1 POWER DISTRIBUTION SYSTEM

Bus Bar, split bus bar system, special purpose cables. Electrical diagram and identification scheme. Circuit controlling devices. Power utilization-typical application to avionics.

Bus Bar - Introduction

In most of aircrafts, the output from the generating sources is coupled to one or more low impedance conductors referred as bus bars. This are situated at central points within the aircraft and provides positive supplies to various consumer circuits. In a very simple system a bus bar can take the form of a strip of interlinked terminals while in complex system. Main bus bars are thick metal strips or rods to which input and output supply connections can be made.

Bus Bar Systems Requirements:

i) Power-consuming equipment must not be deprived of power in the event of power source failures.

ii) Failure on the distribution system should have the minimum effect on system functioning.

iii) Power consuming equipment faults must not endanger the supply of power to other equipment.

Types of Consumer Services:

i) Vital Services:

These services are connected directly to the battery. For Example, during an emergency wheels up landing emergency lighting and crash switch operation of fire extinguishers are required.

ii) Essential Services:

Those are required to ensure safe flight in an in-flight emergency situation. They are connected to dc or ac bus bars.

iii) Non-Essential Services:

These are isolated in an in-flight emergency for load shedding purposes.

Bus bar System:

From the below diagram 1.1 the power supplies are 28 volts dc from engine driven generators, 115 volts 400 Hz ac from rotary inverters and 28 volts dc from batteries.

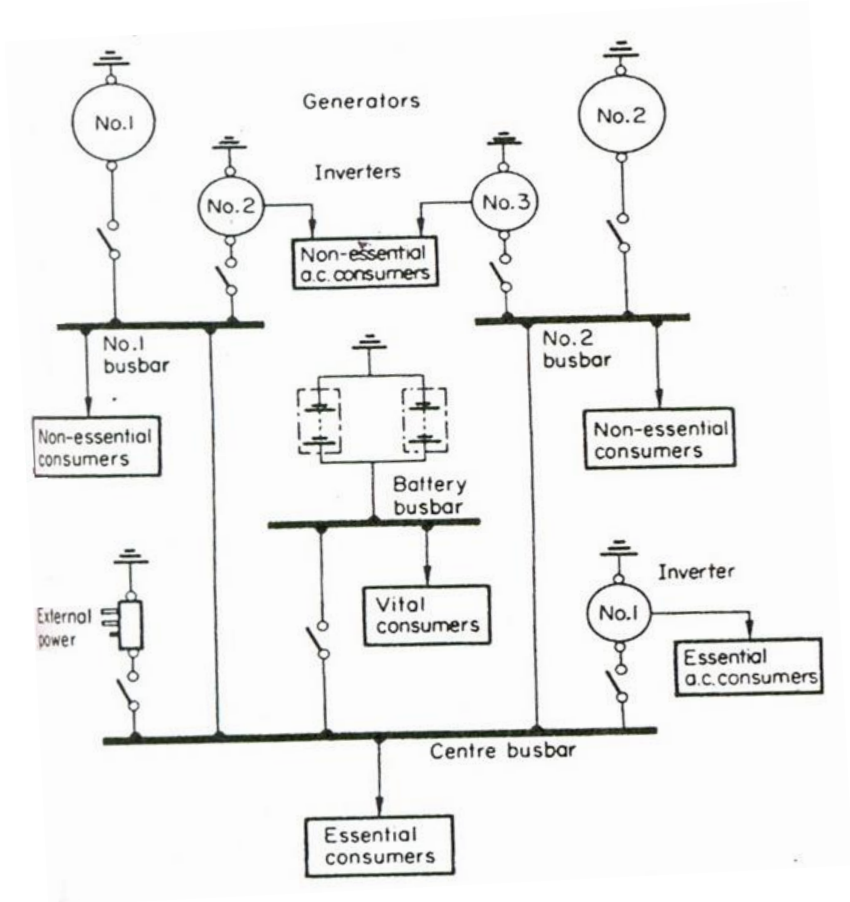


Figure 1.1 Bus bar System

Each generator has its own bus bars to which are connected to the non-essential consumer services. Both bus bars are connected to a single bus bar which supplies power to the essential services. So, with both generators operating, all consumers requiring dc power are supplied.

The essential services bus bar is also connected to the battery bus bar.

In the event of one generator failure it is automatically isolated from its respective bus bar and all bus bar loads are then taken over by the operative generator.

When both generator fails, non-essential customers can no longer be supplied, but the batteries will supply power to the essential services, and keep them operating for a pre-determined period.

The dc supplies for driving the inverters are taken from bus bars to supply the ac to the consumers. The essential ac consumers are operated by No 1 inverter and Non essential ac consumers are operated by No 2 & 3 inverter, and they are powered by dc from the No 1 & No 2 bus bars.

Split Bus Bar System:

In this system the ac supply is the primary power source and dc supply via Transformer Rectifier Units. (T.R.U) which is shown in figure 1.2.

The generator supplies three-phase power to the two main bus bars and these in turn, supply the non-essential consumer loads and T.R.U's.

The essential ac loads are supplied from the essential bus bar when under normal operating conditions is connected via a change over relay to the No 1 bus bar.

The main bus bars are normally isolated from each other, but if the supply from either of generator fails, the bus bars are automatically interconnected by the 'bus-tie' breaker and serve as one and then maintaining supplies to all ac consumers, and both T.R.U's.

If both the generator fails the non-essential services will be isolated and the changeover relay between No 1 bus bar and the essential bus bar will de-energize and connect the essential bus bar to a static inverter.

The supply of dc is derived from independent T.R.U and from batteries. The No 1 T.R.U supplies essential loads & the No 2 unit supplies non essential loads connected to the main dc bus bar.

In the event of both generators failure the main dc bus bar will be isolated from the essential dc bus bar and then essential dc bus bars will be supplied from the batteries to maintain operation of essential dc & ac consumers.

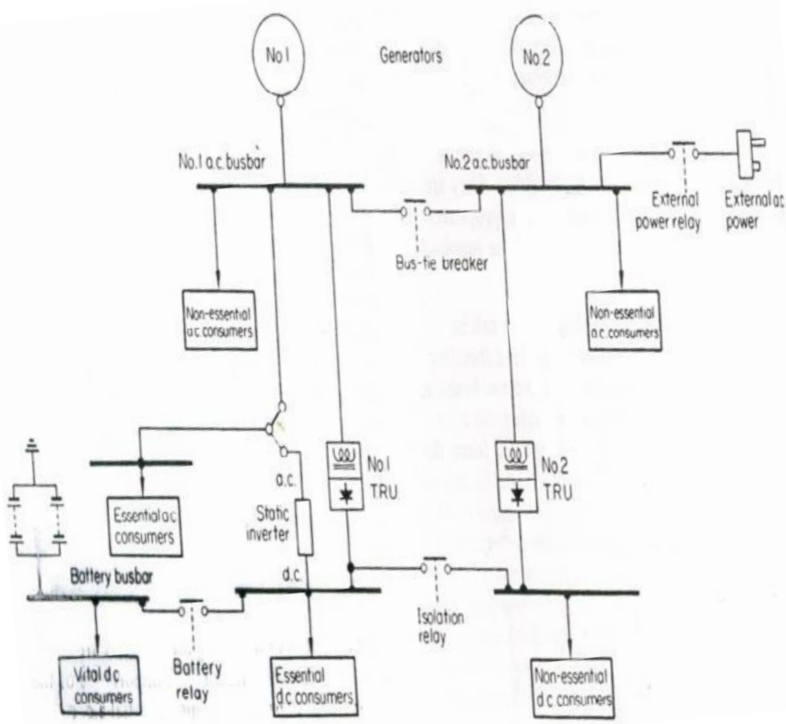


Figure 1.2 Split Bus Bar System

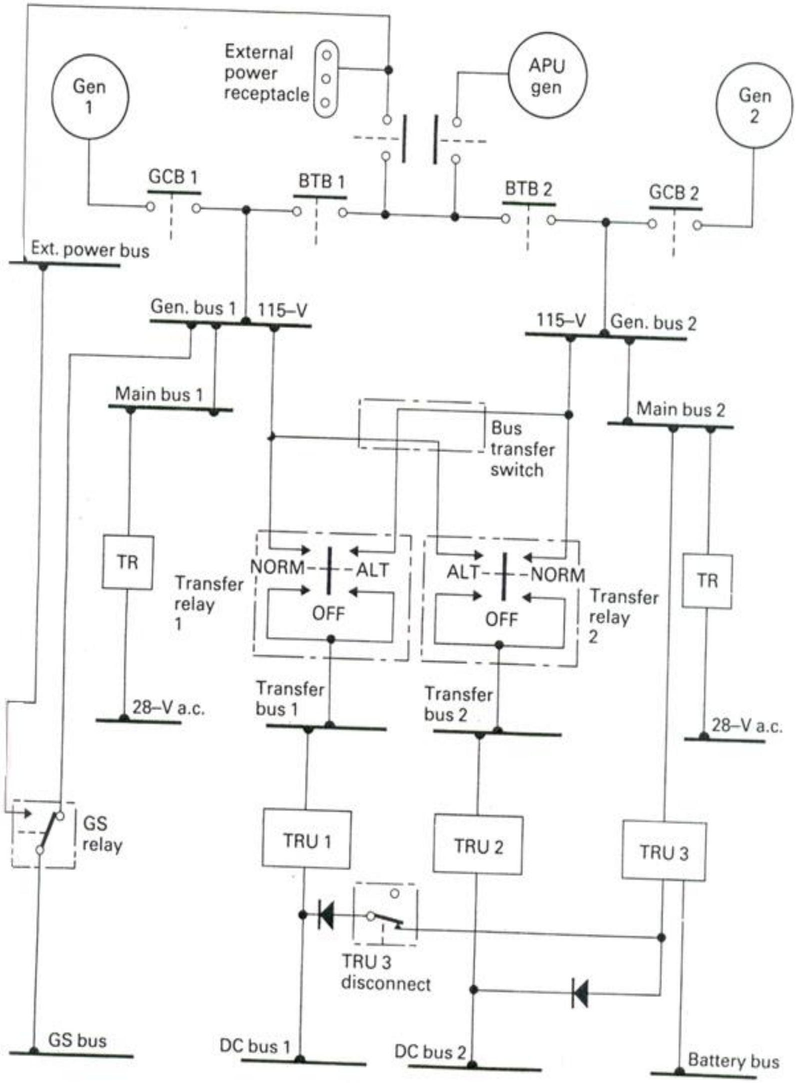


Figure 1.3 B737 Split Bus Bar System

Special Purpose Cables:

For certain types of electrical systems, cables are required to perform a more specialized function.

Types:

Ignition cables, Thermocouple cables, Co-axial cables.

Ignition cables are used for the transmission of high tension voltages in both piston engine and turbine engine ignition systems, and are of single core standard type suitably insulated, and screened by metal braided sheeting to prevent interference.

Thermocouple cables are used for the connection of cylinder head temperature indicators and turbine engine exhaust gas temperature indicators to the thermocouple sensing elements. Copper and constantan for cylinder head thermocouples, chromel and alumel for exhaust gas thermocouples.

Co-axial cables contain two or more separate conductors. The innermost conductor may be of solid or standard copper wire, silver plated or gold plated in some applications. The remaining conductors are in the form of tubes (fine wire braid). The insulation is of polyethylene or Teflon.

i) These cables are shielded against electrostatic and magnetic fields.
ii) Since co-axial cables don't radiate, then won't pick up energy or influenced by other strong fields. Ex: Radio, Dish Antenna.

Electrical Diagrams and Identification Schemes

A diagram is required for the aircraft electrical installations to provide the practical guide to the system. The standards to which all diagrams are drawn are laid down by national organisations like British Standard Institution, Society of British Aerospace Constructors and Air Transport Association of America.

There are usually three types of diagram produced for aircraft namely, circuit diagrams, wiring diagrams and routing charts.

Circuit Diagrams:

These are of a theoretical nature and show the internal circuit arrangements of electrical and electronics components both individually and collectively, as a complete distribution or power consumer system.

Wiring Diagrams:

These diagrams are more practical nature and they show all components and cables of each individual system making up the whole installation, connected to each other, locations within the aircraft and groups of figures and letters to indicate how all components can be identified directly on the aircraft.

Routing Charts:

These charts have a similar function to wiring diagrams, but the components and cables are drawn under location headings, so that the route of distribution can be readily traced out on the aircraft.

Wiring diagrams and routing charts are provided for the use of maintenance engineers to assist them in their practical tasks of testing circuits, fault finding and installation procedures. The number of diagrams or charts required for a particular aircraft depends on the size of the aircraft.

Coding Schemes:

It is used to correlate the details illustrated in any particular diagram with the actual physical conditions, i.e. where items are located, sizes of cables used. The scheme either be to the manufactures own specification, or to one revised as a standard coding scheme.

Example: The coding for cable installations consists of a six position combination of letters and numbers which is quoted on all relevant wiring diagrams and routing charts and it is printed on the outer covering of cables.

1 P 1 A 22 N

Position 1: The number in this position is called the unit number and it is only used where components have identical circuits.

Position 2: A letter in this position is used to indicate the function of the circuit. It designates the circuit or system with which the cable is connected.

Position 3: The number in this position is that of the cable and is used to differentiate between cables which don't have a common terminal in the same circuit.

Position 4: The letter in this position denotes the segment of cable and differentiates between segments in a particular circuit when the same cable number is used throughout. A different letter is used for each of the cable segments having a common terminal or connection.

Position 5: In this position, the number used indicated the cable size and corresponds to the American Wire Gauge range of sizes.

Position 6: A letter used in this position indicates whether a cable is used as a connection to a neutral or earth point, an a.c. phase cable or as a thermocouple cable.

The letter N indicates an earth connected cable; the letter V indicated a supply cable in a single phase circuit. In three phase circuits the cables are identified by the letters, A, B and C. Thermo couple cables are identified by letters which indicate the type of conductor material. AL (Alumel), CH (Chromel), CU (Copper), CN (Constantan).

The coding schemes adopted for items of electrical equipment, control panels, connector groups, junction boxes, etc, are related to physical locations within the aircraft and for this purpose the aircraft is divided into electrical zones. A reference letter and number are allocated to each zone and also to equipment, connectors, panels etc., so that they can be identified within the zones.

Logic Circuits and Diagrams:

The components such as resistors, capacitors and rectifiers are normally interconnected as separate discrete components and embedded in micro size sections of semiconductor material. The form of integration makes possible the production of circuit packs capable of performing number of individually dedicated functions. The packs consists of basic decision making elements referred to as logic gates, which performs combinational operations on their inputs and determines the state of their outputs.

Logic Gates:

Logic Gates are of binary nature. The inputs and the outputs are in one of two states expressed by the digital notation 1 or 0. If the states are represented by voltage levels, one may be positive and the other 0-volts.

The below figure 1.4 is an example of a logic diagram related to a system designed to give warning of low pressure in the pressurised cabin of an aircraft. With the cabin pressure in its normal range, the pressure switch is open and if the cabin pressure go below normal it will be sensed by the pressure switch whose contacts will change over to provide a connection to the inverter, so that the horn will be activated.

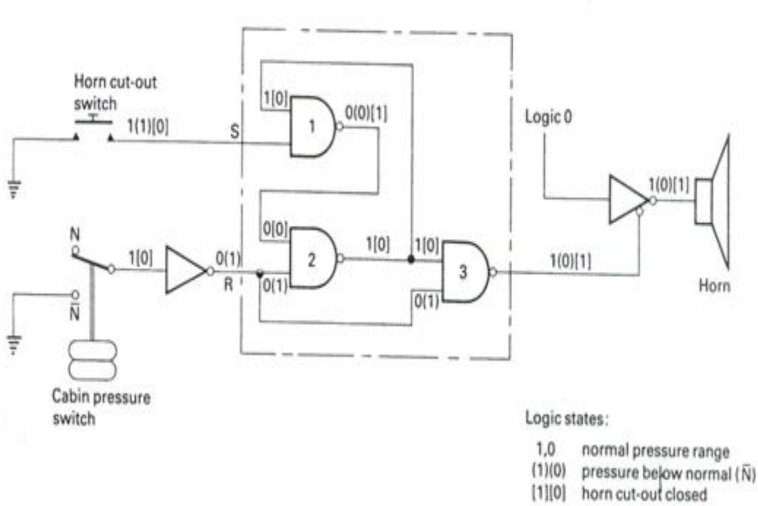


Figure 1.4 Logic diagram of a low pressure warning system

The below logic diagram (figure 1.5) is an example of a landing gear aural warning system. This system operated a horn to warn the flight crew that the landing gear is not down and locked when the trailing edge flaps are set to the landing configuration or any engine thrust lever is set to the idle position. The switches A to F represent input sensors which are activated by the flaps, landing gear and engine thrust levers. When the flaps are in the landing configuration and the landing gear is not down and locked, the horn will make a sound. When the landing gear is fully extended to the down and locked position, the horn will be silenced. The horn can be also be silenced by depressing the cut out switch.

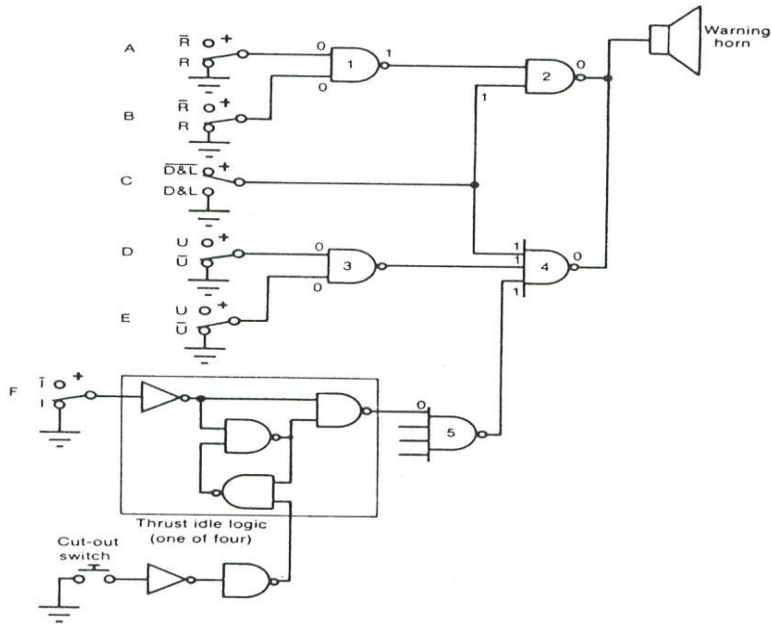


Figure 1.5 Logic diagram of a landing gear warning system

Circuit Controlling Devices:

In aircraft the operating sequences of circuits are performed by switches and relays.

Switches:

It consists of two contacting surfaces which can be isolated from each other or brought together by a movable connecting link. The connecting link is referred as pole.

Types:

i) Single pole, single throw switch
ii) Single pole, double throw
iii) Double pole, single throw
iv) Double pole, double throw
v) Based on number of positions. It is classified into
   a) Single position switch
   b) Two position switch
   c) Three position switch (Selector switch) centre – off, two on position.

Toggle Switches:

Toggle or tumbler type switches are used extensively in various circuits.

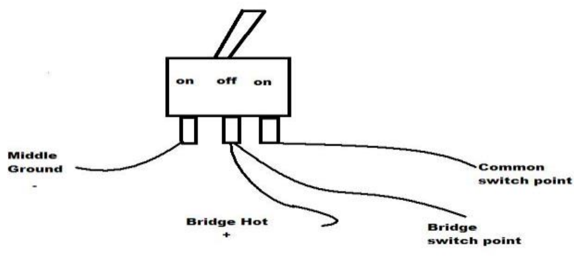


Figure 1.6 Toggle Switch

Push Switches:

It is used primarily for operations of short duration, i.e. when a circuit is to be completed or interrupted for brief periods. Switches may be designed as independent units for either 'push-to-make' or 'push-to-break' operation. In some circuits, for example in a turbo propeller engine starting circuit, switches are designed to be both manual and electromagnetic in operation and it is referred to as 'push-in solenoid switch'.

Rocker-Button Switches:

It combines the action of both toggle and push button type switches and is utilized for circuit control of some equipment.

Rotary Switches:

These are manually operated for certain operating requirements. A typical application is the selection of a single voltmeter to read the voltages at several bus bars.

Micro Switches:

It is mostly used in aircraft, performing a wide range of operations to ensure safe control of variety of systems and components. The term micro-switch designates a switching device in which the differential travel between make and break of the operating mechanism is of the order of a few thousands of an inch. Magnification and snap action of contact mechanism movements are derived from a pre-tensioned mechanically biased spring.

