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1 OBJECTIVES

As a result of tutored experience of Digital Techniques/Electronic Instrument Systems, the student will, in examinations, be able to: -

1.1 LEVEL 1

Demonstrate a familiarization with the principal elements of certain topics so that the student should be: -

1. Familiar with the basic elements of the topic.

2. Able to give simple descriptions of the whole topic by using common words and examples.

3. Able to use typical terms associated with relevant topics.

1.2 LEVEL 2

Demonstrate a general knowledge of the theoretical and practical aspects of certain other topics so that the student is able to;-

1. Understand the theoretical fundamentals of the topic.

2. Give a general description of the topic, using typical examples.

3. Use the mathematical formulas, associated with the appropriate physical laws in describing the topic.

4. Read and understand drawings, schematics and sketches, used to describe a topic.

5. Apply the knowledge gained, in a practical manner, using the relevant, detailed procedures

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2 ELECTRONIC INSTRUMENT SYSTEMS

All instruments essential to the operation of an aircraft are located on panels, the number of which vary in accordance with the number of instruments required for the appropriate type of aircraft and its flight deck layout. The front instrument panel, positioned in the normal line of sight of the pilots, contains all instruments critical for the safe flight of the aircraft. This panel is normally sloped forward 15° from the vertical to minimize parallax errors. Other panels within the flight deck are typically positioned; Overhead, left and right side and centrally between the pilots.

Figure 1 shows the layout of a Boeing 737 Flightdeck.

Boeing 737 Flight-deck
Figure 1

2.1 FLIGHT INSTRUMENTS

There are six flight instruments whose indications are so coordinated as to create a “Picture” of an aircraft’s flight condition and required control movements. These instruments are:

1. Airspeed Indicator.
2. Altimeter.
3. Gyro Horizon Indicator.
4. Direction Indicator
5. Vertical Speed Indicator.
6. Turn & Bank Indicator.

The first real attempt at establishing a standard method of grouping was the “Blind Flying Panel” or “Basic Six”. The “Gyro Horizon Unit (HGU) occupies the top centre position, and since it provides positive and direct indications of the aircraft’s attitude, it is utilized as the “Master Instrument”. As control of airspeed and altitude is directly related to attitude, the “Indicated Air-Speed (IAS), Indicator, Altimeter and Vertical Speed Indicator (VSI) flank the HGU.

Changes in direction are initiated by banking the aircraft, and the degree of heading change is obtained from the “Direction Indicator” (DI). The DI supports the interpretation of the roll attitude and is positioned directly below the HGU. The “Turn & Bank Indicator” serves as a secondary reference instrument for heading changes, so it also supports the interpretation of roll attitude.

With the development and introduction of new types of aircraft with more comprehensive display presentation, afforded by the indicators of flight director systems, a review of the functions of certain instruments and their relative positions within the group resulted in the adoption of the “Basic T” arrangement as the current standard.

There are now four key indicators:

1. Attitude Director Indicator.
2. Horizontal Situation Indicator.
3. Combined Speed indicator.
4. Altimeter.

Figure 2 shows the layout of the basic 6 and T instrument groupings.

Basic “Six” and “T” Flight Instrument Grouping
Figure 2

2.2 ELECTRONIC INSTRUMENT SYSTEMS

Modern technology has enabled some significant changes in the layout of flight instrumentation on most aircraft currently in service. The biggest change has been the introduction of Electronic Instrument systems. These systems have meant that many complex Electro-mechanical instruments have now been replaced by TV type colour displays. These systems also allow the exchange of images between display units in the case of display failures.

There are many different Electronic Instrument Systems, including:

1. Electronic Flight Instrument System (EFIS).
2. Engine Indicating & Crew Alerting System (EICAS).
3. Electronic Centralised Aircraft Monitoring (ECAM).

Figure 3 shows a typical flight deck layout of an Airbus A320.

Flight Deck Electronic Instrumentation Layout
Figure 3

The Electronic Instrument System (EIS) also allows the flight crew to configure the instrument layout by allowing manual transfer of the Primary Flight Display (PFD) with the Navigation Display (ND) and the secondary Electronic Centralised Aircraft Monitoring (ECAM) display with the ND. Figure 4 shows the switching panel from Airbus A320.

A320 EIS Switching Panel
Figure 4

As well as a manual transfer, the system will automatically transfer displays when either the PFD or the primary ECAM display fails. The PFD is automatically transferred onto the corresponding ND, with the ECAM secondary display used for the primary ECAM display.

The system will also automatically transfer the primary ECAM information onto the ND if a double failure of the ECAM display system occurs. Figure 5 shows a block schematic of the EIS for the Airbus 320.

Electronic Instrument System (EIS)
Figure 5

2.3 ELECTRONIC FLIGHT INSTRUMENT SYSTEM

As in the case of conventional flight instrument systems, a complete EFIS installation is made up of left (Captain) and right (First Officer) systems. Each system comprises:

1. Electronic Attitude Director Indicator (EADI).
2. Electronic Horizontal Situation Indicator (EHSI).
3. Display Control Panel.
4. Symbol Generator.

The EADI and EHSI can be positioned side by side or vertically top and bottom. Normally the EADI is positioned on the top or on the on-side position.

2.4 ELECTRONIC ATTITUDE DIRECTOR INDICATOR

2.4.1 GENERAL

The EADI displays traditional attitude information (Pitch & Roll) against a two-colour sphere representing the horizon (Ground/Sky) with an aircraft symbol as a reference. Attitude information is normally supplied from an Attitude Reference System (ARS).

The EADI will also display further flight information, Flight Director commands right/left to capture the flight path to Waypoints, airports and NAVAIDS and up/down to fly to set altitudes. Information related to the aircraft's position w.r.t. Localizer (LOC) and Glideslope (GS) beams transmitted by an ILS. Auto Flight Control System (AFCS) deviations and Autothrottle mode, selected airspeed (Indicated or Mach No) Groundspeed, Radio Altitude and Decision Height information.

Figure 6 shows a typical EADI display

Electronic Attitude Director Indicator (EADI) Display
Figure 6

The EADI has two display formats:

1. Full Time EADI Display (Data which is always present).

2. Part Time EADI Display (Data which is only present when active).

2.4.2 Full Time EADI Display Data

Attitude Sphere: Moves with respect to the aircraft symbol to display actual pitch and roll attitude.

Pitch Attitude: The pitch attitude display has white scale reference marks at 5°, 10°, 15°, 20°, 30°, 40°, 60° and 80° on the sphere.

Roll Attitude: Displays actual roll attitude through a moveable index and fixed scale reference marks at 0°, 10°, 20°, 30°, 45°, 60° and 90°.

Aircraft Symbol: Serves as a stationary symbol of the aircraft. Aircraft pitch and roll attitudes are displayed by the relationship between the fixed miniature aircraft and the moveable sphere.

Flight Director Cue: Displays computed commands to capture and maintain a desired flight path. The commands are satisfied by flying the aircraft symbol to the command cue**.**

Fast/Slow Display: The pointer indicates fast or slow errors provided by an angle-of-attack, airspeed or other reference system.

Inclinometer: The EADI uses a conventional inclinometer, which provides the pilot with a display of aircraft slip or skid, and is used as an aid for coordinated manoeuvres.

Attitude Source Annunciation: The selected attitude source is not annunciated if it is the normal source for that indicator. As other attitude sources are selected, they are annunciated in white at the top left-hand side of the EADI. When the pilot and co-pilot sources are the same, then the annunciation is amber.

2.4.3 Part Time EADI Displays

Several displays are in view only when being used. When not in use, they are removed from the EADI automatically.

Radio Altitude: Displayed by a four-digit display from –20 to 2500 feet. Display resolution between 200 and 2500 feet is in 10 feet increments. The display resolution below 200 is 5 feet. The display disappears for altitudes above 2500 feet (Radio Altitude max altitude is 2,500 feet).

Decision Height: Decision Height is displayed by a three-digit display. The set range is from 0 to 990 feet in 10 feet increments. The DH display may be removed by rotating the DH set knob fully counterclockwise

Note: when the Radio Altimeter height is 100 feet above the DH, a white box appears adjacent to the radio altimeter display. When at or below the DH, an Amber DH will appear inside the white box.

Flight Director Mode Annunciators: Flight director vertical and lateral modes are annunciated along the top of the EADI. Armed vertical and lateral modes are annunciated in white to the left of the captured vertical and lateral mode annunciators. Capture mode annunciators are displayed in green and are located on the top centre for lateral modes and in the top right corner for vertical modes. As the modes transit from armed to capture, a white box is drawn around the capture mode annunciator for 5 seconds.

Marker Beacon: Displayed above the Radio Altimeter height information. The markers are coloured as follows:

Blue	-	Outer Marker.
Amber	-	Middle Marker.
White	-	Inner Marker.

Rising Runway: A miniature rising runway displays Absolute altitude reference above the terrain. It appears at 200 feet, and contacts the aircraft symbol at touchdown (0 feet).

Rate-of-Turn: Pointer and scale at the bottom of the display indicate rate or turn. Used with the inclinometer, will enable coordinated turns to be achieved.

Glide Slope: By tuning to an ILS frequency, the Glide Slope information will be displayed. Aircraft displacement from the Glide Slope beam centreline is then indicated by the relationship of the aircraft to the Glide Slope pointer. The letter “G” inside the vertical scale pointer identifies the information as Glide Slope deviation. When tuning to other than an ILS frequency, the Glide Slope display is removed.

Expanded Localizer: By tuning to an ILS frequency, the Rate-of-Turn display is replaced by the expanded Localizer display. When tuning to other than an ILS frequency, the expanded localizer display is replaced by the Rate-of-Turn display.

Vertical Navigation Display: The deviation pointer indicates the VNAV’s computed path centre to which the aircraft is to be flown. In this mode, the letter “V” inside the vertical scale pointer identifies the information as VNAV deviation.

2.5 ELECTRONIC HORIZONTAL SITUATION INDICATOR

The EHSI presents a selectable, dynamic colour display of flight progress with plan view orientation. The EHSI has a number of different modes of operation which can be selected by the flight crew. The number is dependant on the system fitted.

Figure 7 shows an EHSI display.

Electronic Horizontal Situation Indicator (EHSI) Display
Figure 7

The EHSI has two display formats:

1. Full Time EADI Display (Data which is always present).

2. Part Time EADI Display (Data which are only present when active).

2.5.1 Full Time EHSI Displays

Aircraft Symbol: The aircraft symbol provides a quick visual cue as to the aircraft's position in relation to the selected course and heading, or actual heading.

Heading Dial: Displays the heading information on a rotating heading dial graduated in 5° increments. Fixed heading indexes are located at each 45° position.

Heading "Bug" & Heading Readout: The notched heading bug is positioned around the rotating heading dial by the remote heading select knob on the Display Controller. A digital heading select readout is provided for convenience in setting the heading bug. Heading select error information from the heading bug is used to fly to the bug.

Course Deviation Indicator: The course deviation bar represents the centreline of the selected navigation or localizer course. The aircraft symbol shows the aircraft's position pictorially in relation to the displayed deviation.

Select Course Pointer & Course Readout: Course pointer is positioned inside the heading dial by the remote select knob on the Display Controller. Course error information from the course select pointer is used to fly the selected navigation path. A digital course select readout is provided for convenience in setting the select course pointer.

Distance Display: The distance display indicates the nautical miles to the selected DME station, or LRN Waypoint. Depending on the equipment, the distance will be displayed in a 0 to 399.9 NM or a 0 to 3999 NM format. An Amber "H" adjacent to the distance readout indicates DME Hold. This will indicate to the crew that DME information is from the previous VOR/DME beacon, and not the one providing VOR bearing.

Navigation Source Annunciators: Annunciation of the navigation source is displayed in the upper right hand corner. Long range navigation sources, such as INS, VLF, RNAV and FMS, are displayed in blue to distinguish them from short-range sources, which are annunciated in white.

Time-to-Go/Ground Speed: Either Time-to-Go or Groundspeed can be displayed, selected via the Display Controller. Ground Speed is calculated using the LRN, if fitted. If no LRN, then the EFIS uses the DME distance to calculate Ground Speed.

Drift Angle Bug: The drift angle bug represents drift angle, left or right, of the desired track w.r.t the lubber line. The drift angle bug w.r.t. the compass card represents actual aircraft track. The bug is displayed as a magenta triangle that moves around the outside of the compass card.

Desired Track: When LRN is selected, the Course Pointer now becomes the Desired Track Pointer. The position of the desired Track Pointer is controlled by the LRN. A digital display of desired track (DRAK) is displayed in the upper left-hand corner.

TO-FROM Annunciator: An Arrowhead in the centre of the EHSI indicates whether the selected course will take the aircraft TO or FROM the station or Waypoint. The TO-FROM annunciator is not in view during ILS operation.

Heading Source Annunciation: At the top centre of the EHSI is the heading source annunciator.

Heading SYNC Annunciator: The heading SYNC annunciator is located next to the upper left corner and indicates the state of the compass system in the slaved mode. The bar represents commands to the compass gyro to slew to the indicated direction (+ for increased heading and 0 for decreased heading). Heading SYNC is removed during compass FREE mode and for LRN derived heading displays.

2.5.2 Part Time EHSI Displays

Vertical Navigation Display: The vertical navigation display comes into view when the VNAV mode on the flight director is selected. The deviation pointer then indicates the VNAV's computed path centre to which the aircraft is to be flown. In this mode the letter "V" inside the scale pointer identifies the deviation display.

Glide Slope Deviation: The Glide Slope display comes into view when a VHF NAV source is selected and the NAV source is tuned to an ILS frequency. The deviation pointer then indicates the Glide Slope beam centre to which the aircraft is to be flown. The letter "G" inside the scale pointer identifies the deviation display.

Bearing Pointer Source Annunciators: The bearing pointers indicate relative bearing to the selected NAVAID. Two bearing pointers are available and can be tuned to either VOR or ADF NAVAIDs. If no NAVAIDs are selected then the pointers and annunciators are removed. The bearing source annunciators are colour and symbol coded with the bearing pointers.

Elapsed Time Annunciation: When in the Elapsed Time (ET) mode, the ET display can read minutes and seconds or hours and minutes. The hour/minute mode will be distinguishable from the minute/second mode by an "H" on the left of the digital display.

2.5.3 Partial Compass Format

The partial compass mode displays a 90° ARC of compass coordinates. The Partial mode allows other features such as MAP and Weather Radar displays to be selected. Figure 8 shows a Partial EHSI display (Compass Mode).

EHSI Partial Compass Mode Display
Figure 8

Wind Vector Display: Wind information is displayed in any partial format. The wind information can be shown as magnitude and direction or as head/tail and cross wind component. The display is determined on installation of EFIS. In both cases, the arrow shows the direction and the number indicates the velocity of the wind (in knots). Wind information is calculated from the LRN.

Range Rings: Range rings are displayed to help determine the position of radar returns and NAVAIDs. The range ring is the compass card boundary and represents the selected range on the Radar.

NAVAID Position: NAVAID position can be selected during MAP mode. The source of the NAVAID position marker is selected and annunciated in conjunction with the associated bearing source and is colour coded.

Weather Information: Weather information from the Radar can be displayed in partial compass mode. Weather Radar data is presented in the following colours:

1. Black - No storm.
2. Green - Moderate storm.
3. Yellow - Less severe storm.
4. Red - Severe storm.

Figure 9 shows an EHSI partial format with Weather Radar information.

EHSI Weather Radar Display
Figure 9

2.5.4 MAP MODE

The MAP mode will allow the display of more navigational information in the partial compass mode. Information on the location of Waypoints, airports, NAVAIDs and the planned route can be overlaid on the compass mode. Weather information can also be displayed in the MAP mode to give a very comprehensive display.

Figure 10 shows an EHSI MAP mode display.

EHSI MAP Mode Display.
Figure 10

2.5.5 Composite Display

In the event of a display unit failure, the remaining display can present a "Composite Display". This is selected via the Display Controller and it includes elements from an EADI and EHSI display.

Figure 11 shows a typical composite display.

EFIS Composite Display
Figure 11

2.6 DISPLAY CONTROLLER

Allows the crew to select the required display configuration and the information displayed. Both Captain and Co-Pilot have their own display Controllers. The controllers have two main functions:

Display Controller: Selects the display format for EHSI as FULL, ARC, WX or MAP.

Source Select: Selects the system that will provide information required for display. The source information will be VOR, ADF, INS, FMS, VHF and NAV.

EFIS Display Controllers are shown at Figure 12.

DISPLAY CONTROLLER

SOURCE SELECT CONTROLLER

EFIS Display and Source Controllers
Figure 12

2.6.1 DISPLAY CONTROLLER

FULL/ARC: The FULL/ARC button is used to change the EHSI display from full compass rose display to a partial compass display format. Successive pushes of the button change the display format back and forth between FULL and ARC.

WX (Weather): The WX button is used to call up weather radar returns on the partial compass display. If the EHSI is in the FULL display format, selecting the WX display will automatically select the ARC format. A second push of the WX button will remove the weather information but the ARC format will remain.

GS/TTG: By pressing the GS/TTG button, Groundspeed or the Time-to-GO will be displayed alternately in the lower right corner of the EHSI.

ET: By pressing the ET button, Elapsed Time is displayed. If the ET button is pressed again, it will zero the displayed time. The sequence is:

1. Zero.
2. Start.
3. Stop.

MAP: By pressing the MAP button, the full compass display is changed to the partial compass display, with active Waypoints displayed. Also, VOR/DME ground station positions will be displayed.

SC/CP: By pressing the SC/CP button, the flight director command cues are toggled back and forth from single cue (SC) configuration to cross pointer (CP) configuration.

REV:	In the event of an EADI/EHSI display failure, the REV button may also be used to display a composite format on the remaining good display. The first push of the button will blank the EHSI and put the composite display onto the EADI. The second push blanks the EADI and puts the composite display onto the EHSI. A third push will return EHSI/EADI to normal.
CRS Select Knob:	Rotation of the Course select knob allows the course pointer on the EHSI to be rotated to the desired course.
DIM:	Rotation of the outer concentric DIM knob allows the overall brightness of the EADI, EHSI to be adjusted. After the reference levels are set, photoelectric sensors maintain the brightness level over various lighting conditions.
DH:	Rotation of the inner concentric DH knob allows the Decision Height, displayed on the EADI, to be adjusted. If the knob is rotated fully counterclockwise, the DH display is removed.
TEST:	By pressing the TEST button, the displays will enter the test mode. In the test mode, flags and cautions are presented along with a check of the flight director mode annunciations. If the test is successful a “PASS” is displayed. If the test is unsuccessful then an “FD FAIL” is annunciated.
RASTER DIM TOP/BOT:	Rotation of the outer (Bottom display) and inner (Top display) concentric knobs adjusts the raster scan display (Weather Radar and Attitude Sphere).
HDG:	Rotation of the heading select knob allows the heading select bug to be rotated to the desired heading.

2.6.2 SOURCE CONTROLLER

Used to select the available sources of heading, attitude, bearing and navigation information for display. Since each aircraft is different, the source controller is normally tailored to fit each need.

NAV: This button is used to control the source of VHF NAV display information. Each push of the button will toggle the source between pilot and copilot's NAV information. VHF systems include DME, ILS and VOR.

LRN: Long Range Navigation selections depend on the systems available. These include INS, VLF and FMS systems.

ATT: Attitude button selects the source of attitude information. Each push of the button will select a different source for display. This facility is not available on all aircraft.

BRG: This knob allows the selection of VOR and ADF bearings to be displayed. The selected source is annunciated on the left-hand side of the display and the bearing to the selected beacon via two bearing pointers.

2.7 ELECTRONIC INSTRUMENTS (ENGINE & AIRFRAME)

The display of the parameters associated with engine performance and airframe systems control, by means of CRT type display units has, like those of flight instrument systems, become a standard feature of many types of aircraft.

The display units form part of two principal systems designated as:

1. Engine Indicating and Crew Alerting System (EICAS).

2. Electronic Centralized Aircraft Monitoring (ECAM).

2.8 ENGINE INDICATING & CREW ALERTING SYSTEM

The basic system comprises two display units, a control panel and two computers supplied with analog and digital signals from the engine and system sensors. The computers are designated “Left” and “Right” and only one is in control of the system at any one time, the other is held in standby. In the event of a failure, it may be switched in either manually or automatically.

Operating in conjunction with the system are discrete caution and warning lights, standby engine indicators and a remotely-located panel for selecting maintenance data display. The system provides the flight crew with information on primary engine parameters (Full-time), with secondary engine parameters and advisory/caution/warning alert messages displayed as required.

2.8.1 Display Units

These units provide a wide variety of information relevant to engine operation, and operation of other automated system. The operation of these displays is as for those in the EFIS as previously described.

The upper unit displays primary engine parameters, i.e. N1 speed, EGT, and warning and caution messages. The lower unit displays secondary parameters, i.e. N2 speed, fuel flow, oil quantity, pressure and temperature. In addition, the status of non-engine systems e.g. flight control surface position, hydraulic system, APU, etc., can be displayed.

On the upper unit, a row of Vs will appear when secondary information is being displayed on the lower unit. Seven colours are produced by the CRTs for displaying information. Table 1 shows the colours and a description of their use.

Colour	Description
White	All scales, normal operating range of pointers, digital readouts.
Red	Warning messages, maximum operating limit marks on scales, and digital readouts.
Green	Thrust mode readout and selected EPR/N1 speed marks, or target cursors.
Blue	Testing of system only.
Yellow	Caution and advisory messages, caution limit marks on scale, digital readouts
Magenta	During in-flight engine starting, and for cross bleed messages.
Cyan	Names of all parameters being measured (e.g. N1, oil pressure, TAT, etc.) and status marks or cues.

Table 1

Figure 13 shows layout of the EICAS Displays.

EICAS Primary and Secondary Display Formats
Figure 13

Figure 14 and 15 show display formats for primary and secondary displays.

Primary EICAS Display
Figure 14

Secondary EICAS Display
Figure 15

2.8.2 Display Modes

EICAS is designed to categorize displays and alerts according to the function and usage. For this purpose there are three modes of displaying information:

1. Operational (selected by the flight crew).

2. Status (selected by the flight crew).

3. Maintenance (ground use only and selected via the maintenance panel).

2.8.3 Operational Mode

This mode displays the engine operating information and any alerts requiring action by the crew in flight. Normally only the upper display unit presents information: the lower one remains blank and can be selected to display secondary information as and when required.

2.9 Status Mode

When selected this mode displays data to determine the dispatch readiness of an aircraft, and is closely associated with details contained in the aircraft's Minimum Equipment List. The display shows the positions of the flight control surfaces in the form of pointers registered against vertical scales, selected sub-system parameters, and equipment status messages on the lower display unit. Selection is normally done on the ground, either as part of the pre-flight checks of dispatch items, or prior to shutdown of electrical power to aid the flight crew in making entries in the aircraft's Technical log. Figure 16 shows an example of a status page.

2.10 Maintenance Mode

This mode provides maintenance engineers with information in five different display formats to aid them in fault finding and verification testing of major sub-systems.

EICAS Status Page
Figure 16

2.11 DISPLAY SELECT PANEL

To control the operation of the EICAS, a control panel is situated on the centre pedestal. Figure 17 shows a typical EICAS control panel.

EICAS Control Panel
Figure 17

2.11.1 Display Select Panel Operation

Engine Display Switch: This is a push type switch for removing or presenting the display of secondary information on the lower display.

Status Display Switch: This is a push type switch for removing or presenting the status page on the lower display.

Event Record Switch: Normally, there is an auto event function and this will automatically record any malfunctions as they occur. The push switch enables manual event marking so that the crew can record a suspect malfunction for storage in a non-volatile memory. This data can be retrieved from the memory and displayed by ground engineers by operating the ground maintenance panel. The manual switch can also be used for activating the recording of fault data, either in the air or on the ground, on the Environmental Control system, Electrical Power system, Hydraulic system and APU.

Computer Select Switch: In the “AUTO” position it selects the left, or primary computer and automatically switches to the other in the event of a failure. The other positions are for manually selecting either the right or left computers.

Display Brightness: Controlled by the inner knob for the display intensity, the outer for display brightness.

Thrust Reference Set Switch: Pulling and rotating the inner knob positions the reference cursor on the thrust indicator display (either EPR or N1) for the engines, which are selected by the outer knob.

Max Indicator Reset: If any of the measured parameters e.g. Oil Pressure, EGT etc. exceed normal operating limits, it will be automatically alerted on the display units. The purpose of the reset button is to clear the alerts from the display when the excess limits no longer exist.

Alert Messages

The system will continually monitor a large number of inputs (400+) from engine and airframe systems. If a malfunction is detected, then the appropriate alert message is annunciated on the upper display. Up to 11 messages can be displayed and are at the following levels:

LEVEL A - Warning: Requiring immediate corrective action and are displayed in “RED”. Master warning lights are also activated and aural warnings from the Central Warning System are given.

LEVEL B - Caution: Requiring immediate crew awareness and possible action. They are displayed in “AMBER”. An aural tone is also repeated twice.

LEVEL C - Advisory: Requiring crew awareness, displayed in “AMBER”. There are no caution lights or aural tones associated with this level.

Figure 18 shows a display with the three different types of alert messages Displayed.

Upper EICAS Display – Alert Messages
Figure 18

2.12 MAINTENANCE CONTROL PANEL

The panel is used by maintenance engineers for displaying maintenance data stored within the system's computer memories. Figure 19 shows a typical maintenance control panel.

Maintenance Control Panel
Figure 19

2.13 ELECTRONIC CENTRALIZED AIRCRAFT MONITORING

ECAM differs from EICAS in that the data displayed relate essentially to the primary systems of the aircraft and are displayed in checklist and pictorial or synoptic format.

2.14 DISPLAY UNITS

These can be mounted either side-by-side or top/bottom. The left-hand/top unit is dedicated to information on the status of the system; warnings and corrective action in a sequenced checklist format, while the right-hand/bottom unit is dedicated to associated information in pictorial or synoptic format. Figure 20 shows the layout of ECAM displays.

ECAM Display Layout
Figure 20

2.15 ECAM DISPLAY MODES

There are four display modes, three of which are automatically selected and referred to as phase-related, advisory (mode and status), and failure-related modes. The fourth mode is manual and permits the selection of diagrams related to any one of 12 of the aircraft's systems for routine checking, and also the selection of status messages, provided no warnings have been triggered for display.

Selection of displays is by means of a system control panel. (See Figure 28).

2.15.1 FLIGHT PHASE RELATED MODE

In normal operation, the automatic flight phase-related mode is used and the displays will be appropriate to the current phase of aircraft operation, i.e. Pre-flight, Take-off, Climb, Cruise, Descent, Approach, and post landing. Figure 21 shows display modes. The upper display shows the display for pre-take off, the lower is that displayed for the cruise.

ECAM UPPER DISPLAY

ECAM LOWER DISPLAY - CRUISE

ECAM Upper and Lower Display (Cruise Mode)
Figure 21

2.15.2 ADVISORY MODE

This mode provides the flight crew with a summary of the aircraft's condition following a failure and the possible downgrading of systems. Figure 22 shows an advisory message following a Blue Hydraulic failure.

ECAM Advisory Mode
Figure 22

2.16 ECAM FAILURE MODE

The failure-related mode takes precedence over the other modes. Failures are classified in 3 levels

Level 3: Warning

This corresponds to an emergency configuration. This requires the flight crew to carry out corrective action immediately. This warning has an associated aural warning (fire bell type) and a visual warning (Master Warning), on the glare shield panel.

Level 2: Caution

This corresponds to an abnormal configuration of the aircraft, where the flight crew must be made aware of the caution immediately but does not require immediate corrective action. The flight crew decide on whether action should be taken. These cautions are associated to an aural caution (single chime) and a steady (Master Caution), on the glare shield panel.

Level 1: Advisory

This gives the flight crew information on aircraft configuration that requires monitoring, mainly failures leading to a loss of redundancy or degradation of a system, e.g. Loss of 1 FUEL TANK PUMP LH or RH but not both.

The advisory mode will not trigger any aural warning or ‘attention getters’ but a message appears on the primary ECAM display.

Figure 23 – 27 shows the 12-system pages and status page available.

AIR CONDITIONING SYSTEM PAGE

PRESSURIZATION SYSTEM PAGE

ECAM System Displays
Figure 23

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

ELECTRICAL SYSTEM PAGE

FLIGHT CONTROL SYSTEM PAGE

ECAM System Displays
Figure24

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

FUEL SYSTEM PAGE

HYDRAULIC SYSTEM PAGE

ECAM System Displays
Figure 25

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

LANDING GEAR/WHEEL/BRAKE SYSTEM PAGE

AIR BLEED SYSTEM PAGE

ECAM System Displays
Figure 26

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

The Gear/Wheel page is displayed at the related flight phase.

DOOR/OXY SYSTEM PAGE

APU SYSTEM PAGE

ECAM System Displays
Figure 27

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

Related flight phase.

2.17 CONTROL PANEL

The layout of the control panel is shown in Figure 28.

ECAM Control Panel
Figure 28

SGU Selector Switches: Controls the respective symbol generator units. Lights are off in normal operation of the system. The “FAULT” caption is illuminated amber if the SGU’s internal self-test circuit detects a failure. Releasing the switch isolates the corresponding SGU and causes the “FAULT” caption to extinguish and the “OFF” caption to illuminate white.

System Synoptic Display Switches: Permit individual selection of synoptic diagrams corresponding to each of the 12 systems and illuminate white when pressed. A display is automatically cancelled whenever a warning or advisory occurs.

CLR Switch: Light illuminates white whenever a warning or status message is displayed on the left-hand display unit. Press to clear messages.

STS Switch: Permits manual selection of an aircraft’s status message if no warning is displayed. Illuminates white when pressed also illuminates the CLR switch. Status messages are suppressed if a warning occurs or if the CLR switch is pressed.

RCL Switch: Enables previously cleared warning messages to be recalled, provided the failure conditions which initiated the warnings still exists. Pressing this switch also illuminates the CLR switch. If a failure no longer exists, the message “NO WARNING PRESENT” is displayed on the left-hand display unit.

PAGE
INTENTIONALLY
BLANK

3 NUMBERING SYSTEMS

The majority of digital computers are wired to understand one particular code. This code usually is not the English language or the decimal numbering system but is instead the binary numbering system. A binary code capable of representing letters of the alphabet, decimal numbers, punctuation marks and special control symbols is used by most digital computers on the market today. Before discussing the binary numbering system and its use in computers, a few rules concerning all numbering systems will be presented.

There are three basic characteristics of any number system;

- BASE (OR RADIX).
- POSITION VALUE.
- DIGIT VALUE.

The base of a numbering system is the total number of unique characters or marks within that system. In the decimal system the base is 10 since there are 10 digits (or characters) which make up the system -0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

Each position in a number has a value of B^X where B is the base and X is some exponent. For example, the decimal numbers 365 and 653 have two different values even though they are composed of the same digits. The reason that the numbers have different values is that digits of different values occupy positions of different weights:

10^2	10^1	10^0
3	6	5

The first position 10^0 carries a weight of one. (Any number, except zero, when raised to the zero power is equal to one).

The second position 10^1 carries a weight of 10 and the third position 10^2 carries a weight of 100 etc. Note that each position is ten times greater than the preceding position.

Each digit in a number has a value which exists between zero and the value of the base minus one. For example in the decimal system, the digits range in value from zero to nine. Nine is one less that the base of the system which is ten.

3.1 GENERAL

In describing numbers, one takes into account the value of the various digits and the weight of their respective positions.

10^2	10^1	10^0
3	6	5

is equivalent to:

$$3 \times 10^2 + 6 \times 10^1 + 5 \times 10^0 =$$

$$3 \times 100 + 6 \times 10 + 5 \times 1 =$$

$$300 + 60 + 5 = 365$$

Thus the decimal number 365 is read as three hundred sixty five.

Fractional numbers follow the same rules. For example take the decimal number 1402.35

10^3	10^2	10^1	10^0	10^{-1}	10^{-2}
1	4	0	2	3	5

$$1 \times 10^3 + 4 \times 10^2 + 0 \times 10^1 + 2 \times 10^0 + 3 \times 10^{-1} + 5 \times 10^{-2} =$$

$$1 \times 1000 + 4 \times 100 + 0 \times 10 + 2 \times 1 + 3 \times 1/10 + 5 \times 1/100 =$$

$$1000 + 400 + 2 + 3/10 + 5/100 \text{ or } 1000 + 400 + 2 + 35/100$$

<u>Note</u>: There is an algebraic rule which states that a number raised to a negative exponent is equivalent to one over that number raised to a positive exponent.

$$10^{-2} = 1/10^2 \text{ or } 1/100$$

3.2 BINARY NUMBERING SYSTEM

The prefix 'BI' indicates two of something such as bicycle, bifocal, bi-plane etc. The binary numbering system is named after its base, which is two. Since the base is two there are two digits in the system 0 and 1. Position values for a binary number are 2^X where x is some exponent and each position will be two times greater in weight than that of the preceding position. Consider the binary number 10110.

$2^4\ 2^3\ 2^2\ 2^1\ 2^0$
1 0 1 1 0

$1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 =$

$(1 \times 16) + (0 \times 8) + (1 \times 4) + (1 \times 2) + (0 \times 1) =$

$16 + 0 + 4 + 2 + 0 = 22$

In describing a binary number in terms of decimal values for the positions, one converts from binary to decimal. Thus a binary 10110 is equivalent to a decimal 22. Often the base of a numbering system is indicated by a subscript in parenthesis.

$10110_{(2)} = 22_{(10)}$

Since the binary system uses only digits 0 and 1 all that one needs to do when converting from binary to decimal is to add the weights of those positions which contain ones. For example consider the number $1101001_{(2)}$

BIT POSITION	$2^6\ 2^5\ 2^4\ 2^3\ 2^2\ 2^1\ 2^0$
POSITION WEIGHT	64 32 16 8 4 2 1
	1 1 0 1 0 0 1

$64 + 32 + 8 + 1 = 105_{(10)}$

Therefore: $1101001_{(2)} = 105_{(10)}$

When one desires to convert from decimal to binary there are several methods that may be employed. One method is to use a table. (See table 1).

1024	512	256	128	64	32	16	8	4	2	1	WEIGHT
2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	BIT POS

Decimal to Binary Conversion
Table 1

Assume the following conversion was desired.

$$212_{(10)} = ?_{(2)}$$

The method of using the table is to find the largest number in the table, which does not exceed the decimal number that is being converted. The number 128 is the largest possible in this case hence a 'one' bit in the 2^7 position is required. This immediately defines the size of the binary number as 8 positions (From 2^7 to 2^0). Subtracting 128 from 212 leaves a remainder of 84 to be represented by the remaining binary positions. Since 84 is larger than 64 (which is the weight of the 2^6 position) a 'one' bit is required for the 2^6 position. Subtracting 64 from 84 leaves a remainder of 20.

