- These events are also displayed symbolically on the navigation display.

- the computed aircraft position and vertical guidance from barometric altitude when an RNAV approach has been selected. The FMS also provides speed control.

- At the end of an RNAV approach the crew takes control to carry out the landing using visual references.

- When an ILS approach has been selected, the FMS tunes the ILS frequency and selects the runway heading as required for the runway selected by the crew.

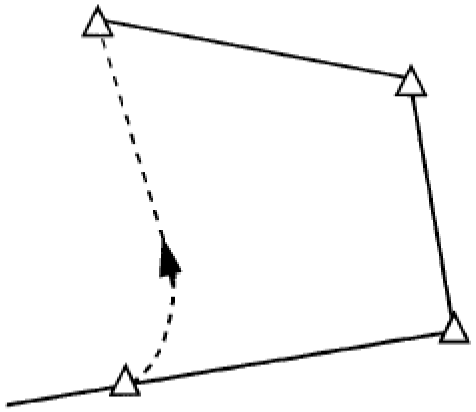
- The approach and landing guidance is carried out by the autopilot using the ILS localizer references for horizontal guidance and the ILS glide slope references for the vertical guidance until the glide extension and flare phases, unless the crew elect to carry out an automatic go around or elect to take over control.

- GO AROUND – This is always assumed. The FMS manages the climb to the accelerating altitude or a selected altitude and provides track guidance from the outbound track defined in the flight plan.

- The lower section of the Navigation Display is known as the 'Vertical Display Zone' and is used to display the vertical flight profile.

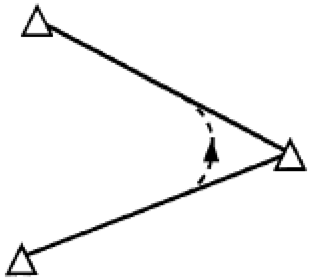
Operational Modes

- *Tangential go direct to mode* – This provides navigation from the current position to any waypoint in the flight plan or entered during the flight.



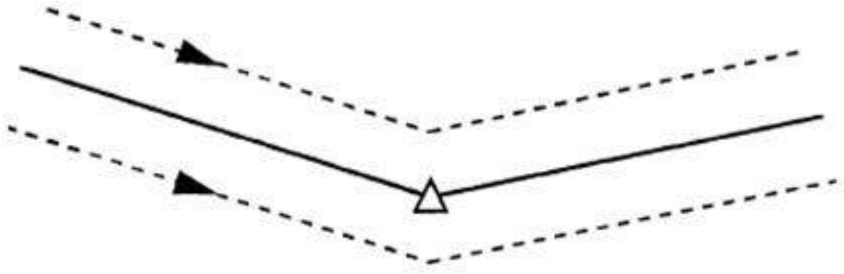
(a) Tangential Go Direct

- *Turn anticipation* – This avoids overshooting waypoints. It reduces both the distance flown and off-track manoeuvring.



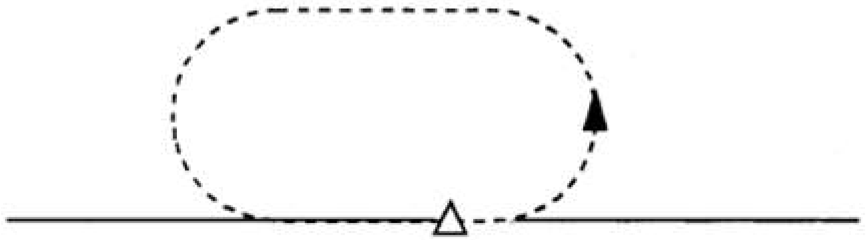
(b) Turn Anticipation

- *Parallel offset tracking* –The lateral offset allows ATC to increase traffic flows in certain cases.



(c) Parallel Offset Tracking

- *Holding pattern* –The FMS produces a precision holding pattern based on published ICAO entry procedure to reduce the pilot work load.



(d) Holding Patterns

4D Flight Management

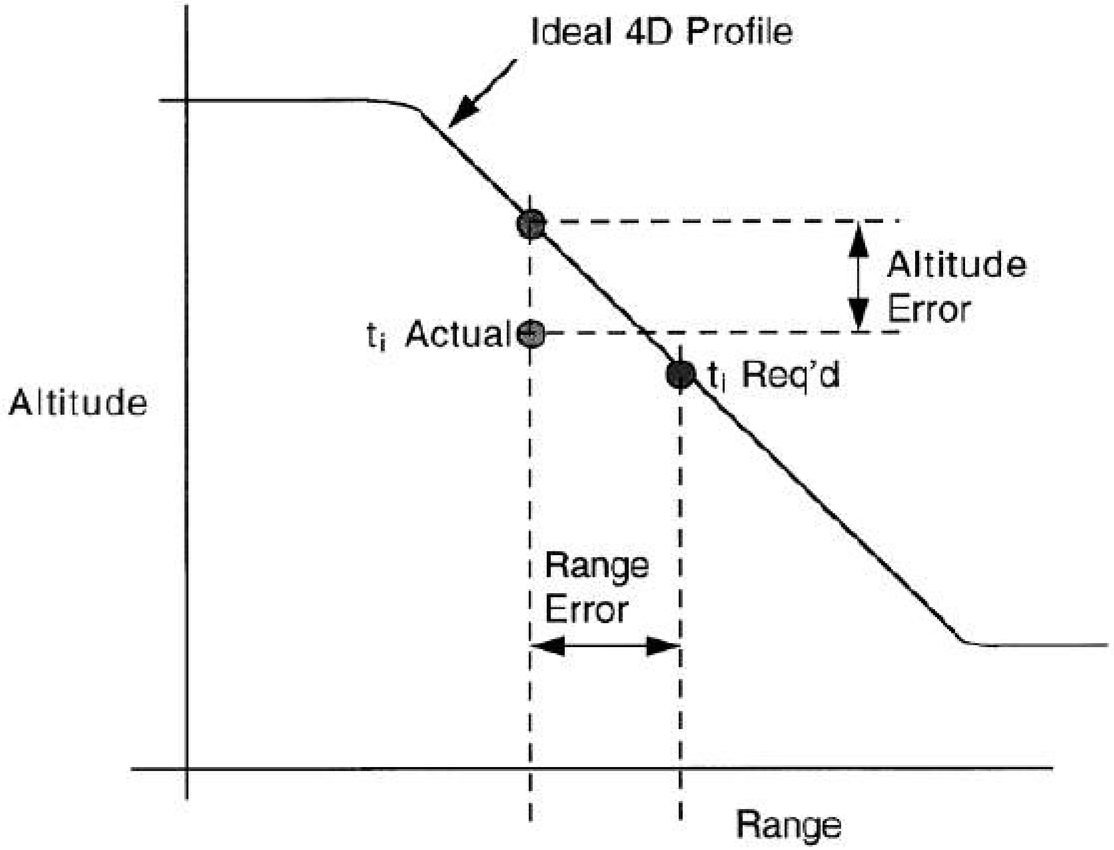


Fig. 8.29 4D descent control variables.

- 4D flight management covers the optimization of the aircraft's flight along the most fuel conservative 3D path through climb, cruise and descent within the constraints of the air traffic control environment.

- Most importantly, the arrival time of the aircraft is also controlled so that it fits into the air traffic flow without incurring or causing delays.

- This is achieved by the automatic closed-loop control exercised by the FMS through the autopilot and auto-throttle systems.

- These control the aircraft's flight path so that its 3D position at any time corresponds closely with the optimum time referenced flight path generated by the FMS computer.

Aircraft Safety and Warning Systems

- Before 1980s, aircraft accidents-many times fatal and catastrophic, were regular at 1-2 major accidents per month. Many of them were attributed to pilot errors, bad weather, aircraft hitting a mountain, dropping to ground due to insufficient airspeed, running out of fuel, careless blocking of vital air data instruments, etc. Five warning systems, amongst other cautionary and warning systems have significantly contributed for enhancing flight safety and they are:

1. Air Data Warning Systems
2. Stall Warning System (SWS)
3. Ground Proximity Warning System (GPWS), and
4. Traffic Collision Avoidance System (TCAS).