These switches are used to sense if a device has moved or has reached its limit of travel. Ex. Flap drive or undercarriage mechanisms. Micro-switches are attached to the structure and the wiring is connected into a control circuit. An example is to sense when the aircraft is on ground and this is achieved by mounting a micro-switch on the oleo leg. When the aircraft is on the ground, the oleo leg compresses and the switch is operated, and these switches are used to sense the mechanical displacement of variety of devices like control surfaces, under carriage, pressure capsules, bi-metallic temperature sensors and mechanical timers.

Rheostats:

These are controlling devices containing a resistance the magnitude of which can be varied, thereby adjusting the current in the circuit in which it is connected.

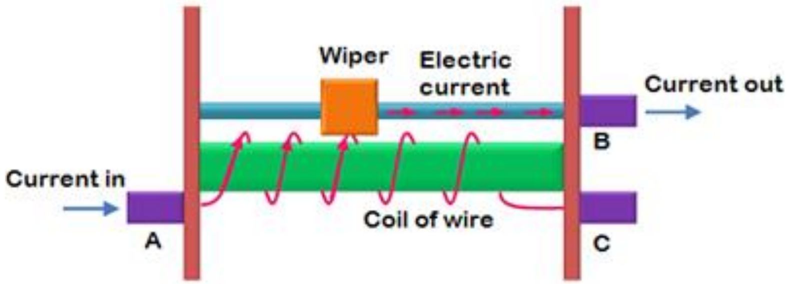


Figure 1.7 Rheostats

Proximity Switches:

They perform the same function as micro switches, they sense the presence of an object by the interruption of a magnetic circuit.

Types: Reed and Solid state.

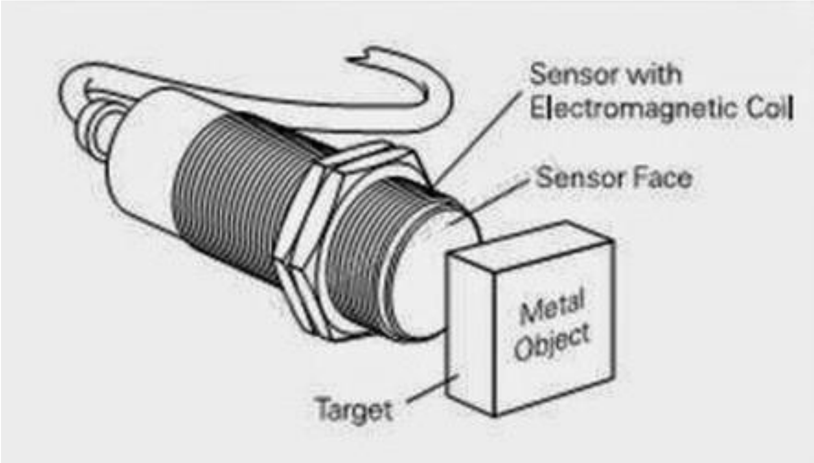


Figure 1.8 Proximity Switch

Time Switches:

In this, switches automatically operated by timing mechanisms. The principle of time switches operation varies, but in general it is based on the one in which a contact assembly is actuated by a cam driven at constant mechanism. In some cases, thermal principle is used.

Mercury Switches:

These are glass tubes into which stationary contacts and a pool of loose mercury are sealed. Tilting the tube causes the mercury to flow in a direction to close or open a gap between the electrodes to make or break the circuit.

Application:

Torque motor circuits of gyro horizons in which the gyro's must be processed to and maintained in the vertical position.

Pressure Switches:

It consists of a metal diaphragm bolted between the flanges of a metal diaphragm bolted between the flanges of two section of the switches body. One side of the diaphragm is open to the pressure source and other side a push rod is placed and connected to the warning or indicator system.

Thermal Switches:

Its principle is based on the effects of differences of expansion between two metals, usually invar and steel.

Power Utilization-Typical Application to Avionics

The various ways in which the power is utilized within the aircraft depends on the size and type of the aircraft. Some typical applications are, motors used in conjunction with mechanical systems (e.g. a motor driven fuel value), systems which are principally electric (e.g. engine starting and ignition system).

Motors:

A variety of components and systems depend upon mechanical energy provided by motors. Some typical application of motors is given in the below table.

System	Function
Actuators	Fuel trimming, cargo door operation, heat exchanger control flap operation, landing flap operation.
Control Values	Hot and cold air mixing for air conditioning and thermal de-icing, fuel shut-off.
Pumps	Fuel delivery, De-icing fluid delivery, hydraulic fluid supply.
Flight instruments	Gyroscope operation
Control system	Servo Control.
Ignition system	Engine Starting.

Lighting

Lighting plays an important role in the operation of an aircraft and its system, it is divided into two groups.

- External Lighting.
- Internal Lighting.

The principal applications of external and internal lighting are given below.

External Lighting:

The marking of an aircraft's position by means of navigation lighting, anti-collision lighting, rotating beam lighting, strobe lighting.

- Positing marking by means of flashing lights.
- Forward illumination for landing and taxing.
- Illumination of wings and engine air intakes to check for icing.
- Illumination to permit evacuation of passengers after an emergency landing.

Internal Lighting

- Illumination of cockpit instruments and control panels.
- Illumination of passenger cabins and passenger information signs.
- Indication and warning of system operating conditions.

Questions

Part – A

1. Brief about the types of consumers.
2. Differentiate bus bar system and split bus bar system.
3. Provide the classification of switches.
4. Write down the application of motors in avionics.
5. Give details about the types of lighting.

Part – B

1. Explain about Bus Bar system with neat diagram.
2. With clear illustration describe about the Split Bus Bar system.
3. Write Notes on. i. Special Purpose Cables ii. Power Utilization.
4. Describe about the circuit controlling devices in the aircraft electrical system.
5. With neat diagram explain about the landing gear warning system.

2

INERTIAL NAVIGATION SYSTEM

Gyroscopic versus Inertial platform. Structure of stable platform. Inertial Navigation units. Inertial alignment. Inertial interface system. Importance of Compass swing.

Gyroscope

Gyroscope is an instrument, which senses inertial angular motion about its input axis without external reference. The angular rate information is obtained either from the inertial reference gyros or from other set of gyros. The Physical laws are utilised to develop operational gyros and they are,

- Gyros based on conservation of angular momentum of a spinning rotor.
- Gyros based on Coriolis effect on a vibrating mass.
- Optical Gyros based on Sagnac effect.

Spinning Rotor Gyro:

In this type of gyroscope (figure 2.1), the rotor or spinning wheel rotating at high speed in a universal mounting, called a GIMBAL, so its axle can be pointed in any direction.

The peculiar actions of a gyroscope, though they may appear to defy physical laws, actually depend entirely upon Sir Isaac Newton's laws of motion.

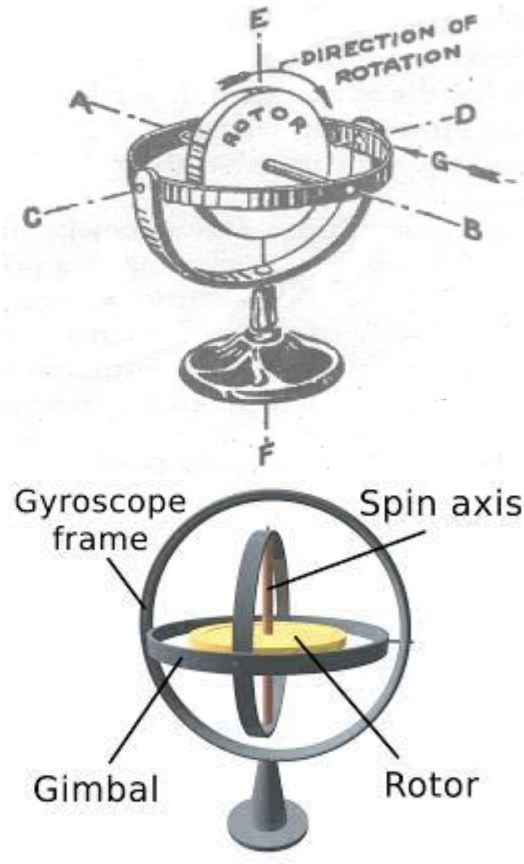


Figure2.1 Spinning Rotor Gyro

CD – Spin Axis
AB – Tilt Axis
EF – Veer Axis

All of the practical applications of the gyroscope are based upon two fundamental characteristics: gyroscopic inertia [rigidity in space] and precession.

Gyroscopic Inertia:

It is the tendency of any rotating body, if undisturbed, to maintain its plane of rotation.

When the rotor is spinning about its axis A-B, the direction of this axis will remain fixed in space, regardless of how the base of the gyroscope is moved around it.

Precession:

It is the tendency of a rotating body, when a force is applied perpendicular to its plane of rotation, to turn in the direction of its rotation 90 degrees to its axis and take up a new plane of rotation parallel to the applied force.

Types of Spinning Rotor Gyro:

1. Single Degree of Freedom Gyro.
2. Two Degrees of Freedom Gyro

GYRO INSTRUMENTS:

Gyro instruments have made the art of piloting an aircraft more precise. In most general aviation aircraft's, there are three gyro instruments namely;

1. The heading indicator.
2. The attitude indicator
3. The turn and slip indicator or turn and bank indicator.

THE HEADING INDICATOR:

- The heading indicator also known as the "Directional Gyro" is an instrument designed to indicate the heading of the aircraft and, because it is steady and accurate, to enable the pilot to steer that heading with the least effort.

❖ The gyro wheel in the heading indicator is mounted vertically and spins about its horizontal axis at approximately 12,000 rpm.

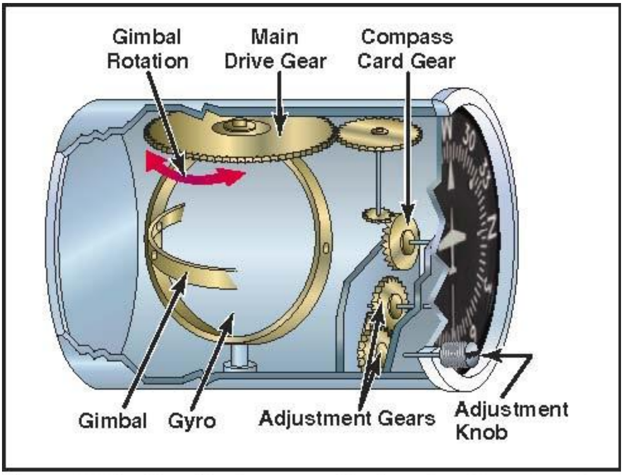


Figure 2.2 Heading Indicator

In the figure 2.2 the heading indicator displays headings based on a 360 deg azimuth, with the final zero omitted. The adjustment knob is used to align the heading indicator with the magnetic compass.

The spinning gyro wheel is mounted in an inner Gimbal ring that is free to turn about the horizontal axis.

- The inner ring is, in turn, mounted inside an outer gimbal ring.
- The compass rose card on the face of the instrument is attached by series of gears to the outer gimbal ring.

- As the aircraft turns, the compass card rotates indicating a turn to the left or right.
- A heading indicator in common use today is shown in figure, the compass rose card turns as the aircraft turns and the heading is read opposite the nose of the aircraft pointer.

THE ATTITUDE INDICATOR:

- The attitude indicator also called the artificial horizon or the gyro horizon provides the pilot with an artificial horizon as a means of reference when the natural horizon cannot be seen because of cloud, fog, rain or other obstructions to visibility.
- It shows the relationship between the wings and nose of the aircraft and the horizon of the earth which is shown in figure 2.3.
- In the attitude indicator, the gyro wheel is mounted horizontally and spins about its vertical axis.

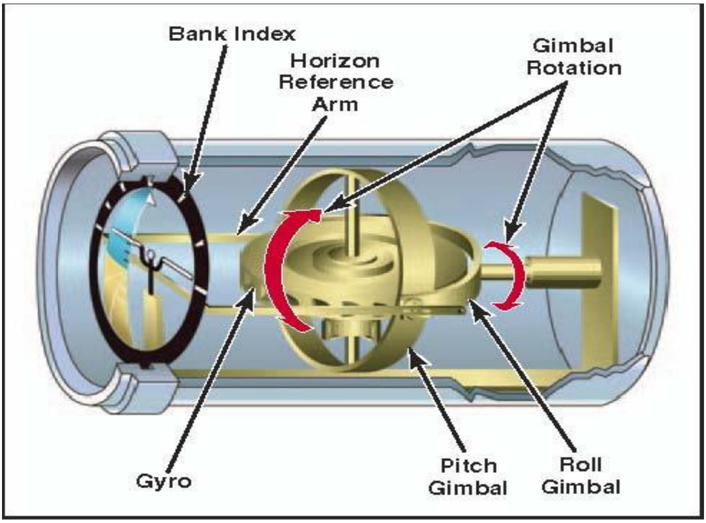


Figure 2.3 Attitude Indicator

- It is mounted in a universal gimbal ring system, free about both the pitching and rolling axes of the aircraft and is therefore able to remain spinning in a horizontal plane parallel to the true horizon, regardless of the rolling or pitching movements of the aircraft around it.
- When the aircraft noses up, the gyro wheel remains horizontal. A relative down force is exerted on the pivoted arm to which the horizon bar is attached, causing the horizon bar to sink below the split bar.
- When the aircraft noses up, the miniature aircraft rises above the horizon bar, indicating a nose high condition.
- When the aircraft noses down, the miniature aircraft sinks below the horizon bar, indicating a nose down condition.
- When the aircraft banks, the miniature airplane banks on the horizon bar and the pointer indicates the degree of bank on the index scale.
- When it is necessary to fly the aircraft slightly nose up or down, according to altitude, power and load, the miniature airplane can be adjusted to match the horizon bar by means of a knob at the bottom of the case.

TURN & SLIP [OR] TURN & BANK INDICATOR

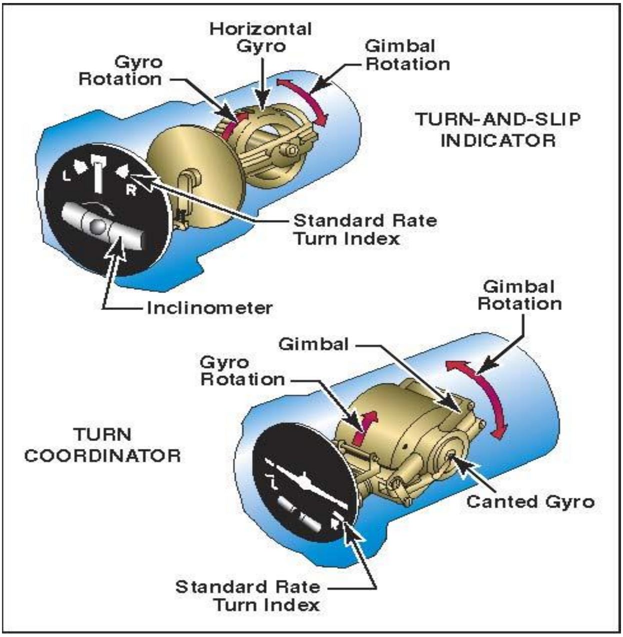


Figure2.4 Turn and Bank Indicator

The turn and slip indicator which is shown in figure 2.4 combines two instruments in one and is sometimes called the needle and ball.

- The needle indicates the direction and approximate rate of turn of the aircraft.
- The ball indicates the amount of bank in the turn, that is, whether there is any slipping or skidding in the turn.
- The ball is controlled by gravity and centrifugal force.
- It is simply an agate or steel ball in a liquid filled, curved glass tube.

- In a balanced turn, the ball will remain in the center as centrifugal force offsets the pull of gravity.
- In a slip, there is not enough rate of turn for the amount of bank.
- The centrifugal force will be weak and this imbalance will be shown by the ball falling down toward the inside of the turn.
- In a skid, the rate of turn is too high for the amount of bank.
- The centrifugal force is too strong and this imbalance is indicated by the ball sliding toward the outside of the turn.
- The turn needle is actuated by a gyro wheel operated either electrically or by a venturi tube or vacuum pump.
- The gyro wheel is mounted vertically and rotates about its horizontal axis.
- The basic principle, which governs the operation of the turn needle, is gyroscopic precession.
- The spinning gyro wheel, or rotor, is mounted in a gimbal ring.
- When the aircraft turns to the right or left, the gyro wheel precesses about its turning axis and rolls the gimbal ring.
- The rolling motion of the gimbal ring in turn rotates the turn needle on the face of the instrument.
- A spring returns the gyro to neutral when the aircraft ceases to turn.
- The turn indicator indicates the rate of the turn, not the amount of the turn.
- The instrument is usually calibrated to indicate a rate one turn when the turn needle is centered on

one of the indexes seen either side of the center index.

1. In a straight and level flight, the ball and needle are both centered.
2. In a correctly banked turn, the needle indicates the rate of turn, the forces acting on the ball cause it to remain centered.
3. If one wing is permitted to drop, the ball will roll towards the side of the low wing, the needle shows the aircraft to be flying straight, but the ball indicates it to be right wing low.
4. If the aircraft is not sufficiently banked in a turn, a skid towards the outside of the turn will occur, the needle indicates a left turn, the ball a right skid outwards.

When the aircraft is over banked in a turn, it will sideslip inwards. The needle indicates a left turn, the ball a sideslip inwards.

Structure of Stable Platform

In this system the accelerometers are kept horizontal which is shown in the figure 2.5, so that they do not sense the gravity vector. This is called as **stable platform (Gimbal) mechanization**.

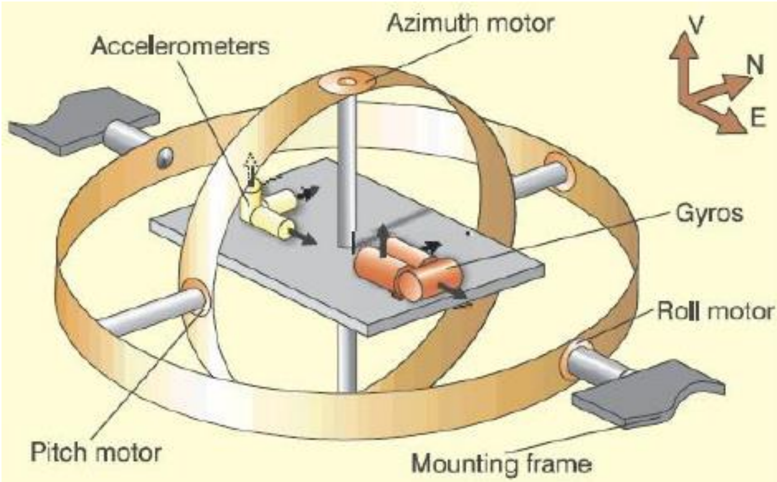


Figure2.5 Stable Platform

Inertial Frame

The term inertial frame means a reference frame that is non-rotating and non-accelerating in inertial space. Newton's laws of motion are valid in this frame. It is a frame where navigation accelerometer measures the specific force without requiring any compensation for Coriolis as well as centrifugal forces. This frame is considered stationary with respect to distance stars. For majority of navigation application, the inertial frame should be earth based, so the Earth Centred Inertial frame has emerged.

Platform Axes

The platform or inertial measuring axis frame commonly adopted for latitudes below 80 deg is an Earth referenced axis frame known as local level, North slaved axis frame.

In the case of a stable platform INS mechanisation, this enables the gimbal angles to provide a direct read out of the aircraft Euler angles. The term platform is used to denote a gimballed stable platform, or the virtual stable platform maintained in the Strapdown INS computer.

Stable Platform and Strap down System

The orientation of an aircraft with respect to a fixed inertial reference frame of axes is defined by the three Euler angles (Definition of Angles of pitch, bank & yaw).

There are two basic inertial mechanizations which are used to derive the Euler angles to the required accuracy.

i) Stable platform system – It has the gyros and accelerometers mounted on a platform which is suspended in a set of gimbals shown in figure 2.6. The gyros then control the gimbal servos, so that the platform maintains a stable orientation in space. Angular position picks-offs on the gimbals then provide a direct read-out of the Euler Angles.