A 'one' bit in the 2^5 position would be equivalent to 32, which is too large, thus zero bit must be used for the 2^5 bit position. So far the binary result is as follows:

$$\begin{array}{cccccccc} 2^7 & 2^6 & 2^5 & 2^4 & 2^3 & 2^2 & 2^1 & 2^0 \\ 1 & 1 & 0 & & & & & \end{array}$$

A 'one' bit in the 2^4 position represents a weight of 16. Sixteen from twenty leaves a remainder of four. Four can be represented in its entirety by a 'one' bit in the 2^2 position. Therefore the 2^3, 2^1 and 2^0 positions should hold zeros.

$$\begin{array}{cccccccc} 2^7 & 2^6 & 2^5 & 2^4 & 2^3 & 2^2 & 2^1 & 2^0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \end{array}$$

A re-conversion to decimal would prove the answer's validity.

$$128 + 64 + 16 + 4 = 212$$

Therefore: $212_{(10)} = 1\ 1\ 0\ 1\ 0\ 1\ 0\ 0_{(2)}$

Another method of converting from decimal to binary is to divide the decimal number by 2 (which is the base of the new number) a successive number of times using the remainders as the digits of the new number. For example consider the following:

$$28_{(10)} = ?_{(2)}$$

0	R = 1 (MSD)
2 ⟌ 1	R = 1
2 ⟌ 3	R = 1
2 ⟌ 7	R = 0
2 ⟌ 14	R = 0 (RIGHT MOST DIGIT OR LSD)
2 ⟌ 28	

Division must continue until a zero quotient is obtained. The first remainder is the rightmost digit or least significant digit (LSD) of the new number.

Therefore: $28_{(10)} = 1\ 1\ 1\ 0\ 0_{(2)}$

A re-conversion to decimal serve as a check.

$$16 + 8 + 4 = 28$$

3.2.1 BINARY FRACTIONS

Although many digital computers do not make use of binary fractions, conversion techniques involving them are relatively simple. Some of these techniques will be presented in order to complete the picture of conversion between the binary and decimal systems.

The position notation method of converting from binary to decimal can include fractions.

Example: $1001.101_{(2)} = ?_{(10)}$

2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}
1	0	0	1.	1	0	1

$1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3} =$

$1 \times 8 + 0 \times 4 + 0 \times 2 + 1 \times 1 + 1 \times 1/2 + 0 \times 1/4 + 1 \times 1/8 =$

$8 + 1 + 1/2 + 1/8$ or $8 + 1 + .5 + .125 = 9.625$

thus: $1001.101_{(2)} = 9.625_{(10)}$

NOTE: $2^{-1} = 1/2^1 = 1/2$, $2^{-2} = 1/2^2 = 1/4$, $2^{-3} = 1/2^3 = 1/8$

An abbreviated table of decimal equivalents to binary fractions is shown in table 2:

Binary Fraction Conversion	
2^{-1}	0.5
2^{-2}	0.25
2^{-3}	0.125
2^{-4}	0.0625
2^{-5}	0.03125
2^{-6}	0.015625

Decimal to Binary Conversion
Table 2

Just as positions to the left of the binary point were two times greater than that of the preceding position, so the positions to the right of the binary point are two times smaller.

Conversion from a decimal fraction to a binary fraction may be done in several ways. One method is to use table 5.2.2.

Example: $.375_{(10)} = ?_{(2)}$

Since .5 is greater than .375 a zero bit should be placed in the 2^{-1} position. A one bit should exist in the 2^{-2} position, however, since .25 is less than .375. Subtracting .25 from .375 leaves a remainder of .125, which can be fully represented by a one bit in the 2^{-3} position. Final result is:

2^{-1}	2^{-2}	2^{-3}
0	1	1

THUS: $.375_{(10)} = .011_{(2)}$

A second technique of converting decimal fractions to binary is to multiply the decimal fraction by 2 and look for a carry beyond the decimal point. A carry will indicate a one bit for the 2^{-1} position; no carry a zero bit. The next step is to again multiply only the fraction portion by 2 and look for a carry. A carry means a one bit for the 2^{-2} position and no carry indicates a zero bit. The process is continued for as many positions as desired.

Example: $.375_{(10)} = ?_{(2)}$

.375	
x 2	
0.750	2^{-1} position should hold a zero
.750	
x 2	
1.500	2^{-2} position should hold a one
.500	
x 2	
1.000	2^{-3} position should hold a one

THUS: $.375_{(10)} = .011_{(2)}$

If a whole number conversion is required in addition to the fraction conversion, the whole number is converted by dividing by two while the fraction is converted by multiplying by 2.

Example:

$18.205_{(10)} = ?_{(2)}$

0	R = 1 (2^4)	.205	
2 | 1	R = 0 (2^3)	x 2	
2 | 2	R = 0 (2^2)	.410	2^{-1} is 0
2 | 4	R = 1 (2^1)	x 2	
2 | 9	R = 0 (2^0)	.820	2^{-2} is 0
2 | 18		x 2	
		1.640	2^{-3} is 1
		x 2	
		1.280	2^{-4} is 1

Accuracy to four places gives the following result:

$$18.205_{(10)} = 1\ 0\ 0\ 1\ 0.\ 0\ 0\ 1\ 1_{(2)}$$

Re-conversion would show that the binary number was not carried out to enough places beyond the binary point to create an exact equivalent. However the number of places of accuracy is up to individual preference.

3.3 ADVANTAGES/DISADVANTAGES OF THE BINARY SYSTEM

The binary numbering system is very applicable to computer hardware design. Since there are only two binary digits 0 and 1 these bits (contraction of BINARY DIGITS) can be represented by a switch being open or closed, a light being off or on, a relay being de-energised or energised, a transistor not conducting or conducting, no hole or a hole on paper tape, no magnetized spot or a magnetized spot on magnetic tape or a core being magnetized in one direction or the other. It would require very complicated and expensive circuits in the computer to handle pure decimal numbers and letters of the alphabet whereas very simple circuits handle binary numbers. The speed at which binary arithmetic operations can be performed is also quite desirable in computer operation. Therefore, all incoming data must be converted to a binary code before entering the computer's memory and must be reconverted for outputs that humans recognise.

A big disadvantage of the binary numbering system is that it is awkward to use in programming or in computer monitoring operations. Thus it is quite common to use an abbreviated code when dealing with binary numbers. A good short hand system for binary is the octal numbering system.

3.4 OCTAL NUMBERING SYSTEM

The prefix 'OCT' implies eight of something such as octagon, octopus, etc. The base of the octal system is eight since there are eight digits 0, 1, 2, 3, 4, 5, 6, 7. Each position of an octal number carries a value of 8^X where x is some exponent.

Consider the following octal number:

$$327_{(8)}$$

Conversion to decimal would be as follows:

$$\begin{array}{ccc} 8^2 & 8^1 & 8^0 \\ 3 & 2 & 7 \end{array}$$

$$3 \times 8^2 + 2 \times 8^1 + 7 \times 8^0 =$$
$$3 \times 64 + 2 \times 8 + 7 \times 1 =$$
$$192 + 16 + 7 = 215_{(10)}$$

One should note that there are no 8's or 9's in the octal system and that each position of an octal number is 8 times greater in weight than the weight of the preceding position.

In converting from decimal to octal one may use a table, such as Table 3, or one may use the 'division by new base' technique.

32768	4096	512	64	8	1	WEIGHT
8^5	8^4	8^3	8^2	8^1	8^0	POS

Decimal to Octal Conversion
Table 3

The later of the two techniques is easier to use.

Example: $169_{(10)} = ?_{(8)}$

```
        0          R = 2
    8 | 2          R = 5
  8 | 21           R = 1
8 | 169
```

Therefore: $169_{(10)} = 251_{(8)}$

A re-conversion would check the result.

$$2 \times 8^2 + 5 \times 8^1 + 1 \times 8^0 =$$
$$2 \times 64 + 5 \times 8 + 1 \times 1 =$$
$$128 + 40 + 1 = 169_{(10)}$$

3.4.1 Octal Fractions

Just as in binary fractions many digital computers do not use octal fractions but the rules of conversion will be presented.

The following abbreviated table of decimal equivalents for octal positions simplifies conversion.

$8^{-1} = 1/8^1 = 1/8 = .125$

$8^{-2} = 1/8^2 = 1/64 = .015625$

$8^{-3} = 1/8^3 = 1/152 = .001953125$

$8^{-4} = 1/8^4 = 1/4096 = .000244140625$

Example: $37.25_{(8)} = ?_{(10)}$

$8^1 \; 8^0 \; 8^{-1} \; 8^{-2}$

3 7 . 2 5

$$3 \times 8^1 + 7 \times 8^0 + 2 \times 8^{-1} + 5 \times 8^{-2} =$$

$$24 + 7 + .250 + .078125$$

Therefore: $37.25_{(8)} = 31.328125_{(10)}$ or $31.33_{(10)}$ (rounded off)
Conversion from a decimal fraction to an octal fraction can also be done by the 'multiply by new base' technique as was done with binary fractions.

Example: $88.49_{(10)} = ?_{(8)}$

```
        0          R = 1 (8^2)
     8| 1          R = 3 (8^1)        .49
   8| 11           R = 0 (8^0)       x 8
 8| 88                               3.92  8^-1 is a 3

                                     x 8
                                     7.36  8^-2 is a 7
```

Thus: $88.49_{(10)} \underline{\underline{\text{o}}} 130.37_{(8)}$

Note that only the decimal fraction is multiplied by 8 each time. Also note that rounding off was done.

3.5 OCTAL - BINARY CONVERSIONS

Since there are only 8 digits in the octal system, each octal digit can be represented by some combination of three binary digits. In fact there are only 8 possible combinations for three binary digits.

Octal	Binary
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Conversion between the octal and binary systems then is quite simple since a direct substitution of 3 binary digits for each octal digit is all that is required.

Example: $715_{(8)} = ?_{(2)}$

7	1	5
111	001	101

Therefore: $715_{(8)} = 111001101_{(2)}$

When converting from binary to octal one marks off groups of three bits from right to left.

Example: $11011100_{(2)} = ?_{(8)}$

011	011	100
3	3	4

Therefore: $11011100_{(2)} = 334_{(8)}$

Note that leading zeros are supplied to fill out 3 digits if necessary.

When dealing with fractions the only rule other than direct substitution is that groups of three binary digits are marked off from left to right in the binary fraction.

Example: $1000111.0101101_{(2)} = ?_{(8)}$

001	000	111.	010	110	100
1	0	7.	2	6	4

Therefore: $1000111.0101101_{(2)} = 107.264_{(8)}$

Note that zeroes are added to the rightmost end of a fraction to fill out the number to three digits.

Example: $137.05_{(8)} = ?_{(2)}$

1	3	7	.	0	5
001	011	111	.	000	101

or $137.05_{(8)} = 1011111.000101_{(2)}$

Note that leading zeros may be truncated.

3.6 ADVANTAGES/DISADVANTAGES OF THE OCTAL SYSTEM

Because the conversion between binary and octal is so simple the octal system is often used as shorthand for binary. For example, a particular computer instruction code might be as follows in binary:

0110001101110110

A programmer could write the operation in octal notation thereby reducing some of the cumbersome notation.

061566

The input device or medium would convert the octal digits to binary prior to entering the combination into the computer's memory.

Another problem in some computers is reading binary numbers on the console (a monitoring device) or instructing someone to set up a binary code from the console. Octal notation can alleviate the problem to a great extent. In fact, there are a number of computers on the market today which require octal notation in programming and/or console display.

Octal techniques in logic design likewise simplify and even save on the number of required circuits as compared to straight binary decoding.

The big disadvantage of the octal system is the fact that humans still prefer decimal notation in the end and thus the use of octal might require multiple conversion facilities for data going into or coming out of the computer.

Memory dumps (print outs) often are available in a choice of codes, one of which is usually octal.

3.7 HEXADECIMAL

Just as octal is a shorthand for binary because three binary digits can be directly substituted by one octal digit, another numbering system known as hexadecimal, is also a shorthand for binary because of its base. The prefix hexa implies 6 of something and since decimal represents 10, the word hexadecimal means 6 + 10 or 16. Thus the base of the hexadecimal system is 16. By definition of the word 'base' the total number of characters in the system must also be 16. These characters include the ten decimal digits 0-9 and six letters of the alphabet A-F. Table 4 shows decimal-hexadecimal conversions.

HEX	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
DECIMAL	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Hexadecimal-Decimal
Table 4

A hexadecimal number therefore is one whose position values are 16^X. The methods of conversion discussed previously still apply.

$6AF_{(16)} = ?_{(10)}$

$$6 \times 16^2 + A \times 16^1 + F \times 16^0 =$$
$$6 \times 256 + 10 \times 16 + 15 \times 1. =$$
$$1536 + 160 + 15 = 1711_{(10)}$$

Decimal-Hexadecimal Example 1:

$108_{(10)} = ?_{(16)}$

```
        0        R = 13     (equivalent to D)
   16 | 13       R = 0
16 | 208
```

<u>Note</u>: Each remainder must be represented by one hexadecimal digit.

Therefore: $208_{(10)} = D0_{(16)}$

Decimal-Hexadecimal Example 2:

$1834_{(10)} = ?_{(16)}$

```
      0          R = 7
   16| 7         R = 2
 16| 114          R = 10
16| 1834
    16
     23
     16
      74
      64
```

$1834_{(10)} = 72A_{(16)}$

3.8 BINARY-HEXADECIMAL

Four binary digits can form sixteen combinations thereby providing an exact equivalent to the hexadecimal system. This is shown in Table 5

BINARY	HEXADECIMAL
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

Binary – Hexadecimal
Table 5

Therefore, direct substitution can take place between hexadecimal and binary. For every 4 binary digits, one hexadecimal digit can be substituted or vice versa.

$1001101_{(2)} = ?_{(16)}$

0100	1101
4	D

$1001101_{(2)} = 4D_{(16)}$

$CBF_{(16} = ?_{(2)}$

C	B	F
1100	1011	1111

$CBF_{(16)} = 110010111111_{(2)}$

Fractions are handled in the same manner:

$$1101110.01111_{(2)} = ?_{(16)}$$

0110	1110.	0111	1000
6	E .	7	8

Therefore: $1101110.01111_{(2)} = 6E.\ 78_{(16)}$

Note that zeros are added to fill out to multiples of 4 binary digits.

The ease with which a binary number can be expressed as a hexadecimal, enables some computer systems to conveniently identify the contents of registers or words in memory. Also it is desirable in business data processing operations to work with decimal numbers. To do this requires a code known as BCD (Binary Coded Decimal). The BCD code is encompassed by the hexadecimal numbering system and thus one may use decimal notation if one desires to do so or hexadecimal and assume that four binary digits represent one decimal or hexadecimal digit.

3.9 BINARY CODED DECIMAL NOTATION

If the binary code is to be used in a computer that can handle commercial data processing as well as communications or scientific processing, there has to be a means of representing decimal numbers, letters of the alphabet, punctuation marks and special symbols.

It is desirable that this special binary code is also easy to handle in terms of decimal arithmetic. The BCD or binary coded decimal notation solves part of this problem. Below is a chart of the BCD code as applied to decimal numbers.

Decimal	BCD
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Direct conversion of any BCD configuration gives the decimal equivalent. BCD notation however does not make use of all 16 possible combinations for four

binary digits and is therefore susceptible to wasting storage space. The decimal number 15 for example in BCD code would be 0001 0101 while the pure binary equivalent for 15 would be 1111. However, as was stated earlier, letters of the alphabet as well as punctuation marks and special symbols are needed in some form of a binary code. Therefore, a number of computer manufacturers use a modified BCD code.

3.10 Binary Arithmetic

One of the tasks a digital computer must be able to perform is to solve complex problems. Some problems require more complex operations than the fundamental operation of addition, subtraction, divide and multiplication. Complex problem solving is achieved by writing it into the computers program (software), however digital circuits (hardware) achieve the fundamental function.

3.11 Binary Addition

In the decimal system, the sum of 11 + 3 is 14 and it is not until the sum of the column is greater than 9 that there is a carry from one column of the addition to the next.. Arithmetic operation are very simple in the binary system because as the base of the system is 2, the carry occurs much earlier, so that a sum of two digits resulting in 2 will involve a carry function. As a result there are only four rules to consider when adding binary numbers, which are:

1. 0 + 0 = 0.
2. 0 + 1 = 1.
3. 1 + 1 = 0 carry 1.
4. 1 + 1 + carry 1 = 1 and carry 1.

Example 1

Addition of 1011^2 (decimal 11) and 0011^2 (decimal 3).

```
 1011
 0011
 1110
```

When adding three or more rows of binary numbers, the addition of all the binary numbers in one column could be carried out as in decimal addition, however, this becomes difficult in remembering how many carries have been made. An easier way is to add two rows at a time, adding the result to the next row and so on.

Example 2

Addition of 1101 + 0111 + 1001 + 0101

a.
```
 1101
  0111
 10100
```

b.
```
 10100
 01001
 11101
```

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4 DATA CONVERSION

4.1 ANALOGUE COMPUTERS

Analogue computers operate by using voltages, currents, shaft angles etc to represent physical quantities.

The basic concept of the analogue computer is as follows:

1. Physical variables, usually voltages, are used to represent the magnitudes of all the variables contained within the equation or problem.

2. Computer "building blocks", each performing a single mathematical function, are interconnected in such a manner that the relationships between the input and output variables correspond to the desired mathematical relationship.

3. The voltage solution exists at a specific point within the system and is made available to the operator in some form.

Generally, there are two types of analogue circuit arrangements in use. The first is a 'general purpose' computing arrangement consisting of a large number of networks, which are capable of providing solutions to a range of problems. The second type is a 'special purpose' arrangement, which is capable of serving as a model for, or simulating, a specific condition.

Since the analogue computer operates by a process of measurement, it is best suited to applications where continually varying quantities are to be dealt with. Although computation involving measurement usually introduces errors, it is possible to attain accuracy of better than 0.1%. This is adequate for many applications and, since small analogue computers can deal with relatively simple problems, this type of computer will be met in some equipment carried in aircraft.

4.2 DIGITAL COMPUTERS

Digital computers are arithmetic machines: that is, they operate by a process of counting numbers or digits (hence their name). The basic operation that a digital computer can perform is addition.
The digital computer is, therefore, used when the problem to be solved is of an arithmetical nature and where an exact answer is required. Digital processing errors are very low, with accuracy in the order of 0.001% being possible, although a digital computer operating in a controlling role will have inputs derived from some form of measurement with consequent errors. For specific tasks, the programme of instructions, which supplies the computer with the information on which it operates, can be built in to the machine; digital computers of this type have many aircraft applications.

4.3 ANALOGUE AND DIGITAL SIGNALS

Analogue (continuous) information is made available in virtually all aircraft equipment. Figure 1 shows the analogue signal created by a variable resistor. In the circuit +0V is present at the output “A” when the potentiometer is at position 1 and +5V when at position 2. These values would represent either a 1 (+5V) or a 0 (+0V). However, it can be seen from the graph of the analogue signal that it does produce distinct values of +5V and +0V as the potentiometer moves from one end to the other.

Analogue Signal Representation
Figure 1

A digital signal is one that contains two distinct values (1 and 0). Figure 2 shows a digital signal being produced by use of a switch. With the switch in the open position, +0V will be present at point (logic 0). When the switch closes, +5V will be present at point (logic 1). Digital signals are often considered to be either “ON” or “OFF” (logic 1 or 0).

Digital Signal Representation
Figure 2

Signals in analogue form can be processed using operational amplifiers and other devices in various configurations and ultimately converted to an observable output by a suitable output device.

Systems, which are completely analogue, are limited in the accuracy that can be achieved both physically and economically, they also suffer from error and distortion for various reasons such as non-linearity, drift, crosstalk, noise etc. Digital systems, especially since the advent of integrated circuits, offer improvements over analogue systems in most respects, thus modern processing systems employ fixed analogue and digital circuitry (hybrid systems) in which, of course, conversion from one form to the other must take place at certain points within the system.

Hybrid systems are more common than all digital systems presumably because of the simplicity of analogue transducers, and the nature of the information to be processed lends itself more readily to analogue representation. For example it would be difficult to digitize an audio signal without converting it from changing air pressure to an electrical analogue by means of a microphone (transducer).
For further computing such an electrical analogue signal would be converted into digital form.

4.4 ANALOGUE TO DIGITAL CONVERTER

In an ADC a range of input values must correspond to a unique digital word. The type of code used depends on the system but here only binary coding will be considered.

Consider an analogue signal, which can take on any value between 0 and 7 volts. For any particular voltage there is a corresponding binary code word. For example, using 3-bit words, the voltage analogue value between 4 and 5 volts would be represented in binary code by the word 100, which would change to 101, when the analogue value passed through 5 volts.

Figure 3 shows digital representation of an analogue input signals.

Digital Representation of Analogue Signals
Figure 3

The levels at which the code changes are known as quantisation levels, and the intervals between them as quantisation intervals. In the example given in Figure 5.3.3, the quantisation levels are 0, 1, 2, 3, 4, 5, 6 and 7 volts, and the quantisation interval is 1 volt.

Using a 3-bit word gives $2^3 = 8$ different quantisation levels. With a 4-bit word we would have $2^4 = 16$ quantisation levels with 0.5 volt quantisation intervals giving improved resolution over the same range of input voltage.

Thus the more bits available the greater the resolution for a given range of analogue signal input. It can be seen from the above that an ADC using an n-bit word would have a resolution of one part in 2^n.

4.5 ANALOGUE TO DIGITAL CONVERSION

In order to convert the analogue signal into a digital signal, an Operational Amplifier is used as a comparator. Figure 4 shows an Op amp comparator.

Comparator Circuit
Figure 4

The output of the comparator will be logic “0” when the reference voltage is greater than the analogue input, changing to logic “1” when the analogue voltage is greater than the reference voltage.

Figure 5 shows the resultant digital waveforms from an analogue input signal using an Op Amp comparator.

WHEN $V_{IN} < V_{REF}$ THEN V_{OUT} = -V MAX

WHEN $V_{IN} > V_{REF}$ THEN V_{OUT} = +V MAX

Analogue/Digital waveforms
Figure 5

In the example in figure 3, the quantisation level was 0 – 7 with a quantisation interval of 1 volt. To convert this range to digital a total of 7 comparator Op Amps would be required. This however would give a word length of 7 bits. We know to represent the range 0 – 7 with an interval of 1 volt will only require a 3-bit word.

To convert the seven bit word to a 3-bit word an encoder circuit is used. The circuit contains a number of logic gates that will convert the 7-bit word down to the required 3-bit notation. Figure 6 shows the layout of an encoder circuit.

Encoder Circuit
Figure 6

4.6 DECIMAL TO BCD ENCODER

Some aircraft systems have a keypad, which is used either to select or input data into the system's computer. The computer requires the key select function to be converted into a BCD code. A decimal to BCD encoder is used to carry out this function. Figure 7 shows decimal to BCD encoder circuit operation.

Decimal – BCD Encoder
Figure 7

4.7 DIGITAL TO ANALOGUE CONVERSION (DAC)

Since many systems used on aircraft will require outputs in analogue form, it will be necessary to be able to convert the digital information back into analogue.

The input to the DAC is effectively a number, usually binary coded. This number must be converted to a corresponding number of units of voltage (or current) by the DAC.

The output of the DAC will thus be stepped as the digital input changes, taking on a series of discrete values. The spacing between these values (quantisation levels) will depend on the length of the input digital word and the maximum range of the output voltage. For example, a DAC, which can provide an output voltage of between 0 and 16 volts, will, with 4-bit word input, have 1 volt between quantisation levels and is illustrated in Figure 8.

DAC Output
Figure 8

Similarly, an output voltage range of 0 to 10 volts with 10-bit word input will give spacing between quantisation levels of approximately 0.01 volts. The stepped nature of the output can of course be smoothed.

To change a digital word into an analogue signal we require a circuit capable of carrying out this function. One method would be to apply the digital word to a corresponding number of resistors (4-bit word – 4 resistors), connected as a potential divider. Figure 9 shows a circuit that would carry out the function of Digital to Analogue conversion.

DAC Weighted Circuit
Figure 9

Figure 10 shows a Digital to analogue converter.

Digital – Analogue Converter
Figure 10

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5 DATA BUSES

The availability of reliable digital semi-conductor technology has enabled the inter-communication task between different equipment to be significantly improved. Previously, large amounts of aircraft wiring were required to connect each signal with all the other equipment. As systems became more complex and more integrated so this problem was aggravated. Digital data transmission techniques use links, which send streams of digital data between equipment. These data links may only comprise two or four wires and therefore the inter-connecting wiring is very much reduced. Recognition of the advantages offered by digital data transmission has led to standardization in both civil and military fields. The most widely used digital data transmission standards are ARINC 429 for civil and MIL-STD-1553B for military systems.

5.1 AERONAUTICAL RADIO INCORPORATED (ARINC) 429

ARINC specification 429 is titled "MARK 33 Digital Information Transfer System" (DITS). We refer to it as ARINC 429 bus, DITS bus, Mark 33 bus or just ‘bus’.

5.1.1 OPERATION

An equipment transmits data, via a 429 transmitter, to other equipment. The information flow is uni-directional. One 429 transmitter supplies the data to a pair of wires that we call the bus. One or more ARINC 429 receivers can be connected to the bus.

The ARINC 429 bus is a twisted and shielded pair of wires and the shield is connected to ground. The data wires are white and blue. The ground connection is a black wire. If the bus runs through a feed-through plug (for instance on a bulkhead), then the shield is also connected to a black wire that runs through the plug.

Figure 1 shows ARINC bus interconnections.

ARINC Bus Interconnection
Figure 1

5.1.2 DATA BUS CABLE

Data bus cable typically consists of a twisted pair of wires surrounded by electrical shielding and insulators. Digital systems operate on different frequencies, voltages and current levels. It is extremely important to ensure that the correct cable is used for the system installed. The cable should not be pinched or bent during installation and data bus cable lengths may also be critical. Refer to current manufacturer's manuals for cable specifications.

Figure 2 shows an example of a data bus cable.

Data Bus (Twisted Pair) Cable
Figure 2

5.2 THE ARINC 429 DATA BUS

Data words contain the information. An example is Indicated Airspeed (IAS). Another example is Total Air Temperature (TAT). A 429 transmitter transmits IAS, then pauses a moment, and then transmits TAT. 255 different data words can be transmitted on one 429 bus. The information is transmitted at high or low speed:

- Low speed is 12 to 14.5 Kbytes/second.
- High speed is 100 Kbytes/second.

Figure 3 shows the ARINC Dataword format.

ARINC 429 Data Word Formats
Figure 3

5.2.1 ARINC 429 SPECIFICATIONS

ARINC 429 sets specifications for the transfer of digital data between aircraft electronic system components and is a “One-way” communication link between a single transmitter and multiple receivers. ARINC 429 system provides for the transmission of up to 32 bits of data. One of three languages must be used to conform to the ARINC 429 standards:

1. Binary.
2. Binary Coded Decimal (BCD).
3. Discrete.

ARINC 429 assigns the first 8 bits as the word label; bits 9 and 10 are the “Source-Destination Indicator” (SDI), bits 11 through to 28 provide data information; bits 29 through to 31 are the “Sign-Status Matrix” (SSM), and bit 32 is a “Parity Bit.

There are 256 combinations of word label in the ARINC 429 code. Each word is coded in an octal notation language and is written in reverse order. The source-destination indicator serves as the address of the 32-bit word. That is, the SDI identifies the source or destination of the word. All information sent to a common serial bus is received by any receiver connected to that bus. Each receiver accepts only that information labelled with its particular address; the receiver ignores all other information.

The information data of an ARINC 429 coded transmission must be contained within the bus numbered 11 through to 28. This data is the actual message that is to be transmitted. For example, a Digital Air Data Computer (DADC) may transmit the binary message 0110101001 for Indicated Airspeed. Translated into decimal form, this means 425, or an airspeed of 425 knots. The sign-status matrix provides information that might be common to several peripherals (plus or minus, north or south, right or left etc). The parity bit of ARINC 429 code is included to permit error checking by the ARINC receiver. The receiver also performs a “Reasonableness Check”, which deletes any unreasonable information. This ensures that if a momentary defect occurs in the transmission system resulting in unreasonable data, the receiver will ignore that signal and wait for the next transmission.

The parity bit will either be set to 1 or 0 depending on the parity used. The parity used in ARINC 429 is “Odd Parity”. If there is an even number of 1 bits in a transmitted word (bits 1 through 31), the parity bit must be 1 to ensure the whole word contains an odd number of 1 bits in the word.
Figure 4 shows the layout of a 32-bit word.

32 Dataword Format
Figure 4

5.3 ARINC 429 WORD REPRESENTING AIRSPEED

Figure 5 represents an ARINC 429 code for a DADC word giving information on the aircraft's indicated airspeed.

ARINC 429 word 206 Indicated Airspeed
Figure 5

The word label for airspeed is 206 and it is transmitted using the octal notation code, which is read in reverse to achieve the word label. E.g. word label 602 would be 011 000 01 (bits 1,6 and 7 set to logic 1), 206 in reverse. The SDI label 00 indicates transmission of this data to all receivers connected to the serial bus. The data segment is read left to right, 0110101001 representing the sum of; 1 x 256 (2^8) + 1 x 128 (2^7) + 1 x 32 (2^5) + 1 x 8 (2^3) + 1 x 1 (2^0). In decimal form this represents 425.

The SMM 011 represents a normal operation of a plus value data; that is, airspeed data is a positive value. The parity bit is set to 1, which denotes an even number of 1_s in the transmitted word and no errors are present according to the parity bit.

5.4 THE ARINC 429 FORMAT

ARINC has a return to zero format. After a bit is transmitted, the voltage returns to zero. If logic 1 is transmitted, line A has a voltage of +5 volts and line B has a voltage of -5 volts with respect to ground. This means that the voltage on line A is 10 volts higher than the voltage on line B. If logic 0 is transmitted, line A has a voltage of -5 volts and line B has a voltage of +5 volts with respect to ground. This means that the voltage on line A is 10 volts lower than the voltage on line B. Spikes caused by interference make the voltage on both wires increase or decrease but have no effect on the voltage of line A with respect to line B. Therefore interference has less effect on the bus.

Figure 6 shows the ARINC 429 dataword format.

ARINC 429 Dataword Format
Figure 6

5.5 DATA TRANSMISSION

Most digital communication data is transmitted in a serial form, that is, only one bit at a time. Transmission of data in serial form means each bit is transmitted for only a very short time period. In most systems, the data transmitted requires less than a milli-second. After one bit is sent, the next bit follows; this process is repeated until all the desired bits have been transmitted. This type of system is often referred to as “Time Sharing”, because each transmitted signal shares the wires for a short time interval.

Parallel data transmission is a continuous-type of transmission requiring two wires (or one wire and ground) for each bit to be sent. Parallel transmission is so called because each circuit is wired in parallel with respect to the next circuit.

With serial data, one pair of transmitting wires can be used to send enormous amounts of serial data. If the data were sent using the parallel method, then hundreds of wires would be required. Most computer systems use the parallel method to transmit data within them, however if the data must be sent to another system, serial data transmission is used.

An interpretation circuit is required to convert all parallel data to serial-type data prior to transmission. The device for sending serial data is called a “Multiplexer (MUX), and the device for receiving serial data is called a “Demultiplexer” (DEMUX). Figure 7 shows a data transfer system.

Data Transfer System
Figure 7

The MUX circuit operation is shown in Figure 8.

Multiplexer Circuit Operation
Figure 8

The X and Y inputs are the control inputs selecting the data to be multiplexed.
Table 1 shows the logic table for X and Y.

X	Y
0	0
1	0
0	1
1	1

Multiplexer Control logic table
Table 1

Figure 9 shows the DEMUX logic circuit.

Demultiplexer Logic Circuit
Figure 9

5.6 ARINC 573 FORMAT

The ARINC 573 format has been established for “Digital Flight Data Recorder” (DFDR). It uses the Harvard bi-phase code, containing the bits in bit-cells. Because each bit-cell is a phase transition, the ARINC 573 is self-clocking.

If the logic = 1, then the bit-cell will have a phase transition: for a logic 0, there is no phase transition. If the DFDR gives no information, the ARINC 537 output is a symmetric square wave.

Figure 10 shows ARINC signal format.

ARINC 537 Signal Format
Figure 10

5.7 CONVERTERS

In analogue circuits we cannot use digital signals and in digital circuits we cannot use analogue signals. For that reason there are analogue to digital converters and digital to analogue converters. Also there are converters that change analogue signals into other analogue signals, e.g. a pressure to frequency converter, which is used in the air data computer.

5.7.1 EXAMPLES OF CONVERTERS

Figure 11 shows three different types of converters.

Converters
Figure 11

5.8 THE MIL-STD-1553B DATA BUS

This digital standard has been used for some time in US military aircraft systems. More recently the UK industry has used it for aircraft and helicopter avionics systems and for land based and marine systems.

5.8.1 DESCRIPTION

Data is transmitted via two separate buses, which gives this system a Dual Redundancy i.e. only one bus is used at any one time with the second held in reserve (Redundant). If one data bus fails, then the second has the capacity to maintain the flow of data. This reserve bus is periodically tested under the control of the internal software, which switches between the two buses.

The system is controlled by a “Bus Controller” (BC), normally situated within a Head-Up Display (HUD) Electronics unit (HEU). The HUE initiates messages by using commands to select Remote Terminals (RT). These RTs are other systems within the aircraft’s avionics suite. The RT will receive or transmit data, then respond with a status word. All words are transmitted in serial format along the bus in both directions, but not simultaneously.

The data bus consists of a twin wire twisted pair along which DATA and (Not) DATA are passed. Data is transmitted at 1MHz using a self clocked Manchester II code.

The transmission of data in true and complement form, down a screened twisted pair together with a message error detection capability offers a high integrity digital data link, which is highly resistant to message corruption.

5.8.2 WORD FORMATS

The Mil Std 1553b data bus defines three word formats:

1. Command Word.
2. Data Word
3. Status Word.

All words consist of 20 bits configured as follows:

1. Bit 1 – 3 - Word Synchronization.
2. Bit 4 –19 - Data/addressing.
3. Bit 20 - Parity.

Message formats are as follows:

1. Bus Controller - Remote Terminal.
2. Remote terminal - Bus Controller.
3. Remote terminal - Remote Terminal.

Validation checks are performed on the words as follows:

a. Word begins with a valid Synchronization.

b. Bits are in valid Manchester II code.

c. Information field has 16 bits and a parity bit.

d. Parity is odd.

Figure 12 shows the format of a Command Word as issued by the BC.

BIT TIMES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SYNC			RT ADDRESS					T R	SUB-ADDRESS					DATA WORD COUNT					P

DATA TRANSFER

SYNC	-	HIGH/LOW
RT ADDRESS	-	UNIQUE TO RT
T/R BIT	-	TRANSMIT = 1 RECEIVE = 0
SUB-ADDRESS	-	SUB-SYSTEM WITHIN SYSTEM
DATA WORD COUNT	-	NUMBER OF DATA WORDS TO BE TRANSMITTED OR RECEIVED BY THE RT (1111 = 31: 00000 = 32)
PARITY	-	ODD PARITY OVER LAST 16 BITS.