Air Data Warning Systems

- There are two air data parameters, which should be monitored and corrective actions taken by the pilots to avoid aircraft damage or catastrophic failures:

1. Air speed,

a. VMO, Maximum operating speed and/or

b. MMO, Maximum operating Mach number.

2. Altitude (height)

When predetermined limits are exceeded, visual and audible warnings are issued. These alerts are in addition to any speed limiting pointer- 'bugs' provided in ASIlMach meter

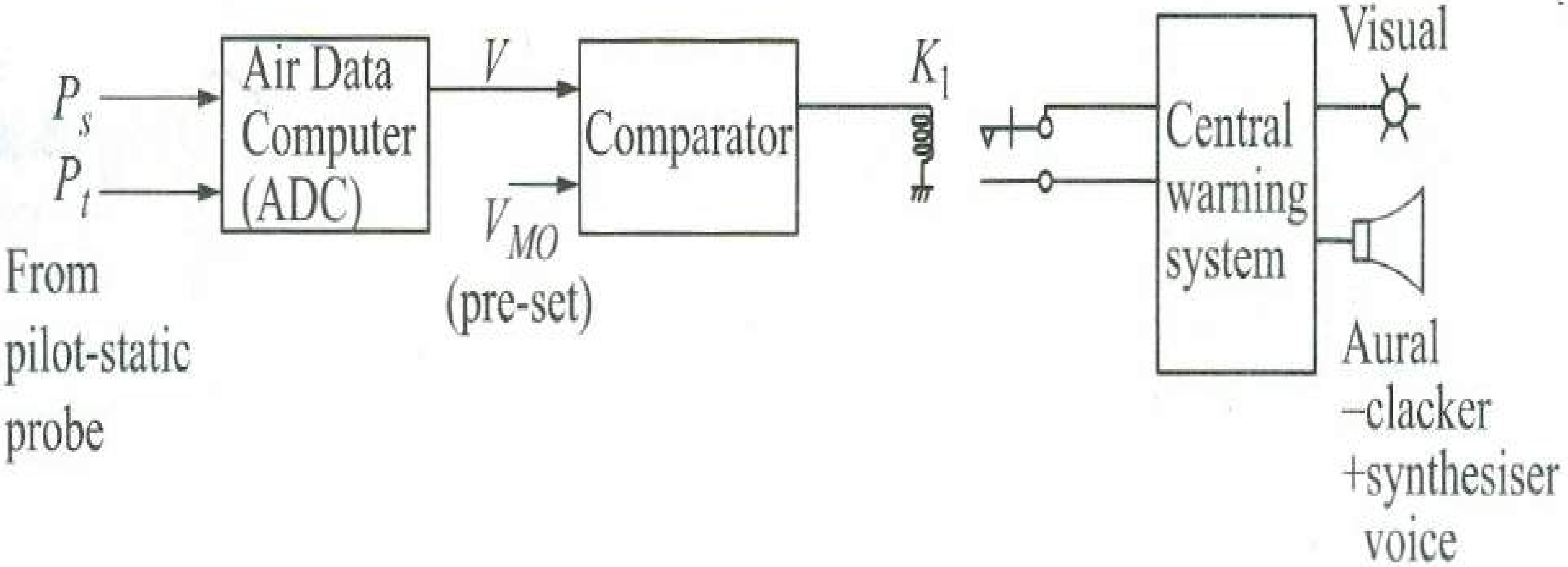


Fig.15.1 Air speed warning system.

- Air Data Computer (ADC) accepts P, and PI from pilot-static probe, computes the present speed of aircraft V.
- V is compared with a predetermined VMO for the type of aircraft.
- When V exceeds VMO, K, relay is turned ON, which in turn issues a specific type of signal as well as visual warning to the pilot.
- The synthesized voice could be just "Air speed".

Mach Warning System

- For high speed aircraft, particularly, if Mach number is exceeded, structural damages in the aircraft occur..
- A simple Mach warning system is shown in Figure.

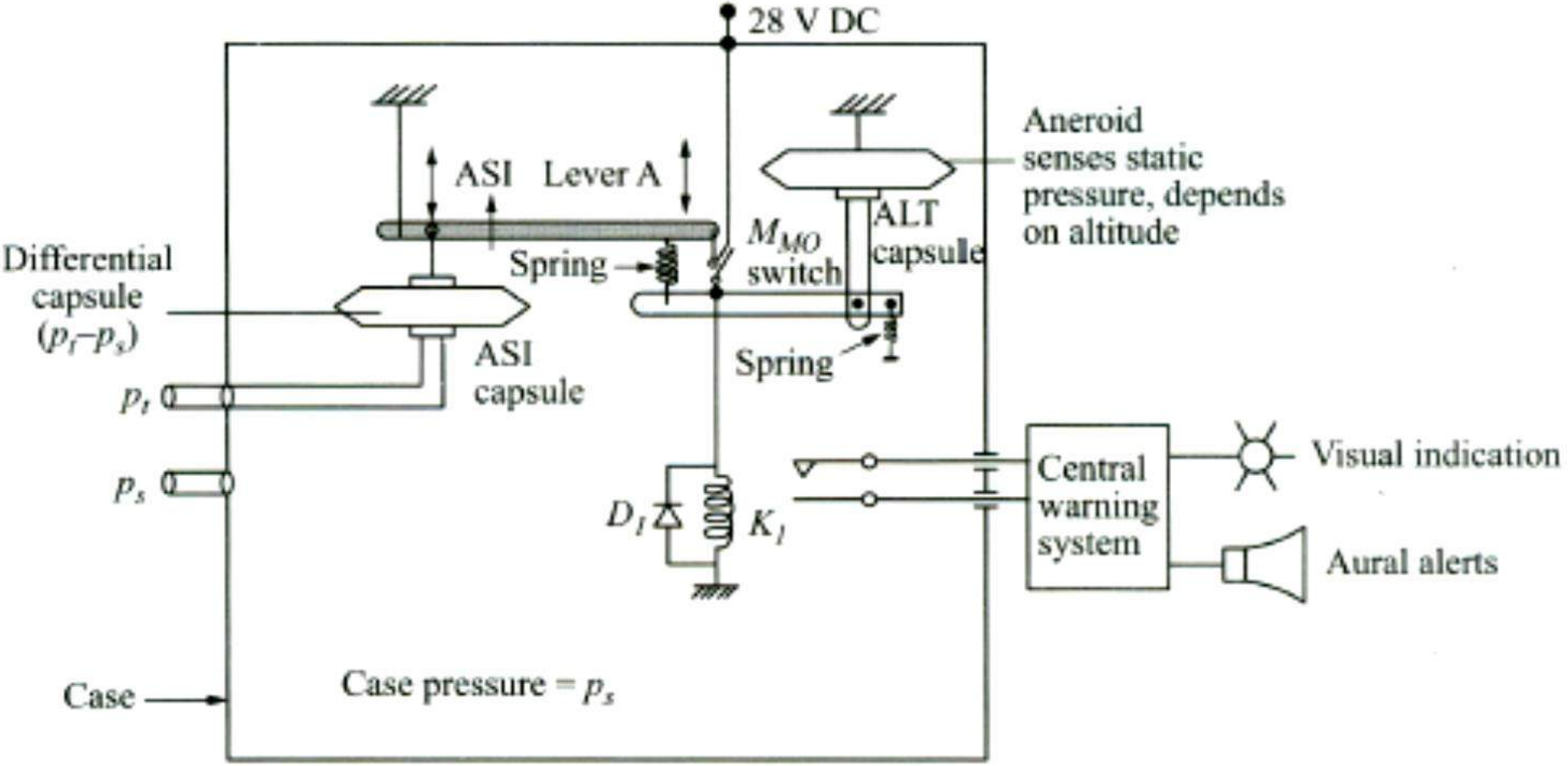


Fig. 15.2 Simple Mach warning system.