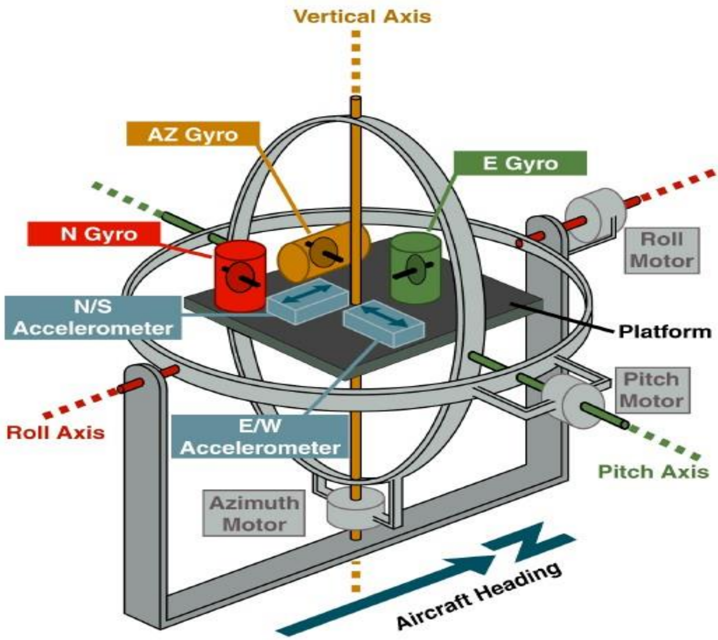


Figure2.6 Stable Platform

ii) Strap-down system – It has the gyros and accelerometers mounted on a rigid frame which is directly fixed, that is strapped down to the airframe. The gyro's and accelerometers thus measure the angular and linear motion of the aircraft with respect to aircraft's body axes, and the Euler angles are computed by the computer.

Inertial Navigation System

It is an autonomous dead reckoning method of navigation. (I.e. it won't require any external inputs or references from ground station). This system was developed by US Military in 1950's and it was introduced in commercial aircrafts in 1970's. This system can compute navigation data such as present position, distance, heading, ground speed and wind speed and wind direction.

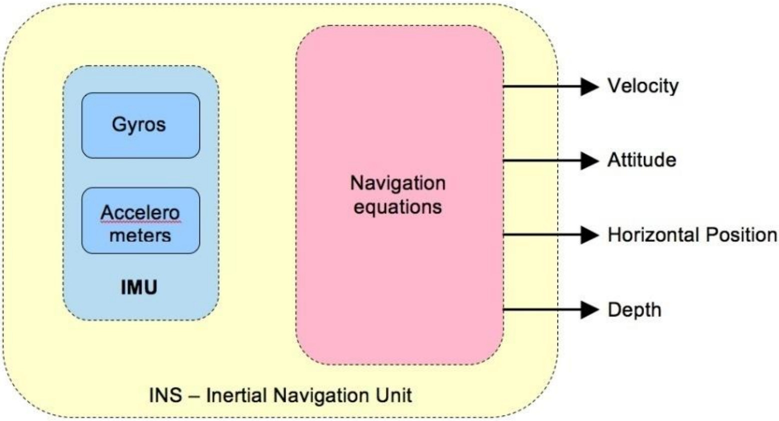


Figure2.7 INS Unit

Principles

The primary sensors used in the system are accelerometers and gyroscopes to determine the motion of the aircraft. These sensors provide reference outputs to develop navigation data.

Accelerometer

This is formed with a mass and two springs within a housing. Moving the accelerometer to the right causes a relative movement of mass to the left. When the accelerometer is moved to the left, the relative movement of mass is to the right.

Inertia

A mass continues in its existing state of rest or movement unless the applied forces changes and this is the property of inertia.

A transducer is used to measure the amount of relative movement of the mass. This relative movement is in direct proportion to the acceleration being applied to the device.

Time x Acceleration = Velocity
Time x Velocity = Distance

So the accelerometer is providing the velocity and distance, but measured in one direction. If we take two accelerometers and mount them on a platform at right angles to each other we can measure the quantities in any lateral direction.

Gyros

Electromechanical gyros are used in inertial navigation system, and these are replaced by more reliable and accurate ring laser gyro. RLG uses interference of laser beam within an optic path or ring to detect the rotational displacement which is shown in figure 2.8.

Inertial Reference Unit = Accelerometer + Gyros
Inertial Navigation Unit = Accelerometer + Gyros + Navigation Processing Unit

Advantages

There is no moving parts in RLG, so no friction, Compact, Light weight, Long and Reliable life time (30000 hrs), Fit and Forget and Low cost.

Sagnac Effect

A beam of light is split and the two beams are made to follow a trajectory in opposite directions. On return to the point of entry the light is allowed to exit the apparatus, in such a way that an interference pattern is obtained. A ring laser is a laser in which the laser cavity has the shape of a ring.

An optical cavity or optical resonator is an arrangement of mirrors that forms a standing wave cavity resonator for light waves.

The detector measure differences in frequency using Doppler principle. The beam that is travelling in the direction of rotation of the plat form has a longer distance to travel having a low frequency. The beam travelling against the direction of motion has a shorter path and a higher frequency. The difference in frequency is directly proportional to the rotation rate.

Resonance

It is the tendency of a system to oscillate at greater amplitude at some frequencies than at others. This resonance was exhibited by a resonator.

Standing wave is formed by the superposition of two waves of the same frequency propagating in opposite directions.

If a ring laser is rotating, the two counter propagating waves are slightly shifted in frequency and a beat interference pattern is observed, which can be used to determine the rotational speed.

Ring laser gyros use interference of a laser beam within an optical path or ring to detect rotational displacement. An IRU contains three such devices for measuring changes in pitch, roll & azimuth. Two laser beams are transmitted in opposite direction within a triangular block. The two laser beams travel the same distance, but in opposite directions, and they arrive at the detector at the same time.

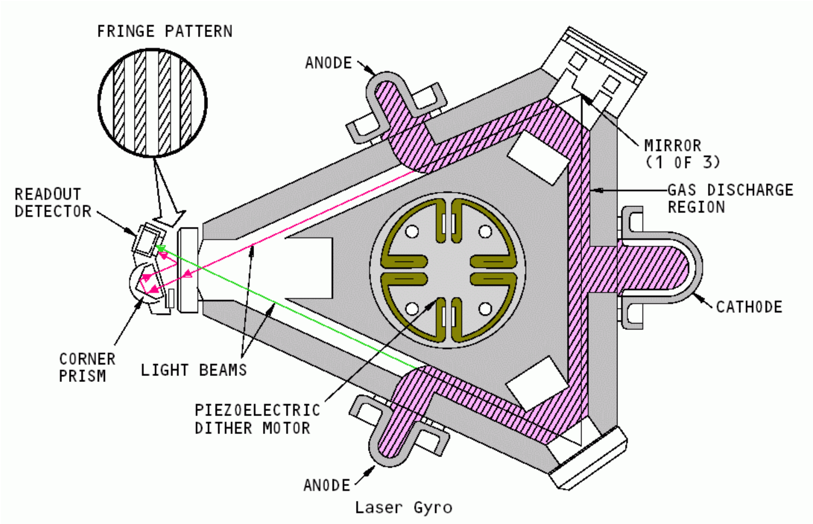


Figure2.8 Laser Gyroscope

In the aircraft RLG application, when the aircraft attitude changes, the RLG rotates. So the laser beam in one path now travels a greater distance than the beam in the other path. This changes its phase at the detector with respect to the other beam.

The angular position is measured by the phase difference of two beams. This phase difference appears as a fringe pattern. The fringe pattern is in the form of light pulses that can be directly translated into a digital signal.

Disadvantages

Lock-in, when the frequency difference between the two beams is low (i.e. 1000 Hz), the two beams merge their frequencies. This can be avoided by mechanically oscillate or either or vibrate the RLG to minimize the amount of time in this lock-in region.

Fibre Optic Gyroscope

The fibre optic gyroscope illustrated in figure 2.9 also uses the interference of light through several kilometres of coiled fibre optic cable to detect angular rotation. Two light beams travel along the fibre in opposite directions and produce a phase shift due to Sagnac effect.

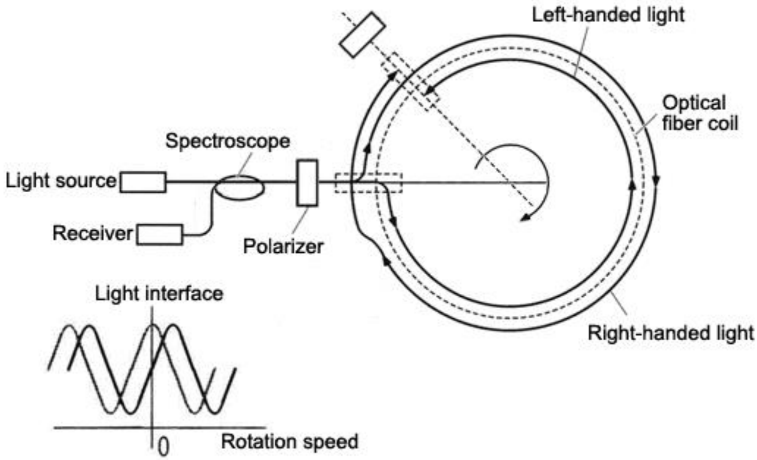


Figure2.9 Fibre Optic Gyroscope

Doppler Navigation

It is a self-contained dead reckoning system. (I.e. It won't require any external inputs or references from ground stations). Ground speed and drift can be determined using Doppler shift. Doppler Navigation Systems are developed in 1940's and introduced in 1950's, as a primary navigation system. This system can be used for long distance navigation over oceans and undeveloped areas of the globe.

Doppler Effect

The frequency of a wave apparently changes as its source moves closer to, or further away from an observer which is shown in figure 2.10.

DNS in aircraft have a focused beam of electromagnetic energy transmitted ahead of the aircraft at a fixed angle θ. This beam is scattered in all directions when it arrives at the surface of the earth. But some of the energy is received back at the aircraft. By measuring the difference in frequency between the transmitted and received signals, the aircraft's ground speed can be calculated.

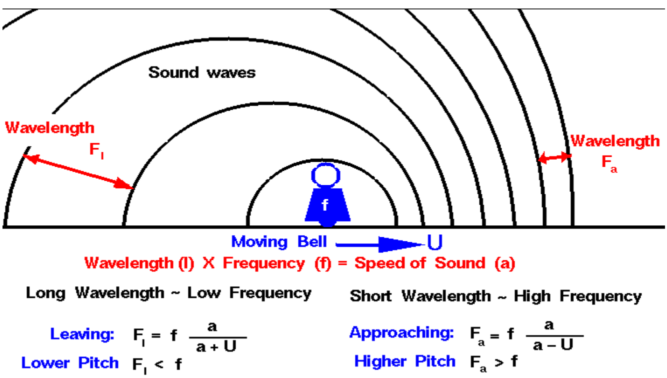


Figure2.10 Doppler Effect

The signal to noise ratio of the received signal is a function of number of factors.

i) Aircraft range to terrain

ii) Backscattering features of the terrain
iii) Atmospheric condition
iv) Radar equipment

If the aircraft pitched up or down, then the angle of beam with respect to aircraft and the surface will change. This can be overcome by any one of two ways.

i) The transmitter and receiver can be mounted on a stabilized platform.
ii) Two beams can be transmitted from the Doppler shift of both beams a true value of ground speed can be calculated.

Drift:

The drift can be calculated by directing a beam at right angles to the direction of travel, and applying the same principle.

Due to wind forces, the direction of movement of aircraft or track is not the same as heading.

The angle between heading and track is known as drift angle.

Ground speed is the speed of an aircraft relative to the ground.

Ground speed – Vector sum of aircraft's True Air Speed, current wind speed & direction.

Satellite Navigation:

Technology: GPS, Wide Area Augmentation system, Ground based Augmentation system, Receiver Autonomous Integrity Monitoring.

GPS is operated and maintained by the US DOD.
Four essential ingredients of GPS satellite are,

i) Start time (Transmission time)
ii) Ephemeris (Satellite location)
iii) Arrival time (Reception time)
iv) Distance travelled (Travel time & range)

Travel time = Arrival time – Start time
Range = Speed of light x Travel time

Operation of three GPS satellites estimate latitude, longitude and altitude.

Inertial Navigation & Global Positioning System

- It is a type of dead Reckoning system.
- It is the self contained, autonomous and unjammable.
- It measures linear motion and rotations using accelerometers and gyroscopes.
- From the initial navigation data obtained from the other navigation system or user, the navigation computer gives the attitude, position and velocity.
- It is faster than the data given by the GPS.
- INS is very accurate over the short distance.
- It is of two different configurations based on the inertial sensor placement. They are

    a. Stable or Gimballed platform.
    b. Strap down platform

Stable or Gimballed Platform system

In which the Accelerometer and Gyro are placed in the stable platform which is maintained stable by the gimbal system. Then the acceleration measured in the inertial coordinates

Strap down Platform

In this system the accelerometers are mounted on the vehicle platform and are therefore fixed to the vehicle coordinate system. The acceleration measured are then in vehicle coordinates

Advantage and Disadvantage of Stable platform.

- It is very reliable, accurate and value for the money.
- The mechanical gimbal arrangement is very complex.
- Expensive and replacing , rebuild are very lengthy process
- Calibrations are very lengthy process

Error in INS

Alignment Errors	Roll, Pitch and Heading Errors
Accelerometer bias or offset	A constant offset in the accelerometer output that changes randomly after each turn-on.
Accelerometer scale factor error	It results in acceleration error proportional to sensed acceleration.
Nonorthogonality of gyros and accelerometers	The axes of accelerometer and gyro uncertainty and misalignment
Gyro drift or bias due to temperature changes.	A constant gyro output without angular rate presence.

Gyro scale factor error	Results in an angular rate error
Random noise	Random noise in measurement

Compass Swing

The process of swinging and compensating a ship or aircraft compass by determining and reducing the deviation coefficients and recording the residual deviations.

When to Perform a Compass Swing?

- Whenever the accuracy of the compass is suspected.
- After a cockpit modification or major replacement involving ferrous metal.
- Whenever a compass has been subjected to a shock; for example, after a hard landing or turbulence.
- After aircraft has passed through a severe electrical storm.
- After a lightning strike.
- Whenever a change is made to the electrical system.
- Whenever a change of cargo is likely to affect the compass.
- After an aircraft has been parked on one heading for more than a year.
- When flux valves are replaced.

Performing the Compass Swing

Mechanics typically use one of two methods to swing the compass on an aircraft. They either perform it on a compass rose at the airport, or use a calibrated master compass to align the aircraft during the swing. Always refer to the maintenance manual for manufacturer-specific swing procedures. Here are the steps involved in performing a compass swing.

With engines running and aircraft in proper configuration, align the aircraft to the 0 degree (north) heading. If the aircraft compass is not in alignment with magnetic north, adjust the north-south compensator screw with a non-metallic screwdriver until the compass reads 0 degrees.

1. Align the aircraft to the 90-degree (east) heading. If the aircraft compass does not indicate 90 degrees, adjust the east-west compensator screw until it reads 90.
2. Align the aircraft to the 180-degree (south) heading. Note the indicated heading on the aircraft compass. If it is not 180, adjust the north-south compensator screw to remove half the difference of the reading and actual heading. For example if the compass reads 184 while the aircraft is positioned at 180 degrees, adjust the north-south compensator until the compass indicates 182 degrees.
3. Align the aircraft to the 270-degree (west) heading. If the compass does not indicate 270, adjust the east-west compensator to split the difference as in the above step.

You are now ready to swing the aircraft around the headings. Starting with the current heading (270) mark down the actual reading on the compass. Turn the aircraft around the compass rose at each 30-degree heading and record the compass readings. Ensure there is not more than a 10-degree difference between any of the indicated headings on the compass and the actual heading. If the compass can't be adjusted to meet the requirements, install another one.

Digital Compass Swing

There is now a unit that can make performing a compass swing somewhat easier. Manufactured by Capital Avionics and distributed by Avionics International, the CA-320 digital compass system can help out of performing compass swings.

How it Works?

The CA-320 consists of two components. The first component is the CA-320A transmitter. The unit is battery operated. It is a digital compass that is accurate to 0.5 degrees. It has a sight laser and a wireless transmitter. The unit mounts outside the aircraft and transmits headings to the second component, the receiver.

The receiver sits in the cockpit visible to the person performing the compass swing. It receives signals from the transmitter and displays the heading on a LCD screen. The transmitter and receiver are wireless, needing no power cords or data link cords for operation.

Find a Clear Area

The first step of using the digital compass system to perform a compass swing is to find a clear area to perform a swing. You want to make sure that the area is free of metal structure that would interfere with the magnetic compass.

If there is a compass rose at your airport, that is a safe area to use. But remember, with this digital compass system, you do not need to be on the compass rose to perform the swing, just a clear area that will not interfere with the compass.

Set Up the Transmitter

The next step is to find a clear area on the wing where the transmitter will be mounted. This area should be free from excessive ferrous material. One way to find out if it is a good point is to place the transmitter on the ramp in front of the area on the wing where you are considering installation. Then, tow the aircraft forward. As the wing passes over the transmitter, look for any change in readings on the receiver. If there are no changes, this is a good place to mount the transmitter. Install the transmitter mounting bracket at this location.

Now you must align the transmitter to the aircraft. The easiest procedure the manufacturer recommends is to use a reciprocal alignment. You first start off by mounting the transmitter on the tripod in front of the aircraft. Then turn on the laser on the transmitter and use it to line up the transmitter to the center line of the aircraft. Once it is aligned properly, look at the reading on the receiver. Whatever that reading is, take the reciprocal reading (180 degrees out) and mount the transmitter on the mounting bracket at that reading. Just place the transmitter in its mounting bracket and rotate it until the desired reading is obtained on the receiver. Once the desired reading is obtained, tighten down the mounting hardware for the transmitter. Verify after tightening the hardware that the reading hasn't changed. Now you are ready to perform your compass swing. The actual procedure for performing a compass swing remains the same except that you will be referencing the readings on the receiver instead of having to line up with the lines on the compass rose.

Questions

Part – A

1. Brief about the properties of gyroscope.
2. Differentiate stable platform and strap down system.
3. Provide the classification of gyros.
4. Write down the application of INS.
5. Give details about the importance of compass swing.

Part – B

1. Explain about the gyroscope with neat diagram.
2. With clear illustration describe about INS.
3. Write Notes on. i. Attitude Indicator ii. Turn and Bank Indicator.
4. Describe about the structure of stable platform.
5. With neat diagram explain about the Doppler Navigation and satellite navigation.

3

FLIGHT CONTROL SYSTEM

Conventional systems, Mechanical Flight control system, Fly-by-wire system: - basic concept and features. Fly by Light. Pitch and Roll rate: - command and response. Control Laws. Frequency response of a typical FBW actuator. Cooper Harper scale. Redundancy and failure survival. Common mode of failures and effects analysis.

Conventional Systems

The attitude of the flight during flight can be controlled with the help of control surfaces. The primary flight control system provides pitch, yaw & roll control of the aircraft. This system includes,

a) Elevator
b) Rudder
c) Aileron

The primary flight control surfaces are incorporated in the wing and the empennage.

Horizontal Tail - Elevators (Pitch)
Vertical Tail - Rudder (Yaw)
Wings - Aileron (Roll)

In addition to the basic primary control surfaces, other surfaces are also used to attain the pitch, yaw and roll action.

Pitch control – Elevators – (Variable Incidence horizontal Stabiliser). It is used where the elevator surface is of In adequate size.

Canards

In order to attain the longitudinal stability the pitch control surfaces can be placed on the front fuselage. This is called as canards.

Longitudinal Stability – Pitch (Up & down)

Lateral Stability – Roll (Up & down)

Directional Stability – Yaw (Turn Right & left)

The yawing can be achieved through rolling.

Elevons

It is a wing trailing edge surface. It is used on tailless delta wing aircraft inorder to provide both the pitch and roll control.

Flaperons

It is a wing trailing edge surface. This is used on the aircraft for lifting from short runways.

Ruddervators

Combination of rudder and the elevator on the tail.

Stabilator

It performs the function of a Horizontal stabilizer and an Elevator. These are used on the light aircraft and the high performance military aircraft.

Secondary Control Surfaces

i) **Trim control surfaces**

Trim tabs were used for trimming an aircraft for straight and level flight. These small auxiliary control surfaces are hinged to the trailing edge of the elevator.

ii) **High Lift Devices**

a) Trailing edge flaps
b) Leading edge flaps or slats

These devices are used to provide higher lift at low speeds for take-off. And also used to increase the drag to slow down the aircraft during landing.

iii) Speed Brakes

These are called as air brakes, dive brakes or drag brakes. This is used to decelerate the aircraft in flight. It is designed to pop out of the wing at a near 90° angle to the airflow, which will increase the drag by spoiling the stream line.

iv) Spoilers

This is used to reduce the lift and the spoilers were first used to overcome aileron reversal due to aero elastic effects.

Mechanical Flight Control System

It is generally used on small aircraft. The primary flight control surfaces are moved manually by using push-pull rods.

Push Pull Rod Type

In this a sequence of rods are used to link the control surfaces to the cabin input.

Bell crank lever is used to alter the direction of the force and to obtain the coupling between stick movement and the control surface deflection.