Command Word Format
Figure 12

Figure 13 shows the format of a Data Word as issued by the BC or RT.

BIT TIMES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SYNC			DATA																P

DATA TRANSFER

SYNC	-	LOW/HIGH
DATA	-	MSB FIRST - UNUSED BITS SET TO 0
PARITY	-	ODD PARITY OVER LAST 16 BITS.

Data Word Format
Figure 13

Figure 14 shows the format of a Status Word as issued by the RT.

BIT TIMES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SYNC			RT ADDRESS					CONTROL BITS			RESERVED			CONTROL BITS					P

DATA TRANSFER

SYNC	-	HIGH/LOW
RT ADDRESS	-	ADDRESS OF RT RESPONDING TO PREVIOUS COMMAND WORD
CONTROL BITS	-	BIT 9 - MESSAGE ERROR. BIT 10 - INSTRUMENTATION BIT BIT 11 - SERVICE REQUEST
RESERVED BITS	-	ALWAYS 0
CONTROL BITS	-	BIT 15 - BROADCAST COMMAND RECEIVED BIT 16 - BUSY BIT 17 - SUB-SYSTEM FLAG BIT 18 - DYNAMIC BUS CONTROL ACCEPT BIT 19 - TERMINAL FLAG
PARITY	-	ODD PARITY OVER LAST 16 BITS.

Status Word Format
Figure 14

Figure 15 shows the layout of a 1553B data bus on a modern military aircraft.

1553B Data Bus Block Schematic (Jaguar Mk 1a)
Figure 15

5.8.3 1553B DATA BUS COUPLING

Because the data bus in the 1553B system is not directly connected to the LRUs it serves, some method of connecting the RT/BC onto the data bus is required. The method used for coupling LRUs onto the data bus is “Transformer Coupling”. Figure 16 shows 1553B data bus coupling.

1553B Data Bus Coupling
Figure 16

5.9 DATA TRANSFER OPERATION

5.9.1 BUS CONTROLLER (BC) TO REMOTE TERMINAL (RT):

The BC transmits a Command Word with bits 4 to 8 set to the address of the RT, which is to receive data. The RT bit is set to 0 and the word count is set to the number of data words to be received (all zeros = 32 data words). This command word is followed, without a break, by the number of data words defined by the word count field.

The receiving RT must respond within a specified time after the end of the last data word with a status word. A specified minimum inter-message gap time must be allowed to elapse before the BC transmits another command.

Figure 17 shows BC to RT data transfer.

** RESPONSE TIME

INTERCHANGE GAP

BC to RT Data Transfer
Figure 17

5.9.2 REMOTE TERMINAL TO BUS CONTROLLER:

The BC transmits a command word with bits 4 to 8 set to the address of the RT, which is to transmit data. The RT bit is set to 1 and the word count is set to the number of data words required. The RT should respond with a status word, followed without a break by the required number of data words.

Figure 18 shows RT to BC data transfer.

** RESPONSE TIME

INTERCHANGE GAP

RT to BC Data Transfer
Figure 18

5.9.3 REMOTE TERMINAL TO REMOTE TERMINAL:

The BC issues a receive command containing the address of the RT which is to receive the data and the number of words to be received. This is followed immediately by a transmit command specifying the address of the RT which is to transmit the data and the number of data words to be transmitted. The transmitting RT should transmit the status word without a break, including the specified number of data words. On receipt of the data words, the receiving RT should respond with a status word.

Figure 19 shows RT to RT data transfer.

** RESPONSE TIME

INTERCHANGE GAP

RT to RT data Transfer
Figure 19

5.10 MANCHESTER II BI-PHASE DATA ENCODING

Figure 20 shows the comparison between normal Non return Zero NRZ format and Manchester II Bi-Phase data encoding.

Data Encoding
Figure 20

5.11 System Comparison

ARINC 429 system has each box sharing its information with several others through a one-way digital data link.

The 1553B system has each of its possible 32 boxes plugged into a bi-directional digital data bus along which information is transmitted and received.

5.12 Data Autonomous Transmission & Communication

This could be the possible replacement for the ARINC 429 standard and will be annotated the standard - ARINC 629. In the DATAC system, the control function is distributed among all the participating terminals present on the bus. These terminals autonomously determine the transmission of data on the bus by means of a protocol termed Carrier Sense/Multiple Access-Clash Avoidance (CS/MA-CA). In simple terms the protocol guarantees access to any participating terminal, but prevents any terminal from access to the bus before all other terminals have had an opportunity to transmit data.

Data transmission by DATAC comprises strings of data words accompanied by a label and address data. The data length is 16 bits as for Mil Std 1553B, however DATAC offers more flexibility in terms of the number of terminals; 120 terminals may be supported in lieu of the maximum 31 offered by Mil Std 1553B.

DATAC will use serial Manchester bi-phase, 1 – 2 MHz data transmission over twisted wire. Note; The 629 data bus is an unscreened cable.

5.13 THE ARINC 629 DATA BUS

The ARINC 629 is a new digital data bus format that offers more flexibility and greater speed than the ARINC 429 system. ARINC 629 permits up to 120 devices to share a “Bi-directional serial data bus”, which can be up to 100M long. The data bus can be either a twisted pair, or a fibre-optic cable.

ARINC 629 has two major improvements over the 429 system; firstly there is a substantial weight savings. The ARINC 429 system requires a separate wire pair for each data transmitter. With the increased number of digital systems on modern aircraft, the ARINC 629 system will save hundreds of pounds by using one data bus for all transmitters.

Secondly, the ARINC 629 bus operates at speeds up to 2 Mbits/sec; the ARINC 429 is only cables of 100Kbits/sec.

Figure 21 shows simplified diagrams of ARINC 429 and 629 bus structures.

ARINC 429/629 Bus Structures
Figure 21

The ARINC 629 system can be thought of as a party line for the various electronic systems on the aircraft. Any particular unit can transmit on the bus or listen for information. At any given time, only one user can transmit, and one or more units can receive data. This “Open Bus” scenario poses some interesting problems for the ARINC 629 system:

1. How to ensure that no single transmitter dominates the use of the bus.

2. How to ensure that the higher-priority systems have a chance to talk first.

3. How to make the bus compatible with a variety of systems.

The answer is found in a system called “Periodic/Aperiodic Multi-transmitter Bus”. Figure 22 shows ARINC 629 bus structure.

ARINC 629 Bus Structure
Figure 22

Each transmitter can use the bus, provided it meets a certain set of conditions.

1. Any transmitter can make only one transmission per terminal interval.

2. Each transmitter is inactive until the terminal gap time for that transmitter has ended.

3. Each transmitter can make only one transmission; then it must wait until the synchronization gap has occurred before it can make a second transmission.

5.13.1 Terminal Interval

The Terminal Interval (TI) is a time period common to all transmitters. The TI begins immediately after any user starts a transmission. The TI inhibits another transmission from the same user until after the TI time period.

5.13.2 Periodic & Aperiodic Interval

A Periodic Interval occurs when all users complete their desired transmission prior to the completion of the TI. If the TI is exceeded, an Aperiodic Interval occurs when one or more users have transmitted a longer than average message.

5.13.3 Terminal Gap

The Terminal Gap (TG) is a unique time period for each user. The TG time determines the priority for user transmissions. Users with a high priority have a short TG. Users with a lesser need to communicate (lower priority) have a longer TG. No two terminals can ever have the same terminal gap. The TG priority is flexible and can be determined through software changes in the receivers/transmitters.

5.13.4 Synchronization Gap

The Synchronization Gap (SG) is a time period common to all users. This gap is a reset signal for the transmitters. Since the Synchronization gap is longer than the terminal gap, the SG will occur on the bus only after each user has had a chance to transmit. If a user chooses not to transmit for a time equal to, or longer than, the SG, the bus is open to all transmitters once again.

5.14 MESSAGE FORMATS

The data is transmitted in groups called “Messages”. Messages are comprised of “Word Strings” and up to 31 word strings can be in a message. Word strings begin with a label, followed by up to 256 data words. Each label and data word is 20 bits long (3 bits for synchronization, 16 data bits and 1 parity bit). Figure 23 shows the complete structure of the ARINC 629 message.

ARINC 629 Message Structure
Figure 23

5.15 ARINC 629 DATA BUS COUPLING

Another unique feature of the ARINC 629 bus is the “Inductive Coupling” technique used to connect the bus to receivers/transmitters. The bus wires are fed through an inductive pick-up, which uses electromagnetic induction to transfer current from the bus to the user, or from the user to the bus. This system improves reliability, since no break in the bus wiring is required to/from connections. Figure 24 shows an example of Inductive Coupling.

ARINC 629 - Inductive Coupling Technique
Figure 24

5.16 STUB CABLES

The stub cables are for bi-directional data movement between LRU and current mode coupler. The stub cables also supply power from the LRUs to the current couplers. The stub cable has four wires, two to transmit and two to receive. These cables are in the normal aircraft wiring bundles.

Figure 25 shows the basic layout for connecting LRUs to the 629 data bus using stub cables. The stub cable length is up to 50ft for TX/RX cable and 75ft for RX only cable.

ARINC 629 Connection
Figure 25

Figure 26 shows ARINC 629 system layout.

ARINC 629 System Layout
Figure 26

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6 LOGIC CIRCUITS

The term logic in electronics refers to the representation and logical manipulation of numbers usually in a code employing two symbols. i.e., bits.

An electronic logic circuit is one whose inputs and outputs can take only one of two states. Where the output of such a circuit depends only on the present state of the input to the circuit, it is called a COMBINATIONAL LOGIC CIRCUIT.

Logic circuits may have many inputs and many outputs and be made up of a large number of elements called LOGIC GATES.

Most modern electronic logic networks are constructed from two state components in the form of integrated circuits fabricated in a single piece of pure silicon and often referred to as a CHIP. They are available as transistor-transistor logic (TTL) and complementary symmetry metal oxide semiconductor (CMOS or COSMOS) which supersede earlier resistor-transistor logic (RTL) and diode-transistor logic (DTL).

Logic circuits are most widely used in computers and calculators, but their use also extends to a wide range of control and test equipment. Figure 1 shows the logic convention.

POSITIVE LOGIC : 0 - LOW VOLTAGE
: 1 - HIGH VOLTAGE

NEGATIVE LOGIC : 0 - HIGH VOLTAGE
: 1 - LOW VOLTAGE

Logic Conventions
Figure 1

As the 'positive logic' representation is favoured by the majority of designers and manufacturers, it is intended to adopt this representation throughout this section. Positive logic refers to the use of a 1 to represent the true or more positive level (e.g. +5v) and 0 to represent the fault, or less positive level (e.g. 0v).

6.1 GATES

The word GATE suggests some kind of forceful control, and LOGIC GATES are the basic elements which actively route the flow of digital information through the logic circuits.

In a logic circuit, groups of gates working together are able to send particular bits of information to specified locations.

A logic gate is a device (usually electronic) that has a single output terminal and a number of inputs, or control terminals. If voltage levels representing the binary states of 1 or 0 are fed to the input terminals, the output terminal will adopt a voltage level equivalent to 1 or 0, depending upon the particular function of the gate. The basic logic gates provide the functions of AND and OR, each being represented by a distinctive symbol. It is sometimes convenient to show the circuit action of the gates by an equivalent contact switching circuit, and these will occasionally be employed to assist in describing the function of a logic gate element.

6.2 BASIC 'AND' GATE

Figure 2 shows the symbol that represents 2 input AND gate together with its truth table. This gate will only adopt a 1 state at its output terminal when both the inputs A and B, are at the 1 state. This function can be represented by two switches, A and B, connected in series such that the circuit is made only when both switches are CLOSED. (i.e., both in the 1 state).

SYMBOL

A	B	A.B
0	0	0
1	0	0
0	1	0
1	1	1

Basic 'AND' Gate
Figure 2

6.3 BASIC "OR" GATE

Figure 3 shows the symbol that represents a 2 input OR gate together with its truth table. This gate will adopt a 1 state at its output terminal when either input A or B or both are at the 1 state. This function can be represented by two switches A and B connected in parallel. Because this gate also performs the AND function (i.e. 1.1 = 1) it is often referred to as an INCLUSIVE OR gate.

A	B	A+B
0	0	0
1	0	1
0	1	1
1	1	1

SYMBOL

Basic 'OR' Gate
Figure 3

6.4 THE 'NAND' GATE

When constructing a NAND gate using transistors as the switching devices, the output often represents the 'inversion' of the “AND” gate. Figure 4 shows an example of a 2 input digital gate consisting of two NPN transistors, TR1 and TR2, which are assumed to be perfect switches. In a positive logic system, when input A and input B are both at the 0 state (0v), both transistors are biased OFF and the output will adopt the 1 state (+ 5v). If input A only is now given the 1 state, transistor TR1 is biased ON but no collector current can flow as TR2 is still OFF. Similarly, if input B only is given the 1 state then transistor TR2 is biased ON but again no current can flow as TR1 is OFF. Only when both input A and input B are at the 1 state together, with both transistors ON, will current be allowed to flow taking the output to the 0 state.

A	B	$\overline{A.B}$
0	0	1
1	0	1
0	1	1
1	1	0

The 'NAND' Gate
Figure 4

6.5 THE 'NOR' GATE

Figure 5 shows a further example of a 2 input digital gate, again consisting of two NPN transistors, TR1 and TR2, in a different configuration. When input A and input B are both at the 0 state (0v), both transistors are biased OFF and the output will adopt the 1 state (+ 5v). If input A only is given the 1 state, transistor TR1 will be biased ON and current will flow, making the output take up the 0 state. Similarly, if input B only is given the 1 state, transistor TR2 will be biased ON, taking the output to the 0 state. Finally if both input A and input B are at the 1 state together, the output will again adopt the 0 state.

A	B	$\overline{A+B}$
0	0	1
1	0	0
0	1	0
1	1	0

The 'NOR' Gate
Figure 5

6.6 'EXCLUSIVE OR' GATE

The basic OR gate illustrated previously in Figure 3 was seen to include the AND operation in that its output will adopt the 1 state not only when either input A or input B is at the 1 state but also when BOTH inputs are at 1. There are many occasions in logic circuits when it is required to perform the OR operation only when input A or input B are exclusively at the 1 state. In other words, a gate is required whose output adopts the 1 state only when the two input states are not identical, and such a device is known as the EXCLUSIVE OR gate.

As an example, suppose the problem is to implement the following logical statement:

"A room has two doors and a central light, and switches are to be fitted at each door such that either switch will turn the light on and off".

By fitting double-pole changeover switches at each door, a switching circuit could be wired to perform the required operation as shown in Figure 6. If each switch position is designated 'down' for the 1 state and 'up' for the 0 state, then symbols can be allocated to each switch position as shown in the diagram. If the lamp L is designated 1 for ON and 0 for OFF, then the truth table will show the circuit conditions for the switching combinations.

As the EXCLUSIVE OR gate can occur frequently in a logic circuit, it has been allocated its own special symbol, as shown in Figure 6, with an equivalent circuit shown at Figure 7.

Also, in Boolean algebra expressions, a CIRCLE SUM $\oplus$ symbol is often employed to signify that a particular expression represents the EXCLUSIVE OR operation.

i.e.: $A \oplus B = \overline{A}B + A\overline{B}$

SYMBOL

A	B	L
0	0	0
1	0	1
0	1	1
1	1	0

"EXCLUSIVE OR" Represented by Switches
Figure 6

XOR Circuit
Figure 7

6.7 THE INVERTER ('NOT' GATE)

Figure 8 shows the symbol for an inverter, where the output will produce the complement of the input. This device is often employed when the complement of a particular signal is required at some point in the logic circuit.

A	$\overline{A}$
1	0
0	1

The Inverter
Figure 8

6.8 INVERTING WITH LOGIC GATES

Either the NAND or the NOR gate can be connected to operate as a simple inverter as illustrated in Figure 9. In diagram (a) a 2 input NAND gate is shown with one input permanently held at the 1 state (+ 5v), and the resulting output will be the inversion of the single input A. Diagram (b) shows a 2 input NOR gate with one input permanently held at the 0 state (0v) again resulting in an output which will be the inversion of the single input A. These configurations can be particularly useful in logic circuits where the inversion of a variable is required without the need for power amplification.

Logic Gate Inverters
Figure 9

6.9 MULTIPLE INPUT GATE SYMBOLS

Digital integrated circuits are manufactured with multiple inputs to a single gate operation, and the approved symbols to be used to illustrate these types are shown in Figure 10. Diagram (a) shows a multiple input NAND gate symbol, whilst diagram (b) shows the symbol for a multiple input NOR gate.

(a)
NAND SYMBOL

(b)
NOR SYMBOL

Multiple Gate Symbols
Figure 10

6.10 EXTENDED INPUT FACILITIES

Another instance where multiple inputs to a single gate operation can occur is with certain types of gate elements that have an 'EXTENDED INPUT' facility provided. The circuit illustrated in Figure 11 is a typical example showing a 3 input NAND gate (element X) using isolating diodes in each of the input lines A, B and C. A connection from the base of the transistor is brought out in order that further inputs (element Y) can be connected to extend the input range (i.e. inputs D and E). When this configuration is employed in a logic circuit the approved form of symbol to be used is shown on the right, with an arrow indicating that the connection is made to an extended input facility at element X.

Extended Input Facilities
Figure 11

6.11 TIME DELAY ELEMENTS

Delay elements are used to 'delay' the travel of a pulse along a line for a short period of time. This is occasionally necessary to ensure that one bit of information does not arrive at some point in the circuit earlier than another. Most delay times are relatively small and only amount to few milli-seconds.

Most delay elements have one input terminal and one output terminal, and if a pulse is fed to the input a similar pulse will appear at the output after the specified time period. Figure 12 shows two types of time delay elements.

(a) - SINGLE OUTPUT

(b) - MULTIPLE OUTPUT

Time Delay Elements
Figure 12

The symbols shown in Figure12 are those used to represent delay elements, and twin vertical lines on the symbol indicate the input side. If the element provides a single delay the duration is included on the symbol as shown in symbol (a). If the delay is tapped to provide multiple outputs, the delay time with respect to the input is included adjacent to the particular tapped output as shown in symbol (b).

6.12 ACTIVE STATE INDICATORS

Logic diagrams make extensive use of the 'active state indicator' which takes the form of a small circle at the input or output terminals of a logic symbol. It is used to indicate that the normal active state of the particular logic level has been inverted at that point in the symbol. Throughout this section the 'positive logic' convention has been adopted and the 1 state has been used to signify the 'active' state with regard to the symbols and the truth tables. In this instance therefore, the significance of an active state indicator attached to a symbol can be defined as follows:

(1) A small circle at the input to any element indicates that a 0 state will now activate the element at that particular input only.

(2) A small circle at the output of any element indicates that the output terminal of that element will adopt the 0 state when activated.

Figure 13 shows examples of Active State Indicators

A	B	$\overline{A}B$
1	0	0
1	1	0
0	0	0
0	1	1

A	B	$\overline{A}+B$
1	0	0
1	1	1
0	0	1
0	1	1

Active State Indicators
Figure 13

6.13 THE 'INHIBIT' GATE

Occasionally it is required to 'hold' one input to an AND gate at a particular logic level in order to disable the entire gate. One method of representing this symbolically is shown in Figure 14, which illustrates a two input gate with an 'INHIBIT' input C carrying an indicator. In this case, with a 1 state at the inhibit input C, the gate is disabled irrespective of the input conditions at A and B. With a 0 state at the inhibit input C however, the gate is now 'enabled' and the output will adopt the 1 state when both input A and input B are at the 1 state.

A	B	C	$AB\overline{C}$
0	0	1	0
1	0	1	0
0	1	1	0
1	1	1	0
0	0	0	0
1	0	0	0
0	1	0	0
1	1	0	1

The 'INHIBIT' Gate
Figure 14

6.14 LOGIC CIRCUIT APPLICATIONS

There are several basic logic circuits that are common to almost every computer, or related peripheral device. These circuits use simple combinations of the AND, OR, NOT and XOR gates. Five of the most common logic circuits are:

1. Adders.
2. Subtractors.
3. Clocks.
4. Latches.
5. Flip-flops.

6.14.1 ADDERS & SUBTRACTORS

Adder and Subtractor circuits are used to perform basic calculations in computer systems. Adders, as their name suggests, add binary digits. Since binary numbers consist of only two digits, 1 and 0, it is almost always necessary to carry a digit to the next higher-order column when adding. For example 1 + 1 = 0 carry 1. There are always 3 inputs into a full adder; the 2 digits being added and the carry from the adjacent lower order column (A, B & CI). Figure 15 shows the circuit for a “Full-adder” function.

Full-Adder Circuit
Figure 15

Subtractor circuits are again a combination of basic gates with the inputs A, B and BRI. BRI is the borrowed digit from the subtraction in the adjacent lower-order column (if applicable). The outputs are D, the difference between the digits in the subtraction, and BRO, the digit borrowed from the adjacent higher-order column (if applicable).

Figure 16 shows the circuit for the subtraction function.

Subtractor Circuit
Figure 16

6.14.2 Digital Clock Circuits

Certain functions of a digital circuit require a consistently timed binary signal. A digital clock provides a stable frequency of binary 1s and 0s. A crystal material is commonly used to control pulse time and produce a consistent binary 1 and 0 waveform (square-wave).

6.14.3 Latches And Flip-Flop Circuits

Latches and Flip-flop circuits are a combination of logic gates that perform basic memory functions for computers and peripherals. Both these circuits retain their output signal even when the input signal has been removed; therefore, these circuits "remember" the input data. Figure 17 shows a RS Latch circuit.

LOGIC SYMBOL

RS Latch
Figure 17

The two inputs to the latch are "SET" (S) and "RESET" (R), with two output signals Q and $\overline{Q}$ (not Q). A logic 1 at the S input will set the latch memory and Q equals 1, while $\overline{Q}$ will be 0. Logic 1 at the R input will reset the latch and Q will equal 0 and $\overline{Q}$ will equals 1.

Flip-flop circuits are similar to latch circuits; however, flip-flops change their output when a trigger pulse is applied. A flip-flop circuit contains three inputs, the S and R signals are identical with the latch circuit, the “Clock Pulse (CP) is an input that controls the circuit switch time. Its output will only change state at given time intervals controlled by the clock pulse.

The advantage of using a clock input for a memory circuit is that all flip-flop output signals change at the same time. This becomes very important when several memory circuits are used simultaneously.

Figure 18 shows a Flip-flop circuit.

Flip-flop circuit
Figure 18

6.14.4 COUNTERS

The flip-flop device when connected in series can function as a binary counter. figure 19 shows the layout for a 4 bit counter.

BINARY 4 BIT COUNTER
Figure 19

Figure 20 shows the resultant waveforms from a 4 bit counter.

Waveform of 4 Bit Counter
Figure 20

6.14.5 OPERATION

The Counter Uses The Jk Flip-Flop Connected In Cascade. The Jk Inputs Are Connected To Logic 1 And The Clock Will Trigger Any Change Of The Output State Of Each Jk Flip-Flop. The Output Of One Jk Flip-Flop Is The Input To The Next. Referring To Figures 18 And 19, It Can Be Seen That Every Time The Input Pulse Changes From 1 To A 0, The Counter Will Increase The Counter By One.

- Q1 IS LEAST SIGNIFICANT BIT.
- Q4 IS MOST SIGNIFICANT BIT.

After the first pulse Q1 = 1, Q2 = 0, Q3 = 0 and Q4 = 0 which is 0001 (decimal 1). After the second pulse Q1 = 0, Q2 = 1, Q3 = 0 and Q4 = 0 which is 0010 (decimal 2).

It can be seen that each flip-flop is acting as a divide by 2 circuit and four flip-flops in a circuit makes a divide by 16 circuit, because the pulse frequency at Q4 is $^{1}/_{16}$ of the input frequency. So this chain of flip-flops can be referred to as either a divide by or multiply by 16 counter or modulo 16 counter (modulo meaning the maximum number a counter can count to).

6.14.6 SHIFT REGISTERS

A register is a number of flip-flops arranged in a circuit used for storing data. A shift register is one that is designed to move the data along the register. Figure 21 shows a 4-bit register using SR flip-flops.

4 Bit Shift Register
Figure 21

Assuming the register is cleared and therefore reads 0000 and externally generated word of 1011 is to be stored in the register. The msb is the first bit to be input, which is logic 1. The first register has logic 1 on s, and its q output will change when the clock pulse is active. So after the first clock pulse 1 =1, 2 = 0, 3 = 0 and 4 = 0.

When the second clock pulse is active Q1 will activate S 1 which changes Q2 to logic 1, Q1 will remain at logic 1, as a reset pulse has not yet reset it. Q3 and Q4 will both = logic 0. The third clock pulse resets Q1, as the input is logic 0 (reset = 1), Q2 and Q3 will be at logic 1 and Q 4 will be logic 0.

The final input is a logic 1 so Q1 = 1, Q2 = 0 (Q1 was at logic 0), Q3 and Q4 both have logic 1. So with four clock pulses the register is loaded. It will take four further clock pulses to empty the register.

This type of register is a Serial in – Serial out register. Registers can also be:

- Serial In – Parallel Out.
- Parallel In – Serial Out.
- Parallel In – Parallel Out.

Figure 22 shows an example of a parallel to parallel register.

Parallel – Parallel Register
Figure 22

Figure 23 shows a Serial to Parallel register circuit.

Serial – Parallel Register
Figure 23

6.15 AIRCRAFT APPLICATIONS

Logic circuits have many uses within aircraft systems, form some simple circuits controlling landing gear selection to complex circuits within systems controlling navigation and system operation.

Figure 24 shows a simple logic circuit for an aircraft landing gear system.

Landing Gear Logic Circuit
Figure 24

6.15.1 Circuit Operation

In order for the “DOWN” light to illuminate, all three landing gear legs must be down and locked, for this function an “AND” gate is used. If all three gears are not down and locked and the throttle is moved back to approach, then the “NOR” gate will activate the horn to warn the crew that they have not selected the gear “DOWN”, with the throttle at approach.

6.15.2 Engine Starting Logic Circuit Operation

The logic circuit at Figure 25 details the various means of starting an engine.

Engine Starting Logic Circuit
Figure 25

6.16 FOKKER 50 MINI AIDS

6.16.1 TAKE OFF REPORT

A take-off report is automatically generated under specific conditions. These are:

- GND/FLT switch is in the “Flight” condition (Logic 0).
- IAS >60kts.
- Propeller running with at least 675 RPM.

When these conditions are met, a time delay of 5 seconds ensures the aircraft is airborne sufficiently to make a report with relevant “Take-off” information. Figure 26 shows the layout of F50 Mini Aids take-off report.

F50 Mini Aids Take-off Report
Figure 26

6.16.2 STABLE CRIUSE REPORTS

There are two stable cruise reports, Stable Cruise 1 and Stable Cruise 2.

The mini AIDS makes these reports under different conditions. The conditions of stable cruise 2 are more critical than the conditions of stable cruise 1. Both cruise reports require the need for the following conditions:

- Altitude of at least 8,000 ft
- IAS of at least 145 kts.
- No change in the Air Conditioning system.
- Both pressure regulating shut-off valves are open (or bleed air valves closed).

In addition Stable cruise 1 requires the following conditions for automatic report generation.

- Air temperature may only vary within 2°C.
- Altitude may only vary within 300 ft.
- IAS may only vary within 3 kts.

These variations may not exceed these limits for a time period of 64 seconds.

The more critical conditions for an automatic stable cruise 2 report generation are:

- Altitude may only vary within 100 ft.
- IAS may only vary within 2 kts.
- Both high and low-pressure turbines may not exceed a variation in RPM of more than 0.5%.
- Both torque forces of the engines may not exceed a variation of 1%.

The mini AIDS also monitors the stable cruise 2 variation for a time period of 64 seconds.

Figure 27 shows a block schematic diagram of the mini AIDS cruise reporting.

F50 Mini AIDS Block Schematic
Figure 27

6.16.3 OPERATION

So that the aircraft first meets the conditions for stable cruise 1, the mini AIDS collects the stable cruise1 report information but does not store it in the non-volatile memory. A 15-minute counter starts to count at the moment the aircraft meets the stable cruise 1 conditions.

When the aircraft meets the more critical condition of the stable cruise 2 within the 15 minutes stable cruise 1 is counting, the mini AIDS stores the stable cruise 2 information in the non-volatile memory. When the aircraft does not meet the stable cruise 2 conditions within the 15 minutes, the mini AIDS finally stores stable cruise 1 into the non-volatile memory.

If the aircraft does not fly for a total of 15 minutes in a stable cruise 1 condition the mini AIDS stores the stable cruise 1 report in the landing phase 33 seconds after touchdown.

After storage of a report 1 or 2, further stable cruise reports are inhibited for that flight. There is however an exception;

- After a power interrupt, the mini AIDS stores the collected stable cruise 1 report in the non volatile memory but does not inhibit a new storage of a stable cruise 1 or 2.

To retrieve the data within the non-volatile memory, a data collector unit, or Laptop computer downloads the data.

7 BASIC COMPUTER STRUCTURE

A computer is an electronic device, which can accept and process data by carrying out a set of stored instructions in sequence. This sequence of mathematical and logic operations is known as a Program.

The computer is constructed from electronic circuits, which operate on an ON/OFF principle. The data and instructions, used in the computer, must therefore be in logical form.

The computer uses the digits "1" and "0" of the binary numbering system to represent "OFF" and "ON". All data and program information must, therefore, be converted into binary form, before being fed into the computer circuitry.

One of the most important characteristics of a computer is that it is a general-purpose device, capable of being used in a number of different applications. By changing the stored program, the same machine can be used to implement totally different tasks.

In general, aircraft computers only have to perform one particular task so that fixed programs can be used.

7.1 ANALOGUE COMPUTERS

A computer is basically a problem-solving device. In aircraft radio systems the problem to be solved is concerned with navigation, in that given certain information, such as range and bearing to a fixed known point, steering commands need to be computed to fly the aircraft to the same, or some other fixed point.

Since the input and output information is continuously changing during flight, analogue computation provides an obvious means of solving the navigation problems.

A block schematic diagram of an analogue computer is shown in Figure 1.

Analogue Computer Block Diagram
Figure 1

The input devices are radio sensors such as VOR, DME, Omega, ADF, Doppler, Loran, Decca, ILS, and non-radio sensors such as the Air Data Unit and Inertial Navigation System. The output of such sensors will be electrical analogues of the quantities being monitored. The electrical signals contain the necessary information needed to solve the navigation problem, the solution being achieved by the computer.

The computer consists of a variety of analogue circuits such as summing amplifiers, integrators, comparators, sine cosine resolvers, servo systems, etc. The patching network determines the way, in which the analogue circuits are interconnected, which will be such as to achieve the required outputs for given inputs.

There is a disadvantage of analogue computers in that different patching is needed for different applications. Thus aircraft analogue computers are purpose built to solve one particular problem and as such usually form an integral part of a particular equipment.

This lack of flexibility, together with limited accuracy and susceptibility to noise and drift, has led to the introduction of digital computers, made possible by integrated circuits. Even so, the analogue computer, or rather analogue computing circuits, are still extensively used because as stated above, the sensors produce analogue signals.

7.2 ANALOGUE COMPUTER EXAMPLE

Consider an aircraft approaching a DME beacon. The distance to go is given as an electrical analogue signal at the output of the aircraft's DME equipment.

By using an analogue computer, this signal can be used to provide an indication to the pilot of his ground speed.

As the input signal represents distance, a sample of change in distance divided by the lapsed time will provide ground speed. A suitable block diagram to carry out this calculation is shown in Figure 2.

Computing Groundspeed from 'Distance to Go'
Figure 2

7.3 DIGITAL COMPUTERS

In the digital computer there are basically two types of input, namely Instructions, and Data from the various radio and non-radio sensors, which will be referred to collectively as information. Information must of course, be coded into a form, which the rest of the computer can understand, such as digital form.

The essential components of a digital computer are shown in Figure 3.

Digital Computer Block Diagram
Figure 3

Coded information is passed to the memory in which it is stored until needed by the other units. The memory is divided into a large number of cells, each of which can store a word representing a piece of information. Each cell has a unique address, through which access to the information contained within that cell can be obtained. There are usually two types of memory, long term and temporary stores. The latter, often termed registers, will be used to hold intermediate results in calculations and data, which is to be processed next in the calculating sequence.

The arithmetic unit performs the actual arithmetic operations called for by instructions. It can be compared with a calculator.

The results of the calculations must be displayed in a suitable form easily interpreted by the pilot. This is the function of the output unit, which reads from the store.

The control unit directs the overall functioning of the computer according to the program of instructions in store. This program is known as software as opposed to the actual circuitry, which is termed hardware. Although control is drawn as a separate unit in the functional block diagram, the control hardware, which comprises timing circuits and electronic switches, is spread throughout the computer.

Information is read into the appropriate address of the store under the control of the software. In aircraft navigation applications, incoming data from sensors updates the contents of the store at a rate dependent upon the timing of the computer control.

The control acts on instructions held in store in the appropriate sequence. The basic task will be to transfer data from store to the arithmetic unit, to carry out the necessary calculations using registers to store the intermediate results, then writing the final result into the store.

The final control function will be to transfer data from store to the output as a result of built in instructions, or on specific instructions from the pilot.

This process of input - store - calculate - store - output is carried out sequentially in accordance with software requirements.

7.4 BUSES

It can be seen from Figure 4 that there are three buses - the data bus, the address bus, and the control bus. Each bus consists of a group of parallel wires.

The data bus transfers data between memory, CPU and I/O units, under the control of signals sent through the control bus. For example, if data is to be transferred (sent) from the CPU to a memory location, the control unit within the CPU places an output instruction on the CPU, and write instruction on the memory unit. When the data arrives at the memory, it must be written into the memory at a given address. The address is already present, having been sent by the CPU along the address bus. Hence, data is stored at the memory address given. Note that if the transfer had been from the CPU to an I/O device, the address of the I/O device would have been given.

The address bus is one-way only. The control bus usually has one set of wires for input sensing lines, and one set for output controls.

Data buses are usually bi-directional; that is, data is either transferred, or fetched along the same set of wires. The control unit usually decides in which direction data will travel. If there are several peripherals, and these all wish to use the CPU at the same time, some method of priority must be established. There are various ways of achieving this. One method uses the control unit to select the lucky peripheral, whilst another method lets the peripherals themselves automatically decide which peripheral takes control.

Computer Buses
Figure 4

7.5 INPUT/OUTPUT (I/O) UNIT

This unit provides the interface between the computer and the computer peripherals. A computer peripheral is any unit, which is attached to, but is not part of, the computer - e.g. visual display units, teleprinters, etc. A simple computing system may have only one input and one output. In such cases, an analogue-to-digital converter (ADC) may suffice for the input, and a digital-to-analogue converter (DAC) for the output. Alternatively, complex-computing systems can literally service thousands of peripherals.