- ASI capsule, in combination with ALTI capsule, actuates MMO switch contact, which in turn is made to actuate relay K, once the preset MMO is exceeded.
- Diode D, protects the relay coil against high voltages, when 28 V is switched in and out.
- The relay contacts of K, is used to issue an aural as well as visual warnings to the pilot.

Altitude Alert System

- Altitude alert system issues an audible as well as visual warning, when the aircraft crosses the preselected altitude.

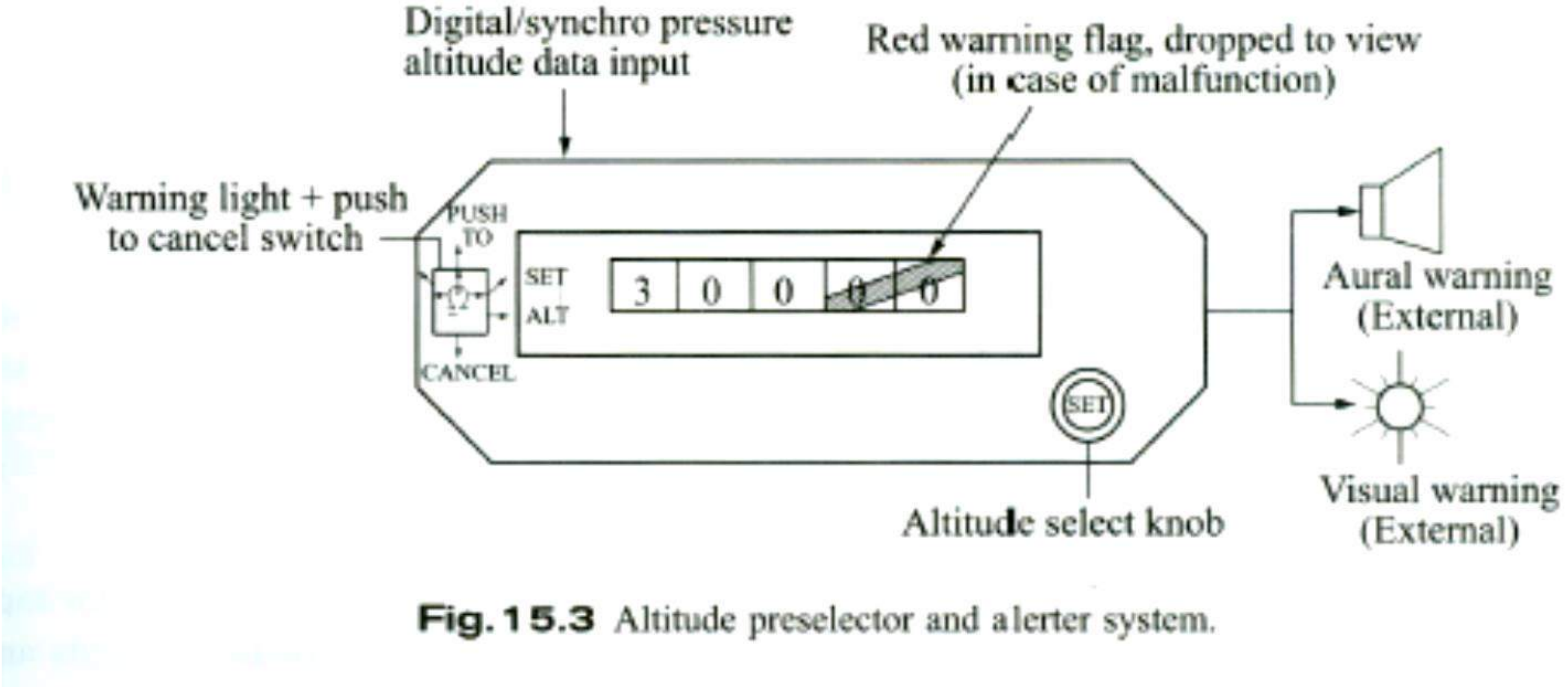


Fig. 15.3 Altitude preselector and alerter system.

- A typical system is shown in Figure
- The preselector/alerter is used to preselect an altitude to be obtained by the FCS (Flight Control System) and to provide the pilot with alerting signals, when approaching or deviating from the selected altitude.
- The preselected altitude is displayed as a 5-digit numeral.
- Visual/audible alarms are generated in two situations:

1. Whether the aircraft is in "capture" mode of the preselect altitude (either in ascent or descent), or
2. (After capture) "deviation mode".

- Altitude can be preset from 0 to 55,000 feet, with a resolution of 100 feet, with last two digits being fixed at zeros.
- "Altitude select" knob is used to set the preselect altitude. In case of malfunction, a red warning flag drops on the last two fixed digits.
- The preselector itself can become faulty, or the baro data may be disconnected, and in both cases, red warning flag drops over the last two digits.

- Consider a descending aircraft (Figure 15.4). Initially there is a large difference between actual altitude of the aircraft and the preset value. As the aircraft descends, the difference is reduced.
- When the difference becomes 900 feet, "Capture mode" is detected and two warnings are issued:

(i) Aural warning lasting 2-seconds, and

(ii) Warning lights in the preselector unit are turned ON.

While continuing the descent, when the difference reduces to 300 feet above preset altitude, no aural warning is issued, and the warning lights are turned ON and OFF.

- The "capture" and "deviation" modes are further illustrated in Figure.

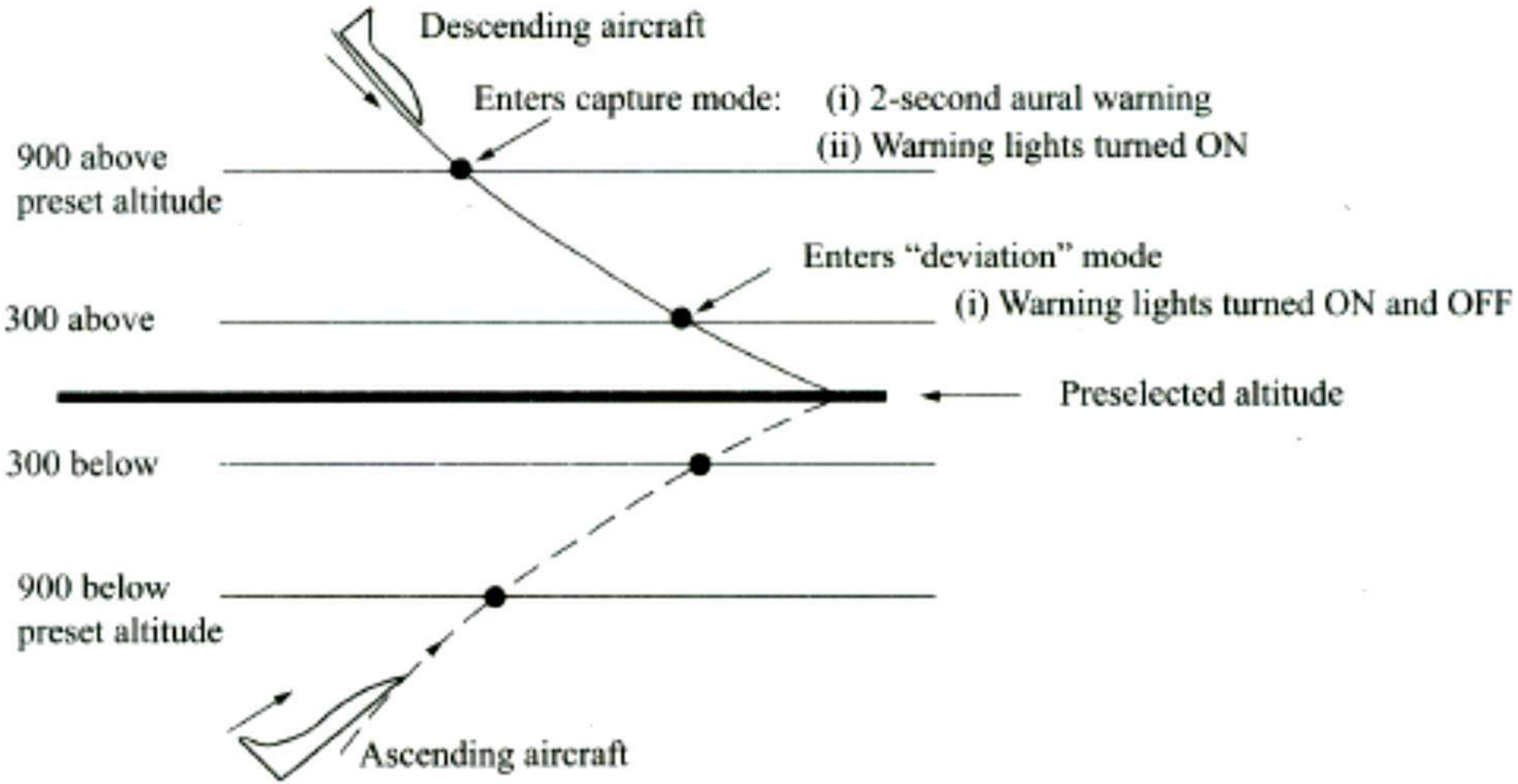


Fig. 15.4 Preselector unit—capture and deviation modes.