This is used to transfer either tension or compression loads.

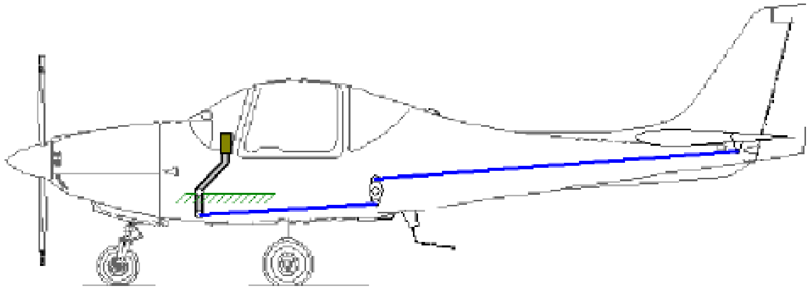


Figure 3.1 Push-Pull Control System Model

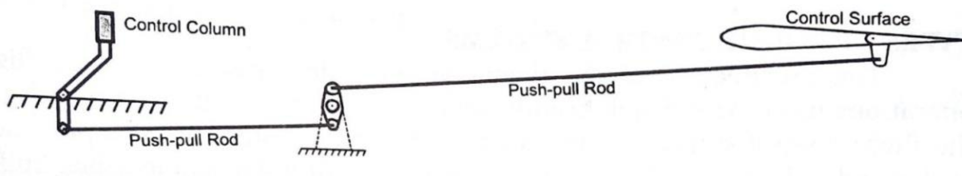


Figure 3.2 Schematic diagram of Push-Pull Control System

Cable Pulley Type

The cable pulley system requires large no of pulleys, brackets and guards. So this system becomes more complex and heavier. In this system we are using the cables instead of rods.

Pulleys – Used to alter the direction of lines.

Quadrant is employed at the base of the control column to impact force and motion to the cable system. A torque tube is attached to the control surface, which changes linear motion of the cable into rotary motion. For large aircrafts this type is preferable, because more flexible.

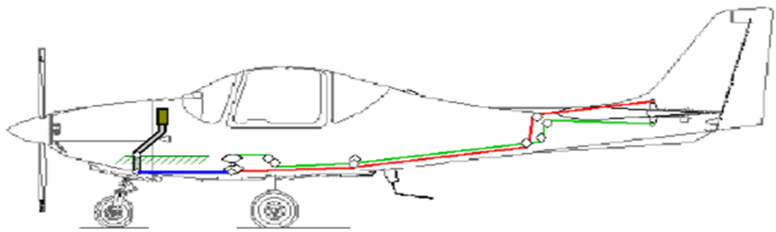


Figure 3.3 Cable Pulley Control System Model

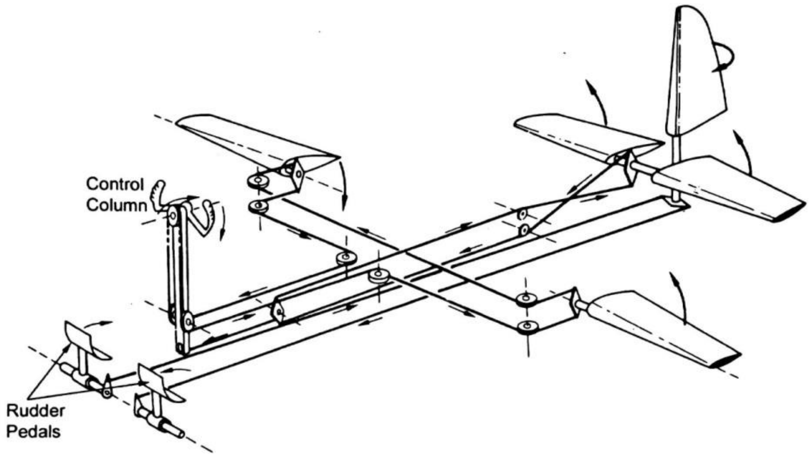


Figure 3.4 Schematic Diagram of Cable Pulley Type

Modern Control System

Due to the advent of advanced micro-electronics (light weight and reliable) systems are used to operate the conventional systems. In this the electronic signals are used to operate hydraulic jacks which can move the control surfaces. This modern control system is divided into two types. (i) FBW (ii) Autopilot

Fly By Wire Basic Concepts & Features

i) Total elimination of all the complex mechanical control runs and linkages. All commands and signals are transmitted electrically along wires.

ii) The interposition of a computer between the pilot's commands and the control surface actuators.

iii) The aircraft motion sensors which feedback the components of the aircraft's angular and linear motion to the computer.

iv) The air data sensors which supply height and airspeed information to the computer.

The pilot thus controls the aircraft through the flight control computer and the computer determines the control surface movement for the aircraft to respond to the pilot's command.

Modern FBW systems use a serial digital data transmission system with TDM, through a digital data bus. Military FBW system uses the MIL STD 1553 B data bus system. It has a data rate of 1 Mbps and a word length of 20 bits, so can receive or transmit upto 50000 data words/ second. The Boeing 777 uses the ARINC 629 data bus system which operates at 2 Mbps.

The FBW system without motion sensor is called as direct electric link system. The motion sensors comprise rate gyros for angular rates and linear accelerometers for linear rates.

Fly By Wire

In this control system the control inputs from the pilot are transmitted to the control surfaces by electronic signals. In this system, the control columns are having electronic transducers which sense the position of the control column and sends that information to independent computers. This information is used to adjust the position of control surfaces. The control signals are transmitted by wires to hydraulic unit. The hydraulic power is used to move the control surfaces.

In this flight control system the actuators are operated by electro – hydraulic servo valves. The electro – hydraulic servo valve is used to convert electric voltages into hydraulic power.

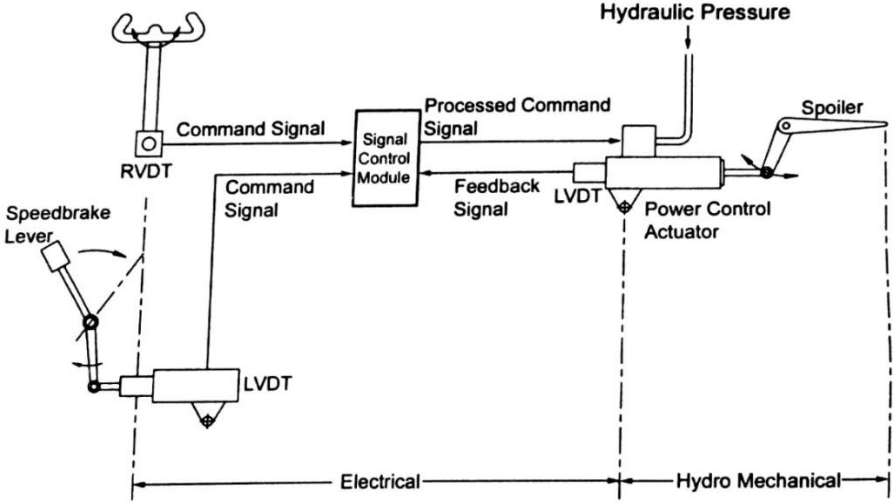


Figure 3.5 Schematic Diagram of Fly-by-wire Control System

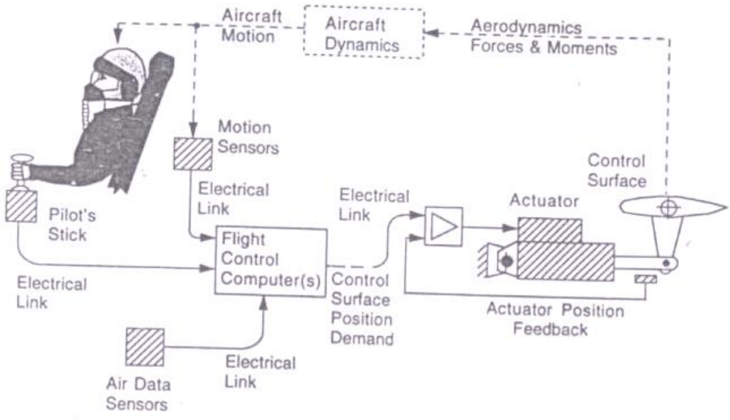


Figure 3.6 Fly-by-wire Control System

Linear Variable Differential Transformation

LVDT are used to translate linear motion into electrical signal.

RVDT are used to translate angular displacements into electrical signal.

The pilot's demand is compared with the feedback from LVDT/RVDT. When the feedback signal is equal to the command signal from the cockpit the movement of control surface stops.

In this system primary and secondary flight control computers are used for calculations concern with aircraft control and sending signals to the actuators. So this system is having fewer amounts of common errors.

In this system the following data are processed,

a) Pitch, Roll, Yaw rate and Linear Accelerations

b) Angle of Attack
c) Airspeed, Altimeter, Mach meter, Pressure gauge Indications.
d) Stick & pedal demands.

Fly By Light

It uses the optic cables for transmitting the control signals. It uses the electro – optic converters for converting light signals into electrical signals for actuating the hydraulic control valves.

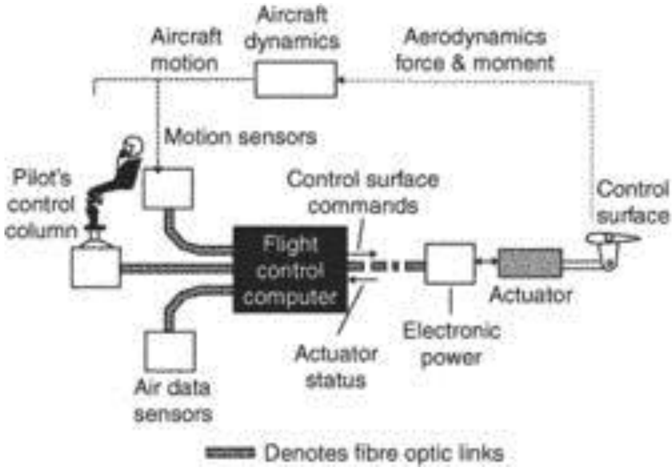


Figure 3.7 Fly-by-light Control System

Advantages

i) Fibre Optic cables are light weight
ii) Fibre optic cables are having high band width
iii) Fibre optic cables are having immunity to EMI
iv) Special shielding is not required.

Autopilot System

Autopilots are used to reduce the work, strain of controlling the aircraft during long flights. It is also used to guide a vehicle without assistance from a person. Autopilots are used in aircraft, boats, space craft, missiles and others. It provides control for one, two or three axis. The three axis system contains ailerons, elevators and rudders.

Autopilot system contains,

i) Gyros (to sense the aircraft's position)
ii) Servos (to move the control surfaces)
iii) Amplifier (to increase the strength of gyro signals)

The Gyro sensing units are connected to flight instruments which indicates direction, rate of turn, bank or pitch. If the flight attitude is changed electrical signals are developed in the gyros, and this is transmitted to the servo unit. And this servo unit is used to convert the electrical signals into mechanical force, which is used to move the control surfaces.

Basic Autopilot Components

i) The sensing elements
ii) Command elements
iii) Output elements
iv) Computing elements

The command unit is manually operated to produce signals which cause the aircraft to climb, dive or turns.

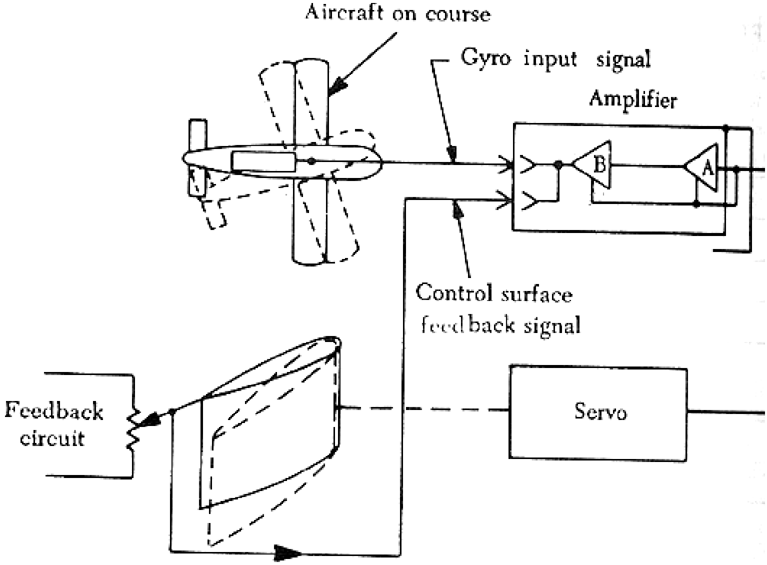


Figure3.8 Basic Autopilot System

Sensing Elements

a) Directional Gyro
b) Turn and Bank Gyro
c) Attitude Gyro
d) Altitude control and Navigation signals
e) Heading Selector

Computing Elements

This is used to process the signal and passes that one to the control surfaces.

Output Elements

Servos – 1) Electric Motors
2) Electro/Pneumatic servos

Servos is used to actuate the control surfaces

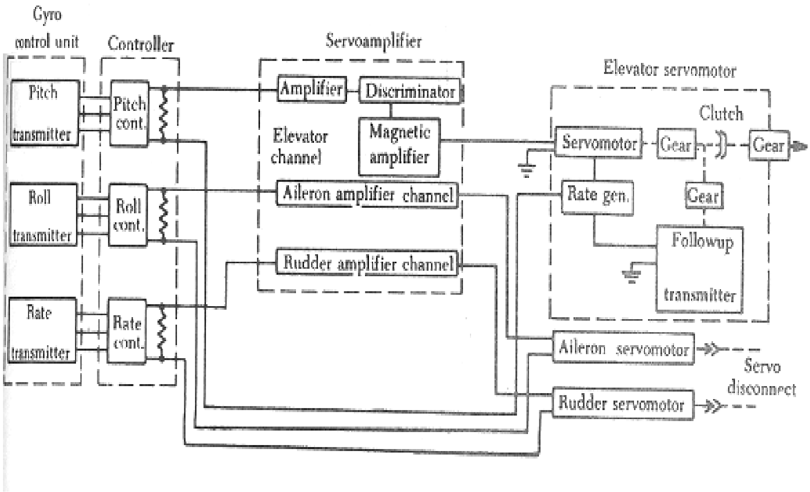


Figure3.9 Three Axis Autopilot System

A single axis autopilot control an aircraft in the roll axis only.
A two axis autopilot controls the pitch and roll axis.
A three axis autopilots controls the yaw, pitch and roll axis.

Modern autopilots use computer software to control the vehicle. The software reads the vehicle’s current position and then controls a flight control system to guide the vehicle. Besides classic flight controls many autopilots incorporate thrust control capabilities that can control throttles to optimize the speed.

The modern autopilots reads the vehicle’s position and attitude from an inertial guidance system, which uses a six dimensional Kalman filter. The six dimensions are Roll, Pitch, Yaw, Altitude, Latitude and Longitude.

Types

a. Longitudinal Autopilot Systems (Displacement Autopilot)
b. Lateral Autopilot Systems (Roll attitude Autopilot)
c. Self-adaptive Autopilot

Control Laws

It is used to define the algorithms relating the control surface demand to the pilot's stick command and the various motion sensor signals and the aircraft height, speed and Mach number.

Simple basic pitch rate command law would be,

$T_D = K (\theta_i - G_q q)$

T_D – Tail plane demand angle
θ_i – Pilot's input command
q – Pitch rate
k – Forward loop gain
G_q – Pitch rate gearing

Pitch Rate command Control

In the pitch rate command FBW flight control system which is illustrated in figure 3.3, the primary feedback of pitch rate for the pitch rate command loop is provided by the pitch rate gyros.

Increase of an aerodynamically unstable aircraft, a quasi incidence term is provided to counteract a positive (unstable) M_α.

Transfer Function:

$\alpha = T_2 \frac{1}{1+T2D}$ q compared with,

$\int q dt = (1/D)\ q$

The relationship between α and ∫ qdt can be seen from equations. Hence $\int q\,dt \approx \alpha$ for values of ω such that $\omega T_2 >> 1$.

Pitch rate Error $q_E = (q_D - q)$, q_D= demanded pitch rate.

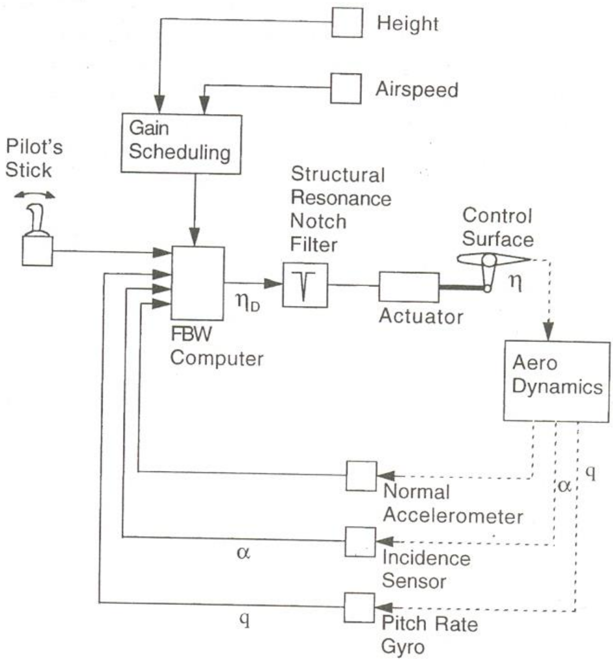


Figure3.10 Pitch rate command FBW loop

Solid State Gyros are very reliable sensors with MTBF (Mean Time Between Failures) in the region of 50000 to 100000 hours.

The airstream incidence sensors can also provide the stabilizing term to counter an unstable M_α, they have two inherent shortcomings, as far as a core stabilizing function is concerned.

i) Vulnerability to damage on the ground, or bird strikes in flight, as the sensors have to be mounted externally in the airstream.
ii) Problems in matching due to the differences in the local airflow at different locations. Ex. Two sensors located on the port side of the fuselage and two sensors on the starboard side.

The blending of normal acceleration and pitch rate is referred as C_N^* control.

Roll Rate Command Control

In this system which is shown in figure 3.4, the primary feedback term being roll rate from the roll rate gyros. Other sensors are used to control the rudder automatically to counteract and suppress the lateral cross-coupling effects. A yaw rate feedback term derived from the yaw rate gyros provides the yaw auto-stabilisation function and yaw incidence angle (β) from yaw incidence sensors and lateral acceleration from lateral accelerometers.

The air data gain scheduling is used to adjust the gearings of the control terms. Notch filters are used to attenuate the loop gain at the structural resonance frequencies.

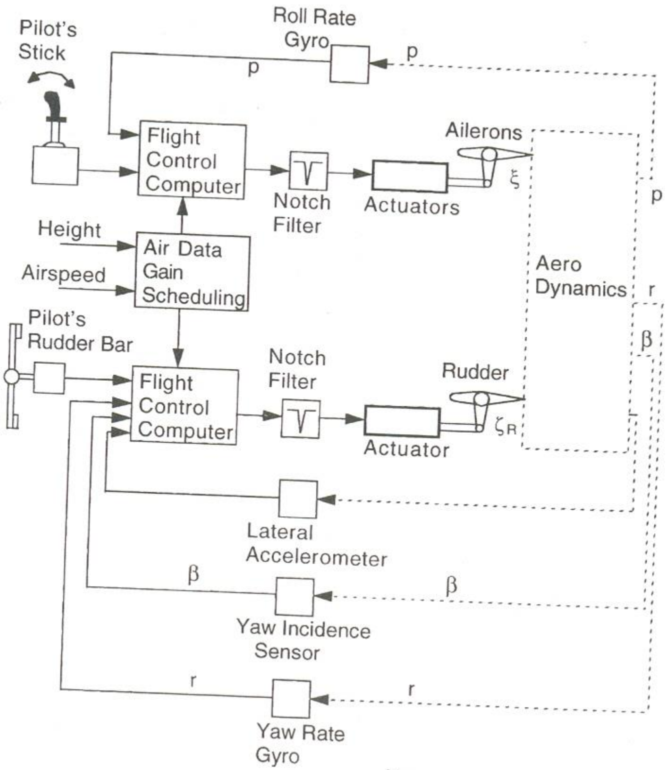


Figure3.11 Roll rate command FBW loop

Frequency response of typical FBW actuator

The response of actuators at low frequencies is basically that of a low pass filter, but as the frequency increases the lags in the first stage actuation system become dominant. The output/input ratio falls at an increasing rate and the phase lag rapidly increases. The frequency response of a typical FBW actuator is shown in the figure 3.5.

From the figure 3.5, the phase lag at 1 Hz is in the region of 10° to 12°, at 5 Hz it reaches around 50° . At 10

Hz, the lag is in the region of 90° and the output/input ratio has fallen to nearly 6 dB.