Figure 5 illustrates a simple I/O unit. The I/O unit can be described as a fan-out (and fan-in) device. The computer's 8-bit bi-directional data bus can be connected to port 1, 2 or 3. The port chosen is dependent upon the address, on the address bus. The system illustrated allows three peripherals to communicate with the computer. Only one peripheral at a time can send data to the computer, or receive data from the computer. However, this is not a problem, because the computer works very much faster than the peripheral, and hence, it appears that the computer services all three peripherals simultaneously.

Input/Output Unit
Figure 5

Peripherals can have either serial or parallel outputs. Also, as stated previously, peripherals work at a much slower speed than that of the computer. The I/O system must, therefore, be capable of 'conditioning' the data received from the peripherals to a form, which is readily digestible by the computer, and vice versa.

7.6 MEMORY

The memory unit is used for the storage of binary coded information. Information consists of instructions and data where:

- Instructions are the coded pieces of information that direct the activities of the CPU.

- Data is the information that is processed by the CPU.

The memory hardware contains a large number of cells or locations. Each location may store a single binary digit or a group of binary digits. The cells are grouped so that a complete binary word is always accessed. Word length varies typically from 4-bits up to 64-bits depending upon machine size. Each location in the memory is identified by a unique address, which then allows access to the word. Consequently, to obtain information from the memory, the correct address must be placed onto the address bus.

There are fundamentally two types of memory - primary memory and secondary memory. Primary memory is essential; no computer can operate without this. Secondary memory is necessary to supplement, or back, the primary memory on large computing systems; hence, it is often called backing memory.

There are two types of semi-conductor primary memory: ROM (Read Only Memory) and RAM (Random Access memory). Both types employ solid state circuitry, and are packaged in IC form.

Figure 6 shows how these primary memories are connected to a simple computer bus.

ROM and RAM Connection to Buses
Figure 6

7.7 RANDOM ACCESS MEMORY (RAM)

The RAM-type memory will allow data to be written into it, as well as read from it. With very few exceptions, RAMS lose their contents when the power is removed and are thus known as “Volatile” memory devices. All computers use RAM to store data and programs written into it either from keyboard, or external sources such as magnetic tape/disk devices.

RAMs are often described in terms of the number of bits, i.e. 1s and 0s, of data that they hold, or in terms of the number of data words, i.e. groups of bits, they can hold. Thus a 16384 bit ram can hold 16384 1s and 0s. This data could be arranged as 16384 1-bit words, 4096 4-bit words or 2084 8-bit words. Semiconductor memories vary in size, e.g. 4K, 64K, 128K, etc. Hence we are using K defined as:

$$K = 2^{10} = 1024$$

Thus a 16K memory has a storage capacity of 16 X 1024 = 16384 words, a 128K memory 0f 1310672 words and so on.
There are two main members of the RAM family:

- Static RAM.
- Dynamic RAM.

The essential difference between them is the way in which bits are stored in the RAM chips. In a static RAM, the bits of data are written in the RAM just once and then left until the data is either read or changed. In a dynamic RAM, the bits of data are repeatedly rewritten in the RAM to ensure that the data is not forgotten.

7.7.1 STATIC RAM

Flip-Flops are the basic memory cells in a static RAM. Each flip-flop is based on either two bipolar transistors or two Metal Oxide Semiconductors Field-Effect Transistors (MOSFETS). As many of these memory cells are needed as there are bits to be stored. Thus, in a 16K-bit static memory there are 16384 flip-flops, i.e. 32768 transistors. All these transistors are accommodated on a single silicon chip approximately 4mm^2. Figure 7 shows a basic memory cell in a static RAM

Static RAM Cell
Figure 7

7.7.2 7489 TTL RAM DEVICE

The 7489 TTL Ram package has 64 memory cells, each cell is capable of holding a single bit of data. The cells are organised into locations, and each location is capable of holding a 4-bit word. Thus the 7489 is capable of storing 4-sixteen 4-bit words, i.e. four memory cells are used at each location. Figure 8 shows the memory organisation of the 7489 static RAM.

7489 RAM Device
Figure 8

Each location is identified by a unique 4-bit address so that data can only be written or read from that location. The number of words stored in the memory determines the length of the address word. I.E. 16 = 2^4.

7.8 READ ONLY MEMORY (ROM)

The problem with RAM is that its memory is volatile, i.e. it loses all its data when the power supply is removed. A non-volatile memory is a permanent memory that never forgets its data. One type of non-volatile memory is the Read Only Memory (ROM). A ROM has a pattern of 0s and 1s imprinted in its memory by the manufacturer. It is not possible to write new data into a ROM, which is why it is called a Read-Only Memory.

The organisation of data in a ROM is similar to that of a RAM. Thus a 256-bit ROM might be organised as a 256 X 4-bit memory, and so on. The ROM may be regarded as the “Reference Library” of a computer.

7.9 MAGNETIC CORE MEMORY

This type of memory is used extensively in airborne digital systems, although integrated circuits are being developed with most modern aircraft systems. This system works by a Ferro-magnetic material will become magnetized if placed in the proximity to an electric current. Each bit in the magnetic core memory is a ferrite ring in which a magnetic field can be induced by a current flowing in a wire. Figure 9 shows typical ferrite ring for storing a single bit.

Ferrite Ring Memory
Figure 9

Although the wire carrying the current is wound round the ring, the same effect is obtained if the wire passes through the ring. This is a more convenient way to set the magnetic state of each ring when a plane of cores is built. The advantage of this type of memory is that when the power is removed it holds its state, i.e. it is a non-volatile memory. A matrix of cores containing 16 bits of information is shown in Figure 10.

16 Bit Ferrite Memory
Figure 10

7.10 PROGRAMMABLE ROM (PROM)

The user can program a PROM after purchase. Each memory bit element in the PROM contains a nichrome or silicon link that acts as a fuse. The user can selectively 'but out' or 'blow' these fuses by applying pulses of current to the appropriate pins of the IC. A memory element with a non-ruptured fuse stores a 1 and a ruptured fuse stores a 0. The programming is irreversible, so it must be right first time. Figure 11 shows the circuit for a PROM.

PROM Circuit
Figure 11

PROMs are capable of high operating speeds, but consume a relatively large amount of power. However, since they are non-volatile, they can be switched off when not being accessed.

7.11 ERASABLE PROGRAMMABLE READ ONLY MEMORY

These memory devices can be programmed, erased and then reprogrammed by the user as often as required. In some devices, the information can be erased by flooding them with ultraviolet light, whilst in others, voltages are applied to the appropriate pins of the device.

7.12 ELECTRICAL ALTERED READ ONLY MEMORY

This memory device combines the non-volatility of the ROM with the electrically alterable characteristic of the RAM. It is, therefore, considered as a non-volatile RAM.

7.13 MEMORY ACCESS

The use of semi-conductor memory elements (bistables) has been made possible by the use of large scale integrated circuits (LSI) which provide reliability, ease of application and good storage capacity per unit volume. A disadvantage of such memories is that a power supply is needed to hold the information stored. Batteries may be provided to prevent loss of memory in case of power failure. This is not necessary for memories made up of ferrite cores.

Typically, 15 elements are needed for one word, therefore for a 2,000 word RAM we would need 30,000 elements arranged in a three dimensional matrix. Figure 12 shows a 9-word store, each word consisting of 3-bits.

Computer Memory
Figure 12

If one wishes to read the word at address W5, the memory address register sends, by way of the X and Y drive and decode circuits, a 1-bit along wires X2 and Y2. The contents of W5 are then read sequentially from least significant bit to most significant bit by the sense wire, which is connected to each of the 27 elements.

As part of a general-purpose computer ROMs may be used to store information which is unchanged over most, if not all, of the operational life of the equipment. If all the hardware of a computer is wired in using ROMs then we no longer have a general-purpose computer and hence have lost the inherent flexibility. However, saving in circuitry results, and some degree of flexibility can be regained by having interchangeable ROMs mounted on printed circuit boards (PCB) which can be removed from and fitted to the computer.

7.14 THE CENTRAL PROCESSING UNIT (CPU)

The CPU is the heart of any computing system. It executes the individual machine instructions, which make up a program. The CPU is formed from the following interconnected units:

1. ALU (Arithmetic Logic Unit).
2. Registers.
3. Control Unit.

These units are shown as part of a computer system in Figure 13.

Central Processing Unit
Figure 13

ALU. This is where the mathematics and logic functions are implemented.

It is not essential for the ALU to subtract, divide, or multiply, as these functions are easily achieved by using addition in conjunction with 2's complement arithmetic.

However, more powerful processors include sophisticated arithmetic hardware capable of division, multiplication, fixed and floating point arithmetic etc. Large processors also employ parallel operation for high speed.

Registers. These are temporary storage units within the CPU. Some registers have dedicated uses, such as the program counter register and the instruction register. Other registers may be used for storing either data or program information. Figure 14 illustrates the principal registers within the CPU.

The CPUs Internal Registers
Figure 14

Program counter register. The instructions that comprise a program are stored in the computer's memory. Consequently, the computer must be able to sequentially access each instruction. The address of the first instruction is loaded into the program register, whereupon the instruction is fetched and loaded into another register, appropriately called the instruction decode register. Whilst the CPU is implementing the fetched instruction (e.g. Add, Shift, etc), the program counter register is incremented by 1 to indicate the address of the next instruction to be executed. This system, therefore, provides sequential execution of a program, provided that the program is written and stored sequentially in the memory.

The instruction decode register. As stated above, the program counter register locates the address at which the next instruction is to be found. The instruction itself is then transferred from memory into the instruction decode register. As the name implies, this register also incorporates a decoder. the output from the decoder places the necessary logic demands onto the ALU - i.e. shift, add, etc.

The accumulator register. This register is really part of the ALU, and it is the main register used for calculations. Consequently, it always stores one of the operands, which is to be operated on by the ALU. The other operand may be stored in any temporary register.

The status register. This register is a set of bistables which operate independently of each other. The bistables independently monitor the accumulator to detect such occurrences as a negative result of a calculation, a zero result, an overflow, etc. When such an occurrence arises, the output of the respective bistable is set (logic 1). It is then said to signal or flag the event. It is this register that gives a computer its decision-making capability. For example, if the result of a calculation in a navigational computer is zero, the program could instruct the autopilot to hold its present course. Alternatively, if the zero flag was not set, the computer would then decide to take corrective action.

There are many other registers within a CPU, some of which are general-purpose registers. These can be used to store operands or intermediate data within the CPU, thus eliminating the need to pass intermediate results back and forth between memory and accumulator.

The control unit. This unit is responsible for the overall action of the computer. It coordinates the units, so that events take place in the correct sequence and at the right time. Because it is responsible for timing operations it includes a clock (normally crystal controlled), so that instructions and data can be transferred between units under strict timing control (synchronous operation). The crystal and the clock generator may either be contained within the CPU, or supplied as separate components.

7.15 THE MICROPROCESSOR

The three fundamental units, which comprise a CPU, have now been discussed in general terms. So too has a microprocessor, because a microprocessor can be defined as the central processing part of a computer contained within an IC (Integrated Circuit). Figure 15 illustrates how a microprocessor can be used as part of a microcomputer.

The microprocessor is small, lightweight, and relatively cheap when compared to any CPU. But it is also relatively slow, capable of processing only hundreds of instructions per second, compared to a large CPU which can process thousands of instructions per second, or a very fast CPU which can process millions of instructions per second (mips). However, many computing applications can tolerate the relative speed disadvantage of the microprocessor hence, its popularity. Microprocessors are typically available in 4, 8 and 16-bit word lengths.

Elementary Microcomputer
Figure 15

The preceding paragraphs defined a microprocessor as a CPU within an IC. This is true of all microprocessors; however, many go beyond this 'minimum' definition. Microprocessors for machine control (lathes, robots, petrol pumps, etc) often incorporate ADC and DAC on the same chip, plus a small amount ROM and RAM.

Some microprocessors incorporate all the elements of a total computing system: I/O, ROM, RAM and CPU. Manufacturers designate these as single chip microcomputers. Obviously, their computing power is somewhat limited, because there is a limited amount of space available in just one IC.

7.16 AIRBORNE DIGITAL COMPUTER OPERATION

7.16.1 FLIGHT MANAGEMENT SYSTEM (FMS)

A Flight Management System (FMS) is a computer-based flight control system and is capable of four main functions:

1. Automatic Flight Control.
2. Performance Management.
3. Navigation and Guidance.
4. Status and Warning Displays.

The FMS utilizes two Flight Management Computers (FMC) for redundancy purposes. During normal operation both computers crosstalk; that is, they share and compare information through the data bus. Each computer is capable of operating completely independently in the event of one failed unit.

The FMC receives input data from four sub-system computers:

1. Flight Control Computer (FCC).
2. Thrust Management Computer (TMC).
3. Digital Air Data Computer (DADC).
4. Engine Indicating & Crew Alerting System (EICAS).

The communication between these computers is typically ARINC 429 data format. Other parallel and serial data inputs are received from flight deck controls, navigation aids and various airframe and engine sensors.
Figure 16 shows a block schematic of the FMS.

Flight Management System (FMS)
Figure 16

The FMC contains a large nonvolatile memory that stores performance and navigation data along with the necessary operating programs. Portions of the nonvolatile memory are used to store information concerning:

a. Airports. b. Standard Flight Routes.

c. Nav Aid Data.

Since this information changes, the FMS incorporates a “Data Loader”. The data loader is either a tape or disk drive that can be plugged into the FMC. This data is updated every 28 days.

Figure 17 shows the layout of FMC memory.

FMC Memory Locations.
Figure 17

Variable parameters for a specific flight are entered into the FMS by either data loader, or “Control Display Unit” (CDU). This data will set the required performance for least-cost or least-time en-route configuration.

7.16.2 FMS CONTROL/DISPLAY UNIT (CDU)

The CDU provides a means for the crew to communicate with the FMC. It contains pushbutton key controllers and a display screen. The keys are of two types: -

1. Alphanumeric keys, which can be used to enter departure and destination points and also Waypoint if not already stored on tape; they will also be used if the flight plan needs to be changed during the flight.

2. Dedicated keys, which are used for specific functions usually connected with display. For example, by using the appropriate key the pilot can call up flight plan, Waypoint data, flight progress, present position, etc.

When, for example, a departure point is entered using alphanumeric keys, the information is often held in a temporary register and displayed to the pilot; this is known as a scratchpad display. Once the pilot has checked the information is correct, he can enter the data into the computer store by pressing the appropriate dedicated key typically labelled "Load" or "Enter".

Figure 18 shows an FMS Control/Display Unit (CDU).

FMS CDU.
Figure 18

During a normal flight, the FMS sends navigation data to the EFIS, which can then display a route map on the EHSI. If the flight plan is altered by the flight crew en-route, then the EHSI map will change automatically.

7.17 COMPUTER INPUT

Figure 19 shows input information for a typical airborne digital computer.

Computer Inputs
Figure 19

The sensors in Figure 19 develop analogue electrical signals representing: -

- Bearing and distance to fixed point (VOR/DME).
- Hyperbolic co-ordinates (Omega).
- Ground speed and drift angle (Doppler).
- Aircraft heading (Compass), etc.

These analogue signals must be converted into digital signals before being fed to the computer memory. ADCs, which may be an integral part of the sensor

equipment achieve this, or alternatively a converter unit may be installed, which carries out all necessary analogue to digital conversion.

7.17.1 Computer Output

Many different kinds of output device are used, including traditional devices such as relative bearing indicators and steering indicators. With these, suitably designed digital to analogue converters must be used. Similar outputs could be fed to an autopilot.

Digital read out can be obtained by use of hybrid (digital and analogue) servo systems, which position an output counter drum or alternatively by use of 7 segment indicators. A ROM, which has the wired in program to convert from binary code to the appropriate drive, drives the segments, which may be light emitting diodes (LED) or liquid crystals (LCD).

Cathode ray tubes (CRT) are being increasingly used as output devices both for display of alphanumeric information and, less commonly, electronic maps. CRTs are essentially analogue devices and as such require DACs, which will provide the necessary fairly, complicated drives.

Moving map displays may also be used as a means of presenting navigation information to the pilot. The map itself may be an actual chart fitted on rollers, or alternatively projected film. Closed loop servos, which drive the map, are fed from the computer via DACs.

7.18 Computer Terms

7.18.1 Access Time

The time interval required to communicate with the memory, or storage unit of a digital computer, or the time interval between the instant at which the arithmetic unit calls for information from the memory and the instant at which this information is delivered.

7.18.2 Address

A name or number that designates the location of information in a storage or memory device.

7.18.3 COMPUTER LANGUAGE

A computer language system is made up of various sub routines that have been evaluated and compiled into one routine that the computer can handle. FORTRAN, COBOL and ALGOL are computer language systems of this type.

7.18.4 CORE MEMORY

A programmable, random access memory consisting of many ferromagnetic cores arranged in matrices.

7.18.5 DATA PROCESSING

The handling, storage and analysis of information in a sequence of systematic and logical operations by a computer.

7.18.6 DECODER

A circuit network in which a combination of inputs produces a single output.

7.18.7 FLOPPY DISC

A backing storage facility for microcomputer systems.

7.18.8 INSTRUCTION

A machine word or set of characters in machine language that directs a computer to take a certain action. Part of the instruction specifies the operation to be performed, and another part specifies the address.

7.18.9 LANGUAGE

A defined group of representative characters of symbols combined with specific rules necessary for their interpretation. The rules enable the translation of the characters into forms (such as digits) which are meaningful to a machine.

7.18.10 MACHINE CODE

A program written in machine code consists of a list of instructions in binary form to be loaded into the computer memory for the computer to obey directly.

7.18.11 MAGNETIC CORE

A form of storage in which information is represented by the direction of magnetization of a core. Advantage of this kind of memory store is it will retain its contents even if electrical power is removed (Non-volatile).

7.18.12 PROGRAMME

A plan for the solution of a problem. A precise sequence of coded instructions or a routine for solving a problem with a computer.

7.18.13 REAL TIME

The actual time during which a physical process takes place and a computation related to it, resulting in its guidance: or, ‘As it happens’.

7.18.14 ROUTINE

A set of coded instructions that direct a computer to perform a certain task.

7.18.15 TIME SHARING

Using a device, such as a computer, to work on two or more tasks, alternating the work from one task to the other. Thus the total operating time available is divided amongst several tasks, using the full capacity of the device.

7.18.16 WORD (OR BYTE)

An ordered set of characters which has at least one meaning and is stored, transferred, or operated upon by the computer circuits as a unit.

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8 FIBRE OPTICS

Light travels in straight lines, even though lenses and mirrors can deflect it, light still travels in a straight line between optical devices. This is fine for most purposes; cameras, binoculars, etc. wouldn't form images correctly if light didn't travel in a straight line. However, there are times when we need to look round corners, or probe inside places that are not in a straight line from our eyes. That is why "FIBRE OPTICS" have been developed.

The working of optical fibres depend on the basic principle of optics and the interaction of light with matter. From a physical standpoint, light can be seen either as "Electromagnetic Waves" or as "Photons". For optics, light should be considered as rays travelling in straight lines between optical elements, which can reflect or refract (bend) them.

Light is only a small part of the entire spectrum of electromagnetic radiation. The fundamental nature of all electromagnetic radiation is the same: it can be viewed as photons or waves travelling at the speed of light (300,000 km/s) or 180,000 miles/sec).

8.1 REFRACTIVE INDEX (N)

The most important optical measurement for any transparent material is its refractive index (n). The refractive index is the ratio of the speed of light (c) in a vacuum to the speed of light in the medium:

The speed of light in a material is always slower than in a vacuum, so the refractive index is always greater than one in the optical part of the spectrum. Although light travels in straight lines through optical materials, something different happens at the surface. Light is bent as it passes through a surface where the refractive index changes. The amount of bending depends on the refractive indexes of the two materials and the angle at which the light strikes the surface between them.

The angle of incidence and refraction are measured not from the plane of the surfaces but from a line perpendicular to the surfaces. The relationship is known as "Snells Law", which is written; $n_i \sin I = n_r \sin R$, where n_i and n_r are the refractive indexes of the initial medium and the medium into which the light is refracted. I and R are the angles of incidence and refraction.

Figure 1 shows an example of light going from air into glass.

Snell's Law on Refraction (Air into Glass)
Figure 1

Snell's law indicates that refraction can't take place when the angle of incidence is too large. If the angle of incidence exceeds a critical angle, where the sine of the angle of refraction would equal one, light cannot get out of the medium. Instead the light undergoes total internal reflection and bounces back into the medium.

Figure 2 illustrates the law that the angle of incidence equals the angle of reflection. It is this phenomenon of total internal reflection that keeps light confined within a fibre optic.

Critical Angle
Figure 2

8.2 LIGHT GUIDING

The two key elements of an optical fibre are its “Core” and “Cladding”. The core is the inner part of the fibre, through which light is guided. The cladding surrounds it completely. The refractive index of the core is higher than that of the cladding, so light in the core that strikes the boundary with cladding at a glancing angle is confined in the core by total internal reflection. Figure 3 shows the make up of a fibre optic.

Fibre Optic (Core and Cladding)
Figure 3

8.3 LIGHT COUPLING

Another way to look at light guiding in a fibre is to measure the fibre's acceptance angle. This angle is the angle within which the light should enter the fibre optic to ensure it is guided through it. The acceptance angle is normally measured as a numerical aperture (NA).

The numerical aperture and acceptance angle measurements are a critical concern in practical fibre optics. Getting light into a fibre is known as "Coupling".

When fibre optics were first developed in the 1950s, no one believed that much light could be coupled into a single fibre. Instead they grouped fibres into bundles to collect a reasonable amount of light. Only when "LASERS" made highly directional beams possible did researchers seriously begin to consider using single optical fibres.

Figure 4 shows light coupling into a fibre optic and the construction of a fibre optic cable.

Light Coupling (Critical Angle)
Figure 4

8.4 ALIGNMENT

Coupling light between fibres requires careful alignment and tight tolerances. The highest efficiency comes when the ends of the two fibres are permanently joined. Temporary junctions between two fibre ends, made by connectors, have a slightly higher loss but allow much greater flexibility in reconfiguring a fibre optic network.

Figure 5 shows the problems associated with incorrect alignment.

Fibre Optic Alignment
Figure 5

8.5 FIBRE OPTIC CONNECTORS

Boeing uses three types of connectors: Type A Connector, Type B Connector and Type C Connector.

8.5.1 TYPE "A" CONNECTOR

The type "A" connector has these technical qualities:

- A threaded coupling mechanism.
- A butt type connector with ceramic terminuses.
- The transmission of a light beam from the end of one optical fibre into the end of another optical fibre.

Figure 6 shows example of "A" type receptacle and plug connectors.

Type "A" Connector
Figure 6

8.5.2 TYPE "B" CONNECTOR

The type "B" connector has these technical qualities:

- A threaded coupling mechanism.
- An extended beam connector that contains a miniature lens behind a protective window.
- The transmission of a light beam by the miniature lens from an optical fibre through the protective window to the opposite miniature lens into the opposite fibre optic.

Figure 7 shows example of a "B" type receptacle and plug connectors.

Type "B" Connector
Figure 7

8.5.3 TYPE "C" CONNECTOR

The type "C" connector has these technical qualities:

- A push-pull coupling mechanism.
- An extended beam connector that contains a miniature lens behind a protective window.
- The transmission of a light beam by the miniature lens from an optical fibre through the protective window to the opposite miniature lens into the opposite fibre optic.

Figure 8 shows example of a "C" type receptacle connector.

Type "C" Connector
Figure 8

Figure 9 shows how the light is transferred in the type B and C connectors using miniature lenses and protective window.

Fibre Optic Connection
Figure 9

Coupling losses can cause substantial attenuation. Dead space at the emitter/fibre and fibre/receiver junctions and (unless optically corrected) the beam spreads of 7° associated with semi-conducting lasers, are the usual sources of launching problems. To limit this light loss a ball lens is used. These lenses (within the connector) focus the light into another fibre optic cable or an optical receiver.

Mono-made fibres are particularly prone to launching losses because it is difficult to produce an accurate square end. Jointing and cabling, in order to produce longer lengths, are currently receiving development attention.

Figure 10 shows example of type “A”, “B” and “C” connectors and identification labels.

BOEING TYPE “A” PLUG CONNECTOR

BOEING TYPE “B” PLUG CONNECTOR

BOEING TYPE “C” PLUG CONNECTOR

Fibre Optic Connectors
Figure 10

8.6 FIBRE OPTIC SPLICER

The most common type of splice is the fusion splice, formed by welding the ends of two optical fibres together. This method requires a special instrument called a 'fusion splicer', which includes a binocular microscope, for viewing the junction and mounting stages, and a precision micrometer to handle the fibres.

8.6.1 ELASTOMERIC SPLICE

This is one of the simplest types of splice and relies on the alignment of the fibre ends in a V-shape groove, as shown in figure 11.

V-Groove Splice
Figure 11

The fibres are confined between two flexible plastic plates, each containing a groove into which the fibre fits. This centres the fibre cores regardless of variations in the outer diameter of the fibre. An indexed-matched fluid, or epoxy, is first inserted into the hole through the splice. One fibre end is inserted until it reaches about halfway through the splice, then the second fibre end is inserted from the other end until it can be felt pushing against the first.

Both fibre ends must be properly finished to avoid excessive losses through reflection or the presence of contaminants.

8.7 ADVANTAGES OF FIBRE OPTICS

Fibre-optic communications systems have a large bandwidth, e.g. 1 GHz. The bandwidth is the maximum rate at which information can be transmitted. It has the benefit of:

- Immunity to electromagnetic interference in electrically noisy situations.
- High security against 'tapping'.
- Much greater flexibility than the majority of waveguides.
- Low weight when compared with copper - 60 per cent less.
- Ability to resist vibration.
- Glass fibres have no fire risk.
- Inability to form unwanted earth loops.
- Inability to short-circuit adjacent filaments when fractured.
- High data capacity (>10Gbits/s with a single fibre).

8.8 DISADVANTAGES OF FIBRE OPTICS

- Difficult to join.
- No transfer of D.C. Power.

8.9 EQUIPMENT IN A FIBRE OPTIC SYSTEM

1. An encoder: a light emitter: an IR-light-emitting diode or a shorter lived, narrower beamed, faster responding semiconducting laser.
2. Optical fibers with 0.02 to 0.10-mm diameter fibres assembled into bundles and further assembled into cables with a possible polystyrene-strengthening member. These multi-mode fibres will probably supersede the single-mode fibres which have both handling and preparation difficulties.
3. A receiver: a pin or avalanche photodiode.
4. A decoder.

The words encoder and decoder are general terms used to describe the pieces of equipment which are the first and last stages in the conversion of the audio-visual input to, and from, the infra-red light which actually travels through the optical fibres.

Figure 12 shows the layout and basic components needed in fibre optic communications.

Fibre Optic Communication
Figure 12

How the fibre may be incorporated in a single circuit is shown in Figure 13.

Fibre Optic Circuit
Figure 13

8.10 SAFETY

When working on Fibre Optic connected equipment, care is required when handling cables. If the equipment is energised, invisible light form the fibre optic cable can be sufficient to cause damage to the eyes.

Before the face of the connector is examined either one of these conditions must be satisfied:

- The connectors are disconnected from equipment at both ends of the cable.
- The power to the equipment is set to “OFF”.

8.11 BASIC OPERATION

1. The input is converted by the encoder to electrical signals, which represent either the sound waves of the voice, or the scanning of visible media.

2. The emitter sends out probes of infra-red light corresponding to the electrical values, in strength and duration.

3. The infra-red light is launched into the fibres, which conduct it to the receiver.

4. The receiver re-converts the light to electrical values.

Figure 14 shows fibre optic connection.

Fibre Optic Connection
Figure 5.10.14

8.12 SYSTEM CONFIGURATION (TOPOLOGY)

The ring and linear bus network topologies are shown at Figure 15. The ring consists of point-to-point links connecting the terminals into a ring. Each stage needs signal re-generation and so this reduces overall reliability. Failure in one stage would cause overall failure of this series system. As fibre optic technology has developed, the linear bus network has proved most favourable. Interconnections are made by 'star' couplers.

RING

LINEAR BUS NETWORK

System Configuration
Figure 15

Figure 16 shows an example of splitters and couplers used in fibre optic systems.

Fibre Optic Coupler/Splitter configuration
Figure 16

8.13 AIRCRAFT APPLICATIONS

8.13.1 OPTICAL DATA BUS

Data transmission systems generally utilise a twisted cable pair as a bus. This has its limitations and fibre optics is under active development as the next step for use in aircraft digital systems.

8.13.2 STANAG 3910 DATA BUS SYSTEM

This is the European standard data bus with a 20 Mbit/sec data rate and will enter service with the new Eurofighter 2000. This advanced data bus system provides an evolutionary increase in capability by using MIL STD 1553B as the controlling protocol for high speed (20Mbit/sec), message transfer over a fibre optic network. Figure 17 shows the architecture of the STANAG 3910 data bus system.

STANAG 3910 Data Bus System
Figure 17

The optical star coupler allows light signals from each fibre stub to be coupled into the other fibre stubs and then to the other sub-systems. The data bus also has the normal operation of the MIL STD 1553B data bus.

The USA is developing its own version of a fibre optic data bus system. This is a High Speed Data Bus (HSDB), and uses Linear Token Passing as its controlling protocol. It operates at 50 Mbits/sec and operates to connect up to 128 sub-systems. Figure 18 shows the architecture of the Linear Token Passing High Speed Data Bus (LTPHSDB).

Linear Token Passing High Speed Data Bus
Figure 18

8.13.3 Fly-By-Light Flight Control System

Extensive tests have been carried out using the Fly-by-Light technology. It has huge advantages over the current Fly-by-Wire systems. Fibre optic cabling is unaffected by EMI and has a considerably faster data transfer rate (20 Mbit/sec to 100 Mbit/sec). The systems are also lighter than conventional screened cabled systems, since fibre optic cable is lighter than conventional cable and offers great weight saving. Figure 19 shows the configuration of a fly-by-light system

Fly-By-Light System
Figure 19

8.13.4 OPERATION

Fibre optic cable interconnects the units of the flight control system and eliminates the possibility of propagating electrical faults between units. They are bi-directional and can be used to convey the system status to the flight crews' control and display panel.

A further advantage of fibre optic data transmission is the ability to use "Wavelength Division Multiplexing" (WDM) whereby a single fibre can be used to transmit several channels of information as coded light pulses of different wavelengths (or colours) simultaneously. The individual data channels are then recovered from the optically mixed data by passing the light signal through wavelength selective optical filters, which are tuned to the respective wavelengths. The WDM has a very high integrity, as the multiplexed channels are effectively optically isolated.

9 ELECTRONIC DISPLAYS

9.1 GENERAL

With the introduction of digital signal-processing technology, it has become possible for drastic changes to both quantitative and qualitative data display methods. This technology has enabled the simplification of many flight deck-instrument layouts, allowing the replacement of complex analogue instruments with state of the art digital instrumentation. This "Glass Cockpit" concept has allowed many instruments to be replaced by one TV type display that can display a large and varied range of information as required.

There are three different methods for displaying digital data, these are:

1. Light-Emitting Diodes (LED).
2. Liquid Crystal Display (LCD).
3. Cathode Ray Tube (CRT).

9.2 DISPLAY CONFIGURATIONS

Displays of LED and LCD types are usually limited to the application in which a single register of alphanumeric values is required, and are based on the seven segment or the dot matrix configuration. CRT type displays have a wider use and can display navigation, engine performance and system status information. Table 1 shows the different applications for electronic displays.

Display Type	Application
Light-Emitting Diode	Digital counter displays of engine performance.
Liquid Crystal Display	Monitoring indicators; Radio frequency selector indicators; Distance Measuring indicators; Control display units of Inertial Navigation Systems, etc.
Cathode Ray Tube	Weather radar indicators; display of navigational data; engine performance data; system status;

Electronic Display Applications
Table1

Figure 1 shows a typical flight-deck instrument panel and the different types of display used.

BAe 146 Electronic Instrument Layout
Figure 1

9.2.1 SEGMENT DISPLAYS

Seven-segment configuration will allow the display of decimal numbers 0-9; it also has the capability to display certain alphabetic characters. To display all alphabetic characters requires an increase in the number of segments from seven to thirteen, and in some cases sixteen segments.

Figure 2 shows both seven and thirteen segment display configurations.

SEVEN-SEGMENT CONFIGURATION

THIRTEEN-SEGMENT CONFIGURATION

Seven and Thirteen Segment Display Formats
Figure 2

In the dot matrix display the patterns generated for each individual character is made up of a specific number of illuminated dots arranged in columns and rows. Figure 3 shows the arrangement for a 4 X 7 configuration (4 columns and 7 rows).

Dot Matrix Configuration
Figure 3

9.3 LIGHT-EMITTING DIODE (LEDS)

One of the most common light sources used in electronics is the “Light Emitting Diode” (LED). A LED is a two terminal semiconductor device comprising a p-n junction, which conducts in one direction only. This semiconductor material emits light when the p-n junction is forward biased and a current is flowing through it. LEDs can be manufactured to emit visible or invisible (infra-red) light.

Visible LEDs are often used as indicators in electronic equipment either singly, for indicating ‘power on’ for instance, or in arrays for alpha/numeric displays.

LEDs are reliable and have a very long life if treated carefully. Light emission in different colours of the spectrum can, when required, be obtained by varying the proportions of the elements comprising the chip, and also by a technique of "doping" with other elements, i.e. nitrogen. Current consumption (typically about 5 – 20 mA) generally limits the usefulness of a LED to equipment that is not battery powered.

9.3.1 OPERATION

The phenomenon which results in the emission of light from a LED is called “Electroluminescence”, or “Injection Luminescence”, and is due to the hole/electron recombinations that take place near a forward biased p-n junction.

When electrons are injected into the n region of a p-n diode and are swept through the region near the junction, they recombine with holes in the region. This generates electromagnetic waves of a frequency determined by the difference in the energy levels of the electron and the hole. In order for this recombination to result in luminescence, there must be a net change in the energy levels, and the proton generated must not be recaptured in the material. Figure 4 shows the operation of a LED.

LED Operation
Figure 4

Figure 5 shows the construction of a LED.

Light-Emitting Diode (LED)
Figure 5

In a typical seven-segment display format it is usual to employ one LED per segment and mount it within a reflective cavity with a plastic overlay and a diffuser plate. The segments are formed as a sealed integrated circuit pack. The connecting pins of the LEDs are soldered to an associated printed circuit board. Depending on the application and the number of digits comprising the appropriate quantitative display, they will use either independent digit packs, or combined multiple digit packs may be used.

Figure 6 shows an LED single digit pack construction.

LED Digit Pack
Figure 6

LEDs can also be used in a dot-matrix configuration. Each dot making up the decimal numbers is an individual LED and can be arranged either in a 4 X 7 or 5

X 9 configuration. Figure 7 shows an Engine Speed Indicator, the dial portion of the indicator is an analogue type, however it uses an LED dot-matrix configuration for the digital readout of engine speed.