Stall Warning System (SWS)

- The purpose of SWS is to give the pilot both audible and tactile (vibrations of control column) warning about an incipient stall.
- At cruise altitude, pilot can readily recover from stall. However, if the aircraft stalls while landing, there is no room for stall recovery and catastrophic accidents have occurred.
- Stall warning system gives audible and tactile warning to the pilots well before the actual stalling occurs. This gives adequate room and time for the pilots to recover from the incipient stalling of the aircraft.

Stalling of an aircraft occurs when there is a sudden loss of lift, as the angle-of- attack, α is increased beyond a certain maximum value α_{max} or α_{crit} . α_{max} is specific to each type of aircraft depending on its tail configuration. Before we describe SWS, we need to understand lift force, L.

Lift force is generated in the aircraft mostly by the two wings and is given by:

$$L = C_L q \text{ and } C_L = \frac{L}{q} \tag{15.1}$$

where, L = lift force
C_L = coefficient of lift
and q = dynamic pressure, = 1/2 ρV^2
ρ = air density
V = airspeed over the wing.

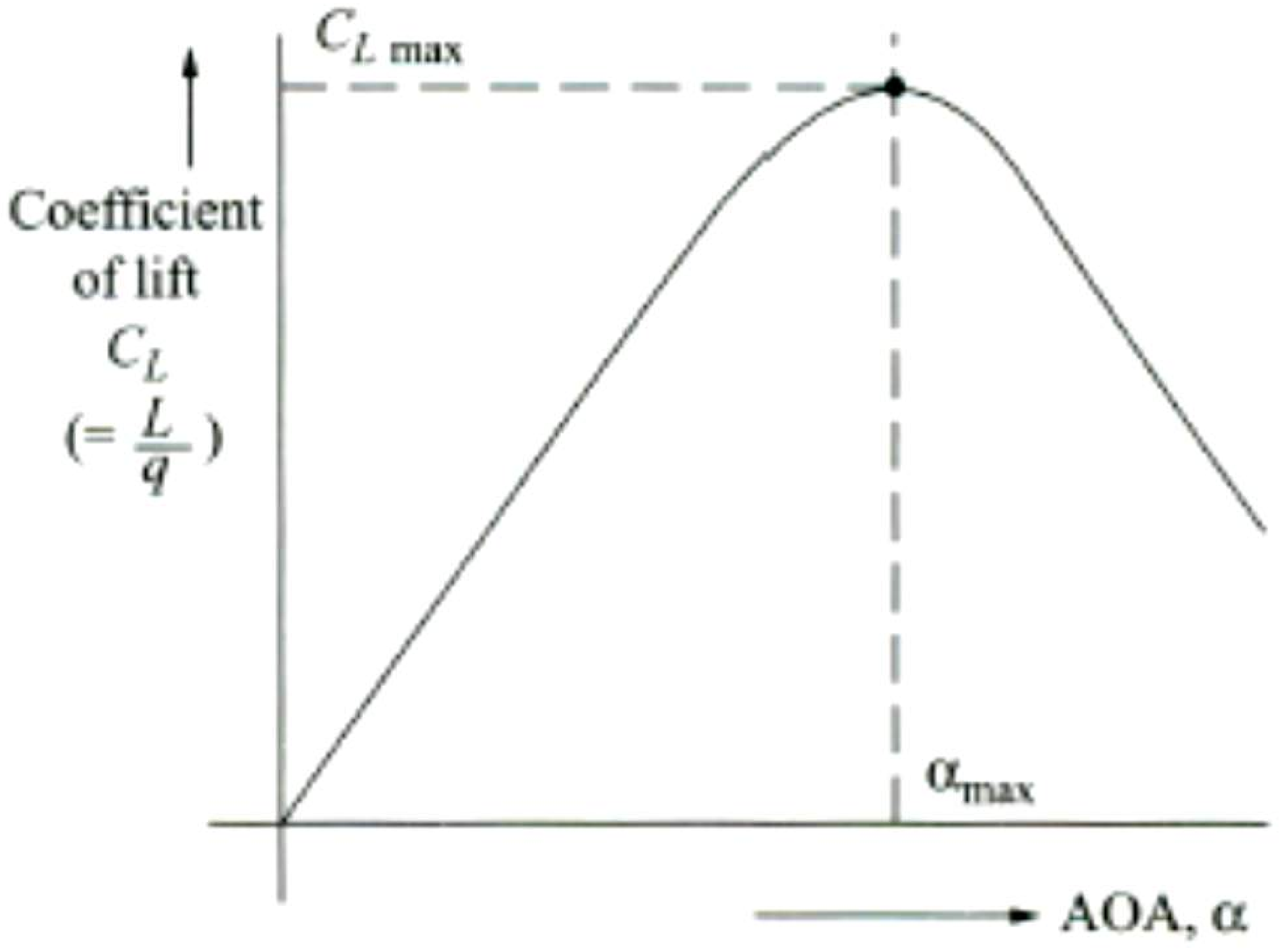


Fig. 15.5 C_L vs angle of attack characteristic of a wing.

- Stall is an extremely dangerous situation, particularly during landing phase. Many catastrophic accidents (including the A-320 accident in Bangalore in 1990) have occurred.
- The flow separation and turbulence is responsible for the sudden loss of lift. This is called the stall condition, and the corresponding angle of attack is known as umax the stall angle.
- The stall condition occurs at a particular angle of attack for the wing and depends on the design of the wing cross-section profile. AOA normally is between 12° and 18°.
- If a stall warning is issued at 10 or 2° below the umax' pilot has sufficient time and height to recover from the incipient fault.
- SWS is designed to generate this warning, precisely.

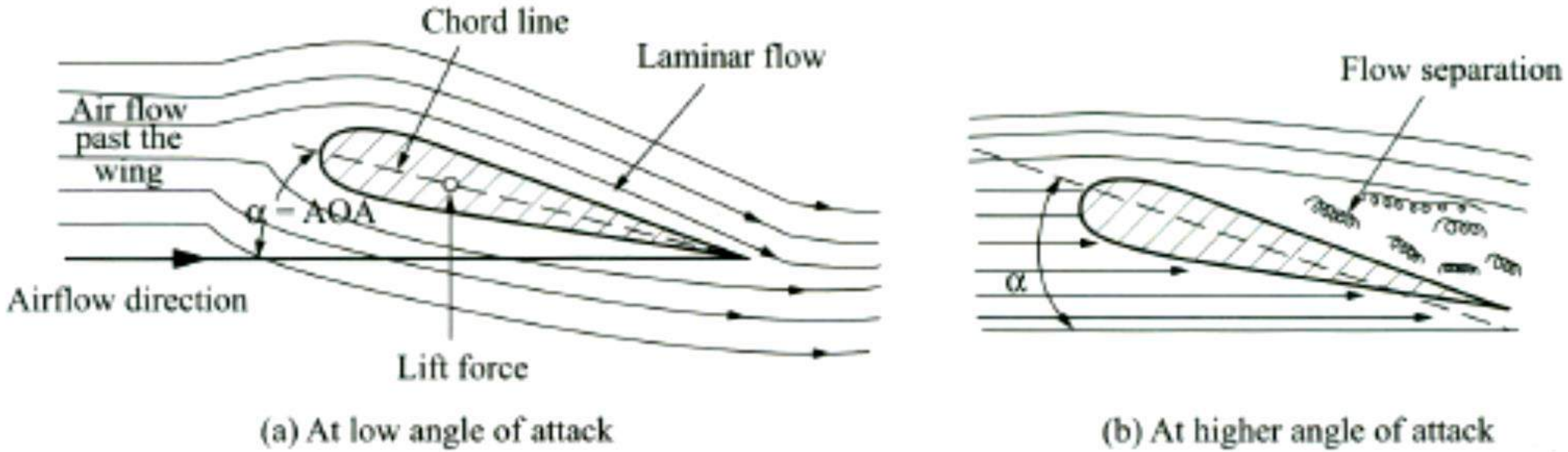


Fig. 15.6 Airflow past the wing of an aircraft.