A full dynamic model of a typical FBW actuator is around an 11th order system when all the elements are taken into consideration, the response can change very suddenly. The response can also change rapidly if rate limiting occurs (it occurs when the control valve travel limits are reached under conditions of large amplitude demands) and the actuator can provide a sudden large increase in phase lag which is shown in dotted lines.

During extreme manoeuvres, if the rate limiting is encountered, the resulting additional phase lag in the actuator response can lead to a severe temporary reduction of the FBW stability margins.

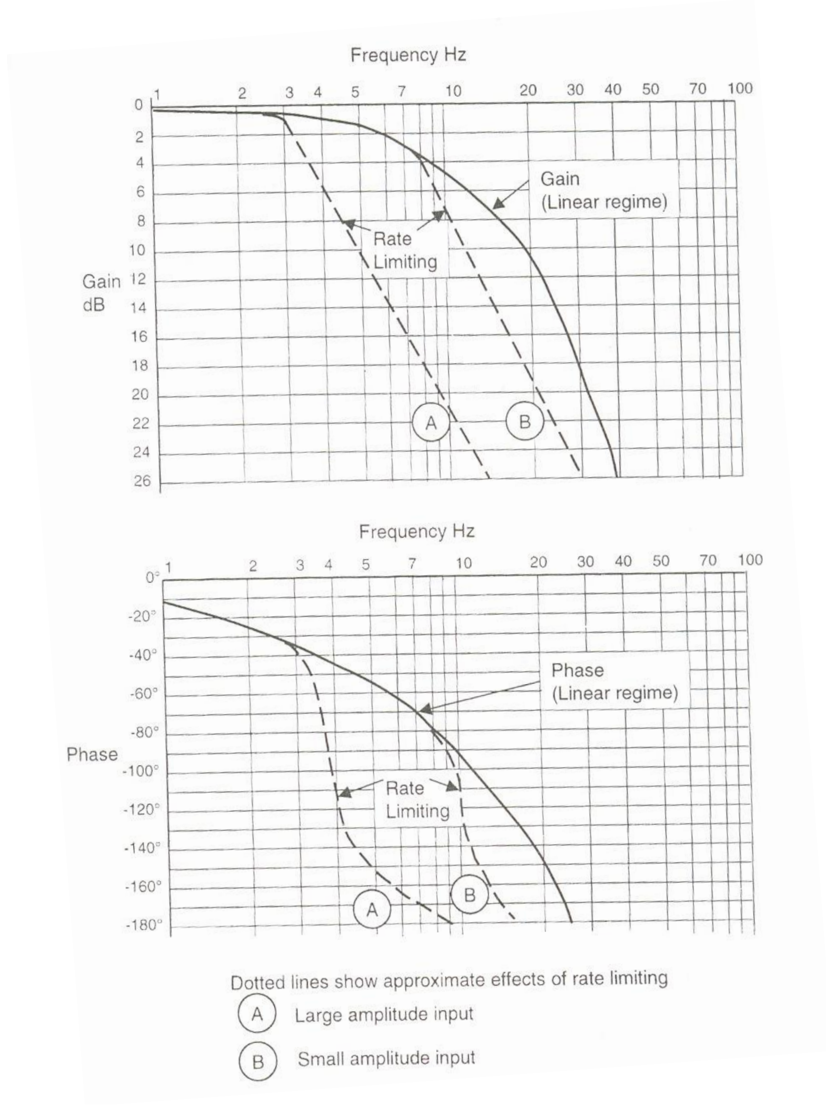


Figure3.12 Frequency response of typical FBW actuator

Cooper – Harper Scale

The quality of the handling characteristics and the pilot workload are generally expressed in terms of the Cooper-Harper scale of ratings from one to ten.

One – Excellent qualities.

Ten – Worst qualities.

These ratings are derived from pilot's comments in carrying out a range of tasks which are defined in terms of flight phase categories A, B and C.

Category A – Demanding tasks such as air to air or air to ground combat and in flight refuelling.

Category B – It covers less demanding tasks such as climb, cruise and descent.

Category C – It covers terminal tasks such as landing and takeoff.

Common Mode Failures

The type of failure which can affect all systems at the same time is termed as common mode failure.

Example:

i) Lightning strike
ii) Electro-magnetic interference
iii) Fire, explosion, battle damage
iv) Incorrect Maintenance
v) Common design errors Ex: Software

For instance, very stringent electro-magnetic shielding practices are used which includes, screened cables, segregation of cables and units, EM shielded boxes for all electronic components, wires with EM filters etc.

An alternative is to transmit all the signals as coded light pulses, suitably time division multiplexed along fibre optic cables, which was unaffected by EM interference. This is called as Fly by Light.

Hazards from fire, explosions or battle damage are minimized by the physical segregation and separation of individual channels and is referred as Brick wall separation philosophy.

The problem of eliminating the possibility of a common mode failure from the cause is known as Dissimilar Redundancy (D.R).

Dissimilar Redundancy

Use of two or more different types of microprocessors with dissimilar software. Use of a back-up analog system in addition to the main digital system.

Use of a back-up system using different sensors, computing and controls means. Modern airliner design practice is to split the basic control surface into two or three section, with each section controlled by its own actuation.

Failure Mode and Effect Analysis

An exhaustive failure modes and effect analysis of the flight control system is required by the flight control system is required by the regulatory authorities before a certificate of Airworthiness is granted.

In this, any part of the system can fail from any cause and it must be shown that the overall system can survive this failure and maintain safe flight.

The MTBF of each element in the system has to be established using well validated statistical data.

Questions

Part – A

1. Give details about conventional flight control system.
2. Define: Control Law.
3. Bestow details on Cooper Harper Scale.
4. Write notes on common modes of failures and effect analysis.
5. Give details about the redundancy and failure survival.

Part – B

1. Describe about the fly by wire basic concept and features.
2. With clear illustration describe about Pitch rate command.
3. Write Notes on roll command system with neat diagram.
4. Describe about the frequency response of FBW actuator.
5. With neat diagram explain about the autopilots.

INTRODUCTION TO AVIONICS SUB SYSTEMS AND ELECTRONIC FLIGHT INSTRUMENT SYSTEMS

4

Typical avionics subsystems. Amplifier, oscillator, aircraft communication system, transmitter, receiver, antenna. Display -units, presentation, failure, and annunciation. Display of air data

Typical Avionics Sub Systems

` The cockpit of an aircraft is a typical location for avionic equipment, including control, monitoring, communication, navigation, weather, and anti-collision systems.

Display Systems

It provides the visual interface between the pilot and the aircraft systems.

Types:

HUD - Head Up Displays

HMD - Helmet Mounted Displays

HDD – Head Down Displays

Communication Systems

It provides the two way communication between the ground bases and the aircraft or between aircrafts. A Radio

Transmitter and Receiver was the first avionics system installed in an aircraft.

Long Range Communication – HF (2 – 30 MHz)
Medium Range Communication – VHF (30 – 100 MHz)
Military Aircraft – VHF (250 – 400 MHz)

Now a day's satellite communications systems are used to provide very reliable communication.

Data Entry & Control System

It is essential for the crew to interact with the avionic system.

Ex: Keyboards, Touch Panels to use direct voice Input, voice warning systems and so on.

Flight Control System

It uses the electronic system in two areas.

(i) Auto Stabilization
   Roll Auto Stabilizer System
   Pitch Auto Stabilizer System

(ii) FBW Flight Control Systems

It provides continuous automatic stabilization of the aircraft by computer control of the control surfaces from appropriate motion sensors.

Aircraft State Sensor Systems

For control and navigation of the aircraft the air data quantities are essential.

Air Data Quantities - (Altitude, Calibrated Airspeed, Vertical speed, True Airspeed, Mach Number, Airstream Incidence Angle)

The air data computing system computes these quantities from the outputs of sensors which measure the static and total pressure and the outside air temperature.

Inertial Reference Systems

The aircraft attitude and the direction in which it is heading are provided by the inertial sensor systems (Comprise a set of gyros and accelerometers which measures the aircraft's angular and linear motion).

Navigation Systems

Dead Reckoning Systems

Position Fixing Systems

Navigation Information (Aircraft's position, Ground speed, Track angle)

DR Navigation systems derive the vehicle's present position by estimating the distance travelled from a known position from knowledge of the speed and direction of the vehicle.

Types of DR Navigation systems are,

i) Inertial Navigation systems (Most Accurate)
ii) Doppler / Heading Reference Systems (Used in Helicopters)
iii) Air Data / Heading Reference Systems (Low Accuracy when compared to above)

Radio Navigation Systems (Position Fixing Systems)

Satellite or ground based transmitter is used to transmit the signal and it was received by the receiver in the aircraft. According to the received signal's a supporting computer is used to derive the aircraft's position.

Prime Position Fixing System (GPS)

Instrument Landing Systems or Microwave Landing System is used for approach guidance to the airfield.

Outside World Sensor Systems

These systems comprise both radar and infrared sensor which enables all weather and night time operation.

Radar Systems

Weather Radar detects water droplets, cloud turbulence and warning about storms. In Fighter Aircrafts Multi Mode Radars are used for Ground attack role and interception role. The Radar must be able to detect aircraft upto 100 miles away and track several aircraft simultaneously (12 aircraft's). The Radar must have a look down capability to track low flying aircraft below it.

Infrared Systems

It is used to provide a video picture of the thermal image scene of the outside world by using fixed FLIR sensor or a gimballed IR imaging sensor. The thermal image picture at night looks similar to the visual picture in day time, but nightlights heat sources such as vehicle engines. FLIR can also be installed in civil aircraft to provide enhanced vision in addition with HUD.

Task Automation Systems

These systems reduce the crew workload and enable minimum crew operation.

Navigation Management System

It comprises the operation of all radio navigation aid systems and the combination of data from all navigation sources such as GPS and INS systems, to provide the best estimation of the aircraft position and ground speed.

Autopilots & Flight Management Systems

The autopilot relieves the pilot in long range mission.

FMS came into use in 1980's (Civil Aircraft). FMS tasks are,

- (i) Flight Planning
- (ii) Navigation Management
- (iii) Engine control to maintain the planned speed
- (iv) Control of Aircraft Flight Path
- (v) Minimizing Fuel consumption
- (vi) Ensuring the aircraft is at the planned 3D position at the planned time slot (for Air Traffic Control).

Engine Control & Management

Modern jet engines are having the Full Authority Digital Engine Control System (FADEC). This controls flow of fuel. This control system ensures the engine's temperature, speed and acceleration in control.

Engine health monitoring system record a wide range of parameters, so it will give early warning of Engine performance deterioration, Excessive wear, Fatigue damage, high vibrations, Excessive temperature etc.,

House Keeping Management

Automation of the background task which are essential for the aircraft's safe and efficient operation. Background tasks include:

i) Fuel Management
ii) Electrical power supply Management
iii) Hydraulic power supply Management
iv) Cabin/Cockpit pressurization systems
v) Environmental Control Systems
vi) Warning Systems
vii) Maintenance and Monitoring Systems.

Amplifier

An amplifier is a device that increases the strength of a signal and they are found in both transmitters and receivers. A transmitter must increase the strength of the signal sent to the antenna so that the electromagnetic waves will travel a useful distance outward from the antenna. A receiver needs amplifiers because the strength of the signal from the antenna is low and must be increased to enable the signal to be heard.

Amplifiers can be divided into Class A, Class B and Class C. The difference between these is the shape of the output waveform which is shown in figure 4.1.

The output of a class A amplifier is complete sine wave just like the input. The class B amplifier has an output which shows only half of each sine wave. The class C amplifier has an output waveform which is less than half of the sine wave. The class C amplifier is often used as a power amplifier because of its higher efficiency.

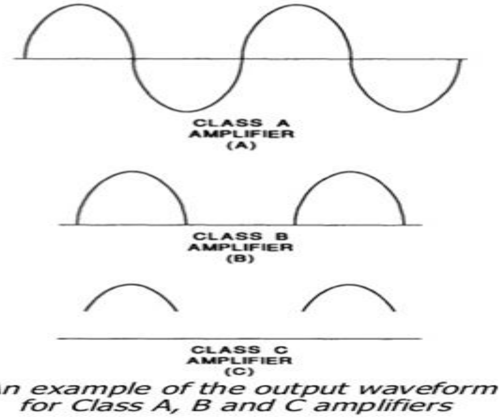
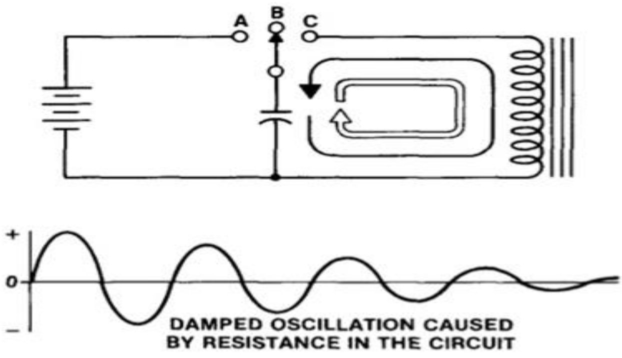


Figure4.1 Amplifier Output Waveforms

Oscillator

An oscillator is a device that produces the frequencies needed by both receivers and transmitters. A simple oscillator is an LC circuit (figure 4.2) or tank circuit made up of a capacitor and inductor in parallel.

The LC circuit will have a resonant frequency which matches the desired frequency. An LC circuit by itself will not continue to oscillate because of resistance in the components and wires. Inorder of maintain oscillations, some energy must be fed back into the tank circuit and a common technique to stabilize the oscillator and produce a more accurate frequency is to use a crystal which is shown in figure 4.3. The piezoelectric effect of the crystal will produce more accurate and consistent output frequency from the oscillator.



A parallel LC tank circuit

Figure 4.2 LC Tank Circuit

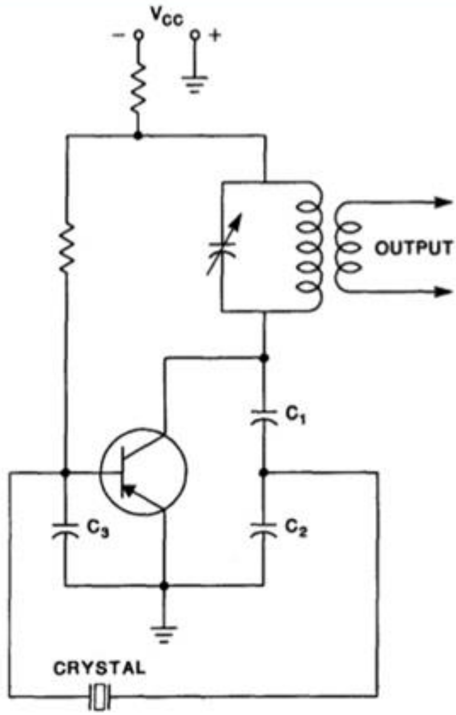


Figure 4.3 Crystal Controlled Oscillator

Modulators and Demodulators

If the AF signal is too weak compared to the RF signal, the modulation rate will be low and the efficiency will be also low. If the modulation rate is over 100%, there will be distortion in the signal due to the gaps created. So most radio transmitters are adjusted to about 90-95% modulation to provide a little margin to prevent distortion.

Modulator combines the AF and RF signals so that information can be transmitted. The output of the modulator is called modulated RF. The amount of modulation is called as modulation rate.

The demodulator removes the RF component of the modulated RF signal and produces an AF output.

Filters

Filter is used in radio circuit to remove the unwanted frequencies. A filter is usually made up of an arrangement of inductors and capacitors.

A low pass filter will remove all frequencies above a certain value and pass the low ones. A high pass filter does the opposite and a band pass filter will allow a certain band of frequencies to go through and block frequencies either above or below that range.

Communication System

Transmitters and receivers are used extensively in aircraft communications and navigation systems. In conjunction with one or more antennas, they are responsible for implementing the vital link between the aircraft, ground stations, other aircraft and satellites.

The figure 4.4 shows a simple radio communication system comprising a transmitter and receiver for use with continuous wave (CW) signals. Communication is achieved by simply switching the radio frequency signal on and off. Keying can be achieved by interrupting the supply to the power amplifier stage or even the oscillator stage.

Modulation

In order to convey information using a radio frequency carrier, the signal information must be superimposed or modulated on to the carrier. Modulation is the name given to the process of changing a particular property of the carrier wave in sympathy with the instantaneous voltage or current signal. The most commonly used methods of modulation are Amplitude Modulation (AM) and Frequency Modulation (FM).

Demodulation

Demodulation is the reverse of modulation and is the means by which the signal information is recovered from the modulated carrier. Demodulation is achieved by means of a demodulator (sometimes also called a detector).

Communication and navigation are the 2 main functions of the airborne radio. Communication systems primarily involve voice transmission and reception between the Aircraft & ground stations. Radios are used in Aircraft as navigational aids in a number of applications. Federal Aviation Regulations require an inspection of radio equipment installations at regular intervals. These inspections include a visual examination for security of attachment, condition of wiring, bonding, shock mounts, radio racks and supporting structure. Also, installation and inspection of radios, antennas, navigation equipment and associated wiring is required.

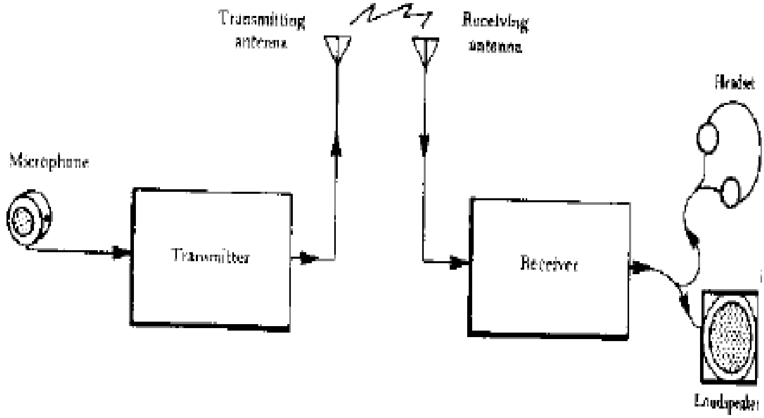


Figure 4.4 Basic Communication System

The basic concept of radio communications involves the transmission and reception of electromagnetic energy waves through space. Alternating current passing through a conductor creates electromagnetic fields around the conductor. Energy is alternately stored in these fields and returned to the conductor. As the frequency of current alternation increases, less of the energy stored returns to the conductor. Instead of returning, the energy is radiated into space as electromagnetic waves. A conductor radiating in this manner is called the transmitting antenna.

Microphone

It is essentially an energy converter that changes Acoustic energy into corresponding electrical energy. When spoken into a microphone, the audio pressure waves generated strike the diaphragm of the microphone causing it to move in and out in accordance with the instantaneous pressure delivered to it. The diaphragm is attached to a device that causes current to flow in proportion to the pressure applied.

Transmitter

A transmitter shown in figure 4.5 may be considered as a generator, which changes electrical power into radio waves. A transmitter must perform the following function,

1. Generate the RF signal.
2. Amplify the RF signal
3. Provide a means of placing intelligence on the signal.

The transmitter contains an oscillator circuit to generate RF signal and an amplifier circuits to increase the output power. The voice [audio] intelligence is added to the RF signal by a special circuit called the modulator. This may be Amplitude Modulated [AM] or Frequency Modulated [FM].

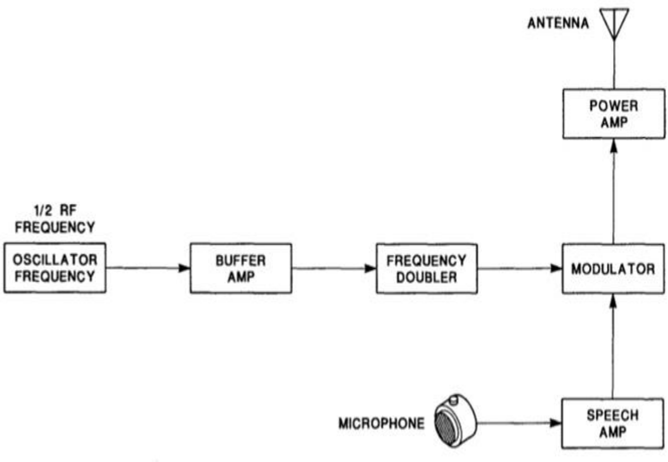


Figure 4.5 Block diagram of a voice radio transmitter

AM Transmitter

An accurate and stable RF oscillator generates the radio frequency carrier signal. The output of the stage is then amplified and passed to a modulated RF power amplifier stage. The inclusion of an amplifier between the RF oscillator and the modulator stage also helps to improve frequency stability.