Engine Speed Indicator
Figure 7

The digital counter is of unique design in that its signal drive circuit causes an apparent "rolling" effect of the digits which simulates the action of a mechanical drum-type counter as it responds to the changes in engine speed.

Figure 8 shows a Power Plant Instrument Group from a Boeing 737-400, which has both LED and dot matrix, displays.

Boeing 737-400 Power Plant Instrument Group
Figure 8

9.4 LIQUID CRYSTAL DISPLAY (LCD)

Liquid Crystal Displays (LCD) are not actually light sources - they generate no light, merely filtering incident light, in a controlled manner. The LCDs seen in watches, clocks and calculators etc, all work by the same principle.

Two transparent but conductive plates sandwich a layer of liquid crystals, which normally all face in the same direction. See Figure 9. Incident light passes through the liquid crystals of polarised particles fairly easily, and is reflected back through the crystals so that an observer sees a light coloured area.

However, a voltage applied across the plates causes the liquid crystals to change direction in an attempt to repolarise themselves with the applied voltage. As they turn, they interact with the current flowing between the plates and a state of turbulence is created. The moving particles scatter the incident light, randomly reflecting and refracting it. Little light is reflected back to the observer, so the area between the transparent plates appears dark.

Selection of the areas, which are turned dark by using a number of plates and different shaped plates, means that practically any shape of character may be displayed.

Figure 9 shows the operation of a LCD.

LED Operation
Figure 9

Figure 10 shows the structure of a seven-segment LCD.

Seven-Segment LCD
Figure 10

The space between the plates is filled with a liquid crystal compound, and the complete assembly is hermetically sealed with a special thermoplastic material to prevent contamination.

When a low-voltage, low-current signal is applied to the segments, the polarisation of the compound is changed together with a change in its optical appearance from transparent to reflective. The magnitude of the optical change is basically a measure of the light reflected from, or transmitted through, the segment area to the light reflected from the background area. Thus, unlike a LED, it does not emit light, but merely acts on light passing through it. Depending on the polarisation film orientation, and whether the display is reflective or transmissive, the segment may appear dark on a light background (such as in digital watches and pocket calculators) or light on a dark background.

Figure 11 shows a BCD to seven-segment decoder.

BCD – Seven-Segment decoder
Figure 11

9.5 CATHODE RAY TUBE (CRT)

Displays of this type, which are based on the electron beam scanning technique, have been used in aircraft for many years. They were first used to display weather radar information and have continued to be an essential part of the "Avionics Fit" in today's modern aircraft.

The CRT is a thermionic device, i.e. one in which electrons are liberated as a result of heat energy. It consists of an evacuated glass envelope inside which are positioned an "Electron Gun", "Beam-Focusing" and "Beam-Deflection" system. The inside surface of the screen is coated with a crystalline solid material known as a phosphor.

Figure 12 shows a cross-section of a CRT.

Cathode Ray Tube CRT Cross-Section
Figure 12

9.5.1 ELECTRON GUN

The electron gun consists of the following:

1. Cathode: An indirectly heated cathode (negatively biased w.r.t. the screen).

2. Grid: A cylindrical grid surrounding the cathode.

3. Anode: Two (sometimes three) anodes.

The cathode is a tube of metal closed at one end, with a coating of material that will emit electrons when heated, covering the closed end. To operate the cathode needs to be heated; this is achieved using a coil of insulated wire connected to the cathode.

Because the screen of the CRT contains conducting material at a high voltage (5 - 15kV), electrons will be attracted away from the cathode.

The free electrons have to pass through a pinhole in a metal plate (Control Grid). Altering the voltage of the grid can control the movement of the electrons through this hole. The voltage of the grid is always negative w.r.t. Cathode.

The free electrons are then formed into a beam by the action of the first anode. The anode is of a cylindrical shape and by adjusting the voltage on the anode, the beam can be made to come to a small point at the screen end of the CRT. The screen end of the CRT is coated with a material called a “Phosphor”, which will glow when struck by electrons. The phosphor is usually coated with a thin film of aluminum so that it can be connected to the final accelerating (anode) voltage. The whole tube is formed as a vacuum.

Figure 13 shows the typical voltages used in a small CRT.

CRT Voltages
Figure 13

This arrangement will produce a point of light at the centre of the screen, but to make the CRT useful for displaying data, this beam of electrons must be able to be moved around the screen. For this, two sets of metal plates are used and if a voltage is passed through them, then the beam will deflect on the screen. These plates are called “Deflection Plates”. These plates are arranged at right angles to each other. The beam can be deflected if a voltage is applied to these plates; this is called “Electrostatic” deflection. Movement of the beam left/right is controlled by the “X” Plates, with the “Y” Plates controlling movement up/down.

Figure 14 shows the arrangement for the deflection plates.

X and Y Deflection Plates
Figure 14

The other method used for deflection is Electromagnetic. This method is used for TV, computer monitors and most aircraft CRT displays. As an electron moves, it constitutes an electric current, and so a magnetic field will exist around it in the same way as a field around a current-carrying conductor.

In the same way that a conductor will experience a deflecting force when placed in a permanent magnetic field, so an electron beam can be forced to move when subjected to electromagnetic fields acting across the space within the tube. Coils are therefore provided around the neck of the tube, and are configured so that fields are produced horizontally (Y-axis field) and vertically (X-axis field). The coils are connected to the signal sources whose variables are to be displayed. The electron beam can be deflected to the left or right, up or down or along a resultant direction depending on the polarities produced by the coils, and on whether one alone is energised, or both are energised simultaneously.

Figure 15 shows electromagnetic coil configuration and resultant deflections.

Electromagnetic Deflection
Figure 15

The most common form of deflection for CRT is a “Linear Sweep”. This means that the beam is taken across the screen at a steady rate from one edge to the other, and is then returned very rapidly (an action called “Fly Back”). To generate such a linear sweep in electrostatic deflection, a Saw-tooth Waveform is used. . Figure 16 shows a Saw-tooth Waveform.

Saw-tooth Waveform
Figure 16

The sawtooth voltage waveform derived for the electrostatic time base is no use for electromagnetic coil deflection because a voltage sawtooth will not produce a linear rise of current through the deflection coils.

A practical deflection, or scan coil, will have resistance as well as inductance. The voltage across the resistance of a coil “R” is proportional to the current through it. A linear current ramp in a resistance can only be produced by a steadily rising voltage.

Inductor voltage is proportional to the rate of change of current and since the rate of change of current is constant, then the voltage across the inductor must also be constant. A constant applied voltage, therefore, will produce a linear current ramp in an inductor.
To provide for both resistance and inductance, the voltage applied to the scan coils to produce a linear current ramp must be a constant value for the inductance

and a voltage ramp for the resistance, giving the distinctive “Trapezoidal” shape. Figure 17 shows the scan coil graphs for electromagnetic deflection.

Scan Coil Graphs
Figure 17

9.6 COLOUR CRT DISPLAYS

Information from Weather Radar systems is required to be displayed in colour to enable the user to see a clear representation of the weather condition ahead. To do this we require the display to be drawn in colour. Weather Radar data is presented in the following colours:

1.	Level 0	-	Black	-	No storm.
2.	Level 1	-	Green	-	Moderate storm.
3.	Level 2	-	Yellow	-	Less severe storm.
4.	Level 3	-	Red	-	Severe storm.

Figure 18 shows a display of "Weather Radar" data.

Weather Radar Data
Figure 18

9.6.1 Screen Format

To display the weather data on the CRT, the screen is divided into two halves representing the two quadrants in the co-ordinate system. The origin is at the bottom centre, so that values of X are negative to the left and positive to the right. All values of Y will be positive.

The screen is scanned in 256 horizontal lines, with 256 bits of data in each line. Each line is located by the value of Y and each bit by a value of X. The screen is therefore a 256 X 256 matrix.

The data from the weather radar system is converted into digital form and is supplied to the display on two data lines. This data represents the weather levels; 1, 2, 3 or 4, at the relative range. This data is stored in memories within the display and is updated with each scan of the radar system.

The X and Y values are used to address the memory and display the information stored there at the appropriate time i.e. as the scan occurs. Each part of the memory contains one address for every bit on every line in the display. Each memory, therefore is also a 256 X 256 matrix. This will allow the entire weather display to be stored continuously.

As the screen is scanned, the memory is addressed at each point on each line by two counters: a horizontal or X counter for addressing the rows in the memory, and a vertical or Y counter for addressing the columns. The X counter starts on the left at number 126, counting down to 0 then up to 126 (X scanning is negative/positive depending on which side of the screen the data is to be displayed). The Y counter counts from 0 – 255.

Figure 19 shows a weather display screen format.

CRT Screen Format
Figure 19

9.7 COLOUR GENERATION

A colour CRT has three electron guns, each of which can direct an electron beam at the screen. The screen is coated with three different kinds of phosphor material. On being bombarded by electron beams, the phosphors luminesce in each of the three primary colours: Red, Green and Blue.

The screen is divided into a large number of small areas or dots, each of which contains a phosphor of each kind. Figures 20 and 21 show a colour CRT.

Colour CRT
Figure 20

Colour CRT
Figure 21

Beams emitted from each gun pass through the perforations of the mask, which causes the phosphor dots in the coating to luminesce in the appropriate colour. If a beam is only emitted by the red electron gun only, then only the red dots will luminesce, and if the beam completes a full raster scan of the screen, then a completely red screen will be seen. To achieve a colour display, the three guns are used to mix the three primary colours to give the required colour.

9.7.1 Mixing Colours

Most colours of light can be made by mixing together the primary colours of: Red, Blue and Green. When these colours are added together in different proportions, they create other colours. Example:

1.	Red and Green	=	Yellow.	Secondary Colours
2.	Red and Blue	=	Magenta (Pink),	
3.	Green and Blue	=	Cyan (light blue).	

Note: Red, Blue and Green added together make White light.

9.8 STROKE SCANNING

In addition to the raster display, which produces solid colour blocks, there will also be a requirment to display symbols and alphanumeric characters. This is achieved by using a “Stroke” scanning method.

The display of data in alphanumeric and symbol form is extremely wide-ranging. Example; Weather radar display not only has to display the weather returns (raster) but also the selected mode, range circles and range data. Figure 22 shows the Weather Radar display with additional alphanumeric data overlaid on the weather picture.

Weather Radar Display
Figure 22

In other display configurations there is the requirement for considerable information to be drawn using the stroke scanning method as well as the raster scanning method. Figure 23 shows an Electronic Attitude Director Indicator (EADI), which uses both “Raster” scanning (for the Attitude Sphere) and “Stroke” scanning for the remainder of the display.

EADI Display
Figure 23

The position on the display screen of the alphanumeric or symbol is pre-determined and stored in the memory matrix (typically using 5 X 7 matrix). When the matrix is addressed, the character is formed within the corresponding matrix of dots on the screen by video signal pulses produced as the lines are scanned.

Figure 24 shows the make up of letters using the 5 X 7-matrix configuration.

Alphanumeric Display
Figure 24

Spacing is necessary between individual characters and also between the rows of characters. To achieve this, an extra line called “Blanking Bits” is used. It can be seen from figure 24, that the width of the character uses 5 of the 8 bits allocated, 3 bits representing the blanking bits creating a space between each character on the line. The height of each character is 7 bits with a 3 bits representing the blanking bits, which will create line spacing between the characters.

9.9 DISPLAY SYSTEMS

The CRT display units of the more comprehensive electronic instrument systems operate on the same fundamental principles as those describe in this module. However, to apply these principles, more extensive micro-processing circuit arrangements are required in order to display far greater amounts of changing data in both quantitative and qualitative form.

The microprocessor processes information from the “Data Highway” bus and, from the memory circuits, it is instructed to call up sub-programs. Each of these programs corresponds to the individual sets of data required to be displayed. Signals are then generated in the relevant binary format, and are supplied to a “Symbol Generator” unit.

The Symbol Generator will then generate the relevant supplies to be applied to the beam deflection and colour gun circuits in order to draw the correct display. The beam will be scanned both in the raster and stroke formats. The displayed data is in two basic forms:

1. Fixed data.
2. Moving data.

Table 2 shows the types of fixed and moving data required for displayed data

FIXED DATA	MOVING DATA
SYMBOLS	SYMBOLIC POINTERS
SCALE MARKINGS	INDEX MARKS
SYSTEM NAMES	DIGITAL COUNTERS
DATUM MARKS	SYSTEM STATUS MESSAGES

Displayed data
Table 2

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10 ELECTROSTATIC SENSITIVE DEVICES

Static electricity is generated and stored on the surface of non-conductive materials and discharges to the first available ground source. Items such as human hands, air, and glass store high positive charges, whereas plastics store large charges of negative electricity.

Table 1 lists typical measured static charges for the human body.

SITUATION	Relative Humidity of Air	
	Low 10-20%	High 65-90%
	Volts	Volts
Walking across a carpet	35,000	1,500
Walking over vinyl floor covering	12,000	250
Worker at bench	6,000	100
Vinyl envelopes containing work instructions	7,000	600
Polythene bag picked up from bench	20,000	1,200
Work chair padded with urethane foam	18,000	1,500

Static Charges
Table 1

10.1 HANDLING OF MICROELECTRONIC DEVICES

The voltage and current requirements for microelectronic devices are of a very low magnitude. It is therefore necessary to observe strict precautions to avoid damage or destruction when carrying out functional testing and fault diagnosis. There are some devices whose circuits can, by the very nature of their construction, be damaged or destroyed by “Static Electricity” discharges resulting simply from the manner in which they are handled.

These device are referred to as “Electrostatic-Sensitive Devices” (ESD). The type of devices that are most susceptible to damage by static electricity are listed in Table 2

Device	Electrostatic discharge range where damage can occur (V)
Field effect transistors (MOSFET)	100 – 200
Complementary metal oxide silicon (CMOS)	250 – 2000
Schottky diodes (TTL)	300 – 2500
Bipolar transistors	380 – 7000
Precision thin-film resistors	150 – 1000
Emitter coupled logic (ECL)	500
Silicon-controlled rectifiers (SCR)	680 - 1000

ESD Sensitivity Levels
Table 2

10.2 STATIC DAMAGE

If static discharge can be seen or felt, then it may be assumed that the potential difference prior to discharge can be measured in thousands of volts. As Table 2 shows, this is more than enough to cause damage to an electronic circuit. Therefore, electrostatic discharge damage can occur even though the discharge is of insufficient strength to be felt or seen. The low energy source that most commonly destroys ESDs is the human body which, in conjunction with nonconductive garments and floor coverings, generates and retains static electricity.

10.3 PRECAUTIONS

In order to adequately protect electrostatic sensitive devices, the device and everything that it comes into contact with must be brought to ground potential by providing conducting surfaces and discharge paths.

In avionic workshops, equipment-containing ESDs is serviced at an electrostatic-free workstation. In general, the workstation consists of a conductive work surface which, together with the operator and tools in use, is bonded electrically to a common ground. The floor area in front of the workstation is also covered with conductive material and bonded to the work surface.

The operator wears a wrist strap, which is electrically bonded to the work surface through a resistance (1 –2 MΩ). Under no circumstances should the operator, or anyone else, touch the ESDs, or assemblies containing such devices, without first placing a wrist strap in direct contact with their wrist.

10.4 Storage And Transportation

Wherever there are ESDs, there will also be the problem of protecting them during transportation and storage, and so specialised packaging is essential for individual devices, PCB modules and the complete LRU. The packaging for devices and PCB modules takes the form of “Bags”. These bags are made from a material which is “Quasi-conductive” (a material whose surface or volume resistivities are too high to be conductive, but conductive enough to “bleed off” charges in no more than a few milliseconds).

Other protective measures involve shorting the connecting leads or pins of devices by means of wire, spring clips, metal foil or by inserting the leads or pins into a conductive foam material. For PCB modules having edge connectors, specially formed strips called “Shunts” are placed over the connectors to keep them all at the same potential and also protect them against physical damage.

10.5 On Aircraft Precautions

When replacing Line Replacement Units (LRUs), containing ESDs on aircraft, the following safety precautions must be observed.

a). All electrical power from the system should be removed by pulling the system circuit breaker(s).

b). If the power is not removed during LRU removal or installation, transient voltages may cause permanent damage.

c). After the removal of an LRU from its rack, a conductive shorting dust cap must be installed on each of its electrical connectors. Under no circumstances must the electrical pins in the connectors be touched by hand.

d). The conductive dust caps from the unit to be installed can be use on the unit being removed.

e). The removed unit is then transported with the conductive dust caps fitted.

Aircraft are often fitted with racks containing removable circuit boards, or cards, which often contain ESDs.

During the removal and replacement of the cards, the following procedure is to be followed:

a). The body of the operator must be grounded by using the wrist strap provided, connected to the appropriate ground jack.

b). The card is removed using the top and bottom, or left and right, extractors on the card. Touching the connectors, leads or edge connectors of the card must be avoided.

c). The removed card is placed in the conductive bag, which is then secured, in accordance with the manufacturer's approved procedure.
Note: Should the bag need to be secured with a tie, cotton twine should be used, since this is 'neutral' as far as static electricity is concerned.

d). The replacement card is then removed from its conductive bag and installed following the precautions listed above.

10.6 LABELLING

An obviously important requirement is the identification of the packaging containing ESDs and of any assembly, be it a PCB of an LRU, which contains ESDs. For this purpose there are special decals. These are affixed to packaging and assemblies.

In the case where the connector pins of an LRU may be susceptible to a discharge, an additional decal is often affixed near the connector as a warning to personnel not to touch the connector pins.

Figure 1 shows the type of ESD symbols and labels in use today.

COMMERCIAL

GOVERNMENT

INTERNATIONAL (BOEING)

ESD Labels
Figure 1

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11 SOFTWARE MANAGEMENT CONTROL

In the normal maintaining of aircraft, an assessment of system and function criticality is made. With the increasing role of computers in today's aircraft, responsible Design Organisations assign, to each software-based system or equipment, software levels relating to the severity of the effect of possible software errors within user systems or equipments.

Table 1 shows the relationship between function criticality category and software level.

Effect on Aircraft and occupants of failure conditions or design error	FAR 25.1309 & JAR 25.1309 definitions	No significant degradation of aircraft capability or crew ability	Reduction of the aircraft capability or of the crew ability to cope with adverse operating conditions		Prevention of continued safe flight and landing of the aircraft
	ACJ No 1 Jar 25.1309 definitions	Slight reduction of safety margins, Slight increase in workload, e.g. routine changes in flight or plan or Physical effects but no injury to occupants	Significant reduction in safety margins Reduction in the ability of the flight crew such that they cannot be relied upon to perform their tasks accurately, or injury to occupants	Large reduction in safety margins Physical distress or workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely, or serious injury to or death of a relatively small proportion of the occupants	Loss of aircraft and/or fatalities
ACJ No 1 to JAR 25.1309 Definition of Criticality Category		Minor Effect	Major Effect	Hazardous Effect	Catastrophic Effect
FAA Advisory Circular 25.1409-1 definition of Criticality Category		Non-essential	Essential		Critical
DO-178A/ED-12A Software level*		Level 3	Level 2		Level 1

Table 1

* Using appropriate design and/or implementation techniques, it may be possible to use a software level lower than the functional categorisation. Refer to Section 5 of DO-178A/ED-12A, which provides further guidance.

11.1 CERTIFICATION OF SOFTWARE

For initial certification of a software-based system or equipment, the responsible Design Organisation provides evidence to the CAA that the software has been designed, tested and integrated with the hardware in a manner which ensures compliance with the relevant requirements of BCAR.

The primary document for use by certifying authorities is the Software Accomplishment Summary. Its content is listed below to demonstrate the stringency of software control both during certification and continued use when it may be subject to further development and modification. The following is taken from AWN 45A. Related document references have been left in but not clarified.

11.2 CONTENT OF SOFTWARE ACCOMPLISHMENT SUMMARY

As a minimum, information relevant to the particular software version should be included in the summary under the following headings: -

(a) i) **System and Equipment Description** This section should briefly describe the equipment functions and hardware including safety features, which rely on hardware devices or system architecture.

ii) **Organisation of Software** This section should identify the particular software version and briefly describe the software functions and architecture with particular emphasis on the safety and partitioning concepts used.

The size of the final software design should be stated, e.g. in terms of memory bytes, number of modules. The language(s) used should also be stated.

(b) **Criticality Categories and Software Levels** This section should state the software levels applicable to the various parts of the software. The rationale for their choice should be stated, either directly, or by reference to other documents.

(c) **Design Disciplines** This section should briefly describe the design procedures and associated disciplines, which were applied to ensure the quality of the software. The Organisations which were involved in the production and testing (including flight-testing) of the software should be identified and their responsibilities stated.

(d) **Development Phases** The development phases of the project should be summarised. This information could be included in sub-paragraph (h) below.

(e) **Software Verification Plan** This section should briefly summarise the plan (Document No. 11 as defined in DO-178A/ED-12A) and the test results.

(f) **Configuration Management** The principles adopted for software identification, modification, storage and release should be briefly summarised.

(g) **Quality Assurance** The procedures relating to quality assurance of the software should be summarised including, where applicable, those procedures which applied to liaison between the equipment manufacturer and the aircraft, engine or propeller constructor, as appropriate.

(h) **Certification Plan** This section should provide a schedule detailing major milestones achieved and their relationship to the various software releases.

(j) **Organisation and Identification of Documents** This section should identify the documents, which satisfy, paragraph 8.1 of DO-178A/ED-12A.

(k) **Software Status** Any known errors, temporary patches, functional limitations or similar shortcomings associated with the delivered software should be declared and the proposed timescale for corrective action stated.

11.3 MODIFICATION OF SOFTWARE

In respect of systems and equipment with Level 1 or Level 2 software, a modification, which affects software, shall not be embodied unless it has been approved by the responsible Design Organisation.

Modifications to software will be subject to the same approval procedures as are applied to hardware modifications. Modified software will need to be identified and controlled in accordance with the procedures stated in the software configuration management plan.

The CAA will require the design and investigation of modifications, including those proposed by the aircraft operator, to involve the support service provided by the responsible Design Organisation. The re-certification effort will need to be related to the software levels.

Aircraft operators will need to ensure that their defect reporting procedures will report software problems to the responsible Design Organisation.

12 ELECTROMAGNETIC ENVIRONMENT

With the development of electronics and digital systems in aviation, aircraft are becoming increasingly susceptible to High Intensity Radio Frequencies (HIRF). Design philosophies in the area of aircraft bonding for protection against HIRF employ methods which may not have been encountered previously by maintenance personnel. Because of this, HIRF protection can be unintentionally compromised during normal maintenance, repair and modification. It is therefore critical that procedures contained in assembly and repair manuals contain reliable procedures to detect any incorrect installation, which could degrade the HIRF protection features.

12.1 PROTECTION AGAINST HIRF

There are three primary areas to be considered for aircraft operating in HIRF environments.

- Aircraft Structure - (aircraft skin and frame).
- Electrical Wiring Installation Protection - (Solid or braided shielding/connectors).
- Equipment Protection - (LRU case, electronics input/output protection).

Table 1 gives some indication as to the maintenance tasks which may be applied to certain types of electro magnetic protection features:

PROTECTION TYPE	CABLE SHIELDING	AIRCRAFT STRUCTURE SHIELDING					CIRCUIT PROTECTION DEVICES
Description	Over braid shield, critical individual cable shield	Raceway, conduits	RF gaskets	Shield for non conductive surfaces	Structural bonding		HIRF protection devices
Examples	Metallic conduit, braid	Raceway, conduits	Removable panels	Conductive coating	Contact bonds, rivet joints	Bonding lead and straps, pigtails	Resistors, Zener diodes, EMI filters, filter pins.
Degradation or Failure Mode	Corrosion, damage	Corrosion, damage	Corrosion, damage, deformation	Damage, erosion	Corrosion, damage	Corrosion, damage, security of attachment	Short circuit, open circuit
Maintenance Operations	Visual inspection, measurement of cable shielding bonding	Visual inspection, bonding measurement	Visual inspection of gaskets, bonding leads and straps	Visual inspection, measurement of shielding effectiveness	Visual inspection, bonding measurement	Visual inspection for corrosion attachment and condition, bonding measurement	Check at test/repair facility in accordance with maintenance or surveillance plan.

Applicable Maintenance Tasks for HIRF Protection Measures
Table 1

Note: “Raceway conduits” refers to separate conduits used to route individual cables to the various areas of an aircraft system.

“RF gaskets” are gaskets having conductive properties to maintain the bonding integrity of a system.

12.2 TESTING TECHNIQUES

Tests of HIRF protection carried out depend upon the criticality of the system under test. Types of test are as follows.

12.3 VISUAL INSPECTION

The protection feature should be inspected for damage and corrosion. Degradation may be found in this way but where integrity cannot be assured, other tests may be carried out.

12.4 DC RESISTANCE

The milliohm meter is often used to measure the ground path resistance of ground straps or bonding. This technique is limited to the indication of only single path resistance values.

12.5 LOW FREQUENCY LOOP IMPEDANCE

Low frequency loop impedance testing is a useful method complementary to DC bonding testing. A visual inspection of cable bundle shields, complemented by a low frequency loop impedance test, gives good confidence in the integrity of the shielding provisions.

Low frequency loop impedance testing is a method developed to check that adequate bonding exists between over braid (conduit) shields and structure. To achieve the shielding performance required, it is often necessary that both ends of a cable bundle shield be bonded to aircraft structure. In such cases, it is hard to check bonding integrity by the standard DC bonding test method. If the bond between shield and structure at one end is degraded while the other one is still good, there is little chance to find this defect by performing DC bonding measurements. The remaining bond still ensures a low resistance to ground but the current loop through the shield is interrupted, causing degradation of shielding performance. The fault can easily be detected by performing a low frequency loop impedance test.

The test set-up requires simple test equipment, refer to Figure 1. A current of about 1 kHz is fed into the conduit under test while measuring the voltage necessary to drive that current. Other versions of the loop impedance test arrangement use different frequencies (200 Hz is typical), and provide the resistive and reactive parts of the loop impedance.

$$Z_{CONDUIT} + Z_{STRUCTURE} = V1/II$$

Loop Impedance Test
Figure 1

The test equipment consists of a generator operating at 1 kHz feeding an injection probe and a current monitoring probe, connected to an AC millivoltmeter. A voltmeter connected to the generator enables the voltage necessary to drive the current to be measured. 1 kHz is a high enough frequency to drive the injection and the monitoring probes and is also enough to avoid specific RF effects, like non-uniform current distribution along the loop under test.

If, in practice, the current is set to 1A, the voltage figure, when expressed in millivolts, gives the loop impedance in milliohms directly. The loop impedance is normally in the range 1-100 milliohms. In this range, accurate results can easily be achieved.

If too high loop impedance is found, the joint determining the problem has to be identified. This can be performed by measuring the voltage drop across each joint. The joint with the high voltage drop across it is the defective one, refer to Figure 2.

V2 = V1 ACROSS BAD JOINT

Identification of A Bad Joint
Figure 2

As there is no need for a wide band swept RF generator, the test equipment can be quite simple and easy to handle. Hand held battery powered test equipment, especially designed for production monitoring and routine maintenance, is available on the market.

12.6 ELECTRO MAGNETIC INTERFERENCE (EMI)

EMI is a subject closely allied to HIRF. Interference can occur in systems from internal sources and external sources.

Its prevention and maintenance of measures taken is described under High Intensity Radio Frequencies.

12.7 ELECTRO MAGNETIC COMPATIBILITY (EMC)

A further allied subject is EMC. If a new avionics system is introduced into an aircraft, it must be operated at its full range of operating frequencies to ensure no interference to other systems is caused. Similarly, other systems must be operated across their full range to ensure no interference occurs to that system introduced.

Full tests to be carried out are normally stipulated by the manufacturer or design organisation.

12.8 LIGHTNING/LIGHTNING PROTECTION

Lightning protection is given by the primary and secondary conductors of an aircraft's bonding system. The system is enhanced by the methods discussed under HIRF.

12.9 DEGAUSSING

If an aircraft is struck by lightning, structural damage can occur and parts of the aircraft may remain magnetised. This magnetic force remaining is called 'Residual Magnetism', and since it could adversely effect some aircraft systems, areas affected must be de-magnetised.

The process of de-magnetising is called 'degaussing'. Effected areas are detected using a hand held compass, then an ac electromagnet is passed over these areas to disperse the residual magnetism. A discrepancy between an Aircraft's main compass and standby compass of (typically) 8° indicates that degaussing is necessary.

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13 ELECTRONIC/DIGITAL AIRCRAFT SYSTEMS

Electronic and digital processes are used in many of today's aircraft for a variety of purposes: navigation, dissemination of information, flying and controlling the aircraft. It should be borne in mind that as each manufacturer introduces such a system to the market the chances are that new names for it are added to the dictionary of terms. For instance, an Engine Indication and Crew Alerting System (EICAS) is much the same as a Multi-Function Display System (MFDS), the main difference being the manufacturer.

This module will deal with the following Electronic/Digital Systems:

1. ARINC Communication Addressing & Reporting System (ACARS).
2. Electronic Centralized Monitoring System (ECAM).
3. Electronic Flight Instrument System (EFIS).
4. Engine Indicating & Crew Alerting System (EICAS).
5. Fly By Wire (FBW).
6. Flight Management System (FMS).
7. Global Positioning Systems (GPS).
8. Inertial Reference/Navigation Systems (IRS/INS).
9. Traffic Alert & Collision Avoidance System (TCAS).
10. Ground Proximity Warning System (GPWS).
11. Flight Data Recorder System (FDRS).

13.1 ARINC COMMUNICATION, ADDRESSING & REPORTING SYSTEM

The ACARS is a digital data link for either ground-air or air-ground connections. The system reduces the flight crew's workload because it transmits routine reports automatically and simplifies other reporting.

The ACARS network is made up of three sections:

- Airborne System.
- Ground Network.
- Airline Operations Centre.

The airborne system has an ACARS Management Computer (MU) which manages the incoming and outgoing messages, and a Multi-Purpose Interactive Display Unit (MPIDU) which is used by the flight crew to interface with the ACARS system. A printer can also be installed to allow incoming messages to be printed for future reference.

ACARS operates using the VHF 3 communications system on a frequency of 131.55 MHz. Since ACARS only operates on one frequency, all transmitted messages must be as short as possible. To achieve a short message, a special code block using a maximum of 220 characters is transmitted in a digital format. If longer messages are required, more than one block will be transmitted. Each ACARS message takes approximately 1 second of airtime to be sent. Sending and receiving data over the ACARS network reduces the number of voice contacts required on any one flight, thereby reducing communication workload.

ACARS operates in two modes:

- Demand Mode.
- Polled Mode.

13.1.1 Demand Mode

The demand mode allows the flight crew of airborne equipment to initiate communications. To transmit a message, the MU determines if the ACARS channel is free from other communications from other ACARS, if it is clear, the message is sent. If the ACARS VHF channel is busy, then the MU waits until the frequency is available. The ground station sends a reply to the message transmitted from the aircraft. If an error reply or no reply is received, the MU continues to transmit the message at the next opportunity. After six attempts (and failures), the airborne equipment notifies the flight crew.

13.1.2 Polled Mode

In the polled mode, the ACARS only operates when interrogated by the ground facility. The ground facility routinely uplinks “questions” to the aircraft equipment and when a channel is free the MU responds with a transmitted message. The MU organises and formats flight data prior to transmission and upon request, the flight information is transmitted to the ground facility.

The ground station receives and relays messages or reports to the ARINC ACARS Control Centre. The control centre sorts the messages and sends them to the operator's control centre (several airlines participate in the ACARS network).

The ACARS also reduces the congestion of the VHF communication channels because transmissions of ACARS take fractions of a second while the same report/message in aural form may have taken in excess of ten seconds.

ACARS may be connected to other airplane systems such as the “Digital Flight Data Acquisition Unit” (DFDAU). The DFDAU collects data from many of the aircraft’s systems such as Air Data Computer, Navigation and Engine monitoring systems, and in turn makes this data available to ACARS.

More recent ACARS installations have been connected to the “Flight Management Computer” (FMC), permitting flight plan updates, predicated wind data, take-off data and position reports to be sent over the ACARS network.

The ACARS in use vary greatly from one airline to another and are tailored to meet each airline’s operational needs. When satellite communication systems are adopted, ACARS will take on a truly global aspect. Figure 1 shows an ACARS network.

ACARS Network
Figure 1

13.1.3 DESCRIPTION

The ACARS is operational as soon as the electrical power is supplied and does not have an ON/OFF switch.

The ACARS has the following components:

1. ACARS Management Unit (MU).
2. Multi-Purpose Interactive Display Unit (MPIDU).
3. Ident plug.
4. Program pins.
5. Thermal Printer.

13.1.4 MANAGEMENT UNIT (MU)

The Management Unit (MU) converts the data from and to the VHF-COMM. Requests from ground-stations for communication or reports go from the MU to the MIDU or Flight Data Acquisition Unit (FDAU). Most of the reports are generated in the FDAU. The MU itself makes the report. The unit uses information from the FWS for this message (parking brake and ground/flight for example). The interface wiring between MU and FDAU/MIDU is ARINC 429.

The MU codes the messages for VHF-COMM. The messages contain the aircraft's registration and the airline code. This information comes from the ident plug. The MU also decodes the messages from the VHF-COMM. When there is a message for the crew, the MIDU shows a message annunciation, while the MU also makes a discrete for the Flight Warning System (FWS) to make an alert.

The VHF-COMM can be used for data transmissions for the ACARS or normal communication. You can select the voice or data mode on the MIDU.

13.1.5 MULTI-PURPOSE INTERACTIVE DISPLAY UNIT (MPIDU)

Displays messages, reports and communication requests to the crew. It incorporates touch-screen control in lieu of external pushbuttons and knobs. The touch-screen control is made possible by the use of infrared sensors along the sides of the display. Control inputs are made from menus displayed on the MIDU.

Figure 2 show the display layout of the MIDU.

Multipurpose Interactive Display Unit (MIDU)
Figure 2

13.1.6 ACARS PRINTER

A thermal printer is provided for the printing of ACARS messages. Operation of the printer is optional as all printed information can be viewed on the MIDU. Weather report information is sent directly to the printer from the ACARS ground-station.

The printer uses rolls of 4.25” thermal paper. A red stripe appears along the edge of the paper when the supply is low.

Figure 3 shows the ACARS Printer.

ACARS Thermal Printer
Figure 3

13.1.7 PRINTER OPERATION

The printer is normally located aft of the centre pedestal and has a “Self Test” feature for pre-flight operational testing.

- SELF TEST PUSH BUTTON: Pushing the “Self Test” pushbutton activates a printer self test which prints the following:

  THE QUICK BROWN FOX JUMPED
  OVER THE 1 2 3 4 5 6 7 8 9 0 LAZY DOGS

- PPR ADV PUSHBUTTON: Used to advance the paper.
- DOOR LOCKING SCREW: Secures the paper loading door shut.
- PWR ON LIGHT: Illuminates when power is applied to the printer.
- ALERT RESET: Resets the printer if an alert is detected.
- PTR BUSY LIGHT: Illuminates amber when the printer is printing. Remains ON until paper advance is complete.
- PAPER LOADING DOOR: Printer paper roll is replaced via opening this door.
- PAPER CUTTING EDGE: Allows for smooth paper cutting when a printed message is removed from the printer.