- The aircraft behaviour as it approaches stalling condition depends on many factors, which are summarised below:

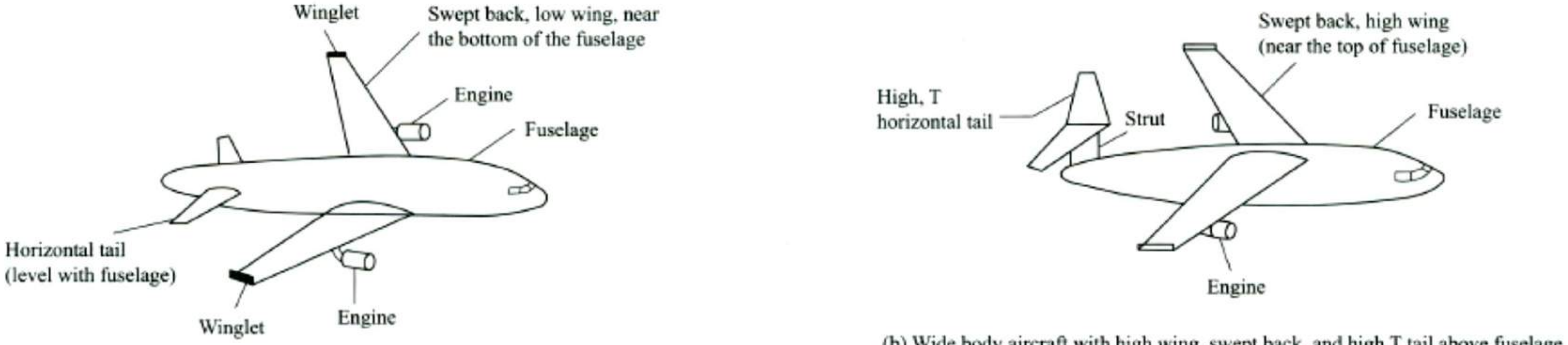
(i) Aircraft design characteristics like:

- - wing configuration
- - high wing (at the top of fuselage)
- - low wing (at the bottom of fuselage)
- - swept back
- - horizontal tail
- - T tail (above the fuselage)
- - Level with wing

(ii) Existing aircraft speed, which in turn depends on:

- - engine power settings
- - flap angles
- - bank angles
- - pitching rate.

- Figure 15.7 shows different aircraft configurations. In modem aircraft, pilot simply pushes a switch called "TOGA“ (Take Off and Go Around). Activating the switch automatically increases the engine thrust, and the aircraft pitches up, in order to recover from stall



(a) Wide body aircraft with low wing, swept back, and with horizontal tail level with fuselage.

(b) Wide body aircraft with high wing, swept back, and high T tail above fuselage

Fig. 15.7 Different aircraft configurations.


60
80
100
120
140
160
180
200
250
300
350
400
MACH
.85
385
KNOTS

- Stall warning systems typically comprises:

1. AOA sensor
2. SWS computer and
3. Warning indicators

- - stick shaker
- - aural warning.

The block schematic diagram is shown in Figure 15.8.

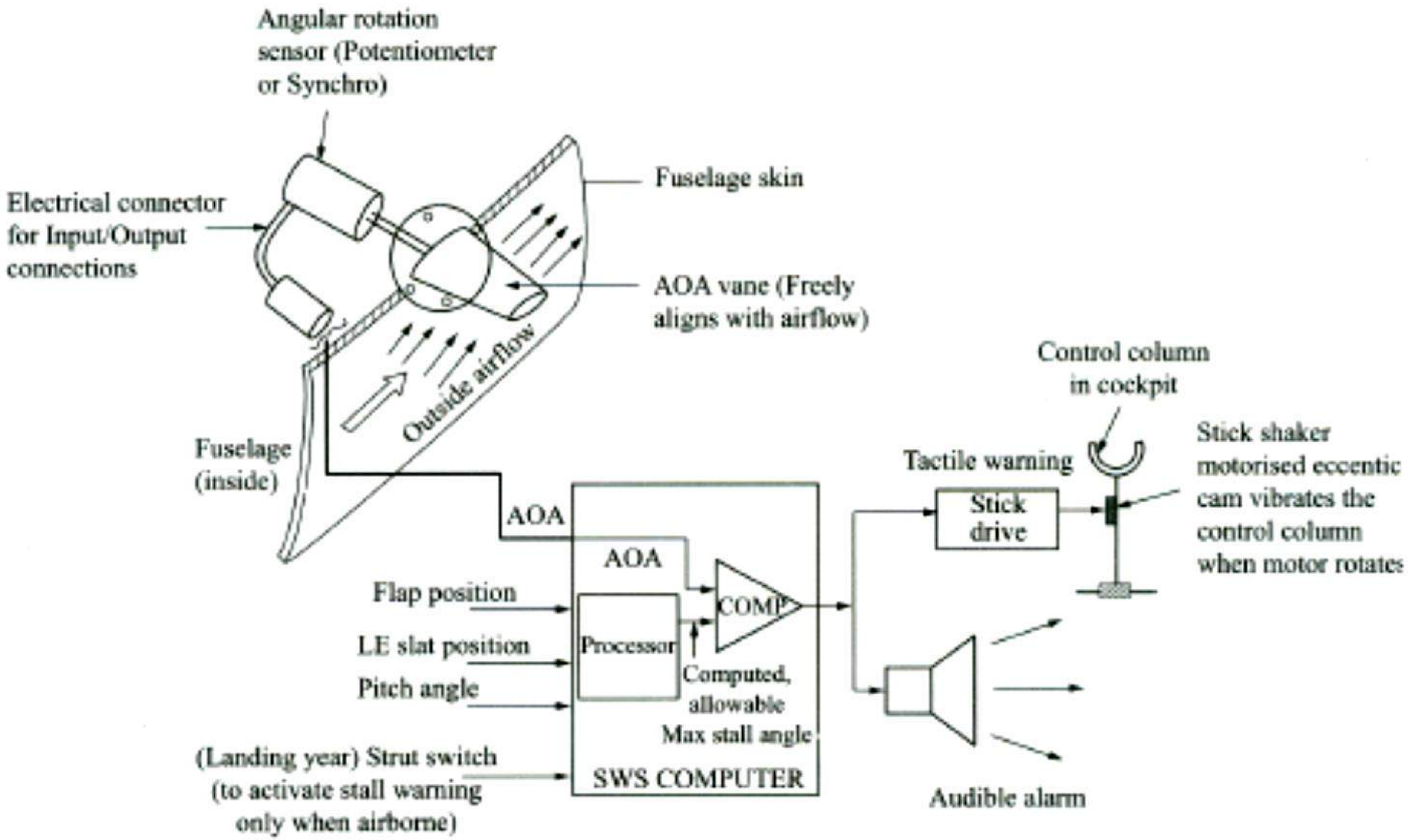


Fig. 15.8 Stall warning system.

AOA Sensor: Consists of a hinged-vane-type sensor, located at the front of the fuselage so that the vane-protrudes into the airstream.