The low level signal from the microphone is amplified using an AF amplifier before it is passed to an AF power amplifier. The output of the power amplifier is then fed as the supply to the modulated RF power amplifier stage .increasing and reducing the amplitude of its RF output signal.

The modulated RF signal is then passed through an antenna coupling unit matches the antenna to the RF power amplifier and also helps to reduce the level of any unwanted harmonic components that may be present.

FM Transmitter

Once again an accurate and stable RF oscillator generates the radio frequency carrier signal. As with the output of the stage is then amplified and passed to a modulated RF power amplifier stage. Here again the inclusion of an amplifier between the RF oscillator and the modulator stage also helps to improve frequency stability.

The low level signal from the microphone is amplified using an AF amplifier before it is passed to a variable reactance element within the RF oscillator tuned circuit.

As with the AM transmitter the final RF signal from the power amplifier is then passed through an antenna coupling unit matches the antenna to the RF power amplifier and also helps to reduce the level of any unwanted harmonic components that may be present.

Receivers

The communications receiver must select radio frequency signals and convert the intelligence contained on these signals into a usable form. A receiver must be able to select the desired frequency from all those present and amplify the small AC signal voltage. It contains a demodulator circuit to remove the intelligence [AM or FM].

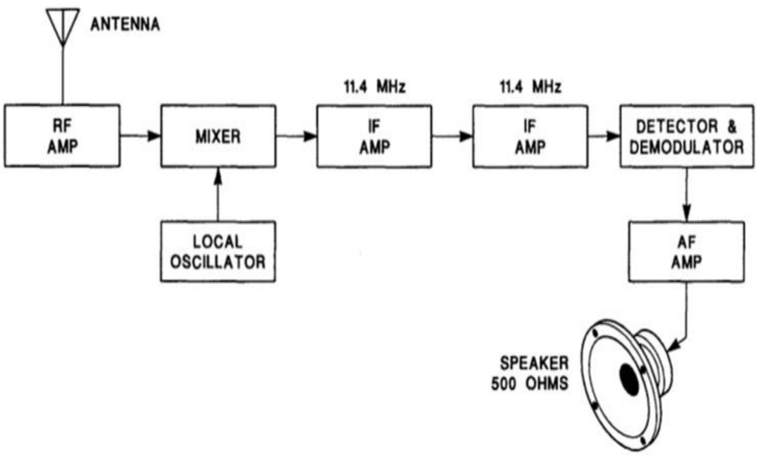


Figure 4.6 Block diagram of a radio Receiver

Superhet Receiver

In the 1920s, a new type of radio receiver was invented that produced better sound quality. It was called the Superhet radio shown in figure 4.6. The only major difference between the Superhet and earlier radios was that is reduced the modulated RF signal from the antenna to an AF signal in more than one jump or stage.

Superhet receivers provide both improved sensitivity (the ability to receive weak signal) and improved selectivity (the ability to discriminate signals on adjacent channels). Superhet receivers are based on the supersonic–heterodyne principle where the wanted input signal is converted to a fixed intermediate frequency. The output of the RF amplifier stage is applied to the mixer stage. This stage combines the RF signal with the signal derived from the local oscillator stage in order to produce a signal at the intermediate frequency.

Antennas

It is a special type of electrical circuit designed to radiate and receive the electromagnetic energy. It is a conductor that radiates electromagnetic waves when a radio frequency current is passed through it. Depending upon the frequency to be transmitted and specific purpose, they vary in shape and design which is shown in figure 4.7.

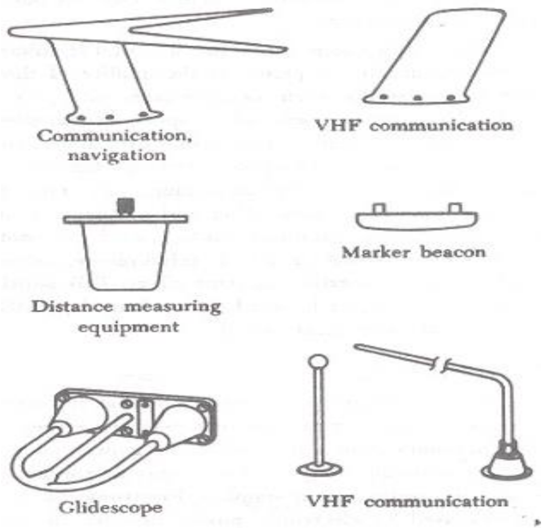


Figure 4.7 Antennas

Aircraft Communication Systems

In aviation, communications between the aircraft and the ground (air traffic/local approach/ground handling) have historically been by means of voice communication. More recently, data-link communications have been introduced owing to their higher data rates and in some cases superior operating characteristics. As will be seen, data links are becoming widely used in the HF and VHF bands for basic communications.

Communications systems comprise the following:

- High-Frequency (HF) radio transmit/receive.
- Very High Frequency (VHF) radio transmit/receive and an Aircraft Communications And Reporting System (ACARS).
- Ultra High-Frequency (UHF) radio transmit/receive – mainly used in military communications.
- SATellite COMmunications (SATCOM) including passenger telephone communications.
- Aircraft transponder and Air Traffic Control (ATC) mode A/C and S [also known in the military environment as Identification Friend or Foe/Secondary Surveillance Radar (IFF/SSR)].
- Traffic Collision and Avoidance System (TCAS).
- Communications control.

High Frequency

High Frequency covers the communications band between 3 and 30 MHz and is a very common communications means for land, sea, and air. The utilized frequency range is 2.000 – 29.999 MHz using a 1 kHz (0.001 MHz) channel spacing. The primary advantage of HF communications is that this system offers communication beyond the line of sight which is provided in the figure 4.8. This method does, however, suffer from idiosyncrasies with regard to the means of signal propagation.

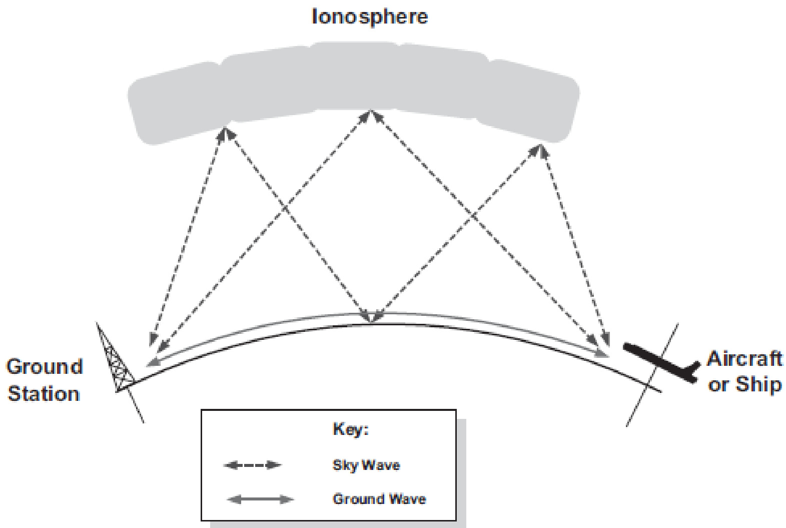


Figure 4.8 HF communication signal propagation

The above figure shows that there are two main means of propagation, known as the sky wave and the ground wave. The sky wave method of propagation relies upon single or multiple-path bounces between the Earth and the ionosphere until the signal reaches its intended location. The behaviour of the ionosphere is itself greatly affected by radiation falling upon the Earth, notably solar radiation. Times of high sunspot activity are known adversely to affect the ability of the ionosphere as a reflector. It may also be affected by the time of day and other atmospheric conditions. The sky wave as a means of propagation may therefore be severely degraded by a variety of conditions, occasionally to the point of being unusable.

The ground wave method of propagation relies upon the ability of the wave to follow the curvature of the earth until it reaches its intended destination. As for the sky wave, the ground wave may on occasions be adversely affected by atmospheric conditions. Therefore, on occasions HF voice communications may be corrupted and prove unreliable, although HF data links are more resistant to these propagation upsets as described below.

HF communications are one of the main methods of communicating over long ranges between air and ground during oceanic and wilderness crossings when there is no line of sight between the aircraft and ground communications stations. For reasons of availability, most long-range civil aircraft are equipped with two HF sets, with an increasing tendency also to use HF Data Link (HFDL) if polar operations are contemplated.

Very High Frequency

Very High Frequency (VHF) voice communication is probably the most heavily used method of communication used by civil aircraft given in figure 4.9. The VHF band for aeronautical applications operates in the frequency range 118.000 – 135.975 MHz with channel spacing in recent years of 25 kHz (0.025 MHz). In recent years, to overcome frequency congestion, and taking advantage of digital radio technology, channel spacing has been reduced to 8.33 kHz (0.00833 MHz), which permits 3 times more radio channels in the available spectrum.

The VHF band also experiences limitations in the method of propagation. Except in exceptional circumstances, VHF signals will only propagate over line of sight. That is, the signal will only be detected by the receiver when it has line of sight or can 'see' the transmitter. VHF transmissions possess neither of the qualities of HF transmission and accordingly neither sky wave nor ground wave properties apply. This line-of-sight property is affected by the relative heights of the radio tower and aircraft which is shown in the below figure.

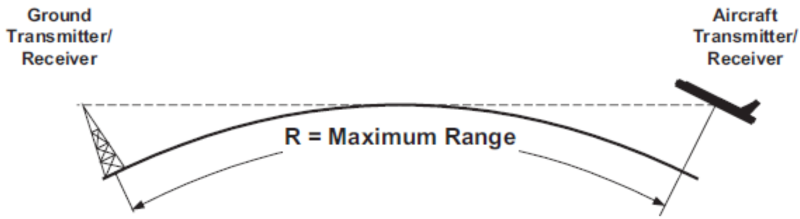


Figure 4.9 VHF signal propagation

The formula that determines the line-of sight range for VHF transmissions is as follows

$$R = 1.2\sqrt{H_t} + 1.2\sqrt{H_a}$$

where, R is the range (nautical miles), H_t is the height of the transmission tower (ft), and H_a is the height of the aircraft (ft). Therefore, for an aircraft flying at 35000 ft, transmissions will generally be received by a 100 ft high radio tower if the aircraft is within a range of around 235 nautical miles.

Satellite Communications

Satellite communications provide a more reliable method of communications using the International

Maritime Satellite Organization (INMARSAT) satellite constellation which was originally developed for maritime use. Now, satellite communications, abbreviated to SATCOM, form a useful component of aerospace communications. The principles of operation of SATCOM are shown in the below figure 4.10.

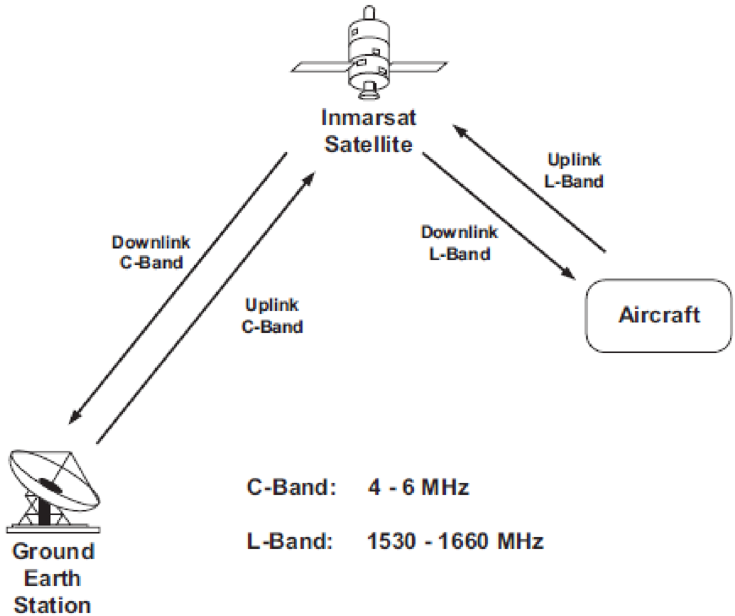


Figure4.10 SATCOM Principles of Operation

The aircraft communicates via the INMARSAT constellation and remote ground earth station by means of C-band uplinks and downlinks to/from the ground stations and L-band links to/from the aircraft. In this way, communications are routed from the aircraft via the satellite to the ground station and on to the destination.

Conversely, communications to the aircraft are routed in the reverse fashion. Therefore, provided the aircraft is within the area of coverage or footprint of a satellite, then communication may be established.

The airborne SATCOM terminal transmits on frequencies in the range 1626.5 – 1660.5 MHz and receives messages on frequencies in the range 1530.0 – 1559.0 MHz. Upon power-up, the Radio Frequency Unit (RFU) scans a stored set of frequencies and locates the transmission of the appropriate satellite. The aircraft logs onto the ground earth station network so that any ground stations are able to locate the aircraft. Once logged onto the system-communications between the aircraft and any user may begin. The satellite-to-ground C-band uplink/downlink are invisible to the aircraft, as is the remainder of the Earth support network. The coverage offered by the INMARSAT constellation was a total of four satellites in 2001. Further satellites are planned to be launched.

Air Traffic Control (ATC) transponder

As a means to aid the identification of individual aircraft and to facilitate the safe passage of aircraft through controlled airspace, the ATC transponder allows ground surveillance radars to interrogate aircraft and decode data, which enables correlation of a radar track with a specific aircraft. The principle of transponder operation is shown in the Figure 4.11.

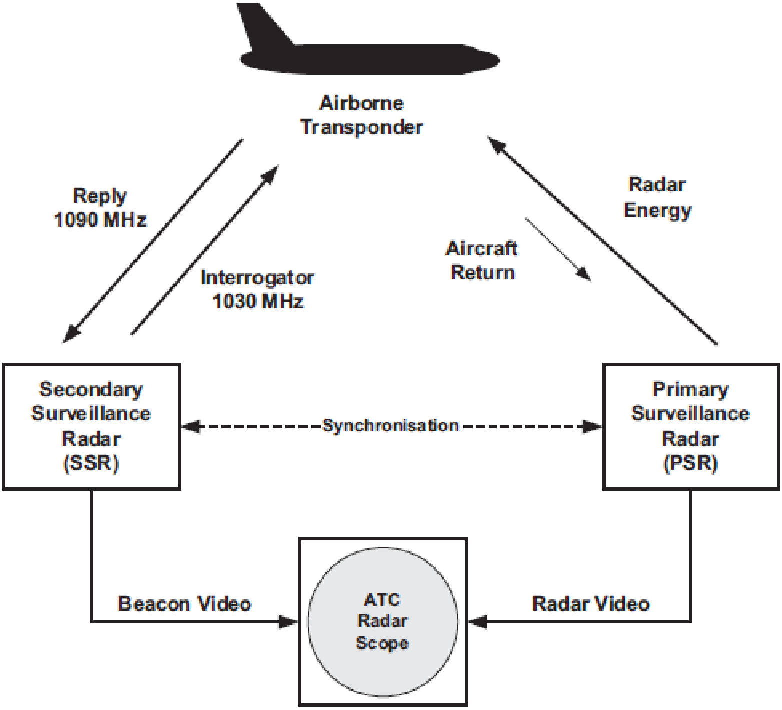


Figure 4.11 Principle of Transponder Operation

A ground-based Primary Surveillance Radar (PSR) will transmit radar energy and will be able to detect an aircraft by means of the reflected radar energy – termed the aircraft return. This will enable the aircraft return to be displayed on an ATC console at a range and bearing commensurate with the aircraft position. Coincident with the primary radar operation, a Secondary Surveillance Radar (SSR) will transmit a series of interrogation pulses that are received by the on-board aircraft transponder. The transponder aircraft replies with a different series of pulses that give information relating to the aircraft, normally aircraft identifier and altitude. If the PSR and

SSR are synchronized, then both the presented radar returns and the aircraft transponder information may be presented together on the ATC console (figure 4.12). Therefore, the controller will have aircraft identification (e.g. BA 123) and altitude presented alongside the aircraft radar return, thereby greatly improving the controller's situational awareness.

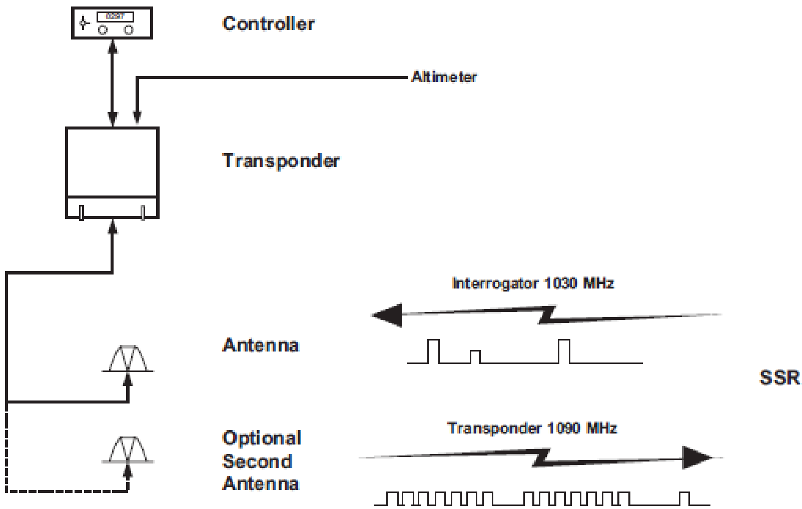


Figure 4.12 Airborne Transponder Equipment

The system is also known as Identification Friend or Foe (IFF)/Secondary Surveillance Radar (SSR), and this nomenclature is in common use in the military field. On-board the aircraft, the equipment fit is as shown in the above figure. The main elements are:

- ATC transponder controller unit for setting modes and response codes.
- Dedicated ATC transponder unit.

- An ATC antenna unit with an optional second antenna. It is usual to utilize both upper and lower mounted antenna to prevent blanking effects as the aircraft manoeuvres.

The SSR interrogates the aircraft by means of a transmission on the dedicated frequency of 1030 MHz which contains the interrogation pulse sequence. The aircraft transponder replies on a dedicated frequency of 1090 MHz with a response that contains the reply pulse sequence with additional information suitably encoded in the pulse stream. In its present form, the ATC transponder allows aircraft identification – usually the airline call-sign – to be transmitted when using mode A. When mode C is selected, the aircraft will respond with its identifier, together with altitude information.

More recently, an additional mode – mode S or mode Select – has been introduced with the intention of expanding this capability. In ATC mode S, the SSR uses more sophisticated monopulse techniques that enable the aircraft azimuth bearing to be determined more quickly. Upon determining the address and location of the aircraft, it is entered into a roll call file. This, together with details of all the other aircraft detected within the interrogator's sphere of operation, forms a complete tally of all the aircraft in the vicinity. Each mode S reply contains a discrete 24 bit address identifier. This unique address, together with the fact that the interrogator knows where to expect the aircraft from its roll call file, enables a large number of aircraft to operate in a busy air traffic control environment.

Mode S is improved conventional secondary radar operating at the same frequencies (1030/1090 MHz). Its 'selectivity' is based on unambiguous identification of each aircraft by the unique 24 bit address. This acts as its technical telecommunications address, but does not replace the mode A code. There are also plans for recovery of the A and C codes via mode S.

Traffic Collision and Avoidance System

The TCAS was developed in prototype form during the 1960s and 1970s to provide a surveillance and collision avoidance system to help aircraft avoid collisions. It was certified by the FAA in the 1980s and has been in widespread use in the United States in its initial form. TCAS is based on the beacon interrogator and operates in a similar fashion to the ground-based SSR already described. The system comprises two elements: a surveillance system and a collision avoidance system. TCAS detects the range bearing and altitude of aircraft in the near proximity for display to the pilots.

TCAS transmits a mode C interrogation search pattern for mode A and C transponder equipped aircraft and receives replies from all such equipped aircraft. In addition, TCAS transmits one mode S interrogation for each mode S transponder equipped aircraft, receiving individual responses from each one. It will be recalled that mode A relates to range and bearing, while mode C relates to range, bearing, and altitude and mode S relates to range, bearing, and altitude with a unique mode S reply. The aircraft TCAS equipment comprises a radio transmitter and receiver, directional antennae, a computer, and flight deck display. Whenever another aircraft receives an interrogation, it transmits a reply and the TCAS computer is able to determine the range from the time taken to receive the reply. The directional antennae enable the bearing of the responding aircraft to be measured. TCAS can track up to 30 aircraft but only display 25, the highest-priority targets being the ones that are displayed.

TCAS is unable to detect aircraft that are not carrying an appropriately operating transponder or that have unserviceable equipment. A transponder is mandated if an aircraft flies above 10000 ft or within 30 miles of major airports; consequently, all commercial aircraft and the great majority of corporate and general aviation aircraft are fitted with the equipment.