ACARS communications are accomplished via the ARINC network and the VHF 3 transceiver. VHF 3 is dedicated to this purpose and is automatically controlled by the ACARS frequency of 131.55 MHz and is tuned remotely by the ground stations if frequency change is necessary.

Figure 4 shows a block schematic of the ACARS.

ACARS Schematic Diagram
Figure 4

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13.2 ELECTRONIC CENTRALIZED AIRCRAFT MONITORING

13.2.1 INTRODUCTION

In the ECAM system (originally developed for Airbus aircraft), data relating to the primary system is displayed in checklist, pictorial or abbreviated form on two Cathode Ray Tube (CRT) units.

Figure 5 shows the ECAM system functional diagram.

ECAM Functional Diagram
Figure 5

13.3 ECAM SYSTEM COMPONENTS

13.3.1 FLIGHT WARNING COMPUTER (FWC)

The two FWCs acquire all data necessary for the generation of alert messages associated with the relevant system failures:

- Directly form the aircraft sensors or systems for warnings (mainly identified by red colour).
- Through the SDACs for cautions from the aircraft systems (mainly identified by amber colour).

The FWCs generate alphanumeric codes corresponding to all texts/messages to be displayed on the ECAM display units. These can be either be:

- Procedures associated to failures.
- Status functions (giving the operational status of the aircraft and postponable procedures).
- Memo function (giving a reminder of functions/systems, which are temporarily used or items of normal checklist).

13.3.2 SYSTEM DATA ACQUISITION CONCENTRATORS (SDAC)

The two SDACs acquire from the aircraft systems malfunctions/failure data corresponding to caution situations and send them to the FWCs for generation of the corresponding alert and procedure messages. The two SDACs acquire then send to the 3 DMCs all aircraft system signals necessary for display of the system information and engine monitoring secondary parameters through animated synoptic diagrams.

All signals (discrete, analog, digital) entering the SDACs are concentrated and converted into digital format.

13.3.3 DISPLAY MANAGEMENT COMPUTERS (DMC)

The 3 DMCs are identical. Each integrates the EFIS/ECAM functions and is able to drive either ECAM display units (engine/warning or system/status). The DMCs acquire and process all the signals received from various aircraft sensors and computers in order to generate proper codes of graphic instructions corresponding to the images to be displayed.

13.3.4 Display Units

These can be mounted either side-by-side or top/bottom. The left-hand/top unit is dedicated to information on the status of the system; warnings and corrective action in a sequenced checklist format, while the right-hand/bottom unit is dedicated to associated information in pictorial or synoptic format. Figure 6 shows the layout of ECAM displays.

ECAM Display Layout
Figure 6

13.3.5 ECAM DISPLAY MODES

There are four display modes, three of which are automatically selected and referred to as phase-related, advisory (mode and status), and failure-related modes. The fourth mode is manual and permits the selection of diagrams related to any one of 12 of the aircraft's systems for routine checking, and the selection of status messages, provided no warnings have been triggered for display.

Selection of displays is by means of a system control panel. See Figure 14.

13.3.6 FLIGHT PHASE RELATED MODE

In normal operation the automatic flight phase-related mode is used, and the displays will be appropriate to the current phase of aircraft operation, i.e. Pre-flight, Take-off, Climb, Cruise, Descent, Approach, and post landing. Figure 7 shows display modes. The upper display shows the display for pre-take off, the lower is that displayed for the cruise.

ECAM UPPER DISPLAY

ECAM LOWER DISPLAY - CRUISE

ECAM Upper and Lower Display (Cruise Mode)
Figure 7

13.3.7 ADVISORY MODE

This mode provides the flight crew with a summary of the aircraft's condition following a failure and the possible downgrading of systems. Figure 8 shows an advisory message following a Blue Hydraulic failure.

ECAM Advisory Mode
Figure 8

13.3.8 ECAM FAILURE MODE

The failure-related mode takes precedence over the other modes. Failures are classified in 3 levels

Level 3: Warning

This corresponds to an emergency configuration. This requires the flight crew to carry out corrective action immediately. This warning has an associated aural warning (fire bell type) and a visual warning (Master Warning), on the glare shield panel.

Level 2: Caution

This corresponds to an abnormal configuration of the aircraft, where the flight crew must be made aware of the caution immediately but does not require immediate corrective action. This gives the flight crew the decision on whether action should be carried out. These cautions are associated to an aural caution (single chime) and a steady (Master Caution), on the glare shield panel.

Level 1: Advisory

This gives the flight crew information on aircraft configuration that requires the monitoring, mainly failures leading to a loss of redundancy or degradation of a system, e.g. Loss of 1 FUEL TANK PUMP LH or RH but not both.

The advisory mode will not trigger any aural warning or ‘attention getters’ but a message appears on the primary ECAM display.

Figures 9 – 13 show the 12-system and status pages available.

AIR CONDITIONING SYSTEM PAGE

PRESSURIZATION SYSTEM PAGE

ECAM System Displays
Figure 9

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

ELECTRICAL SYSTEM PAGE

FLIGHT CONTROL SYSTEM PAGE

ECAM System Displays
Figure 10

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

FUEL SYSTEM PAGE

HYDRAULIC SYSTEM PAGE

ECAM System Displays
Figure 11

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

LANDING GEAR/WHEEL/BRAKE SYSTEM PAGE

AIR BLEED SYSTEM PAGE

ECAM System Displays
Figure 12

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

The Gear/Wheel page is displayed at the related flight phase.

DOOR/OXY SYSTEM PAGE

APU SYSTEM PAGE

ECAM System Displays
Figure 13

Note; These pages are displayed:

Automatically due to an advisory or failure related to the system.

Whenever called manually.

Related flight phase.

13.3.9 CONTROL PANEL

The layout of the control panel is shown in Figure 14.

ECAM Control Panel
Figure 14

13.3.10 ECAM CONTROL PANEL

SGU Selector Switches: Controls the respective symbol generator units. Lights are off in normal operation of the system. The “FAULT” caption is illuminated amber if the SGU’s internal self-test circuit detects a failure. Releasing the switch isolates the corresponding SGU and causes the “FAULT” caption to extinguish, and the “OFF” caption to illuminate white.

System Synoptic Display Switches: Permit individual selection of synoptic diagrams corresponding to each of the 12 systems, and illuminate white when pressed. A display is automatically cancelled whenever a warning or advisory occurs.

CLR Switch: Light illuminates white whenever a warning or status message is displayed on the left-hand display unit. Press to clear messages.

STS Switch: Permits manual selection of an aircraft’s status message if no warning is displayed. Illuminates white when pressed also illuminates the CLR switch. Status messages are suppressed if a warning occurs or if the CLR switch is pressed.

RCL Switch: Enables previously cleared warning messages to be recalled provided the failure conditions which initiated the warnings still exists. Pressing this switch also illuminates the CLR switch. If a failure no longer exists, the message “NO WARNING PRESENT” is displayed on the left-hand display unit.

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13.4 ELECTRONIC FLIGHT INSTRUMENT SYSTEM (EFIS)

With the introduction of fully integrated, computer-based navigation system, most electro/mechanical instrumentation has been replaced with TV type colour displays. The EFIS system provides the crew with two displays:

1. Electronic Attitude Direction Indicator (EADI).
2. Electronic Horizontal Situation Indicator (EHSI).

The EADI is often referred to as the Primary Flight Display (PFD) and the EHSI as the Navigation Display (ND). The EADI and EHSI are arranged either side by side, with the EADI positioned on the left, or vertically, with the EADI on the top.

13.4.1 SYSTEM LAYOUT

As is the case with conventional flight director systems, a complete EFIS installation consists of two systems. The Captain's EFIS on the left and the First Officer's on the right.

The EFIS comprises the following units:

1. Symbol Generator (SG).
2. Display units X 2 (EADI & EHSI).
3. Control Panel.
4. Remote Light Sensor.

13.4.2 SYMBOL GENERATOR

These provide the analog, discrete and digital signal interfaces between the aircraft's systems, the display units and the control panel. They provide symbol generation, system monitoring, power control and the main control functions of the EFIS overall.

Figure 15 shows the interface between the modules within the SG.

Symbol Generator Module Interface
Figure 15

Table 1 gives details of the functions of the SG modules.

Module	Function
Input 1 & 2	Supply of data for use by the main computer.
Main Processor	Carries the main control and data processing of the SG.
Main RAM	Address decoding, read/write memory and input/output functions for the system.
Main PROM	Read-only memory for the system.
Display Control	Master transfer bus interface.
WX Input	Time scheduling and interleaving for raster, refresh, input and standby function of weather radar input data.
WX Memory	RAM selection for single input data, row and column shifters for rotate/translate algorithm, and shift registers for video output.
Display Sequencer	Loads data into registers on stroke and raster generator cards.
Stroke Generator	Generates all single characters, special symbols, straight and curved lines and arcs on display units.
Raster Generator	Generates master timing signals for raster, stroke, EADI and EHSI functions.
Display Driver	Converts and multiplexes X and Y digital stroke and raster inputs into analog for driver operation, and also monitors deflection outputs for correct operation.

Symbol Generator Module Functions
Table 1

13.4.3 Display Units

Each display unit consists of the following modules:

1. Cathode Ray Tube.
2. Video Monitor Card.
3. Power Supply Unit.
4. Digital Line Receivers.
5. Analog Line Receivers.
6. Convergence Card.

Figure 16 shows a block schematic of the display unit.

EFIS Display Unit Block Schematic
Figure 16

13.4.4 Low/High Power Supplies

All a.c. and d.c. power requirements for the overall operation of the DU is provided by a low power supply and a high power supply. They are supplied by 115V 400Hz from the aircraft power supplies. Supplies are automatically regulated and monitored for under/over voltage conditions.

13.4.5 Digital Line Receivers

Receives digital signals from the SG (R,G,B control, test signal, raster and stroke signals and beam intensity). It contains a Digital/Analog converter so that it can provide analog signals to the Video Monitor card.

13.4.6 Analog Line Receivers

Receive analog inputs form the SG representing the required X and Y deflections for display writing.

13.4.7 Video Monitor Card

Contains a video control microprocessor, video amplifiers and monitoring logic for the display unit. It calculates the gain factors for the three-video amplifiers (R, G and B). It also performs input, sensor and display unit monitoring.

13.4.8 Deflection Card

Provides X and Y beam deflection signals for stroke and raster scanning.

13.4.9 Convergence Card

Takes X and Y deflection signals and develops drive signals for the three radial convergence coils (R, G and B) of the CRT. Voltage compensators monitor the deflection signals in order to establish on which part of the CRT screen the beams are located. Right or left for the X comparator: top or bottom for the Y comparator.

Figure 17 shows the EFIS units and signal interface in block schematic form.

EFIS Block Schematic
Figure 17

13.4.10 CONTROL PANEL

Allows the crew to select the required display configuration and what information is to be displayed. Both Captain and Co-Pilot have their own display controllers. The controllers have two main functions:

Display Controller: Selects the display format for EHSI as FULL, ARC, WX or MAP.

Source Select: Selects the system that will provide information required for display. The source information will be VOR, ADF, INS, FMS, VHF and NAV.

EFIS Display Controller is shown at Figure 18, and the Source Controller is at 19.

EFIS Display Controller
Figure 18

EFIS Source Controller
Figure 19

13.4.11 ELECTRONIC ATTITUDE DIRECTOR INDICATOR (EADI)

The EADI displays traditional attitude information (Pitch & Roll) against a two-colour sphere representing the horizon (Ground/Sky) with an aircraft symbol as a reference. Attitude information is normally supplied from an Attitude Reference System (ARS).

The EADI will also display further flight information. Flight Director commands right/left to capture the flight path to Waypoints: airports and NAVAIDS and up/down to fly to set altitudes: information related to the aircraft's position w.r.t. Localizer (LOC) and Glideslope (GS) beams transmitted by an ILS.

Auto Flight Control System (AFCS) deviations and Autothrottle mode, selected airspeed (Indicated or Mach No) Groundspeed, Radio Altitude and Decision Height information are also shown.

Figure 20 shows a typical EADI display

Electronic Attitude Director Indicator (EADI) Display
Figure 20

13.4.12 ELECTRONIC HORIZONTAL SITUATION INDICATOR (EHSI)

The EHSI presents a selectable, dynamic colour display of flight progress with plan view orientation. The EHSI has a number of different modes of operation, these are selectable by the flight crew and the number will be dependent on the system fitted.

Figure 21 shows an EHSI display.

Electronic Horizontal Situation Indicator (EHSI) Display
Figure 21

13.4.13 PARTIAL COMPASS FORMAT

The partial compass mode displays a 90° ARC of compass coordinates. It allows other features, such as MAP and Weather Radar displays, to be selected. Figure 22 shows a Partial EHSI display (Compass Mode).

EHSI Partial Compass Mode Display
Figure 22

Figure 23 shows an EHSI partial format with Weather Radar information.

EHSI Weather Radar Display
Figure 23

13.4.14 MAP MODE

The MAP mode will allow the display of more navigational information in the partial compass mode. Information on the location of Waypoints, airports, NAVAIDs and the planned route can be overlaid.
Weather information can also be displayed in the MAP mode to give a very comprehensive display.

Figure 24 shows an EHSI MAP mode display.

EHSI MAP Mode Display.
Figure 24

13.4.15 COMPOSITE DISPLAY

In the event of a display unit failure, the remaining unit can display a "Composite Display". This display is selected via the Display Controller and it consists of elements from an EADI and EHSI display.

Figure 25 shows a typical composite display.

EFIS Composite Display
Figure 25

13.4.16 TESTING

Test is controlled from the DH/TEST knob located on the EFIS control panel. The test, if carried out using the First Officer's control panel, will have the following effect on the Captain's EADI:

- Runway symbol will fall.
- Rad Alt digital display indicates 95 to 100 feet.
- The First Officer's EADI warning will be activated:
- Amber dashes are displayed on the Rad Alt digital display.
- Amber dashes are displayed on the selected DH digital display.

When the TEST button is pressed on the Captain's EFIS control panel the same test sequence takes place. The test altitude value remains displayed as long as the TEST button is pressed. Releasing the knob causes actual altitude to be displayed and digits of the DH display to show the selected value at the end of the test.

The test sequence can be initiated during flight except during APP (Approach).

13.4.17 SYMBOL GENERATOR TEST

Some EFIS systems have the capability of carrying out a comprehensive Symbol Generator BITE. As an example, the BAe 146 EFIS SG Self-test is described.

Initiated by selecting SELF-TEST on the dimming panel and pressing the verifying (DATA), button on the EFIS Control panel. Refer to Figure 26

EFIS CONTROL PANEL

DIMMING PANEL

BAe 146 EFIS Control & Dimming Panels
Figure 26

The Display unit will now display the “Maintenance Master Menu” format as shown in Figure 27. Using the backspace – forward space controls on the EFIS control panel, select “SG SELF TEST”.

Maintenance Master Menu Display
Figure 27

The Symbol Generator Self-Test sequence is automatic and the process is as shown in Figure 28.

SG Self-Test Process
Figure 28

The test fail message will appear if any failures internal to EFIS are detected. Depressing the “Forward Space” key after “FAIL”, on completion of the self-test, brings up a self-test failure page that lists the first test that failed. Depressing the “Forward Space” key again brings up the Interface Status page.

Depressing the “Forward Space” after “PASS”, on completion of the self-test, brings up the Interface Status page. This page lists any interfaces that are not valid.

After confirming the status of the “Self-test Failures” and “Interface Status”, then the operator can reselect the Maintenance Format page to carry out further testing.

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13.5 ENGINE INDICATION AND CREW ALERTING SYSTEM

13.5.1 INTRODUCTION

EICAS is a further system to indicate parameters associated with engine performance and airframe control by means of CRT display units. This particular variation first appeared on Boeing 757 and 767 aircraft.

13.5.2 SYSTEM LAYOUT

EICAS comprises two display units, a control panel and two computers, which receive analogue and digital signals from engine and system sensors. Only one computer is in control, the other being on standby in the event of failure occurring. It may be selected automatically or manually. A functional diagram of an EICAS layout is shown at Figure 29.

EICAS Block Schematic
Figure 29

13.5.3 DESCRIPTION

Referring to Figure 29, the upper DU displays warnings and cautions and the engine primary parameters:

- N_1 Speed.
- EGT.

If required, program pinning enables EPR to be displayed also.

Secondary engine parameters are displayed on the lower DU:

- N_2 Speed.
- Fuel Flow.
- Oil Quantity Pressure
- Engine Temperature
- Engine Vibration.

Other system status messages can also be presented on the lower DU for example:

- Flight Control Position.
- Hydraulic system status.

13.5.4 DISPLAYS

Figure 30 shows displays presented on the Primary and Secondary DUs.

EICAS Primary & Secondary Displays
Figure 30

13.5.5 Display Modes

There are three modes of displaying information:

- Operation Mode.
- Status Mode.
- Maintenance Mode.

13.5.6 Operation Mode

The Operational Mode is selected by the crew and displays engine operating information and any alerts requiring action by the crew in flight. Normally only the upper unit displays information. The lower unit remains blank and can be selected to display secondary information as required.

13.5.7 Status Mode

When selected this mode displays data to determine the dispatch readiness of an aircraft, and is closely associated with details contained in an aircraft's "Minimum Equipment List". Shown on the lower display unit is the position of the flight control surfaces (Elevator, Ailerons and Rudder), in the form of pointers registered against vertical and horizontal scales. Also displayed are selected sub-system parameters, and equipment status messages.
Selection is normally done on the ground, either as part of the Pre-flight checks of dispatch items, or prior to shut-down of electrical power to aid the flight crew in making entries in the aircraft's technical log.

Figure 31 shows a status mode display.

AICAS Status Mode Display
Figure 31

13.5.8 MAINTENANCE MODE

Used by maintenance engineers with information in five different display formats to aid troubleshooting and test verification of the major sub-systems. These displays appear on the lower DU and are not available in flight.

13.5.9 SELECTION PANEL

Control of EICAS functions and displays is via the EICAS Control Panel. This can be used both in flight and on the ground. It is normally located on the centre pedestal of an aircraft's flight deck, and its controls are as follows:

- **Engine Display Switch:** This is of the momentary-push type for removing or presenting the display of secondary information on the lower display unit.

- **Status Display Switch:** Also of the momentary-push type, this is used for displaying the status mode information, referred to earlier, on the lower display unit.

- **Event Record Switch:** This is of the momentary-push type and is used in the air or on the ground, to activate the recording of fault data relevant to the environmental control system, electrical power, hydraulic system, performance and APU. Normally, if any malfunction occurs in a system, it is recorded automatically (called an 'auto event') and stored in a non-volatile memory of the EICAS computer. The push switch enables the flight crew to record a suspect malfunction for storage, and this is called a 'manual event'. The relevant data can only be retrieved from memory and displayed when the aircraft is on the ground and by operating switches on the maintenance control panel.

- **Computer Select Switch:** In the 'AUTO' position it selects the left, or primary, computer and automatically switches to the other computer in the event of failure. The other positions are for the manual selection of left or right computers.

- **Display Brightness Control:** The inner knob controls the intensity of the displays, and the outer knob controls brightness balance between displays.

- **Thrust Reference Set Switch**: Pulling and rotating the inner knob positions the reference cursor on the thrust indicator display (either EPR or N_l) for the engine(s) selected by the outer knob.

- **Maximum Indicator Reset Switch:** If any one of the measured parameters, e.g. Oil Pressure, EGT, should exceed normal operating limits, it will be automatically alerted on the display units. The purpose of the reset switch is to clear the alerts from the display when the limit exceedance no longer exists.

Figure 32 shows an EICAS Control Panel

EICAS Control Panel
Figure 32

13.5.10 ALERT MESSAGES

Up to eleven alert messages can be displayed on the upper display. They appear in order of priority and in appropriate colour.

Level A	-	Red	-	Warnings.
Level B	-	Amber	-	Cautions.
Level C	-	Amber	-	Advisory.

Level A

These warnings require “immediate action” by the crew to correct the failure. Master warning lights are also illuminated along with corresponding aural alerts from the central warning system.

Level B

These cautions require “immediate awareness” of the crew and also may require possible corrective action. Caution lights and aural tones, were applicable, may accompany the caution.

Level C

These advisories require “awareness” of the crew. No other warnings/cautions are given and no aural tones are associated with this level.

The messages appear on the top line at the left of the display screen. In order to differentiate between a caution and an advisory, the advisory is always indented one space to the right.

Figure 33. shows EICAS alert messages Level A, B and C.

EICAS Alert Messages
Figure 33

The master warning and caution lights are located adjacent to the display units together with a “Cancel” and “Recall” switch (see Figure 29). Pushing the “Cancel” switch removes only the caution and advisory messages, warning messages cannot be cancelled. The “Recall” switch is used to recall the previously cancelled caution and advisory messages for display. On the display, the word RECALL appears on the bottom of the display.

Messages are automatically removed from the display when the associated condition no longer exists. If more than one message is being displayed, then as a message is automatically removed, all messages below it will move up one line. If a new fault appears, its associated message is inserted on the appropriate line of the display. This will cause old messages to move down one line.

If there are more messages than can be displayed at one time, the whole list forms what is termed a “Page”, and the lower messages are removed and a page number appears on the lower right-hand side of the list. Additional pages are selected by pressing the “Cancel” switch on the Master Warning/Caution panel.

13.5.11 Failure Of DU/Display Select Panel

Should a DU fail, all messages, primary and secondary, appear on the remaining DU. Secondary messages may be removed by pressing the 'ENGINE' switch on the display select panel. They may be re-established by pressing the same switch. The format displaying all information is referred to as 'Compact Format'. Should the display select panel fail, status information cannot be displayed.

13.5.12 MAINTENANCE FORMAT

Maintenance pages can be called forward on the ground using the Maintenance Panel, refer to Figure 34.

EICAS Maintenance Panel
Figure 34

Maintenance pages appear on the lower DU and include system failures, which have occurred in flight or during ground operations. While these pages are selected, the upper DU displays a 'Compact Format' with the message 'PARKING BRAKE' in the top left of the screen.

A self-test of the whole system, which can only be activated when an aircraft is on the ground and the parking brake set, is performed by means of the “TEST” switch on the maintenance panel.

When the switch is momentarily pressed, a complete test routine of the system, including interface and all signal-processing circuits and power supplies, is automatically performed. For this purpose an initial test pattern is displayed on both display units with a message in white to indicate the system being tested, i.e. 'L or R EICAS' depending on the setting of the selector switch on the display select panel. During the test, the master caution and warning lights and aural devices are activated, and the standby engine indicator is turned on if its display control switch is at 'AUTO'.

The message 'TEST IN PROGRESS' appears at the top left of display unit screens and remains in view while testing is in progress. On satisfactory completion of the test, the message 'TEST OK' will appear. If a computer or display unit failure has occurred, the message 'TEST FAIL' will appear followed by messages indicating which of the units has failed.

A test may be terminated by pressing the 'TEST' switch a second time or, if it is safe to do so, by releasing an aircraft's parking brake. The display units revert to their normal primary and secondary information displays.

Figure 35 shows the display formats seen during the Maintenance format.

Maintenance Mode Displays
Figure 35

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13.6 FLY BY WIRE

13.6.1 INTRODUCTION

A different control system which, may be considered under the heading of "Powered Flying Controls", is the one referred to as a "Fly-By-Wire (FBW) Control System. Although not new in concept, complete re-development of the system was seen to be necessary in recent years, as a means of controlling some highly sophisticated types of aircraft coming into service.

The FBW system, as the name suggests, is one that carries control surface commands from the flight crew input to powered flight control surfaces via electrical wiring, thus replacing the requirement for complex mechanical linkages. In operation, movements of the control column and rudder pedals, and the forces exerted by the pilot, are measured by electrical transducers, and the signals produced are then amplified and relayed to operate hydraulic actuator units, which are directly connected to the flight control surfaces.

In some current types of aircraft the application of the FBW principles is limited to the control of only certain flight control surfaces (Boeing 767 wing spoiler panels), see Figure 36.

13.6.2 OPERATION

For lateral control, the deployment of the spoiler panels is initiated by movement of the pilot's control column to the left or right as appropriate. This movement operates position transducers, in the form of "Rotary Variable Differential Transformers" (RVDT) via mechanical gear drive form the control wheels. The RVDTs produce command voltage signals proportional to control wheel position and these signals are fed to a spoiler control module for processing and channel selection.

The spoiler control module output signals are then supplied to a solenoid valve forming an integral part of a hydraulic power actuator. This valve directs hydraulic fluid under pressure to one side, or the other, of the actuator piston, which then raises or lowers the spoiler panel connected to the piston rod.

As the actuator piston rod moves, it actuates a position transducer of the "Linear Variable Differential Transformer" (LVDT) type, and this produces a voltage feedback signal proportional to spoiler panel position. When the feedback signal equals the commanded signal, a null condition is reached and the spoiler panel movement stops.

Deployment of the spoiler panels, to act as speedbrakes, is initiated by movement of a speedbrake lever. The lever operates a LVDT type transducer, which produces a command voltage signal for processing by the signal control module. The output signal operates the actuator in the same way as for lateral

movement, except the spoiler panels are deployed to their maximum up position. Feedback is again used to null the command signal.

Boeing 767 Fly-by-Wire Control
Figure36

13.6.3 Side Stick Controller

An attraction of a FBW system is the ability to replace the conventional control wheel/column with a small side stick or arm controller. Apart from the size and location and lack of movement, it acts in the same way as a normal flight control.

Figure 37 shows the Side Stick controller as fitted to the Airbus 320.

Side stick Control A320
Figure 37

The side stick controllers are installed on the captain's and first officer's forward lateral consoles. An adjustable armrest is fitted on each seat to facilitate the side stick control. The side stick controllers are electrically coupled.
In the case of one pilot wanting to take control of the aircraft (priority), the “Take-over” button is used to signal the priority system. A visual indication is given on

the glare shield to the pilots to indicate left or right sidestick priority. In autopilot operation the sidestick controllers remain in neutral position.

13.6.4 Advanced Fly By Wire Concepts

The introduction of FBW to an aircraft could simply provide a computer link between the pilot's controls and the control surfaces. This level of development would provide the weight savings promised by FBW but would do little to improve the handling of the aircraft, and would not advance the technology very far towards allowing the aircraft with relaxed stability to be flown. In order to achieve both these goals the computer must be made to do a little more and, typically, this would be to cause the aircraft to respond in a certain manner to the pilot's inputs by driving the controls as appropriate.

For FBW systems to be effective, both the computers and the actuators employed must be "Fast-acting" to minimize the destabilizing effects of control delays. The speeds of reaction required will be dependent to an extent on the natural handling characteristics of the aircraft, an unstable aircraft requiring a much faster acting system than one with stable handling.

13.6.5 Fly By Wire Architecture

In order to provide some redundancy and to improve safety by allowing comparisons to be made of the output demands of more than one computation, it is normal for an active control system to comprise several different computers.

Figure 38 shows the computer arrangement.

Computer Architecture
Figure 38

As can be seen from Figure 38, the computer arrangement is such that neither the ELACs nor the SECs provide the only control to either the pitch or the roll axis. This is designed to decrease the risk of a common design fault having an uncontained effect on the aircraft. Furthermore, redundancy and safety is increased through the different microprocessor types, different suppliers, segregation of the signalling lanes and the division of each computer into two physically separated units.

The power supplies are also segregated and, as with most other aircraft, the individual control surfaces are signalled by different lanes and powered by different hydraulic systems.

Each one of the computers within the FBW system will have a specific function, however no one computer will be permitted to exercise control without its commands being monitored by at least one other computer. Ideally, the computers should be constructed separately and their programs written independently in order to avoid the possibility of a design fault or software error being common to them all. Communication between the FBW system computer is via the ARINC 429 data bus.

13.6.6 Control Laws

Regardless of the architecture of the flight control system, control laws must be designed which determine how the pilot's control demands are translated into control surface movements. The pilot could be enabled, for example, to demand changes in the pitch rate or the flightpath of the aircraft rather than demand simple control surface movements. Such an FBW system is often called an "Active Control" system because the control system itself is more than a passive conveyor of instructions.

The flight control system will be programmed to provide a particular form of aircraft response as the result of the pilot's input. Control in the pitching plane is the most complex and will be considered in these notes.

13.6.7 Pitch Control

The ELACs control the aircraft in pitch in the so-called normal control law and they do so by sending commands to the left and right elevators and also by sending longer term trim commands to the "Trimmable Horizontal Stabilizer" (THS), refer to Figure 40. In the event that the ELACs are unserviceable or unavailable due to failures in their supplies, two of the three SECs (No 1 and 2), will take over control of the elevators, the so-called alternate control law.

Under the alternate law, the aircraft should handle almost exactly as in normal control but many of the envelope protection features would not be available. These features include high angle of attack protection and pitch attitude protection. A further degradation requiring, for example, the loss of all three Inertial reference systems (IRS) would cause the selection of the "Direct Law" in which movement of the side sick controller in pitch is translated directly into movement of the elevator. The only limits to elevator movement are determined by the position of the aircraft's "Centre of Gravity" (CG) and flap position. A complete failure of both ELACs and SECs No 1 & 2 would require the aircraft to be flown through use of the trim wheel. This condition is known as "Mechanical" pitch back up.

Figure 39 shows the different levels of redundancy available in the pitch system.

Pitch Channel Redundancy Levels
Figure 39

Figure 40 shows the pitch control for the Airbus A320.

Airbus A320 Pitch Control
Figure 40

13.6.8 Roll Control

Roll control is provided by both the ELACs (controlling the ailerons), and the SECs (controlling the spoilers). In normal control law, both types of computer contribute to roll control, but in the event of a failure of one channel the other can assume total authority, albeit with different control laws.

Figure 41 shows the roll control architecture.

Roll Control
Figure 41

13.6.9 YAW CONTROL

Yaw control is achieved through signalling from the Flight Augmentation Computers (FAC) to the rudder actuators, although the FACs themselves receive their input signals from the ELACs and the autopilot. A mechanical connection is retained between the rudder pedals and the rudder actuators to allow for the control of the aircraft in roll (through the secondary effect of yaw) in the event of a complete failure of the Electronic Flight Control System (EFCS) or the electrical supplies. Total mechanical back up is thus available through the use of the pitch trim wheel and the rudders.

Figure 42 shows the yaw control architecture.

Yaw control
Figure 42

Figures 43 to 45 show the FBW for the Airbus A320.

Figure 43 shows the lay out for the ELAC control of pitch and roll.

A320 FBW ELAC Operation
Figure 43

Figure 44 shows the lay out for the SECs control of pitch and roll.

A320 FBW SEC Operation
Figure 44

Figure 45 shows the lay out for the FAC control of YAW.

A320 FBW YAW Operation
Figure 45

13.6.10 HYDRAULIC SUPPLIES

The Airbus A320 aircraft has three independent hydraulic systems:

- Blue Hydraulic System (B).
- Green Hydraulic System (G).
- Yellow Hydraulic System (Y).

Priority valves are fitted within common hydraulic lines supplying large actuators to give priority to the primary flight controls. This eliminates any operational reduction after a single hydraulic failure in flight. The blue hydraulic circuit is pressurized by the ram air turbine (RAT) in emergency conditions. Figure 46 shows the complete FBW schematic diagram for the A320.

A320 FBW Schematic Diagram
Figure 46

13.6.11 LOAD ALLEVIATION FUNCTION (LAF)

The load alleviation function, which operates through the ailerons and spoilers 4 and 5, becomes active only in conditions of turbulence in order to relieve wing structure loads. The high hydraulic demands required to achieve the rapid surface movements are provided with the help of dedicated hydraulic accumulators. The LAF becomes active when the difference between the aircraft load factor and the pilot demanded load factor exceeds 0.3 in which case:

- The ailerons are deflected symmetrically upwards (ELAC's – maximum 10° added to roll demand, if any).
- The spoilers 4 and 5 are deflected symmetrically (SEC's – maximum 25° added to roll demand, if any).
- The LAF function is inhibited with:
- Flaps lever not in zero position.
- Speeds below 200 kts.
- Slats/flaps wing-tip brake engaged.
- Pitch alternate law without protection, or with direct law.

There are four specific accelerometers installed in the forward fuselage station to provide the electrical flight control computers (FCU) with vertical acceleration values. These sense the up gust and input a corresponding signal into the SECs and ELACs.

Figure 47 shows a block schematic diagram of the LAF function.

LAF Function
Figure 47

13.6.12 BOEING 777

In this aircraft, two separate flight control systems are used. The Primary Flight Control System (PFC), and the High Lift Control System (HLCS). Both are 'fly-by-wire' systems, the PFC controlling roll, pitch and yaw via ailerons, flaps, elevators, rudder and horizontal stabilizers and the HLCS controlling high lift with outboard trailing edge flaps, leading edge slats and Krueger flaps. Both the PFC and HLCS systems utilize the ARINC 629 digital bus.

13.6.13 PRIMARY FLIGHT CONTROL SYSTEM (PFC)

The PFC is a 3 bus fly-by-wire system. The system calculates commands to position the control surfaces using sensor inputs from the (conventional) control wheel, control column, rudder pedal, speed brake lever and pitch trim switch. The analogue signals given by the control wheels, control columns, rudder pedals and speed-brake lever all go to the Actuator Control Electronics (ACEs). These convert the signals to digital format and send them to the PFCs and the PFCs use mid-value 'voting' to reject a hard or passive failure of input signals. The PFCs also receive information from the Aircraft Information Management System (AIMS), Air Data Inertial Reference Unit (ADIRU) and Standby Attitude & Air Data Reference Unit (SAARU). These signals relate to airspeed, inertial reference data, angle of attack and flap position and the PFCS calculate the flight control commands based on control laws augmentation and flight envelope protections.

Figure 48 shows one channel of the Boeing 777 system.

Boeing 777 Primary Flight Control System (PFCS)
Figure 48

Related abbreviations:

ACE - Actuator Control Electronics
ADIRU - Air Data Inertial Reference Unit
AFDC - Autopilot Flight Director Computer
AIMS - Aircraft Information Management System
SAARU - Secondary Attitude Air Data Reference Unit
PCU - Power Control Unit
PFC - Primary Flight Computer

The digital command signals then go to the ACEs, which return the digital format to analogue before sending them to the PCUs. One, two or three PCUs control each control surface. The PCU contains a hydraulic actuator, electro-hydraulic servo-valve and a position feedback transducer. Feedback is returned as an analogue signal to the ACEs, converted to digital format and supplied to the PFCs, which stop the PCU commands when the feedback signals equal commanded position. Autopilot commands from three AFDCs are used in the same manner but in this system there is 'backdrive' which moves the pilot's controls according to autopilot commands to provide flight-deck reference.