The vane follows the airstream and in normal level flight, AOA sensor is parallel to airflow. When the attitude (pitch/roll) of the aircraft changes, the airflow angle also changes, and the freely rotating vane deflects to be in line with airflow.

The vane position indicating AOA is sensed either through a synchro or using a potentiometer to give AOA data to the SWS computer.

SWS Computer: Incoming data from the AOA sensor is processed and compared with the allowable stall limit-angle which is one or two degrees below the critical stall angle. The limit angle is computed, taking into account the following inputs:

(i) Flap position

(ii) Leading edge slat position

(iii) Pitching rate

(iv) Bank angle, etc.

Ground Proximity Warning System (GPWS)

- GPWS monitors an aircraft's height above ground using a radio altimeter (RA).
- An on-board computer keeps track of these readings, calculates trends and warns the pilot with visual and aural warnings/messages if the aircraft happens to be in certain defined flying "modes" or configuration.

- GPWS was designed in 1987 by Don Bateman of Allied Signal (now Honeywell) to alert the pilot if the aircraft is in immediate danger of flying into ground or an obstacle.
- The development of GPWS, after a series of controlled flight into terrain (CFIT) accidents killed hundreds of people and destroyed many aircraft.

- Traditional GPWS can only gather data directly below the aircraft. If there is sudden change in terrain such as a rising hill or steep slope, GPWS will not be able to sense the aircraft closure rate until it is too late to take any evasive action.
- In the late 1990s, this shortcoming was also addressed and GPWS was combined with GPS and worldwide digital terrain database. Onboard computers used the current location of the aircraft and the database of earth's terrain to give the pilot a visual orientation to high and low points in the vicinity of the aircraft. The GPS aided GPWS is called Enhanced GPWS or EGPWS.

- EGPWS improved the warning capability by introducing the terrain database for look-ahead-protection.
- Terrain display gives the pilots a visual orientation to high and low points nearby aircraft.
- Thus the horizontal as well as vertical situational awareness is significantly enhanced, by combining GPS technology and worldwide digital map database.

- Pilots must respond to GPWS warning and act quickly and accordingly in mandated procedures.
- Honeywell is a major supplier of EGPWS to a vast majority of aircraft.
- EGPWS uses aircraft inputs such as position, altitude, air speed and glideslope, which along with internal terrain, obstacles, and airport databases, predict a potential conflict between the aircraft's flight path and terrain obstacle.
- Figure 15.10 shows the block diagram of EGPWS, showing all the inputs and outputs

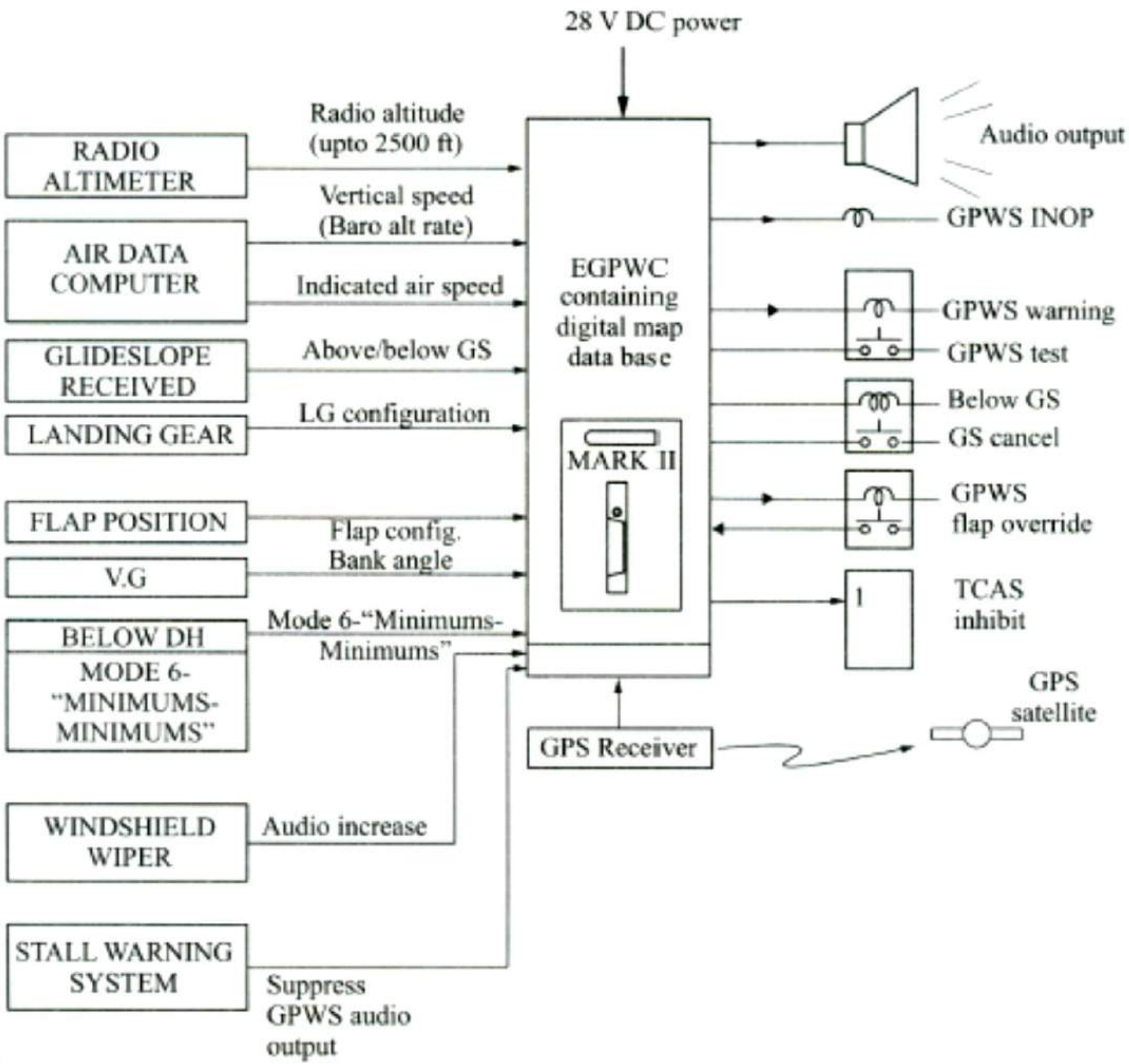


Fig. 15.10 EGPWS block diagram.

- GPWS will generate both aural and visual warnings to the pilot, if the aircraft enters the flight path to the ground that could lead to a potentially dangerous situation.
- Prior to GPWS there were many accidents due to Controlled Flight Into Terrain (CFIT), where pilot was not aware that the aircraft is heading towards a hill or a tall building.
- GPWS is powered by the 28 V DC and consists of Ground Proximity Warning Computer (GPWC), contained in a rack-mounted avionic type Line Replaceable Unit (LRU).

The signal sources are:

- Radio Altimeter (RA) to provide accurate (± 0.1 m) height of aircraft above ground.
- Air Data Computer or equivalent input to provide baro altitude and airspeed.
- Glide Slope Receiver (ILS) to provide the aircraft actual glide path.
- Landing Gear Logic (LG) to determine whether the aircraft is in landing configuration.
- Flap Position Logic (FP) to know if high-lift devices are deployed
- Vertical Gyro (VG) to provide altitude (pitch roll) of aircraft.
- GPS Receiver to determine the present position in the Digital Map database, to provide a moving map display for terrain awareness.