TCAS exists in two forms: **TCAS I** and **TCAS II.** TCAS I indicates the range and bearing of aircraft within a selected range, usually 15 – 40 nautical miles forward, 5 – 15 nautical miles aft, and 10 – 20 nautical miles on each side. The system also warns of aircraft within ±8700 ft of the aircraft's own altitude.

The collision avoidance system element predicts the time to, and separation at, the intruder's closest point of approach. These calculations are undertaken using range, closure rate, altitude, and vertical speed. Should the TCAS ascertain that certain safety boundaries will be violated, it will issue traffic advisory (TA) to alert the crew that closing traffic is in the vicinity via the display of certain coloured symbols. Upon receiving a TA, the flight crew must visually identify the intruding aircraft and may alter their altitude by up to 300 ft. A TA will normally be advised between 20 and 48 sec before the point of closest approach with a simple audio warning in the flight crew's headsets: 'TRAFFIC, TRAFFIC'. TCAS I does not offer any deconfliction solutions but does provide the crew with vital data in order that they may determine the best course of action.

TCAS II offers a more comprehensive capability, with the provision of Resolution Advisories (RAs). TCAS II determines the relative motion of the two aircraft and determines an appropriate course of action. The system issues an RA via mode S, advising the pilots to execute the necessary manoeuvre to avoid the other aircraft. An RA will usually be issued when the point of closest approach is within 15 and 35 sec and the deconfliction symbology is displayed coincident with the appropriate warning.

A total of ten audio warnings may be issued. Examples are:

- ‘CLIMB, CLIMB, CLIMB’.
- ‘DESCEND, DESCEND, DESCEND’.
- ‘REDUCE CLIMB, REDUCE CLIMB’.

Finally, when the situation is resolved, ‘CLEAR OF CONFLICT’.

Communications control system

The control of the aircraft suite of communications systems, including internal communications, has become an increasingly complex task. This task has expanded as aircraft speeds and traffic density have increased and the breadth of communications types has expanded. The communications control function is increasingly being absorbed into the flight management function as the management of communications type, frequency selection, and intended aircraft flight path become more interwoven. Now, the flight management system can automatically select and tune the communications and navigation aids required for a particular flight leg, reducing crew workload and allowing the crew to concentrate more on managing the on-board systems.

Aircraft State Sensor Systems

For control and navigation of the aircraft the air data quantities are essential.

Air Data Quantities - (Altitude, Calibrated Airspeed, Vertical speed, True Airspeed, Mach Number, Airstream Incidence Angle)

The air data computing system computes these quantities from the outputs of sensors which measure the static and total pressure and the outside air temperature.

Annunciation

An annunciator panel, also known in some aircraft as the 'Centralized Warning Panel (CWP), is a group of lights used as a central indicator of status of equipment or systems in an aircraft, industrial process, building or other installation. Usually, the annunciator panel includes a main warning lamp or audible signal to draw the attention of operating personnel to the annunciator panel for abnormal events or conditions.

In the aircraft industry, annunciator panels are groupings of annunciator lights that indicate status of the aircraft's subsystems. The lights are usually accompanied with a test switch, which when pressed illuminates all the lights to confirm they are in working order. More advanced modern aircraft replaces these with the integrated electronic Engine Indicating and Crew Alerting System or Electronic Centralized Aircraft Monitor.

An aviation annunciator panel will have a test switch to check for burned out lamps. Indicator lights are grouped together by their associated systems into various panels of lights.

Lamp colours are normally given the following meanings:

- Red: Warning, this systems condition is critical and requires immediate attention (such as an engine fire, hydraulic pump failure)
- Amber: Caution, this system requires timely attention or may do so in the future (ice detected, fuel imbalance)
- Green: Advisory/Indication, a system is in use or ready for operation (such as landing gear down and locked, APU operating)
- White/blue: Advisory/Indication, a system is in use (seatbelt signs on, anti-ice system in-use, landing lights on)

More complicated aircraft will feature "Master Warning" and "Master Caution" lights/switches. In the event of any red or yellow annunciator being activated, the yellow or red master light, usually located elsewhere in the pilots line of sight will illuminate, in most installations they flash and an audible alert will accompany them. These "masters" will not stop flashing until they have been acknowledged, usually by pressing the light itself and in some cases the audible alert will also continue until this acknowledgement.

Display of Air Data

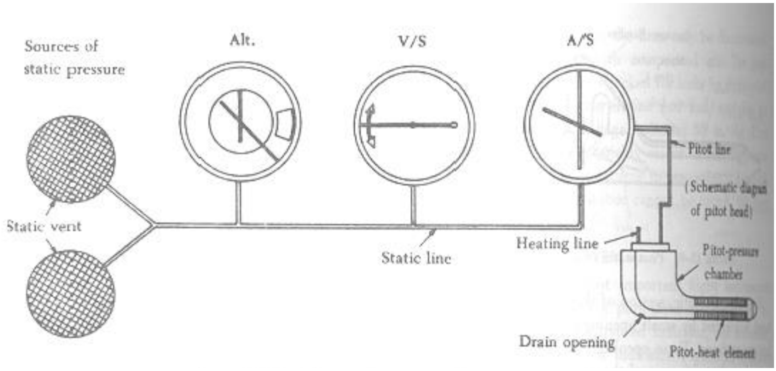


Figure 4.13 Pitot-Static Instruments

Instruments connected to the Pitot static pressure system include the airspeed indicator, the altimeter and the vertical speed indicator.

- This system includes a Pitot pressure source and a static pressure source.
- The Pitot pressure source is usually located on the leading edge of the wing where it is clear of slipstream, in a position to be as free as possible of air disturbance and facing the line of flight.
- When the aircraft is in flight, the atmospheric pressure in the Pitot pressure system is increased by dynamic due to forward motion of the aircraft through the air.
- The Air speed indicator is the only instrument concerned to the Pitot pressure source.

Altimeter

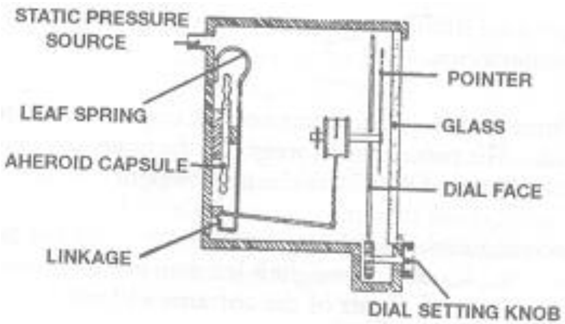


Figure 4.14 Altimeter

The altimeter which is shown in figure 4.14 is a special form of Aneroid Barometer [a barometer without liquid] that measures the pressure of the atmosphere.

- It is concerned to the static pressure source through an outlet in the back of the case.
- The outlet serves as a vent to allow static atmospheric pressure to move into and out of the altimeter case as the airplane climbs or descends.
- The atmospheric pressure at any section at any point is due to the weight of the overlying air above, which decreases as the height above the sea level increases.
- Hence the instrument can be calibrated to read in terms of height.
- Under standard air conditions of 15‘C, the weight of a column of air, one square inch in area is 14.7 lb., at sea level.
- It exerts a pressure of 14.7 lbs per square inch.

- The pressure is recorded on the barometer as 29.92 inches of mercury and by an altimeter as 0 feet.
- At 10,000 feet the weight of one square inch air column has decreased to 10.11 lb., the corresponding barometric pressure to 20.58 inches, and altimeter records 10,000 feet.
- The decrease in pressure is sensed by the altimeter and registered as an increase in height.

Construction

The basic components of the altimeter are a sack of aneroid capsules located inside the case. These capsules are sealed and contain standard sea level pressure. Atmospheric pressure admitted to the case through the static pressure system causes these capsules to expand and contract.

The expansion and contraction of the capsules transmits motion directly to gears and levers, which rotate hands on the face of the altimeter.

A large hand records altitude in units of thousands of feet; a smaller hand records altitude in units of thousands of feet; and the third still smaller hand records altitude in units of thousand feet.

Working

As the aircraft climbs, the outside barometric pressure decreases and air moves out of the case through the static pressure system.

As a result, the aneroid capsules expand, causing an increased altitude reading.

As the aircraft descends, air moves into the altimeter case and the capsules contract, causing a decreased altitude reading.

The Vertical Speed Indicator [VSI]

The vertical speed indicator [vertical velocity or rate of climb] shows the rate, in feet per minute, at which the aircraft is ascending or descending.

- The principle on which it operates is the change in barometric pressure, which occurs with any change in height.
- This instrument is contained in a sealed case and is also connected to the static air pressure system.
- Atmospheric pressure is led from the static pressure source directly into an aneroid capsule, or diaphragm, contained within the case of the instrument.
- Air is also permitted to leak at a relatively slow rate through a capillary tube into the case of the instrument.
- The difference between the quick change in pressure, which occurs within the aneroid capsule, and the relatively slow rate at which this pressure is equalized within the case causes the capsule to expand or contract.
- This movement is amplified and transmitted by linkage to the pointer on the dial of the instrument.

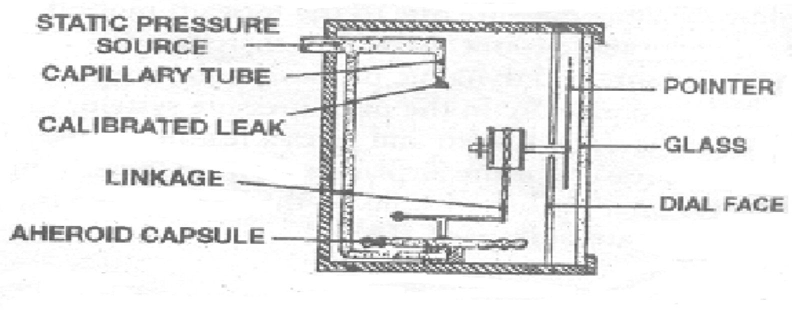


Figure 4.15 Vertical Speed Indicator

Working:

- When the aircraft loses altitude, pressure within the capsule increases almost immediately, while pressure within the case changes slowly.
- The capsule therefore expands and the pointer indicates DOWN in feet per minute.
- When the aircraft gains altitude, the process is reversed and the pointer indicates UP.
- When the airplane remains level, the pressures equalize and the pointer indicates 0.
- Note that the vertical speed indicator registers the rate of climb or descent, not the attitude of the aircraft.
- An aircraft may gain height in a vertical up current of air when it is flying perfectly level.
- The vertical speed indicator should be closely co-coordinated with the air speed indicator.
- Corrections for the altitude gained or lost in cruising flight should be made by nosing the aircraft up or down [by use of the elevators].

- Intentional change in altitude should be made by increasing or decreasing power at a given airspeed [by use of the throttle].

The Airspeed Indicator

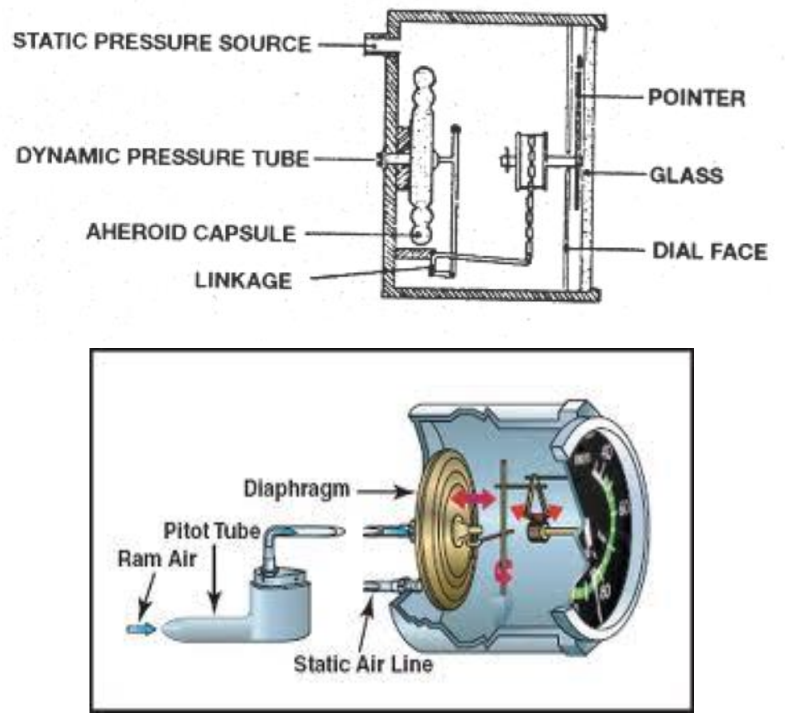


Figure 4.16 Air Speed Indicator

The airspeed indicator shown in figure 4.16 tells the pilot the speed at which he is travelling through the air [not over the ground].

❖ The dial is calibrated in knots and miles per hour.

Construction

The airspeed indicator is connected to both the Pitot & static pressure sources.

To give a reading of speed through the air, the instrument measures the difference between the pressure in the Pitot pressure system and the pressure in the static system.

- When the airplane is standing on the ground, the pressure in the two systems is equal and the airspeed indicator registers 0.
- When the aircraft is in motion, the pressure in the Pitot pressure system is increased by dynamic pressure due to the forward motion of the aircraft through the air [Pitot pressure is therefore the sum of atmospheric pressure and dynamic pressure].

Working:

- ❖ The airspeed indicator senses the total pressure in the Pitot pressure system, subtracts the pressure in the static system and gives reading of the dynamic pressure, the measure of the aircraft's forward speed.
- ❖ This reading is displayed on a graduated scale on the face of the instrument and is called indicated airspeed.
- ❖ The Pitot pressure source is connected to the interior of a thin corrugated metal expansion box called the aneroid capsule and admits Pitot pressure into the capsule.
- ❖ The static pressure source is connected to the inside of the instrument case and maintains the air in the case at the prevailing atmospheric pressure.
- ❖ Changes in dynamic pressure inside the aneroid capsule cause it to expand or contract.

❖ This movement is transmitted through a system of linkage to a hand that rotates around a dial calibrated in knots and/or miles per hour.

Mach Meter

- A mach indicator given in figure 4.17 provides a continuous indication of the ratio of an aircraft's airspeed to the local speed of sound at that particular altitude and temperature existing at any time during flight.
- It expresses airspeed as Mach number by measuring and correlating dynamic and static pressures.

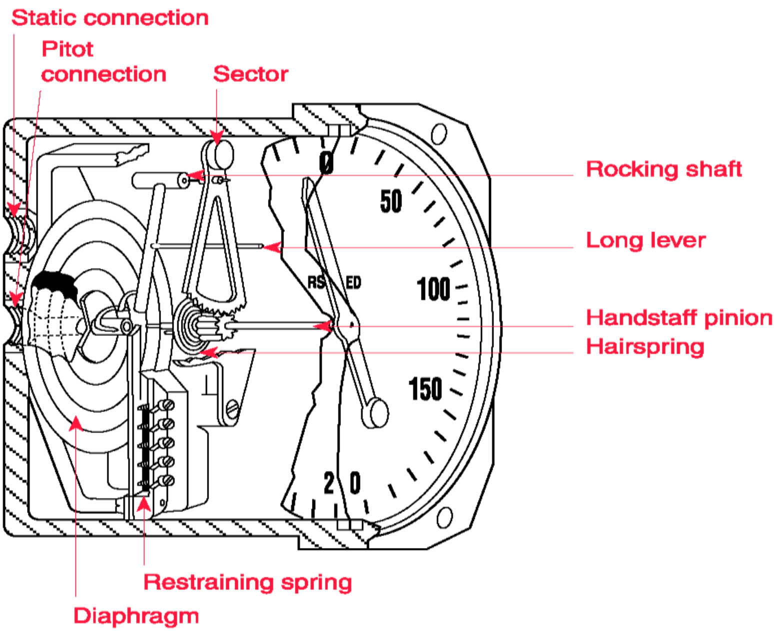


Figure 4.17 Mach Meter

Construction:

- Construction of mach meter is much the same as that of an airspeed indicator.
- The instrument comprises two aneroid capsules enclosed in a sealed case that is connected to the aircraft's static pressure system.
- One aneroid is connected to the dynamic pressure source which reacts to both dynamic and static pressure and therefore measures airspeed, while the other is sealed and partly evacuated, which reacts only to the static pressure and therefore measures altitude.

[Note-Mach number equals airspeed divided by speed of sound]

Working

A change in any sensed pressure causes appropriate expansion or contraction in one or both capsules.

- The capsules are geared to a pointer on the face of the instrument.
- The pointer reacting to the expanding and contracting capsules indicates the airspeed of the aircraft in which it is installed.

Airspeed Definitions

Indicated Airspeed

IAS is the uncorrected speed read from the airspeed dial. It is the measurement of the difference between the total pressure and the atmospheric pressure in the Pitot static system. [That is, the Pitot pressure which is the sum of the atmospheric pressure and the dynamic pressure].

Calibrated Airspeed

CAS is the indicated airspeed corrected for instrument error and installation error in the Pitot- static system. As the aircraft flight attitude or configuration is changed the airflow in the vicinity of the static pressure sources may introduce impact pressure into the static source, which results in erroneous airspeed indications. The Pitot section of the system is subject to error at high angles of attack, since the impact pressure entering the system is reduced when the Pitot pressure source is not parallel to the relative airflow. Performance data in the aircraft flight manuals is normally based on calibrated airspeed.

Equivalent Airspeed

EAS is calibrated airspeed corrected for compressibility factor. This value is very significant to pilots of high-speed aircraft, but relatively unimportant to pilots operating at speeds below 250 knots at altitudes below 10,000 feet.

True Airspeed

EAS is calibrated [or equivalent airspeed] corrected for the airspeed indicator error due to density and temperature. TAS is the actual speed of the airspeed of the aircraft through the air mass.

Questions

Part – A

1. Give details about avionics sub systems.
2. Write brief description about annunciation.
3. Bestow details on A/C communication system.
4. Write notes on aircraft communication frequency ranges.
5. Define : EAS and TAS

Part – B

1. Describe about the aircraft communication system with neat diagrams.
2. With clear illustration describe about display of air data.
3. Write Notes on transmitter, receiver and antennas.
4. Describe about the avionics subsystems.
5. With neat diagram explain about Amplifiers, Oscillators, Filters and Modulators.

AVIONICS SYSTEMS INTEGRATION

5

Avionics equipment fit. Electrical data bus system. Communication Systems, Navigation systems, Flight control systems, Radar Electronic Warfare, and fire control system.

Avionics Equipment Fit

The avionics equipment fit comprises,

Radar – target acquisition in all weather conditions.

Doppler – accurate velocity sensor for DR navigation.

Attitude heading reference system – attitude and heading information for pilot's displays, navigation computer, weapon aiming computer and autopilot.

Air data computer – height, calibrated airspeed, true airspeed, Mach number information for pilot's displays, weapon aiming, reversionary DR navigation and autopilot.

Radio altimeter – very low level flight profile during attack phase and all weather operation.

Navigation Computer – essential for mission.

Autopilot – essential for reduction of pilot work load.

Weapon aiming computer – essential for mission.

HUD – all the advantages of the HUD plus weapon aiming for low level attack; for example toss bombing.

Stores management system – control and release of the weapons.

Electronic warfare systems – radar warning receivers, radar jamming equipment. Essential for survivability in hostile environment.

Identification system – essential to avoid attack by friendly forces.
Radio navigation aids – location of parent ship on return from missions.
Communication radio suite – essential for communicating to parent ship, co-operating aircraft, etc.

Electrical Data Bus System
Busbars

In most of aircrafts, the output from the generating sources is coupled to one or more low impedance conductors referred as busbars. These are situated at central points within the aircraft and provides positive supplies to various consumer circuits. In a very simple system a busbar can take the form of a strip of interlinked terminals while in complex system. Main busbars are thick metal strips or rods to which input and output supply connections can be made. The electrical data bus system used in the aircraft is divided into two types.

i. Bus Bar System
ii. Split Bus Bar System.

Busbar Systems Requirements

1. Power-consuming equipment must not be deprived of power in the event of power source failures.
2. Failure on the distribution system should have the minimum effect on system functioning.
3. Power consuming equipment faults must not endanger the supply of power to other equipment.

Types of Consumer Services

1. Vital Services

These services are connected directly to the battery. For Example, during an emergency wheels up landing emergency lighting and crash s/w operation of fire extinguishers are required.

2. Essential Services

Those are required to ensure safe flight in an in-flight emergency situation. They are connected to dc or ac bus bars.

3. Non-Essential Services

These are isolated in an in-flight emergency for load shedding purposes.