13.6.14 PFC REDUNDANCY

There are three separate systems within the PFC: left, centre and right. All three are called "Channels", and are of the same design. The redundancy is within the actual PFC. Each unit contains three independent "lanes" containing different sets of microprocessors, ARINC 629 interface, and power supplies. All the lanes perform identical calculations; failure of one will only cause that lane to be shut down. A channel can operate normally on two lanes; another lane failure will cause that channel to be shut down.

Figure 49 shows the layout of the PFC system.

Primary Flight Computer System Layout
Figure 49

Figure 50 shows the layout of the PFC lanes.

PFC Lane Structure
Figure 50

Figure 51 shows the complete Boeing 777 FBW system.

Boeing 777 FBW
Figure 51

13.6.15 HIGH LIFT CONTROL SYSTEM (HLCS)

The high lift control system (HLCS) extends and retracts the leading and trailing edge devices.

The HLCS has three operating modes:

1. Primary.
2. Secondary.
3. Alternate.

13.6.16 PRIMARY MODE

In the primary mode, the flap lever position sensors send input signals to the Flap/Slat Electronics Unit (FSEU). The FSEU uses these signals to calculate the flap slat commands. The FSEU sends commands to the control valves, which supply hydraulic power to the flap slat Power Drive Units (PDU). Hydraulic motors within the PDU then move the flaps and slats mechanisms. The primary mode operates as a closed loop system; this stops the command when a feedback signal equals the command signal.

13.6.17 SECONDARY MODE

In the secondary mode, the FSEU receive input signals from the flap lever position sensors. The FSEU then energise the secondary/alternate control relays. These relays energise bypass solenoids in the primary control valves to stop hydraulic power to the hydraulic motors. These relays control electrical power to the flap slat electrical motor in the PDUs. The electric motors then move the flap slat mechanism. The secondary mode also operates as a closed loop system; this stops the command when a feedback signal equals the command signal.

13.6.18 ALTERNATE MODE

The flight crew manually control the alternate mode with switches on the alternate flap control panel. The arm switch on this panel sends a discrete to the FSEU to disengage the primary and secondary modes. This switch also energises two of the secondary/alternate control relays, which energise bypass solenoids in the primary control valves to stop hydraulic power to the hydraulic motors. The alternate mode operates in the open loop configuration and the command signal will only stop when the command is removed or when the flap slat surfaces are at their limits.

Figure 52 shows the layout of a HLCS.

High Lift Control System
Figure 52

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13.7 FLIGHT MANAGEMENT SYSTEM (FMS)

13.7.1 INTRODUCTION

A Flight Management System (FMS) is a computer-based flight control system and is capable of four main functions:

- Automatic Flight Control.
- Performance Management.
- Navigation and Guidance.
- Status and Warning Displays.

The FMS utilizes two Flight Management Computers (FMC) for redundancy purposes. During normal operation both computers cross-talk; that is, they share and compare information through the data bus. Each computer is capable of operating completely independently in the event of one failed unit.

The FMC receives input data from four sub-system computers:

- Flight Control Computer (FCC).
- Thrust Management Computer (TMC).
- Digital Air Data Computer (DADC).
- Engine Indicating & Crew Alerting System (EICAS).

The communication between these computers is typically ARINC 429 data format. Other parallel and serial data inputs are received from flight deck controls, navigation aids and various airframe and engine sensors.
The FMC contains a large nonvolatile memory that stores performance and navigation data along with the necessary operating programs. Portions of the nonvolatile memory are used to store information concerning:

- Airports.
- Standard Flight Routes.
- Nav Aid Data.

Since this information changes, the FMS incorporates a “Data Loader”. The data loader is either a tape or disk drive that can be plugged into the FMC. This data is updated periodically every 28 days.

Figure 53 shows the layout of FMC memory.

FMC Memory Locations
Figure 53

13.7.2 Major Functions Of FMS

The major functions of a FMS are as follows:

- Storage of navigation, aerodynamic, and engine data with provisions for routine updating of the navigation database on a 28-day cycle.
- Provision for automatic data entry for alignment of the inertial reference units.
- Means for entry, storage, and in-flight modification of a complete flight plan from the departure runway to the destination runway via company routes, Standard Instrument Departure (SID) and Standard Arrival Route (STAR) airways, and named or pilot-defined waypoints.
- Means for entry of performance optimization and reference data including gross weight, fuel on board, cruise temperature and wind, fuel reserves, cost index, and computations of the optimum vertical profile utilizing this data plus the entered route.
- Transmission of data to generate a map of the route on the Navigation Display (ND), including relative positions of pertinent points such as NAVAIDs, airports, runways, etc.
- Calculation of the aircraft's position and transmission of this information for display on the ND map and Control and Display Unit (CDU).
- Capability to automatically tune or manually select VOR/DME stations that will yield the most accurate estimate of airplane position and tune the receivers automatically.
- Capability to transmit pitch, roll, and thrust commands to the autopilot, autothrottle, and flight director to fly an optimum vertical flight profile for climb, cruise, descent, and approach while automatically controlling the lateral portion of the flight plan.
- Capability for pilot input of up to 20 waypoints and 20 NAVAIDs into the navigation database.

13.7.3 Control And Display Unit (CDU)

The CDU is the interface between the pilot and the Flight Management Computer (FMC). It provides the means for manually inserting system control parameters and selecting modes of operation. In addition, it provides FMC readout capability as well as verification of data entered into memory. Flight plan and advisory data is continuously available for display on the CDU.

The CDU keyboard assembly provides a full alphanumeric keyboard combined with mode, function, data entry, slew switches, and advisory annunciators. In addition, the keyboard assembly contains two integral automatic light sensors and a manual knob to control display brightness.

Figure 54 shows a typical FMS Control Display Unit.

FMS Control Display Unit CDU
Figure 54

13.7.4 OPERATION

During pre-flight the flight crew first enters all the flight plan information. The initial latitude and longitude of the aircraft, navigational waypoints, destinations, alternates, and flight altitudes are all entered and the FMC generates a flight plan for display on the CDU. The flight crew checks the configuration and if correct, it is confirmed to put the data into the active memory.

Performance data is selected in a similar way. This data contains takeoff, climb, cruise and descent parameters. This function optimizes the aircraft's vertical profile for three, pilot selected, strategic flight modes:

- Economy (ECON).
- Minimum Fuel (MIN FUEL).
- Minimum Time (MIN TIME).

Speed targets associated with these modes are:

ECON - The ECON climb, cruise and descent phase speed/mach targets are calculated to obtain the minimum operating cost per mile travelled en route. Some factors considered in these calculations are cost index, cruise flight level, gross weight, temperature, and current or predicted winds.

Note; cost index accounts for the cost of time in addition to fuel cost.

MIN FUEL – The MIN Fuel speed/mach targets are calculated with a cost index of zero, thus ignoring the cost of time.

MIN TIME – The MIN TIME speed/mach targets are based on operation at maximum flight envelope speeds.

During normal flight, the FMS sends navigational data to the (EFIS), which then displays a route map on the EHSI. If the flight plan is altered during flight, then the EHSI map display will automatically change to display the new route.

Since there are two CDUs in a FMS, during normal operation one unit is commonly used to display performance data and the other is used to display navigational information.

Figure 55 shows FMS block schematic detailing system interface with other aircraft systems. Note; each pilot is served by a separate system.

FMS Block Schematic Diagram
Figure 55

13.7.5 Performance Modes

Performance modes are split into four phases:

1. Take-off Phase.
2. Climb Phase.
3. Cruise Phase.
4. Descent and Approach Phase.

13.7.6 Takeoff Phase

The takeoff phase extends to the thrust reduction altitude where takeoff go around (TOGA) thrust is reduced to climb thrust. If the FMS PROF mode is armed prior to takeoff, profile coupling to the Automatic Flight Control System (AFCS) and Autothrottle System (ATS) for thrust reduction will be automatic at the thrust reduction altitude.

If the FMS NAV mode is armed prior to takeoff, navigation coupling to the autopilot will be automatic when the aircraft is more than 30 feet above origin altitude.

13.7.7 Climb Phase

The climb phase extends from the thrust reduction altitude to the top of climb (T/C). The climb mode will provide guidance for accelerating the aircraft when the aircraft climbs above the terminal area, speed restriction zone. The mode will observe speed/altitude constraints that have been stored in the FMC database or have been inserted by the flight crew. The FMC will provide speed targets to the AFCS during climb.

Generally, speed is controlled by pitch, except where level off is required to observe altitude constraints, in which case speed will be controlled through the throttles.

13.7.8 Cruise Phase

The cruise phase extends from the T/C point to the top of descent (T/D). Cruise could include a step climb as well as a step descent. The FMC will calculate the optimum step climb, or descent point for the flight crew. Initiation of the step climb or step descent requires a correct setting of a new altitude target on the Flight Mode Panel (FMP).

13.7.9 Descent & Approach Phase

The descent and approach phases extend from the T/D to the destination airport. The FMC will calculate the appropriate point for the start of the descent and will initiate the descent automatically, provided the FMP altitude has been previously lowered and the aircraft is coupled to the PROF mode. However, the flight crew may command an immediate descent, which defaults to 1000 ft/min and is changeable if required by ATC. FMS PROF guidance is terminated when the ILS glide-slope is intercepted; automatic NAV guidance is terminated when ILS localizer is intercepted.

13.7.10 Navigation

Short-period position and velocity information from the Inertial Reference System (IRS) is combined with long-period range and bearing information from VOR/DME stations to form an accurate and stable estimate of the aircraft's position and ground speed (GS).

The primary mode of operation is to combine range from two DME stations as well as position and ground speed information from the three Inertial Reference Units (IRU). If two DME stations are not available, range and bearing from a single VOR/DME station is used with the IRS data. As the aircraft progresses along its route, the FMC uses a current estimate of the aircraft's position and the inertial navigation database to tune the VOR/DME receivers to the stations that will yield the most accurate estimate of position.

The FMC database contains information on the class and figure of merit of the available navaids. The classes of a navaid are defined as VOR, DME, VOR/DME, VORTEC, or LOC. The figure of merit is based on usable distance and altitude of the station relative to the aircraft.

The criteria used for the FMC selection of navaids for the internal calculation of a radio-derived aircraft position is shown in Figure 56.

FMC Navaid Autotune Function
Figure 56

In Figure 56, three frequencies are being tuned by the FMC. These are TRA (114.70 MHz), STR (115.60 MHz) and AUG (115.90 MHz). TRA is being used for displaying the bearing and range to the next waypoint; STR and AUG are being used for FMC internal calculation of the aircraft's present position from DME data. The FMC has automatically selected STR and AUG because these stations meet the figure of merit distance requirement.

The FMC also has the capability to tune stations for display on the EFIS, which do not necessarily correspond to the stations being used internally by the FMC for aircraft position determination.

Each FMC independently computes the IRS position as a weighted average of all three IRUs. If, at any time, latitude or longitude data from one IRU differs from the previous average by ½° or more, that IRU will not be used in the averaging process until the output of that IRU is within ½° of the previous average. When only two valid IRUs are available, each FMC will use one valid IRU for its independent calculation of the aircraft's position.

13.7.11 PERFORMANCE

The performance function includes the computation of optimal speeds; estimates of fuel consumption and gross weight; and predictions of time, fuel and distances at all flight plan waypoints. It also covers the computations of reference parameters such as optimum altitude, maximum altitude, approach speed, data base recall and FMC calculation of the operational speed envelope.

Flight path predictions are computed by the FMC using an origin to destination trajectory along the lateral flight plan. The parameters used in this calculation include; gross weight, cost index, predicted cruise winds, speed/altitude/time constraints at specific waypoints, specified speed modes for climb, cruise and descent, allowances for takeoff, approach, and acceleration/deceleration segments between the legs with different speed targets. The predictions are updated periodically as the flight progresses incorporating aircraft performance and groundspeed.

13.7.12 GUIDANCE

The guidance function implemented as part of the FMS provides commands for controlling aircraft roll, pitch, speed and engine thrust. Fully automatic, performance-optimized guidance along flight paths in two or three dimensions is available. This is achieved using NAV/PROF modes of the FMS and AFCS controlled via the FMP. NAV and PROF may be used separately or together. NAV provides lateral guidance, and PROF provides vertical guidance and speed/thrust control.

13.7.13 LATERAL GUIDANCE

The primary flight plan provides lateral guidance with automatic route leg sequencing. The NAV guidance function compares the aircraft’s actual position with the desired flight path and generates steering commands to the autopilot and flight director systems. This causes the aircraft to fly along the desired flight path. Direct guidance from the aircraft’s present position to any waypoint is also available.

Figure 57 shows two lateral flight plans. These routes may be selected via the CDU by inserting specific waypoints on the route, or by inserting a code for individual company routes, which enhance all waypoints required.

FMS Lateral Flight Plans
Figure 57

13.7.14 VERTICAL GUIDANCE

The vertical guidance encompasses the climb, cruise and descent phases of the flight. The flight planning capability of the FMS includes means to enter a published departure, arrival and approach segments and individual waypoints that include speed/altitude constraints. These constraints, as well as the entered cruise altitude and cost index, define the vertical profile for which FMS provides guidance.

In the climb portion of the profile, the AFCS will control thrust and speed through PROF thrust and pitch targets. The aircraft will climb at climb limit thrust to each altitude constraint, fly level until past the constraining waypoint and then resume the climb at climb limit thrust. Automatic level off will also occur as a function of the clearance altitude setting on the FMP.

Figure 58 shows FMS performance modes within a vertical flight profile.

FMS Vertical Profile Performance
Figure 58

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13.8 GLOBAL POSITIONING SYSTEM (GPS)

GPS is a space based radio navigation system, which provides worldwide, highly accurate three-dimensional position, velocity and time information. The overall system is divided into three parts.

1. Space Segment.
2. Control Segment.
3. User Segment.

13.8.1 SPACE SEGMENT

Consists of 24 satellites (21 active + 3 spare), in six orbital planes with 4 satellites in each orbit. They are orbiting the earth every 12 hours at an approximate altitude of between 11,000nm – 12,500nm. The orbits are such that a minimum of 6 satellites are in view from any point on the earth. This provides redundancy, as only 4 satellites are required for three-dimensional position. Figure 59 shows the Space Segment.

GPS Space Segment
Figure 59

13.8.2 Control Segment

This is a ground station that controls all satellites and is made up of:

1. Master Control Station.
2. Monitor Stations.

The Master Control Station is located at Colorado, USA, and is responsible for processing satellite-tracking information received from the Monitor Stations. The Control Segment monitors total system performance, corrects satellite position and re-calibrates the on-board atomic time standards as necessary. The Monitor Stations are located to provide continuous "ground" visibility of every satellite.

13.8.3 Operation

GPS operates by measuring the time it takes a signal to travel from a satellite to a receiver on board the aircraft. This time is multiplied by the speed of light to obtain the distance measurement. This distance results in a Line Of Position (LOP). Figure 60 shows GPS LOP.

GPS Line of Sight (LOP)
Figure 60

The satellites transmit a signal pattern, which is computer generated, in a repeatable random code. The receiver on the aircraft also generates the same code and the first step in the process of using GPS data is to synchronize these two codes. The receiver will receive the LOPs from three different satellites and uses this information to establish synchronization. The receiver is programmed to receive signals that intersect the same point, if they don't, then the two codes are not synchronized. The receiver will now add or subtract time from its code to establish the LOPs intersecting the same point and thus synchronize its code with the one from the satellite. Figure 61 shows GPS operation.

GPS Operation
Figure 61

13.8.4 Signal Structure

GPS satellites transmit on 2 frequencies in 2 modes in the UHF band. The 2 modes are:

- Precision Mode (P).
- Coarse/Acquisition Mode (C/A).

The P code is for military use only. Both codes transmit signals in a "Pseudo Random Code" at a certain rate.

13.8.5 Time Measurements

Once the GPS receiver has synchronized with the satellite code, it can then measure the elapsed time since transmission by comparing the phase shift between the two codes. The larger the phase shift, the longer the length of time since transmission. The length of time since transmission, times the speed of light, equals distance. Figure 62 shows code synchronization and time measurements.

Code synchronization and Time measurement
Figure 62

13.8.6 Position Fixing

If we know our distance from a specific point in space (satellite), then it follows that we are located somewhere on the surface of a sphere, with its radius of that distance. The addition of a second satellite and a second distance measurement further refines the position calculation as the two LOPs intersect each other. The addition of a third distance measurement from a third satellite further refines the position calculation. We now have three LOPs intersecting at a specific point in space. This point in space represents the distance measured between the aircraft and the three satellites. Figure 63 shows the process of position fixing.

GPS Position Fixing
Figure 63

13.8.7 Ionospheric Propagation Error

The ionosphere refracts UHF satellite transmission in the same way it refracts VLF, L.MF and HF transmissions, only to a lesser degree. Since a refracted signal has a greater distance to travel than a straight signal, it will arrive later in time, causing an error in the distance measurement. The ionosphere refracts signals by an amount inversely proportional to the square of their frequencies. This means that the higher the frequency, the less the refraction and hence the less error induced in the distance measurement.

Since the GPS satellites transmit two different UHF frequencies (1575.42 MHz and 1227.60 MHz), each frequency will be affected by the ionosphere differently. By comparing the phase shift between the two frequencies, the amount of ionosphere distortion can be measured directly. By knowing the amount of distortion that is induced, the exact correction factor can be entered into the computer and effectively cancel ionosphere propagation error. Figure 64 shows Ionospheric Propagation Error.

Ionospheric Propagation Error
Figure 64

13.8.7.1 DERIVED INFORMATION

Although the GPS is primarily a position determining system, it is possible to derive certain data by taking into account the change in position over time. Actual track can be obtained by looking at several position fixes. Ground speed can be calculated by measuring the distance between two fixes. Drift angle can be obtained by comparing the aircraft's heading, with the actual track of the aircraft. GPS is able to produce all the derived data commonly associated with existing long-range navigation systems such as INS.

13.8.8 NAVIGATION MANAGEMENT

A typical GPS provides Great Circle navigation from its present Position direct to any waypoint or via a prescribed flight plan. When necessary, a new route can be quickly programmed in flight.

Up to 999 waypoints and up to 56 flight plans are retained by the GNS-X when power is turned off or interrupted. Selection of waypoints or of the leg to be flown is not necessary to determine aircraft position; however, when these are provided, the GNS-X computes and displays on the Colour Control Display Unit all pertinent navigation data including:

Greenwich Date and Mean Time.
Present Position Coordinates.
Magnetic Variation.
Stored Waypoint Coordinates.
Stored Flight Plans.
Departure Time/Time at last Waypoint.
Bearing to Waypoint.
Distance to Waypoint.
Estimated Time to Waypoint (ETE).
Estimated Time of Arrival (ETA).
Wind Direction and Speed.
Desired Track.
Drift Angle.
Ground Speed.
Track Angle.
Crosstrack Distance.
HSI/CDI/RMI Course Display.

The computer determines the composite position based on sensor position/velocity. Plotting multiple moving position points allows determination of Track Angle and the rate of change of position equals groundspeed. Drift Angle becomes available with the Heading input, and a True Airspeed (TAS) input allows calculation of the Wind direction and speed.

The computer is constantly processing all available inputs. The displays of Present Position, Distance-to-Go, and Crosstrack as well as the displays of Track Angle, Drift Angle, Groundspeed, Wind, and Estimated Time Enroute are updated at periodic intervals.

Figure 65 shows the system structure of the Boeing 777 GPS structure.

Boeing 777 GPS Structure
Figure 65

13.8.9 Receiver Autonomous Integrity Monitoring (RAIM)

RAIM is a method of monitoring all satellites used to provide a three dimensional position and alerting the flight crew to a loss of that Information due to satellite failure. Although a minimum of four satellites are required for navigation, additional satellites are required for RAIM, and Fault Detection and Exclusion (FDE).

RAIM calculations are legally required for Enroute IFR use of stand-alone GPS.

Figure 66 shows RAIM Satellite Monitoring Operation.

GPS RAIM Monitoring Operation
Figure 66

Calculations require at least one extra satellite to be received. RAIM circuitry within the GNS-XIs will select each received satellite in turn and compare its data with relation to the four or more satellites currently in use for navigation.

If a satellite's data proves to be 'Inaccurate' to that currently used for navigation, the GNS-XIs will indicate that "NO RAIM" Is available. This may also be caused by poor geometry.

13.8.10 FAULT DETECTION AND EXCLUSION (FDE)

FDE is a function of the GNS-XIs which detects the satellite sending faulty data, and will then exclude that satellite's distance measurement from any calculations of position.

FDE calculations are legally required for "Primary Means GPS Navigation for Oceanic/Remote Operations".

For FDE calculations, six or more satellites have to be received. If only five are available FDE can still be performed with an altitude input. As with RAIM, poor geometry can effect FDE.

13.8.11 FDE PREDICTION

For an entered flight plan, a FDE prediction can be made to ensure good satellite coverage. This is required for Oceanic/Remote operations.

Figure 67 shows FDE operation.

GPS FDE Operation
Figure 67

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13.9 INERTIAL NAVIGATION SYSTEM (INS)

13.9.1 INTRODUCTION

The modern inertial navigation system is the only self-contained single source for all navigation data. After being supplied with initial position information, it is capable of continuously updating extremely accurate displays of the aircraft's:

- Position.
- Ground Speed.
- Attitude.
- Heading.

It can also provide guidance and steering information for the auto pilot and flight instruments. Figure 68 shows a representation of Inertial Navigation principal.

Navigation Triangle
Figure 68

13.9.2 General Principle

In order to understand an inertial navigation system we must consider both the definition of “Inertia” and the basic laws of motion as described by Sir Isaac Newton. Inertia can be described as follows:

1. Newton’s first law of motion states:

   - “A body continues in a state of rest, or uniform motion in a straight line, unless acted upon by an external force”.

2. Newton’s second law of motion states:

   - “The acceleration of a body is directly proportional to the sum of the forces acting on the body.”

3. Newton’s third law states:

   - “For every action, there is an equal and opposite reaction”.

With these laws we can mechanize a device which is able to detect minute changes in acceleration and velocity, ability necessary in the development of inertial systems. Velocity and distance are computed from sensed acceleration by the application of basic calculus. The relationship between acceleration, velocity and displacement are shown in figure 69.

Acceleration, Velocity and Distance Graphs.
Figure 69

Note: velocity changes whenever acceleration exists and remains constant when acceleration is zero.

13.9.3 INS OPERATION

The basic measuring instrument of the inertial navigation system is the accelerometer. Two accelerometers are mounted in the system. One will measure the aircraft's accelerations in the north-south direction and the other will measure the aircraft's accelerations in the east-west direction. When the aircraft accelerates, the accelerometer detects the motion and a signal is produced proportional to the amount of acceleration. This signal is amplified, current from the amplifier is sent back to the accelerometer to a torque motor and this restores the accelerometer to its null position.

The acceleration signal from the amplifier is also sent to an integrator, which is a time multiplication device. It starts with acceleration, which is in feet per second squared (feet per sec per sec) and ends up after multiplication by time with velocity (feet per second).

The velocity signal is then fed through another integrator, which again is a time multiplier, which gives a result in distance in feet. So from an accelerometer we can derive:

- Ground Speed.
- Distance Flown.

If the computer associated with the INS knows the latitude and longitude of the starting point and calculates the aircraft has travelled a certain distance north/south and east/west, it can calculate the aircraft's present position.

Figure 70 shows INS Operation.

INS Operation
Figure 70

To accurately compute the aircraft's present position, the accelerometers must be maintained about their sensing axes. To maintain the correct axes, the accelerometers are mounted on a gimbal assembly, commonly referred to as the platform. The platform is nothing more than a mechanical device, which allows the aircraft to go through any attitude change, at the same time maintaining the accelerometers level. The inner element of the platform contains the accelerometers as well as gyroscopes to stabilize the platform. The gyros provide signals to motors, which in turn control the gimbals of the platform. Figure 71 shows an Inertial Platform (IP).

Inertial Platform
Figure 71

We can also measure the angular distance between the aircraft and the platform in the three axes, giving us the aircraft's pitch, roll and heading angles. These can be used in the navigation computations and also give heading and attitude information to the relative systems.

The gyro and accelerometer are mounted on a common gimbal. When this gimbal tips off the level position, the spin axis of the gyro remains fixed. The case of the gyro moves with the gimbal, and the movement is detected by a signal pick-off within the gyro. This signal is amplified and sent to the gimbal motor, which restores the gimbal back to the level position. Figure 72 shows the operation of gyro stabilization.

Gyro Stabilization
Figure 72

13.9.4 ALIGNMENT

The accuracy of an INS is dependent on the precise alignment of the inertial platform to a known reference (True North), with respect to the latitude and longitude of the ground starting position at the time of "Starting Up" the system. The inertial system computer carries out a self-alignment calibration procedure over a given period of time before the system is ready to navigate the aircraft.

The computer requires the following information prior to alignment so that it can calculate the position of "True North":

- Aircraft's Latitude Position.
- Aircraft's Longitude Position.
- Aircraft's Magnetic Heading (from Magnetic Heading System).

The alignment procedure can only be carried out on the ground, during which the aircraft must not be moved. Once started the alignment procedure is automatic

13.9.5 THE NAVIGATION MODE

In the navigation mode the pitch, roll attitude and the magnetic heading information is updated mainly with the attitude changes sensed by gyros. Because the IRS is aligned to true north a variation angle is used to calculate the direction to magnetic north. Each location on earth has its own variation angle. All variation angles between the 73 North and 60 South latitude are stored in the IRS.

The present position is updated mainly with accelerations sensed by the accelerometers. The accelerations are corrected for the pitch and roll attitude and calculated with respect to the true north direction.

13.9.6 Strapdown Inertial Navigation

As already discussed, inertial navigation is the process of determining an aircraft's location using internal inertial sensors. Unlike the gimballed system, in a strapdown system the accelerometers and gyros are mounted solidly to the aircraft's axis. There are no gimbals to keep the sensors level with the earth's surface, so that one sensor is always on the aircraft's longitudinal axis: one on the lateral axis and one on the vertical axis. Likewise, the gyros are mounted such that one will detect the aircraft's pitch, another the roll and the third the aircraft's heading.

The accelerometer produces an output that is proportional to the acceleration applied along the sensor's input axis. A microprocessor integrates the acceleration signal to calculate a velocity and position. Although it is used to calculate velocity and position, acceleration is meaningless to the system without additional information.

Example: Consider the acceleration signal from the accelerometer strapped to the aircraft's longitudinal axis. It is measuring the forward acceleration of the aircraft, however, is the aircraft accelerating north, south, east, west, up or down? In order to navigate over the surface of the earth, the system must know how its acceleration is related to the earth's surface.

Because the accelerometers are mounted on the aircraft's longitudual, lateral and vertical axes of the aircraft, the IRS must know the relationship of each of these axes to the surface of the earth. The Laser Ring Gyros (LRGs) in the strapdown system make measurements necessary to describe this relationship in terms of pitch, roll and heading angles. These angles are calculated from angular rates measured by the gyros through integration. e.g. Gyro measures an angular rate of 3°/sec for 30 seconds in the yaw axes. Through integration, the microprocessor calculates that the heading has changed by 90° after 30 seconds.

Given the knowledge of pitch, roll and heading that the gyros provide, the microprocessor resolves the acceleration signals into earth-related accelerations, and then performs the horizontal and vertical navigation calculations. Under normal conditions, all six sensors sense motion simultaneously and continuously, thereby entailing calculations that are substantially more complex than a normal INS. Therefore a powerful, high-speed microprocessor, is required in the IRS in order to rapidly and accurately handle the additional complexity.

13.9.7 Laser Ring Gyro Operation

Laser Ring Gyros (LRG) are not in fact gyros, but sensors of angular rate of rotation about a single axis. They are made of a triangular block of temperature stable glass. Very small tunnels are precisely drilled parallel to the perimeter of the triangle, and reflecting mirrors are placed in each corner. A small charge of Helium-neon gas is inserted and sealed into an aperture in the glass at the base of the triangle.

When a high voltage is run between the anodes and the cathode, the gas is ionized, and two beams of light are generated, each travelling around the cavity in opposite directions.

Since both contra-rotating beams travel at the same speed (speed of light), it takes the exact same time to complete a circuit. However, if the gyro were rotated on its axis, the path length of one beam would be shortened, while the other would be lengthened. A laser beam adjusts its wavelength for the length of the path it travels, so the beam that travelled the shortest distance would rise in frequency, while the beam that travelled the longer distance would have a frequency decrease.

The frequency difference between the two beams is directly proportional to the angular rate of turn about the gyro's axis. Thus the frequency difference becomes a measure of rotation rate. If the gyro doesn't move about its axis, both frequencies remain the same and the angular rate is zero. Figure 73 shows a Laser Ring Gyro.

Laser Ring Gyro (LRG)
Figure 73

13.9.8 MODE SELECT UNIT (MSU)

The mode select unit controls the mode of operation of the IRS. There are two types in common use:

- Six Annunciator MSU.
- Triple-Channel MSU.

The six-annunciator MSU provides mode selection, status indication and test initiation for one Inertial Reference Unit (IRU). Figure 74 shows a six-annunciator MSU and Figure 75 shows a triple-channel MSU.

IRS Six-Annunciator MSU
Figure 74

IRS Triple-Channel MSU
Figure 75

13.9.9 Mode Select Unit Modes

IRS Modes or set by setting the MSU mode select switch as follows:

OFF-TO-ALIGN – The IRU enters the power-on/built-in test equipment (BITE) submode. When BITE is complete after approximately 13 seconds, the IRU enters the alignment mode. The IRU remains in the alignment mode until the mode select switch is set to OFF, NAV or ATT. The NAV RDY annunciator illuminates upon completion of the alignment.

OFF-TO-NAV – The IRU enters the power-on/built-in test equipment (BITE) submode. When BITE is complete after approximately 13 seconds, the IRU enters the alignment mode. Upon completion of the alignment mode the system enters the navigation mode.

ALIGN-TO-NAV – The IRU enters navigate mode from alignment mode upon completion of alignment.

NAV-TO-ALIGN - The IRU enters the align downmode from the navigate mode.

NAV-TO-ALIGN-TO-NAV – The IRU enters the align downmode and after 30 seconds, automatically re-enters the navigate mode.

ALIGN-TO-ATT or NAV-TO-ATT – The IRU enters the erect attitude submode for 20 seconds, during which the MSU ALIGN annunciator illuminates. The IRU then enters the attitude mode.

MSU Annunciators

ALIGN – Indicates that the IRU is in the alignment mode. A flashing ALIGN annunciator indicates incorrect LAT/LONG entry, excessive aircraft movement during align.

NAV RDY – Indicates that the alignment is complete.

FAULT – Indicates an IRS fault.
ON BATT – Indicates that the back-up battery power is being used.

BATT FAIL – Indicates that the back-up battery power is inadequate to sustain IRS operation during back-up battery operation (less than 21 volts).

NO AIR – Indicates that cooling airflow is inadequate to cool the IRU.

13.9.10 INERTIAL SYSTEM DISPLAY UNIT (ISDU)

The ISDU selects data from any one of three IRUs for display and provides initial position or heading data to the IRUs. Figure 76 shows an ISDU.

Inertial System Display Unit (ISDU)
Figure 76

13.9.11 KEYBOARD

The keyboard is used to enter latitude and longitude in the alignment mode, or magnetic heading in the attitude mode. The ISDU then sends the entered data simultaneously to all IRUs when ENT pressed.

The keyboard contains 12 keys, five of the 12 keys are dual function: N/2, W/4, H/5,E/6 AND S/8. A dual function key is used to select either the type of data (latitude, longitude or heading) or numerical data to be entered. Single function keys are used to select only numerical data.
The CLR (clear) and ENT (enter) keys contain green cue lights which, when lit, indicate that the operator action is required. CLR is used to remove data erroneously entered onto the display; ENT is used to send data to the IRU.

13.9.12 DISPLAY

The 13-digit alphanumeric spilt display shows two types of navigation data at the same time. The display is separated into one group of 6 digits (position 1 through 6) and one group of 7 digits (positions 7 through 13). Punctuation marks (located in positions 3,5,6,10,12,and 13) light when necessary to indicate degrees, decimal points, and minutes.

13.9.13 SYSTEM DISPLAY SWITCH (SYS DSPL)

The SYS DSPL switch is used to select the IRU (position 1,2 or 3) from which the displayed data originates. If the switch is set to OFF, the ISDU cannot send or receive data from any of the 3 IRUs.

13.9.14 DISPLAY SELECTOR SWITCH (DSPL SEL)

The DSPL SEL switch has five positions to select data displayed on the ISDU.

TEST – Selects a display test that illuminates all display elements and keyboard cue lights to allow inspection for possible malfunctions. The DSPL SEL switch is spring loaded and must be held in this position.

TK/GS – Selects track angle in degrees on the left display and ground speed in knots on the right.

PPOS – Selects the aircraft's present position as latitude on the left display and longitude on the right. Both latitude and longitude are displayed in degrees, minutes, and tenths of a minute.

WIND – Selects wind direction in degrees on the left display and wind speed in knots on the right display.
HDG/STS – Selects heading or alignment status for display, depending upon the current IRU mode. Heading is displayed in degrees and tenths of degrees, and time-to-alignment completion is displayed in minutes and tenths of minutes. In the alignment mode, the ISDU displays alignment status (time to NAV ready) in the right display. In the NAV mode, the ISDU displays true heading in the left display. In the attitude mode, the ISDU displays magnetic heading in the left display and ATT in the right display.

13.9.15 DIMMER KNOB

The dimmer knob is mounted on but operates independently of, the DSPL SEL switch. As the dimmer knob is rotated clockwise, the display brightens.

13.9.16 INERTIAL REFERENCE UNIT (IRU)

The IRU is the main electronic assembly of the IRS. The IRU contains an inertial sensor assembly, microprocessors, and power supplies and aircraft electronic interface. Accelerometers and LRG in the inertial sensor assembly measure acceleration and angular rates of the aircraft.
The IRU microprocessors performs computations required for:

- Primary Attitude.
- Present Position.
- Inertial Velocity Vectors.
- Magnetic and True North Reference.
- Sensor Error Compensation.

The power supplies receive a.c. and d.c. power from aircraft and back-up batteries. They supply power to the IRS, and provide switching to primary a.c. and d.c. or backup battery power

The aircraft electronic interface converts ARINC inputs for use by the IRS. The electronic interface also provides IRS outputs in ARINC formats for use by associated aircraft equipment.

A fault ball indicator and a manual “Interface Test” switch are mounted on the front of the IRU and are visible when the IRU is mounted in an avionics rack.

Figure 77 shows an IRU

Inertial Reference Unit
Figure 77

13.9.17 IRS ALIGNMENT MODE

During alignment the inertial reference system determines the local vertical and the direction of true north.

13.9.18 GYROCOMPASS PROCESS

Inside the inertial reference unit, the three gyros sense angular rate of the aircraft. Since the aircraft is stationary during alignment, the angular rate is due to earth rotation. The IRU computer uses this angular rate to determine the direction of true north.