- GPWS provides six (6) different MODES of alerts and warnings.
- Modes 1-5 refer to specific types of CFIT accidents, which have occurred and have been documented.
- Mode 6 has optional alerts and synthesised callouts, which enhance situational awareness of the pilots.
- The six GWPS modes are

Mode	Flight condition	Synthesised aural warning
Mode 1 :	Excessive descent rate	PULL UP, SINK RATE
Mode 2 :	Excessive terrain closure rate	TERRAIN, PULL UP
Mode 3 :	Altitude loss after take-off	DONT SINK
Mode 4 :	Unsafe terrain clearance	TOO LOW-TERRAIN
		TOO LOW-GEAR
		TOO LOW-FLAPS
Mode 5 :	Excessive deviation below Glideslope	GLIDESLOPE
Mode 6 :	Bank angle protection	BANK ANGLE
	There is also an optional 7th mode for wind shear (clear air turbulence).	
Mode 7 :	Wind shear encounter	WIND SHEAR

Table 15.1 Pilot actions for different aural annunciations

Mode	Annunciation	Pilot Action, Recommended
1	SINK RATE	Level wings and reduce descent rate
2	TERRAIN TERRAIN	Adjust flight path away from terrain
3	DONT SINK	Level wings, and immediately establish climb rate
4	A) TOO LOW, TERRAIN	Adjust flight path to recover safe terrain clearance until visual and aural alerts cease
	B) TOO LOW, GEAR	Execute Go Around
	C) TOO LOW, FLAPS	Execute Go Around
5	GLIDE SLOPE	Immediately climb to re-establish glide path—or Execute GA procedure
6	1. BANK ANGLE	Level wings
	2. "MINIMUMS MINIMUMS"	Execute Go Around

Traffic Collision Avoidance System (TCAS)

- The main objective and purpose of TCAS is to help the pilot in avoiding mid-air collisions of aircraft.
- TCAS achieves this, by co-operative (Q&A) communication about position of neighbouring aircraft, which must necessarily have TCAS capability for successful query and answer.
- TCAS spans the vicinity by interrogating the transponders of other aircraft.
- The received transponder signals are used to compute distance, bearing and altitude of other aircraft relative to the own aircraft.

- TCAS is an USA acronym. The internationally accepted name is Airborne Collision Avoidance System (ACAS).
- TCAS works independently of the normal Air Traffic Control (ATC), which is manually supervised, using a primary radar (pulse echo technique).
- TCAS is an implementation of Airborne Collision Avoidance System (ACAS) mandated by International Civil Aviation organisation to be fitted to all aircraft which has a weight over 5700 kg or having a seating capacity of more than 19 passengers.

- TCAS is an aircraft system using secondary surveillance radar SSR transponder signals which operates independent of ground-based equipment to advice the pilot on potential conflicting aircraft that are equipped with similar SSR transponders. (SSR is Secondary Surveillance Radar).
- In older aircraft, TCAS was integrated with Instantaneous Vertical Speed Indicator (IVSI), which indicates the rate (feet per minute) of climb or descent as shown in Figure 15.16. But in modem aircraft with 'glass cockpit', TCAS is integrated with Navigational Display (ND), which provides good situational awareness to the pilots.

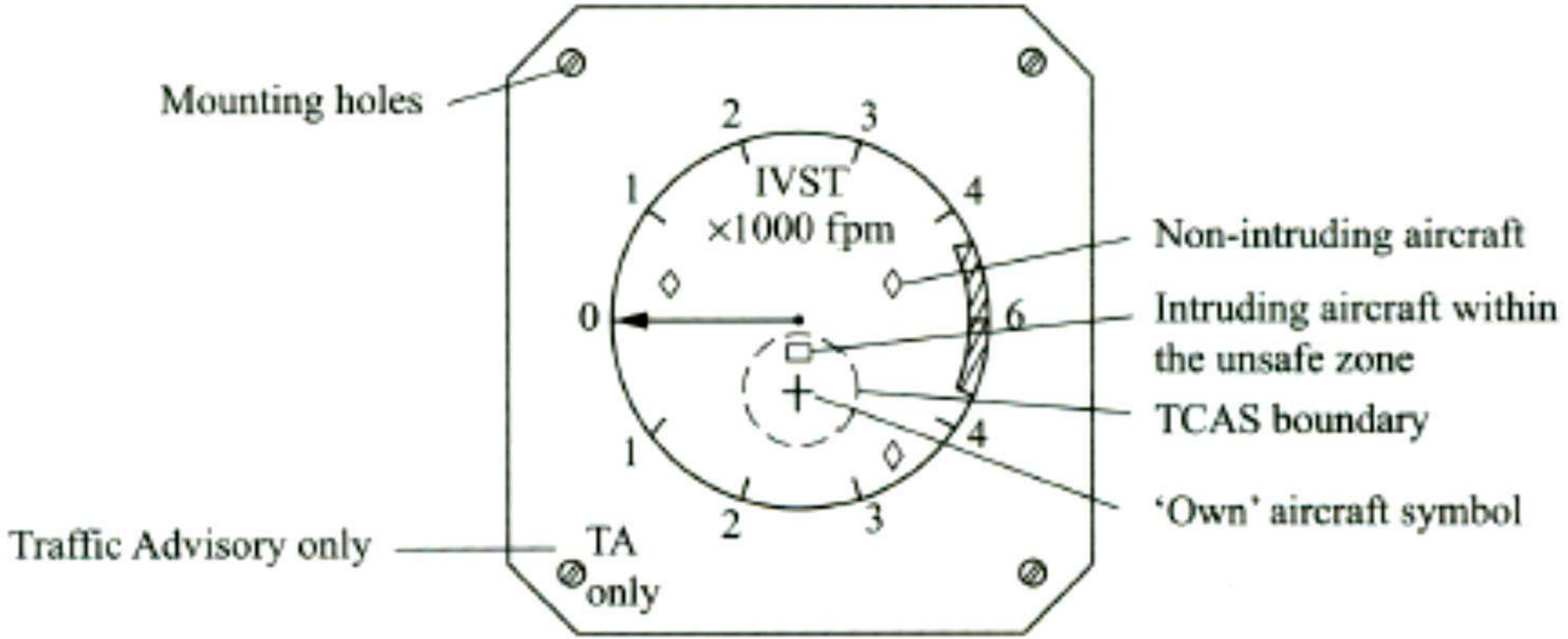


Fig. 15.16 TCAS and IVSI indicator.


2
1
4
-5
0
6
-5
4
1
2

Basic Principle

- TCAS depends on radio communication between 'OWN' aircraft and 'cooperating other aircraft'- meaning aircraft fitted with similar TCAS transponder.
- Each TCAS equipped aircraft radio interrogates all other aircraft within a predetermined range, about their LATILONG position. The interrogation frequency is 1030 MHz (or 1.03 GHz)-L-band.
- All other aircraft send their reply to OWN interrogating aircraft at a slightly higher frequency-1090 MHz (1.09 GHz). This "interrogation-reply" cycle occurs several times within a second. This is the data acquisition mode.

- Based on this frequent and constant "interrogation-reply" cycles, TCAS electronic system builds a 3-dimensional map of the aircraft in space, using primary navigational data like bearing, altitude, and range.
- The built-in computer extrapolates current range and altitude differences to anticipated future values, in order to determine, if a potential collision-threat exists.
- If a threat exists, appropriate aural and visual warnings are provided in the form of either visual warnings or through cockpit displays.
- Aural advisory warning in the form of synthesised voice is also issued

There are two types of advisories:

1. Traffic Advisory (TA) giving only information on potential threats, or

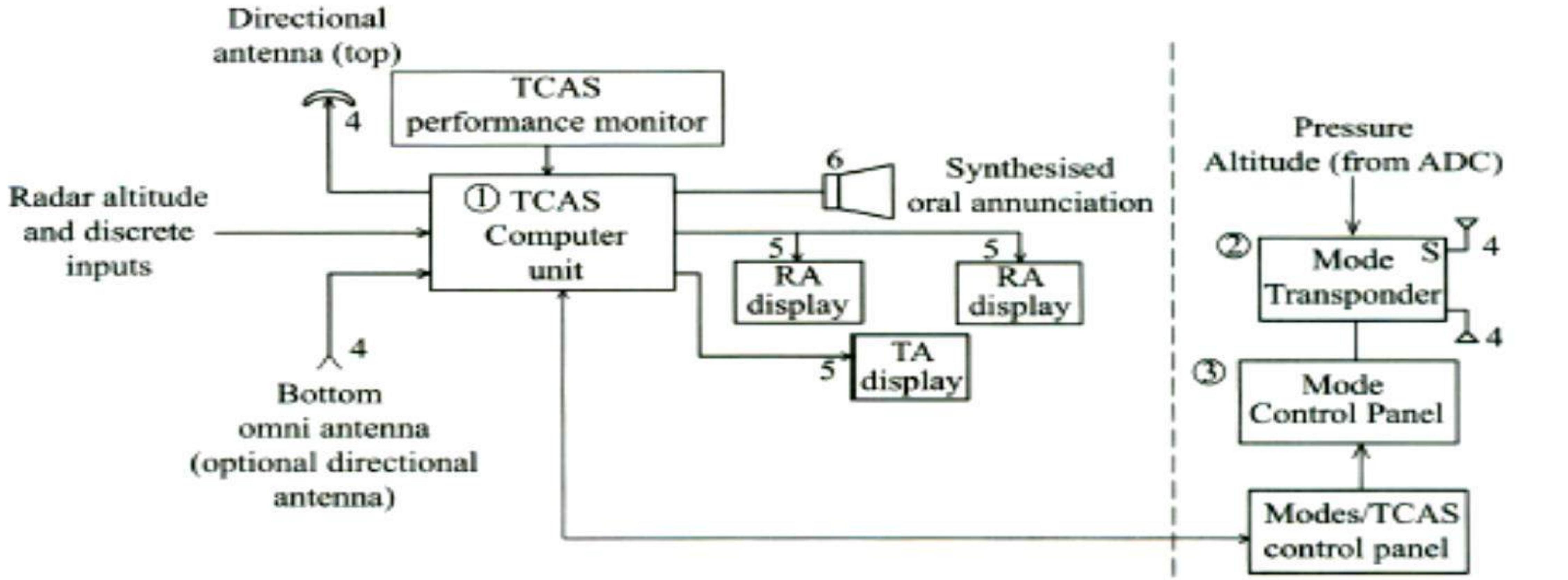
2. More recent Resolution Advisory (RA) giving in addition to TA, cues (synthesised voice) for the pilot to evade potential threats. This is an improvement on TA, giving threat resolution. There are several improvements made in TCAS development since the inception of concept.

- TCAS-II, is the second and present generation TCAS system fitted on most of the contemporary commercial airliners.
- TCAS-II provides, in addition to whatever TCAS I offers, vocal instructions to overcome the impending danger. This is called Resolutional Advisory- RA, suggesting to the pilot either "DESCEND, DESCEND" or "CLIMB, CLIMB" or "ADJUST VERTICAL SPEED ADJUST"- meaning, alter the vertical speed.
- TCAS-II systems work in a coordinated manner-i.e. if one aircraft is advised to CLIMB, the other aircraft is told to DESCEND, thereby increasing the vertical separation. TCAS II essentially ensures vertical separation.

Technical Description of TCAS-II

- Figure 15.17 is the basic block diagram of TCAS-II. The major components are:

1. TCAS computer unit
2. Mode S transponder
3. Mode control panel
4. Antennas
5. Cockpit display, Traffic display.



(a) TCAS II system, providing traffic and resolution advisories

(b) Mode S Transponder automatically reporting altitude

Fig. 15.17 Block diagrams of TCAS II and Mode S transponder.

TCAS computer unit:

This computer performs airspace surveillance, intruder tracking, its own altitude tracking, threat detection, RA manoeuvre determination and selection, and generation of coordinated advisories.

Coordination is required so as not to give conflicting commands to own and intruder aircraft.

Mode S Transponder

A mode S transponder is required to be installed and operational for TCAS to be functional.

If mode S transponder fails, then TCAS performance monitor will detect this failure and automatically places TCAS on a STANDBY mode.

The mode S transponder performs normal functions to support the ground-based ATC system.

Mode control panel:

Pilots can select and control all TCAS equipment including the TCAS computer, the mode S transponder, and in some cases TCAS displays using this control panel. A typical control panel provides four basic control positions as follows:

- **Standby:** Power is applied to TCAS processor and the mode S transponders. But TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.
- **Transponder**: Mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. But TCAS remains in standby.
- **TA only:** Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will issue only traffic advisories (TA). But Resolution Advisories (RAs) will be inhibited.
- **Automatic or TAIRA:** Mode S transponder is fully operational. TCAS will operate normally and issue appropriate interrogations and perform all tracking functions. TCAS will issue both TAs and RAs, when appropriate.

TCAS Antennas:

TCAS II antennas include a directional antenna that is usually mounted on the top of the aircraft, and either an omni- or directional antenna mounted at the bottom of the aircraft.

TCAS Cockpit displays: The TCAS interface with the pilots IS accomplished using two displays- TA display and RA display.

The information displayed on each of the two displays is identical. The display symbology is as follows:

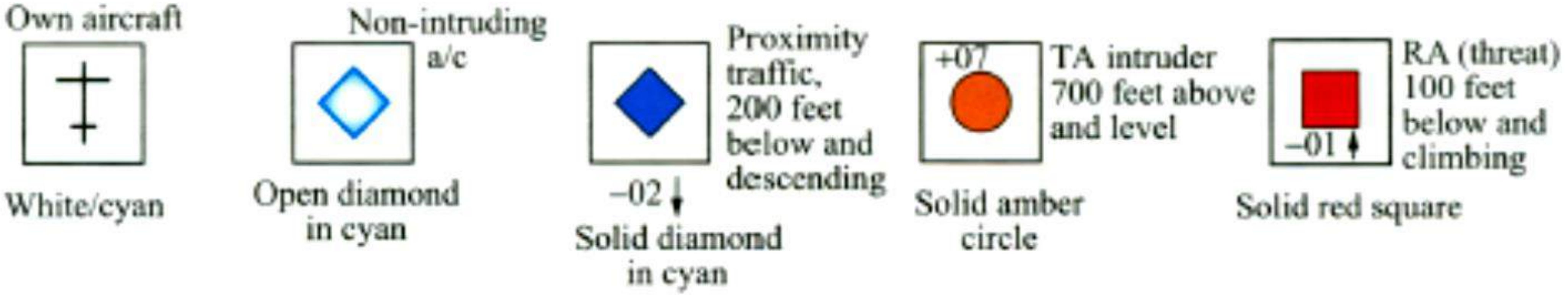


Fig. 15.18 Display symbology in TCAS.

- TCAS-II takes into account only vertical separation.
- TCAS-III is the next generation system, which gives RA for both vertical and lateral separation.

Pilot Priorities/TCAS

- Pilots are required to operate under the following strict instructions:

l. To regard all TCAS messages as genuine alerts demanding an immediate and high-priority response.

2. Only stall warning and ground proximity warnings have higher priorities than TCAS warnings.

3. TCAS-RA has the higher priority than ATC commands.

4. An RA is ignored only if the two pilots visually identify the potentially conflicting traffic and decide to have no deviation from the current flight path.

Limitations of TCAS II

There are certain limitations before full advantages of TCAS II can be exploited:

1. All other conflicting aircraft in the surrounding airspace must also have TCAS capability. TCAS is not incorporated in smaller aircraft due to the high costs involved ($25,000 to $150,000). Hence, intruding small aircraft are not displayed and this is a serious threat.

2. Present generation TCAS II is limited to vertical (altitude) separation only. Lateral separationis not taken into consideration.

3. ATC is unaware of RAs to aircraft and may issue conflicting instructions, thus confusing the pilot. TCAS does not automatically communicate with ATC, and ATC is not kept informed.

4. RAs to all other surrounding and conflicting aircraft are not shared by other aircraft. Thus, pilots are not sure whether the other aircraft is obeying RAs issued to them. Crucial realtime changes of other aircraft are not known to participating aircraft.

5. Present TCAS is range-based (i.e. distance-based). Instead, time-based TCAS would be more appropriate.

6. There is a possibility of hitting the local terrain, if RAs are followed.

7. RAs may demand climb/descent rates beyond the aircraft performance capabilities.

8. There is no link of RAs, to scheduled flight plans. TCAS is primarily (extrapolation oriented), using TCAS algorithms, having no link to flight plans or ATC instructions.

THANK YOU