13.9.19 INITIAL LATITUDE

During the alignment period, the IRU computer has determined true north by sensing the direction of the earth's rotation. The magnitude of the earth's rotation vector allows the IRU computer to estimate latitude of the initial present position. This calculated latitude is compared with the latitude entered by the operator during initialization.

13.9.20 ALIGNMENT MODE

For the IRU to enter ALIGN mode, the mode select switch is set to either the ALIGN or NAV position. The systems software performs a vertical levelling and determines aircraft true heading and latitude.

The levelling operation brings pitch and roll attitudes to within 1° accuracy (course levelling), followed by fine levelling and heading determination. Initial latitude and longitude data must be entered manually, either via the IRS CDU or the Flight Management System CDU.

Upon ALIGN completion, the IRS will enter NAV mode automatically if the mode select switch was set to NAV during align. If the mode select switch was set to ALIGN, the system will remain in align until NAV mode is selected. The alignment time is approximately 10 minutes.

Figure 78 shows a block schematic of a three IRU inertial system.

IRS Block Schematic
Figure 78

Figure 79 shows a block schematic of the interface of the IRS with the aircraft's avionics systems.

IRS Interface – Block Schematic
Figure 79

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13.10 ATC RADIO BEACON SYSTEM (ATCRBS)

Until 1989, the only type of ATC system in use was ATCRBS (Air Traffic Control Radar Beacon System). All ground stations were ATCRBS, and all transponder-equipped aircraft were equipped with ATCRBS-only transponders. Interrogations (and replies) were in mode A (identification) or mode C (altitude).

Figure 80 shows operation of ATCRBS system.

ATCRBS Operation
Figure 80

13.10.1 MODE S TRANSPONDER

After 1989, a completely new type of ATC system was introduced. This system is called mode S (mode select). The new interrogators and transponders are called ATCRBS/mode S because they are capable of working with the old ATCRBS equipment or with new mode S equipment.

For the present time, there will be ATCRBS only equipped aircraft sharing airspace with ATCRBS/mode S equipped aircraft. On the ground, most of the stations are ATCRBS-only, but there will be a gradual phasing in of ATCRBS/mode S ground stations. Both types of station can interrogate either type of transponder, and both types of transponder can respond to either type of ground station. TCAS-equipped aircraft interrogate both ATCRBS and ATCRBS/mode S equipped aircraft just as an ATCRBS/mode S ground station would do.

At some point in the future, all ATCRBS-only equipment will be phased out for commercial aviation. All ground stations and aircraft will then operate in mode S only.

The mode S ATC system enables ground stations to interrogate aircraft as to identification code and altitude just as the ATCRBS system does. These interrogations, however, are only part of a larger list of (up-link and downlink) formats comprising the mode S data link capacity. One of the most important aspects of mode S is the ability to discretely address one aircraft so that only the specific aircraft being interrogated responds, instead of all transponder-equipped aircraft within the range of the interrogator.

13.10.2 MODE S INTERROGATION AND REPLIES

The ATCRBS/Mode S system operates in a way similar to ATCRBS. As a transponder equipped aircraft enters the airspace, it receives either a Mode S only all-call interrogation or an ATCRBS/Mode S all-call interrogation which can be identified by both ATCRBS and Mode S transponders. ATCRBS transponders reply in Mode A and Mode C, while the Mode S transponder replies with a Mode S format that includes that aircraft's unique discrete 24-bit Mode S address. The Mode S only all-call is used by the interrogators if Mode S targets are to be acquired without interrogating ATCRBS targets.

13.10.3 DISCRETE ADDRESSING

The address and the Location of the Mode S aircraft is entered into a roll-call file by the Mode S ground station. On the next scan, the Mode S aircraft is discretely addressed. The discrete interrogations of a Mode S aircraft contain a command field that may desensitize the Mode S transponder to further Mode S all-call interrogations. This is called Mode S lockout. ATCRBS interrogations (from ATCRBS only interrogators) are not affected by this lockout. Mode S transponders reply to the interrogations of an ATCRBS interrogator under all circumstances.

TCAS separately interrogates ATCRBS transponders and Mode S transponders. During the Mode S segment of the surveillance update period, TCAS commences to interrogate Mode S intruders on its own roll-call list.

Because of the selective address features of the Mode S system, TCAS surveillance of Mode S- equipped aircraft is straight forward.

Figure 81 shows “Mode S” operation.

Mode S Operation
Figure 81

13.10.4 OPERATION

As a Mode S aircraft flies into the airspace served by another Mode S interrogator, the first Mode S interrogator may send position information and the aircraft's discrete address to the second interrogator by way of ground lines. Thus, the need to remove the lockout may be eliminated, and the second interrogator may schedule discrete roll-call interrogations for the aircraft. Because of the discrete addressing feature of Mode S, the interrogators may work at a lower rate (or handle more aircraft).

In areas where Mode S interrogators are not connected by way of ground lines, the protocol for the transponder is for it to be in the lockout state for only those interrogators that have the aircraft on the roll-call. If the aircraft enters airspace served by a different Mode S interrogator, the new interrogator may acquire the aircraft via the replay to an all-call interrogation. Also, if the aircraft does not receive an interrogation for 16 seconds, the transponder automatically cancels the lockout.

13.11 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM

13.11.1 INTRODUCTION

TCAS is an airborne traffic alert and collision avoidance advisory system, which operates without support from ATC ground stations. TCAS detects the presence of nearby intruder aircraft equipped with transponders that reply to Air Traffic Control Radar Beacon Systems (ATCRBS) Mode C or Mode S interrogations. TCAS tracks and continuously evaluates the threat potential of intruder aircraft to its own aircraft and provides a display of the nearby transponder-equipped aircraft on a traffic display. During threat situations TCAS provides traffic advisory alerts and vertical manoeuvring resolution advisories to assist the flight crew in avoiding mid-air collisions.

TCAS I provides proximity warning only, to assist the pilot in the visual acquisition of intruder aircraft. It is intended for use by smaller commuter and general aviation aircraft.

TCAS II provides traffic advisories and resolution advisories (recommended escape manoeuvres) in a vertical direction to avoid conflicting traffic. Airline, larger commuter and business aircraft will use TCAS II equipment.

TCAS III Still under development, will provide traffic advisories and resolution advisories in the horizontal as well as the vertical direction to avoid conflicting traffic.

The level of protection provided by TCAS equipment depends on the type of transponder the target aircraft is carrying. It should be noted that TCAS provides no protection against aircraft that do not have an operating transponder.

Table 4 shows levels of protection offered by the transponder carried by individual aircraft.

		OWN AIRCRAFT		
		TCAS I	TCAS II	TCAS III
TARGET AIRCRAFT EQUIPMENT	Mode A XPDR Only	TA	TA	TA
	Mode C Or Mode S XPDR	TA	TA VRA	TA VRA HRA
	TCAS I	TA	TA VRA	TA VRA HRA
	TCAS II	TA	TA VRA TTC	TA VRA HRA TTC
	TCAS III	TA	TA VRA TTC	TA VRA HRA TTC
	TA – TRAFFIC ADVISORY VRA - VERTICAL RESOLUTION ADVISORY HRA - HORIZONTAL RESOLUTION ADVISORY TTC - TCAS – TCAS COORDINATION			

Table 5.15.4

13.11.2 THE TCAS II SYSTEM

TCAS II provides a traffic display and two types of advisories to the pilot. One type of advisory, called a traffic advisory (TA) informs the pilot that there are aircraft in the area, which are a potential threat to his own aircraft. The other type of advisory is called a resolution advisory (RA), which advises the pilot that a vertical corrective or preventative action is required to avoid a threat aircraft. TCAS II also provides aural alerts to the pilot. Figure 82 shows TCAS protection area.

TCAS Protection area
Figure 82

When a Mode S or Mode C intruder is acquired, TCAS begins tracking the intruder. Tracking is performed by repetitious TCAS interrogations in Mode S and Mode C. When interrogated, transponders reply after a fixed delay. Measurement of the time between interrogation transmission and reply reception allows TCAS to calculate the range of the intruder. If the intruder's transponder is providing altitude in its reply, TCAS is able to determine the relative altitude of the intruder.

Figure 83 shows a block schematic diagram of the TCAS system

TCAS System Block Schematic
Figure 83

Transmission and reception techniques used on TCAS directional aerials allows TCAS to calculate the bearing of the intruder. Based on closure rates and relative position computed from the reply data, TCAS will classify the intruders as non-threat, proximity, TA, or RA threat category aircraft.

If an intruder is being tracked, TCAS displays the intruder aircraft symbol on an electronic VSI or joint-use weather radar and traffic display. Alternatively in some aircraft the TCAS display will be on the EFIS system.

The position on the display shows the range and relative bearing of the intruder. The range of TCAS is about 30 nm in the forward direction. Figure 84 shows TCAS TA and RA calculations.

TCAS RA and TA Calculations
Figure 84

13.11.3 AURAL ANNUNCIATION

Displayed traffic and resolution advisories are supplemented by synthetic voice advisories generated by the TCAS computer. The words "Traffic, Traffic" are annunciated at the time of the traffic advisory, which directs the pilot to look at the TA display to locate the intruding aircraft. If the encounter does not resolve itself, a resolution advisory is annunciated, e.g., "Climb, Climb, Climb". At this point the pilot adjusts or maintains the vertical rate of the aircraft to keep the VSI needle out of the red segments.

Figure 85 gives an overview of TCAS air-to-air operation.

NOTE: TCAS OPERATION IS COMPLETELY INDEPENDENT OF GROUND STATION OPERATION

TCAS Air-to-Air Operation
Figure 85

Figure 86 shows typical Electronic VSI - TCAS indications.

Electronic VSI - TCAS indications
Figure 86

Figure 87 shows examples of TCAS warnings as displayed on EADI.

TCAS Warnings EADI Display
Figure 87

Displayed traffic and resolution advisories are supplemented by synthetic voice advisories generated by the TCAS computer. The words "Traffic, Traffic" are annunciated at the time of the traffic advisory, which directs the pilot to look at the TA display to locate the traffic. If the encounter does not resolve itself, a resolution advisory is annunciated. The aural annunciations listed in Table 5 have been adopted as aviation industry standards.

The single announcement "Clear of Conflict" indicates that the encounter has ended (range has started to increase), and the pilot should promptly but smoothly return to the previous clearance.

Traffic Advisory: TRAFFIC, TRAFFIC
Resolution Advisories: Preventative: MONITOR VERTICAL SPEED, MONITOR VERTICAL SPEED. Ensure that the VSI needle is kept out of the lighted segments.
Corrective: CLIMB-CLIMB-CLIMB. Climb at the rate shown on the RA indicator: nominally 1500 fpm. CLIMB.CROSSING CLIMB-CLIMB, CROSSING CLIMB. As above except that it further indicates that own flightpath will cross through that of the threat. DESCEND-DESCEND-DESCEND. Descend at the rate shown on the RA indicator: nominally 1500 fpm. DESCEND, CROSSING DESCEND-DESCEND, CROSSING DESCEND. As above except that it further indicates that own flight path will cross through that of the threat. REDUCE CLIMB-REDUCE CLIMB. Reduce vertical speed to that shown on the RA indicator. INCREASE CLIMB-INCREASE CLIMB. Follows a "Climb" advisory. The vertical speed of the climb should be increased to that shown on the RA indicator nominally 2500 fpm. INCREASE DESCENT-INCREASE DESCENT. Follows a "Descend" advisory. The vertical speed of the descent should be increased to that shown on the RA indicator: nominally 2500 fpm. CLIMB, CLIMB NOW-CLIMB, CLIMB NOW. Follows a "Descend" advisory when it has been determined that a reversal of vertical speed is needed to provide adequate separation. DESCEND, DESCEND NOW-DESCEND. DESCEND NOW. Follows a "Climb" advisory when it has been determined that a reversal of vertical speed is needed to provide adequate separation.

Table 5

13.11.4 PERFORMANCE MONITORING

It is important for the pilot to know that TCAS is operating properly. For this reason a self-test system is incorporated. Self-test can be initiated at any time, on the ground or in flight, by momentarily pressing the control unit TEST button. If TAs or RAs occur while the self-test is activated in flight, the test will abort and the advisories will be processed and displayed.

When self-test is activated, an aural annunciation "TCAS TEST" is heard and a test pattern with fixed traffic and advisory symbols appears on the display for eight seconds.

After eight seconds "TCAS TEST PASS" or "TCAS TEST FAIL" is aurally announced to indicate the system status.

13.11.5 TCAS UNITS

Figure 88 shows a typical ATC/TCAS control unit.

GABLES G-7130 ATC/TCAS Control Unit
Figure 88

The controls operate as follows:

(1) Transponder Code Display

This shows the ATC code selected by the two dual concentric knobs below the display. The 'System Select' switch (XPDR 1-2) controls input to the display.

Certain fault indications are also indicated on the display. "PASS" will show after a successful functional test and "FAIL" will show if a high level failure is detected under normal operating conditions.

Also shown is the active transponder by displaying ATC 1 or 2.

(2) Mode Control Selector Switch

This is a rotary switch labelled STBY-ALT RPTG OFF-XPNDR-TA-TA/RA. The TCAS system is activated by selecting traffic advisory (TA) or traffic and resolution advisory (TA/RA). When STBY is selected, both transponders are inactive. In the ALT RPTG OFF position the altitude data sources are interrupted, preventing the transmission of altitude.

(3) ABV-N-BLW Switch

This selects the altitude range for the TCAS traffic displays. In the ABV mode the range limits are 7,000 feet above and 2,700 feet below the aircraft. In the BLW mode the limits are 2,700 feet above and 7,000 feet below. When normal (N) is selected the displayed range is 2,700 feet above and below the aircraft.

(4) Traffic Display Switch

When AUTO is selected the TCAS computer sets the displays to "pop-up" mode under a traffic/resolution advisory condition. In MAN the TCAS displays are constantly activated advising of any nearby traffic.

(5) Range Switch

This selects different nautical mile, traffic advisory, horizontal range displays.

(6) IDENT Push-button

When pushed causes the transponder to transmit a special identifier pulse (SPI) in its replies to the ground.

(7) Flight Level Push-button (FL)

This is used to select between relative and absolute attitude information.

Figure 89 shows the front panels of typical TCAS computers.

RT-950

RT-951

Honeywell TCAS Computers
Figure 89

Figure 90 shows an ATC/Mode S Transponder

ATC/Mode S Transponder
Figure 90

13.11.6 SELF TEST

If the test button is momentarily pressed, fault data for the current and previous flight legs can be displayed on the front panel annunciators.

When the TEST is initially activated, all annunciators are on for 3 seconds and then current fault data is displayed for 10 seconds, after which the test terminates and all annunciators are extinguished.

If the test button is pressed again during the 10-second fault display period, the display is aborted and a 2-second lamp test is carried out. The fault data recorded for the previous flight leg is then displayed for 10 seconds.

This procedure can be repeated to obtain recorded data from the previous 10 flight legs.

If the test button is pressed to display fault data after the last recorded data, all annunciators will flash for 3 seconds and then extinguish.

13.11.7 DATA LOADER INTERFACE

Software updates can be incorporated into the computer via a set of ARINC 429 busses and discrete inputs. These allow an interface to either an Airborne Data Loader (ADL) through pins on the unit's rear connector, or to a Portable Data Loader (PDL) through the front panel "DATA LOADER" connector.

The computer works with either ARINC 603 data loader low speed bus or ARINC 615 high-speed bus.

A personal computer (PC) can be connected to the front panel "DATA LOADER" connector. This allows the maintenance log and RA event log to be downloaded to the PC via an RS 232 interface.

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13.12 GROUND PROXIMITY WARNING SYSTEM (GPWS)

The purpose of the Ground Proximity Warning System (GPWS) is to alert the flight crew to the existence of an unsafe condition due to terrain proximity. The various hazardous conditions that may be encountered are divided into 7 Modes. These are:

- Mode 1 - Excessive Descent Rate.
- Mode 2 - Excessive Closure Rate (wrt rising terrain).
- Mode 3 - Excessive Altitude Loss (during climb-out after take-off).
- Mode 4 - Insufficient Terrain Clearance (when not in landing configuration).
- Mode 5 - Excessive Deviation below the Glideslope (ILS Landing).
- Mode 6 - Descent Below selected Decision Height.
- Mode 7 – Windshear.

Figures 91 - 97 show schematics of each of the above modes.

GPWS Mode 1
Figure 91

GPWS Mode 2
Figure 92

GPWS Mode 3
Figure 93

GPWS Mode 4
Figure 94

GPWS Mode 5
Figure 95

GPWS Mode 6
Figure 96

GPWS Mode 7
Figure 97

13.12.1 SYSTEM OPERATION

The main component of the system is the GPWS computer. It receives information from other aircraft systems (Baro/Rad Alt Ht, speed, etc.). From these inputs, the computer makes calculations to determine if the aircraft is in danger of contacting the terrain below. GPWS only operates within the Rad Alt range (50' to 2,500'). Figure 98 shows a block schematic diagram of a typical GPWS.

GPWS Block Schematic
Figure 98

13.12.2 GROUND PROXIMITY WARNING COMPUTER (GPWC)

The GPWC establishes the limits for the GPWS modes and compares the aircraft's flight and terrain clearance status against established mode limits. If the aircraft is found to have entered a GPWS mode, the computer issues appropriate warning or alerting signals. The computer also stores failure data in a non-volatile memory for display on a front panel window on the GPWC.

Figure 99 shows a GPWC and Control panel.

GROUND PROXIMITY WARNING COMPUTER

CONTROL PANEL

GPWC and GPWS Control Panel
Figure 99

13.12.3 GPWS CONTROL PANEL

The GPWS control panel provides the flight crew with visual indications of GPWS operation, self-test capability and flap/gear inhibit capability.

Inop Light

Amber “INOP” light is illuminated when a computer or input signal malfunction is detected, or a GPWS self-test is being performed.

Flap/Gear Inhibit

This switch is a two-position toggle switch, guarded and safety-wired in the “NORMAL” position. When it is placed in the “INHIBIT” position, Modes 2,3 and 4 are inhibited.

Self Test Switch

This switch is used to initiate a GPWS self-test. A self-test can be conducted on the ground or in-flight.

Warning Lights

Two warning lights are provided to give visual indication of ground proximity warnings. These are:

- PULL-UP.
- BELOW G/S.

A “WINDSHEAR” warning message (displayed on the EFIS PFD), provides visual indication of a Windshear condition.

The red PULL-UP light illuminates when Mode 1,2,3 or 4 flight path is detected. The amber BELOW G/S warning light illuminates when glide slope deviation becomes excessive. Pressing the BELOW G/S switch inhibits the warning.

Figure 100 shows a PFD with Windshear annunciation.

Primary Flight Display (Windshear)
Figure 100

13.12.4 GPWS BITE OPERATION

The purpose of the BITE is to perform an internal check of the GPWC functions to record past faults that occur during the last ten flights and to annunciate system status information.

The BITE function carries out three BITE tests:

Continuous Test – Performed during each program loop. This checks the CPU operation and data input integrity for shorts to ground or open circuits. The ADC, IRS, ILS and RAD ALT systems and internal power supplies are also monitored for valid data.

Periodic Test – Tests requiring excessive processing time are subdivided into small segments. Tests on the individual segments are performed sequentially, one segment during each program loop. Periodic tests include checks on the processor instruction sets, program memory contents, RAM addressing and storage functions, voice memory addressing and contents, parity of received data and the ability to read the data.

Event-Initiated Tests – These are performed during or after a specific event has occurred. They include resetting the program a fraction of a second prior to a power supply failure; checksumming the data stored in the non-volatile fault memory at power up; checksumming the data written after entering data; sampling and storing program pin status at power up; restarting the CPU at a known location in the program after loss of CPU.

13.12.5 FAULT RECORDING

Faults are recorded in a non-volatile fault memory by flight segments. The beginning and the end of each flight segment are identified using radio altitude, IAS and Mode 3 – 4 transitions. Up to 24 faults may be recorded during each flight segment.

Figure 101 shows GPWS block schematic for the Boeing 737 aircraft.

GPWS Block Schematic (B737)
Figure 101

13.13 ENHANCED GROUND PROXIMITY WARNING SYSTEM

The EGPWS contains all the modes as with the standard GPWS with some additional features. The system contains a worldwide terrain database, an obstacle database and a worldwide airport database, and using this extra data enables the system to give an Enhanced GPWS. The additional features are as follows:

Terrain alerting and display (TAD) - This provides a graphic display of the surrounding terrain on the Weather Radar Indicator, EFIS or a dedicated GPWS display. Based on the aircraft's position and the internal database (terrain topography), all terrain that is above or within 2000 feet below the aircraft's altitude is presented on the system display. This feature is an option, enabled by program pins during installation.

Peaks – Is a TAD supplemental feature providing additional terrain display features for enhanced situational awareness, independent of the aircraft's altitude. This includes digital elevations for the highest and lowest displayed terrain, additional elevation (colour) bands, and a unique representation of 0 MSL elevation. This feature is an option enabled by program pins during installation.

Obstacles – This feature utilizes an obstacle database for obstacle conflict alerting and display. EGPWS caution and warning visual and audio alerts are provided when a conflict is detected. Additionally, when TAD is enabled, obstacles are graphically displayed similar to terrain. This feature is an option, enabled by program pins during installation.

Terrain Clearance Floor – This feature adds an additional element of protection by alerting the flight crew of possible premature descent. This is intended for non-precision approaches and is based on the current aircraft position relative to the nearest runway. This feature is enabled with the TAD feature.

Geometric Altitude – Based on the GPS altitude, this is a computed pseudo-barometric altitude designed to reduce or eliminate altitude errors resulting from temperature extremes, non-standard pressure altitude conditions, and altimeter miss-sets. This ensures an optimal EGPWS alerting and display capability.

Note; some of these features have been added to the EGPWS as the system evolved and are not present in all EGPWS part numbers.

13.13.1 CONTROLLED FLIGHT INTO TERRAIN (CFIT)

Because the overwhelming majority of “Controlled Flight Into terrain” accidents occur near to an airport, and the fact that aircraft operate in close proximity to terrain near an airport, the terrain database contains higher resolution grids for airport areas. Lower resolution grids are used outside airports areas where aircraft enroute altitudes make CFIT accidents less likely and terrain feature detail is less important to the flight crew.

With the use of accurate GPS and FMS information, the EGPWS is provided aircraft present position, track, and ground speed. With this information the EGPWS is able to present a graphical plan view of the aircraft relative to the terrain and advise the flight crew of any potential conflict with the terrain or an obstacle.

Conflicts are recognized and alerts are provided when terrain violates specific computed envelope boundaries on the projected flight path of the aircraft. Alerts are provided in the form of visual light annunciation of a caution or warning, audio enunciation based on the type of conflict, and colour enhanced visual display of the terrain or obstacle relative to the forward look of the aircraft. Figure 102 shows Terrain/Obstacle database.

Terrain/Obstacle Database
Figure 102

Figure 103 shows a graph of when caution and warning alerts are triggered.

Terrain Caution/Warning Graph
Figure 103

Table 5 shows the different Terrain/Obstacle threat levels and the colour indication present with TAD and Peaks selected.

Colour	Indication
Solid Red	Terrain/Obstacle threat warning.
Solid Yellow	Terrain/Obstacle threat warning.
50% Red Dots	Terrain/Obstacle that is more than 2000 feet above the aircraft.
50% Yellow Dots	Terrain/Obstacle that is between 1000 and 2000 feet above the aircraft's attitude.
25% Yellow Dots	Terrain/Obstacle that is 500 (250 with gear down) feet below to 1000 feet above the aircraft's altitude.
Solid Green (Peaks Only)	Shown only when no red or yellow Terrain/Obstacle areas are within range on the display. Highest terrain/obstacle not within 500 (250 with gear down) feet of the aircraft's altitude.
50% Green Dots	Terrain/Obstacle that is 500 (250 with gear down) feet below to 1000 below the aircraft'' altitude.
50% Green Dots (Peaks Only)	Terrain/Obstacle that is in the middle elevation band when there is no red or yellow terrain areas within range on the display.
16% Green	Terrain/Obstacle that is 1000 to 2000 feet below the aircraft's altitude.
16% Green (peaks Only)	Terrain/Obstacle that is the lower elevation band when there is no Red or Yellow terrain areas within range on the display.
Black	No significant Terrain/Obstacle
16% Cyan	Water at Sea Level Elevation (0 feet MSL)
Magenta Dots	Unknown terrain. No terrain data in the database for the magenta area shown.

Terrain/Obstacle Threat Levels
Table 5

Figure 104 shows a Weather Radar Display used for EGPWS displays.

EGPWS Display
Figure 104

13.13.2 TERRAIN ALERTING & DISPLAY (TAD)

With a compatible EFIS or Weather Radar display, the EGPWS TAD feature provides an image of the surrounding terrain represented in various colours and intensities. There are two types of TAD display depending on the options selected:

- Standard TAD – Provides a terrain image only when the aircraft's altitude is 2000 feet or less above the terrain.

- Peaks – Enhances the standard display characteristics to provide a higher degree of terrain awareness independent of the aircraft's altitude.

In either case, terrain and obstacles (if enabled) forward of the aircraft are displayed.

Note; Obstacles are presented on the display as terrain, using the same colour scheme. Peaks and Obstacle functions are enabled by EGPWS program pin selection.

Figure 105 shows the “Peaks” function of EGPWS.

EGPWS “Peaks” Function
Figure 105

13.13.3 ENVELOPE MODULATION

This special feature utilizes the internal database to tailor EGPWS alerts at certain geographical locations to reduce nuisance warning and provide added protection. Due to terrain features at or near certain specific airports around the world, in the past, normal operations have resulted in nuisance or missed alerts at these locations. With the introduction of accurate position information and a terrain and airport database, it is possible to identify these areas and adjust the normal alerting process to compensate for the condition.

An EGPWS Envelope Modulation feature provides improved alert protection and expanded alerting margins at identified key locations throughout the world. This feature is automatic and requires no flight crew action.
Modes 4,5, and 6 are expanded at certain locations to provide alerting protection consistent with normal approaches. Modes 1,2 and 4 are desensitized at other

locations to prevent nuisance warnings that result from unusual terrain or approach procedures. In all cases, very specific information is used to correlate the aircraft position and phase of flight prior to modulating the envelopes.

Figure 106 shows the Envelope Modulation function.

Envelope Modulation
Figure 106

13.13.4 TERRAIN LOOK AHEAD ALERTING

Another enhancement provided by the internal terrain database, is the ability to look ahead of the aircraft and detect terrain or obstacle conflicts with greater alerting time. This is accomplished (when enabled) based on the aircraft position, flight path angle, track and speed relative to the terrain database image forward of the aircraft.

Through sophisticated look ahead algorithms, both caution and warning alerts are generated if terrain or an obstacle conflict with “Ribbons” projected forward of the aircraft. Figure 107 shows the Terrain Look Ahead Alerting function.

Terrain Look Ahead Alerting
Figure 107

These ribbons project down, forward, then up from the aircraft with a width of 3° laterally (more if turning). The look-ahead and up angles are a function of the aircraft flight path angle, and the look-ahead distance are a function of the aircraft's altitude with respect to the nearest runway. This relationship prevents undesired alerts when taking off and landing.

The look-ahead distance is a function of the aircraft's speed and distance to the nearest runway. A terrain conflict intruding into the caution ribbon activates the EGPWS caution lights and the aural message "CAUTION TERRAIN, CAUTION TERRAIN" or "TERRAIN AHEAD, TERRAIN AHEAD". The caution alert is given typically 60 seconds ahead of the terrain conflict and is repeated every seven seconds, as long as the conflict remains within the caution area.

When the warning ribbon is intruded, typically 30 seconds ahead of the terrain, EGPWS warning lights activate and the aural message "TERRAIN, TERRAIN, PULL UP" is enunciated with "PULL UP" repeating continuously while the conflict is within the warning area.

Note; the specific aural message provided is established during the initial installation of the EGPWS and is a function of whether or not the terrain features are enabled and the selected audio menu (via program pins).

13.13.5 TERRAIN CLEARANCE FLOOR (TCF)

The TCF function enhances the basic GPWS Modes by alerting the flight crew of a descent below a defined "Terrain Clearance Floor", regardless of the aircraft's configuration. The TCF alert is a function of the aircraft's RAD ALT and distance (calculated from Lat/Long position) relative to the centre of the nearest runway in the database.

TCF alerts result in the illumination of the EGPWS caution lights and the aural message "TOO LOW TERRAIN". The audio message is provided once when initial envelope penetration occurs and again only for an additional 20% decrease in RAD ALT altitude. The EGPWS caution lights will remain on until the TCF envelope is exited.

The TCF envelope is shown in Figure 108.

Terrain Clearance Floor
Figure 108

13.13.6 TCF/TAD CONTROL

The EGPWS TCF and TAD functions are available when all required data is present and acceptable. Aircraft position and numerous other parameters are monitored and verified for adequacy in order to perform these functions. If determined invalid or unavailable, the system will display **"TERRAIN INOPERATIVE"** or 'unavailable annunciations' and discontinue the terrain display if active. TAD/TCF functions may be inhibited by manual selection of a cockpit "TERRAIN INHIBIT SWITCH".

Note: neither loss, nor inhibited TAD/TCF effects the basics GPWS functions Modes 1 –7.

Figure 109 shows EGPWS control switches and annunciations.

EGPWS Control Switches & Annunciation
Figure 109

Figure 110 shows an EGPWS Computer.

EGPWS Computer
Figure 110

13.13.7 EGPWS INTERFACE

The EGPWS uses various input signals from other on-board systems. The full compliment of these other systems depends on the EGPWS configuration and options selected. The basic enhanced facilities require:

- Altitude (RAD ALT/GPS/IRS).
- Airspeed (IAS/TAS).
- Attitude (IRS).
- Glideslope (ILS).
- Present Position (FMS/IRS/GPS).
- Flap/Gear Position.

The Windshear function requires additional information of:

- Accelerations (IRS).
- Angle of Attack.
- Flap Position.

Inputs are also required for discrete signals. These discrete inputs are used for system configuration, signal/status input and control input functions. EGPWS program pins are utilized to inform the system of the type of aircraft and interface in use. These are established during EGPWS installation.

Discrete signals also include signals for “Decision Height”, Landing Flaps” selected, display range and status discrete such as RAD ALT/ILS valid.

EGPWS provides both visual and audio outputs. The visual outputs provide discrete alert and status annunciations and display terrain video on a compatible CRT screen. Audio annunciations are provided (via the aircraft’s interphone system) at specific alert phases.

Figure 111 shows EGPWS system schematic.

EGPWS System
Figure 111

13.13.8 SYSTEM ACTIVATION

The EGPWS is fully active when the following systems are powered and functioning normally:

- EGPWS.
- RADIO ALTIMETER.
- AIR DATA SYSTEM
- ILS (Glideslope).
- GPS/FMS or IRS (PP).
- GEAR/FLAPS.
- WEATHER RADAR/EFIS DISPLAY.

In the event that the required data for a particular function is not available, then that function is automatically inhibited and annunciated (e.g. if PP data is not available or determined unacceptable, TAD/TCF is inhibited, any active terrain display is removed and “TERR INOP” indicated on CRT display.

13.13.9 SELF TEST

The EGPWS provides a Self-Test Capability for verifying and indicating intended functions. This Self-Test capability consists of six levels to aid testing and troubleshooting the EGPWS. These six levels are:

- **Level 1 - GO/NO GO Test.** Provides an overview of the current operational functions and an indication of their status. This test is carried out by the flight crew, as part of their “Pre-Flight test”.
- **Level 2 - Current Faults.** Provides a list of internal and external faults currently detected by the EGPWC.
- **Level 3 – EGPWS Configuration.** Indicates the current configuration by listing the EGPWS hardware, software, databases and program pin numbers detected by the EGPWC.
- **Level 4 – Fault History.** Provides an historical record of the internal and external faults detected by the EGPWC.
- **Level 5 – Warning History.** Provides an historical record of the alerts given by the EGPWS.

- **Level 6 – Discrete Test.** Provides audible indication of any change to a discrete input state.

Note: Levels 2 – 6 tests are typically used for installation checkout and maintenance operations.

Figure 112 shows TAD/TCF display test pattern.

TAD/TCF Test Display
Figure 112

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13.14 FLIGHT DATA RECORDER SYSTEM (FDRS)

The flight data recorder receives and stores selected aircraft parameters from various aircraft systems and sensors in a crash-protected solid state memory. The Digital Flight Data Acquisition Unit (DFDAU) of the Aircraft Information Management System (AIMS) receives all the FDR data. The DFDAU then processes the data and sends it to the FDR, where it is stored.

The FDRS operates during any engine start, while the engine is running, during test, or when the aircraft is in the air. The FDR records the most recent 25 hours of flight. In addition to the data recording function, the FDR also has monitor circuits, which send fault information back to the DFDAU.

Note: FDRS fitted to a Helicopter start recording only when the rotors turn (i.e. take-off).

13.14.1 OPERATION

The AIMS receives power control data from several aircraft systems, power goes to the FDR when the logic is valid. Power control data includes:

- Engine Start.
- Engine Running.
- Air/Ground Logic.
- Test.

13.14.2 ANALOGUE DATA

The DFDAU receives status and maintenance flag data from the FDR. The DFDAUs receive key events from the VHF and HF LRUs and variable analogue data from the TAT, AOA and engine RPM sensors.

13.14.3 DIGITAL DATA

The ARINC 429/629 buses provide engine, airframe data and air/ground logic.

Engine data includes:

- Engine parameters, normal and exceedances.
- Commands.
- Actual Thrust.

Airframe data includes:

- Flight deck switch position
- Flight control positions
- Mode selections on control panels in the flight deck.

The DFDAU receives status from the engine and airframe sensors. The DFDAU also receives data and status from the electrical power system.

The flight controls ARINC629 buses provide flight data and navigational data.

Flight data includes:

- Flight control position.
- Commands
- Status.

Navigation data includes:

- Pitch, Roll and Yaw attitude.
- Acceleration data.
- Status.

ARINC 429 bus provides navigational (NAV) radio/NAV data and communication (COMM) radio data.

Radio data includes:

- Radio Frequencies.
- Mode.
- Parameters.
- Status.

NAV data is the aircraft's present position (LAT/LONG) and sensor status.
COMM data is radio control panel frequencies and sensor status.

The left AIMS cabinet sends left/right DFDAU data on the ARINC 573 data bus to the FDR. The DFDAU sends fault data, status and ground test results to the Central Maintenance Computer. Figure 113 shows a FDR.

Flight Data Recorder
Figure 113

Figure 114 shows FDR block schematic diagram.

Flight Data Recorder Block Schematic
Figure 114

The following is taken from ANO Section 1, order 53.

13.14.4 USE OF FLIGHT RECORDING SYSTEMS

1. On any flight on which a FDR, a cockpit voice recorder or a combined cockpit voice recorder/flight data recorder is required to be carried in an airplane, it shall always be in use from the beginning of the take-off run to the end of the landing run.

2. On helicopters, it shall always be in use from the time the rotors first turn for the purpose of taking off until the rotors are next stopped.

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