Communication Systems

This is used for voice transmission and reception between aircraft and aircraft or ground station. The concept of radio communication involves in transmission and reception of electromagnetic energy waves through space. Alternating current passing through a conductor creates an EMF around the conductor. If the frequency of alternating current increases, the energy stored in the field is radiated into the space in the form of electromagnetic waves. A conductor which radiates the energy is called as transmitting antenna. These transmitted radio waves travel at a speed of 186000 miles per second.

If a radiated EMF passes through a conductor, some of the energy in the field will cause the electrons in motion, in the conductor. So this electron flow constitutes a current in the receiving antenna which is similar to the varying current in the transmitting antenna.

Frequency Bands

LF – 30 to 300 KHz
MF – 300 to 3000 KHz
HF – 3000 KHz to 30 MHz
VHF – 30 to 300 MHz
UHF – 300 to 3000 MHz
SHF – 3000 to 30000 MHz

Basic components of a Communication System

a) Microphone

It converts the sound energy into corresponding electrical energy.

b) Transmitter
   (i) Oscillator – to generate RF signal
   (ii) Amplifier – increase the output
   (iii) Modulator – To add the voice signal

c) Transmitting Antenna

   It is the special type of electrical circuit.

d) Receiving Antenna
e) Receiver
f) Power supply

The receiver must be able to select the desired frequency signal from lot of signals present in the air and also it should amplify the small ac signal voltage. The receiver contains demodulator (to remove the added signal). The demodulator contains detector (is used for AM) and discriminator (is used for FM).

Navigation Systems

Navigation is the determination of position and velocity of an aircraft with respect to a reference point.

Navigation Information (Aircraft's position, Ground speed, Track angle). The navigation system is basically divided into two types.

- Dead Reckoning Systems
- Position Fixing Systems

DR Navigation systems derive the vehicle's present position by estimating the distance travelled from a known position from knowledge of the speed and direction of the vehicle.

Types of DR Navigation systems are,

- Inertial Navigation systems (Most Accurate)
- Doppler / Heading Reference Systems (Used in Helicopters)
- Air Data / Heading Reference Systems (Low Accuracy when compared to above)

Radio Navigation Systems (Position Fixing Systems)

Satellite or ground based transmitter is used to transmit the signal and it was received by the receiver in the aircraft. According to the received signals a supporting computer is used to derive the aircraft's position.

Prime Position Fixing System (GPS)

Instrument Landing Systems or Microwave Landing System is used for approach guidance to the airfield.

Navigation Management System

It comprises the operation of all radio navigation aid systems and the combination of data from all navigation sources such as GPS and INS systems, to provide the best estimation of the aircraft position and ground speed.

Classification of Navigation

- **Navigation by Pilotage (Visual Navigation)** in which the pilot can determine the aircraft's position with the help of visible landmarks such as mountains, buildings, lakes, cities etc.
- **Celestial Navigation** uses "sights," or angular measurements taken between a visible celestial body (the sun, the moon, a planet or a star) and the visible horizon. The angle measured between the sun and the visible horizon is most commonly used. Celestial navigation is the process whereby angular measurements (sights) taken between celestial bodies in the sky and the visible horizon are used to locate one's position on the globe, on land as well as at sea. At any given instant of time, any celestial body is located directly over only one specific geographic point, or position on the Earth, whose address is described by latitude and longitude.
- **Radio Navigation** is the application of radio frequencies to determine the position of an aircraft. Common radio navigation aids include **Distance Measuring Equipment** (DME)**, Very High Frequency OmniRange** (VOR)**, Automatic Direction Finding** (ADF)**, TACtical Air Navigation** (TACAN)**, Long Range Navigation**

(LORAN-A and C), **VORTAC** (Combined VOR and TACAN).

- **Dead reckoning navigation** is the process of estimating one's current position based upon a previously determined position, and advancing that position based upon known or estimated speeds over elapsed time, and course. **Inertial Navigation System (INS)** is a simple form of dead reckoning navigation.
- **Global Navigation Satellite Systems** (GNSSs), is the standard generic term for **satellite navigation systems** that provide autonomous geo-spatial positioning with global coverage. GNSS allows small electronic receivers to determine their location (longitude, latitude, and altitude) to within a few metres using time signals transmitted along a line-of-sight by radio from satellites. As of 2010, the United States **NAVSTAR Global Positioning System (GPS)** is the only fully operational GNSS. The Russian **GLONASS** is a GNSS in the process of being restored to full operation (21 of 24 satellites are operational). The European Union's **Galileo** positioning system is a GNSS in initial deployment phase, scheduled to be operational in 2014.of which the Global Positioning System (GPS) is the most notable.
- Navigation also includes landing aids such as **Instrument Landing System** (ILS) and **Microwave Landing System** (MLS) in which the aircraft's position with respect to the runway is known for ease and safe landing.

Distance Measuring Equipment (DME)

- DME shows pilot a distance from a ground station in Nautical Miles (NM).
- It operates in UHF band between **978 -1213 MHz**. Its range is limited to line of sight.
- Its range is about 250 NM depending on the altitude of station and aircraft.
- DME stations are usually co-located with VOR (Very High Frequency Omni Range) stations.
- The distance shown is slant distance shown in figure 5.1.

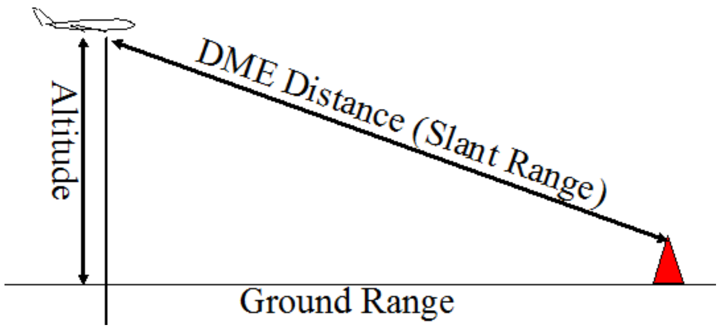


Figure 5.1 DME Slant range

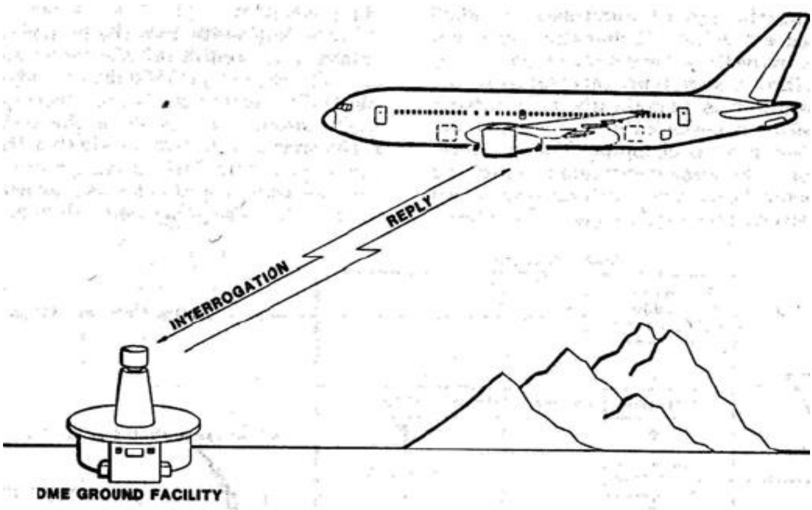


Figure 5.2 DME basic operation

- Aircraft DME unit measures the time elapsed between transmission and reception of the signal.

R = (t-d)/12.36

Where **R** = Slant range to station (NM)

t = Total elapsed time (µs)

d = Fixed delay of ground station (50 µs)

12.36 µs = Typical time for signal to travel 1NM and return.

DME Interrogation (air-to-ground) signal

DME has 100 channels with 1 MHz spacing. Interrogation signal is made of series of pulse pairs (p1-p2, p3-p4, p5-p6, etc.) which is shown in figure 5.3 and 5.4.

X or Y mode (channel) operation.

5-150 pulse pairs per second.

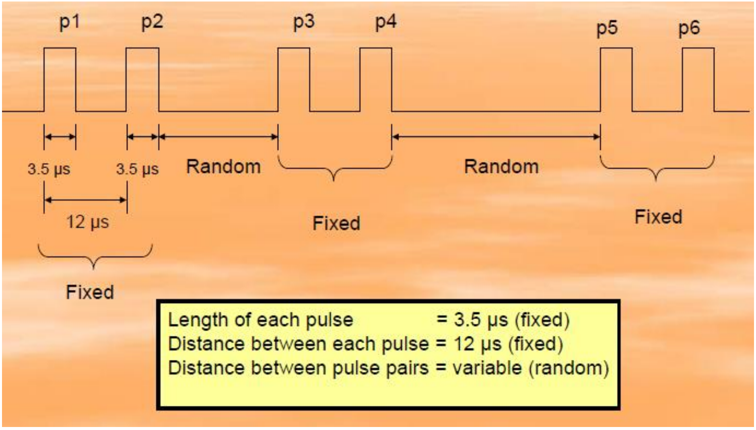


Figure 5.3 DME X mode (channel) interrogation

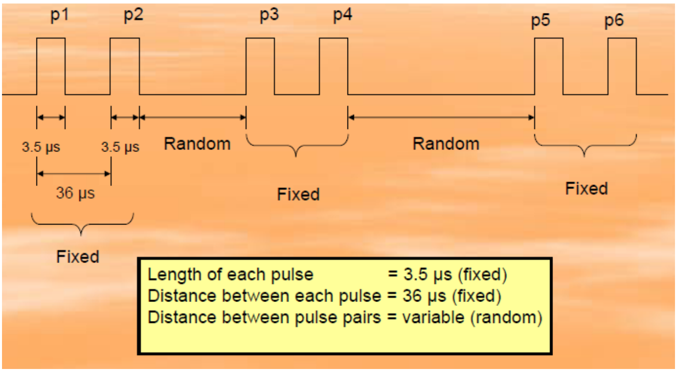


Figure 5.4 DME Y mode (channel) interrogation

DME Reply (ground-to-air) signal

- Reply (Ground-to-air) signal
- Reply is transmitted 63 MHz above or below interrogation signal.
- It is made of series of pulse pairs shown in figure 5.5 and 5.6.
- X or Y mode operation.

- Channels are numbered 1X, 1Y, 2X, 2Y,.... both in interrogation and reply (For example, 962 MHz is known as 1X or 1Y channel).

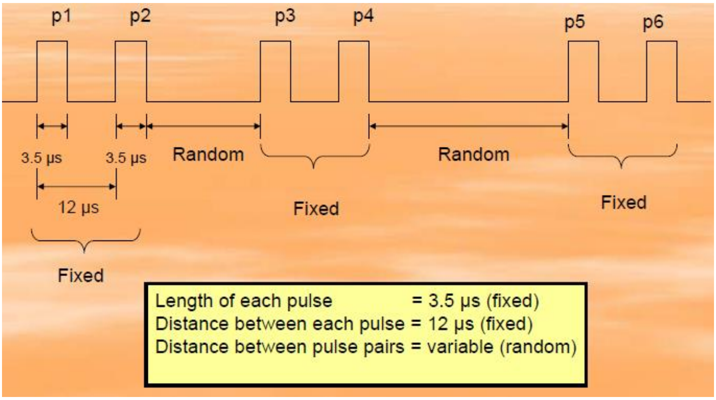


Figure 5.5 DME X mode (channel) reply

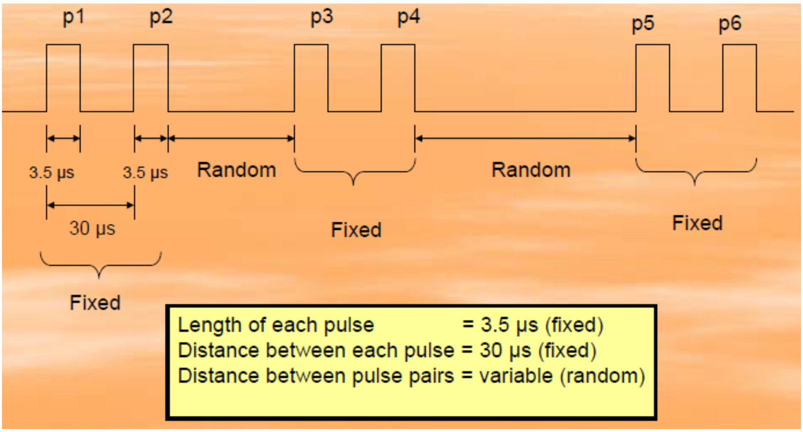


Figure 5.6 DME Y mode (channel) reply

DME Segments

Aircraft segment – Transmitter & Receiver (Transceiver), Indicator, Antenna, Ground segment.

DME Aircraft Transceiver

Transmitter continuously transmits its unique, randomly spaced interrogation signal.

Receiver is able to recognize its own signal when retransmitted back by the ground station with the same spacing. Then it measures the range.

Suppressor bus prevents other radar transmitter from operating when one of them is working.

Transceiver modes of operation – Jitter, Search, Track, Memory, Hold.

Jitter: It is the process of placing random time spacing between the pulse pairs. It is unique to each aircraft and randomly produced.

Search: It is the process in which DME tries to match the transmitted signals to the received signals to recognize its own signals, when it is turned on. During the search period a warning flag in DME indicator is in view, showing that DME system is not operative yet. During search mode, the Pulse repetition rate is about 120-150.

Track mode: During track mode, Continuous range is given as the aircraft moves towards or away from the station. At this mode, the Pulse repetition rate is about 24-30.

Memory mode: This mode becomes active when DME unit loses reply signals from the ground station.

DME Ground station

It operates with the same principle of aircraft unit. When it receives interrogation signal from aircraft it waits 50μs. Then retransmits back to aircraft at a frequency 63 MHz above or below of incoming signal.

The reason for the 50µs delay is that the delay gives time for (i) the transmit/receive switching to take place, (ii) to give the second pulse a chance to get to its destination.

Each ground station can handle up to 100 aircraft simultaneously. It is assumed that 95% of aircraft in track mode and 5% is in search mode. Thus, to serve 100 aircraft at the same time, the station should answer app. 2700 interrogation signals (pulse pairs) in a second.

A ground station is designed to reply 2700 interrogation signal (pulse pairs) always even if the number of aircraft is less than 100. This is known as **constant-duty cycle operation**.

Ground station is designed to emit 2700 reply signals per second (constant duty cycle) assuming 100 aircraft in the region. If there is less than 100 aircraft, the station continues to emit 2700 signals, but some of them are fake (noise) signals. These types of signals are called Squitter. Squitter are not used for range measurement, but may be used for identification of the station by the aircraft.
A ground station also emits an identification signal in Morse code at 1350 Hz. Thus, it can be said that the ground station signals are composed of three types: (i) Real reply signals, (ii) Squitter (noise) signals, (iii) A continuous identification signal. If the number of aircraft interrogation the station is 100, then all ground signals are real reply signals. If number of aircraft less than 100, then some signals are real reply signals and others are noise signals. Assume only one aircraft is in the region and interrogates the station at a rate of 27 pps. Then, the signal composition of the ground station will be 27 real reply signals and 2700-27 = 2673 Squitter signals.

Very High Frequency Omni Range (VOR)

The VHF Omni-directional Radio Range, the abbreviations for which are 'VOR' and 'Omni', enables a pilot to determine the direction of his aircraft from any position to or from a VOR beacon, and, if necessary, track to or from the beacon on a selected bearing. VOR is a Very High Frequency (VHF) navigation aid which operates in the **108 to 117.95 MHz** frequency band. Because it is a VHF aid, its ground to air range is limited to 'line of sight' reception which is typical of VHF transmission. The range achieved is dependent, therefore, on the siting of the VOR beacon with relation to surrounding terrain, and on the height at which the aircraft is flying.

As a VHF navigation aid, the VOR is static-free, and the information given by it is displayed visually on easily read and interpreted cockpit instruments. An infinite number of bearings can be obtained and they may be visualized as radiating from the beacon like spokes from the hub of a wheel. However, for practical purposes the number of bearings can be considered to be limited to 360, one degree apart (like spokes in a wheel), and these 360 bearings are known as radials shown in figure 5.7. A Radial is identified by its magnetic bearing outbound from the VOR beacon.

VOR – Principle of Operation

The VOR beacon transmits two VHF radio signals from the same facility. One of these signals, called the **reference phase**, is omni-directional and radiates from the station in a circular pattern. The phase of this signal is constant through 360° of azimuth. The other signal is transmitted as a rotating field. This signal pattern rotates uniformly at 1800 r.p.m. through 360 degrees (like the beam from the lighthouse), varies in phase with azimuth, and is called the variable phase. Therefore, there is a different phase of this signal at each separate point around the station.

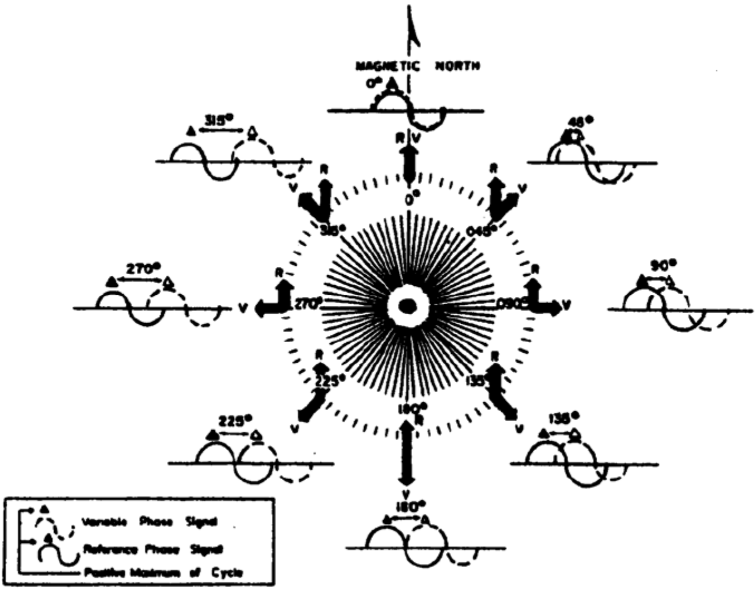


Figure 5.7 VOR phase angle relationships

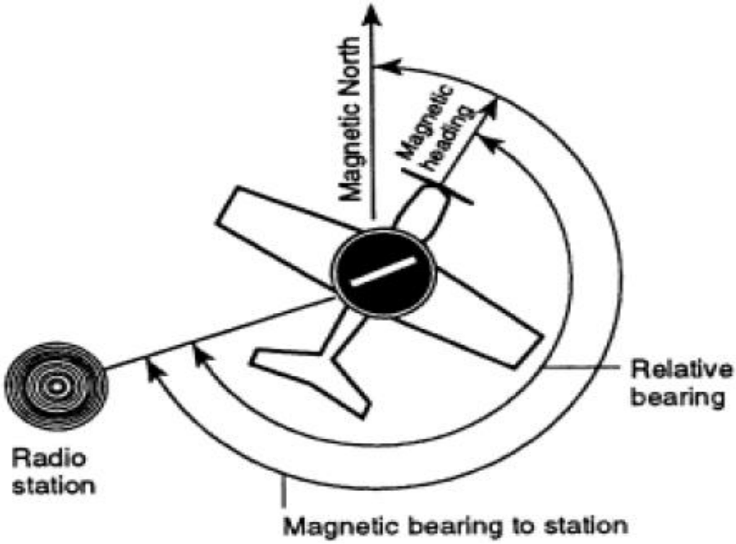


Figure 5.8 Magnetic bearing and Relative bearing

Magnetic north is used as the baseline for measuring the phase relationship between the reference and variable signals. The two signals are aligned so that at magnetic north they are exactly in phase. As can be seen in Figure 5.8, a phase difference, which is analogous to the time difference between the reference phase and the variable phase, exists at any other point of azimuth around the beacon. This phase difference is measured electronically and converted to degrees of angle by the aircraft airborne equipment thus identifying the aircraft position in azimuth around the beacon. The information is presented visually by an indicator on the instrument panel.

An identification signal of two or three Morse Code letters is transmitted by the VOR beacon every ten seconds. It is also possible to transmit voice identification or other information, that is, meteorological information.

Automatic Direction Finder (ADF)

It operates in Low Frequency and Medium Frequency band (190-1799 KHz), thus it is based on ground wave propagation. Its range is not limited to line-of sight distance. It can receive on both Amplitude Modulation radio stations and NDB (non directional beacons). Its operation is similar to listening to a transistor radio.

ADF Components

ADF components are (1) ground stations and (2) aircraft component.

ADF Ground stations

They transmit omnidirectional (in every direction) signals. They are called nondirectional beacons (NDB). Stations have a vertical antenna which emits vertically polarized signal, which is magnetic field of the radio wave horizontal to the ground, electrical field is vertical.

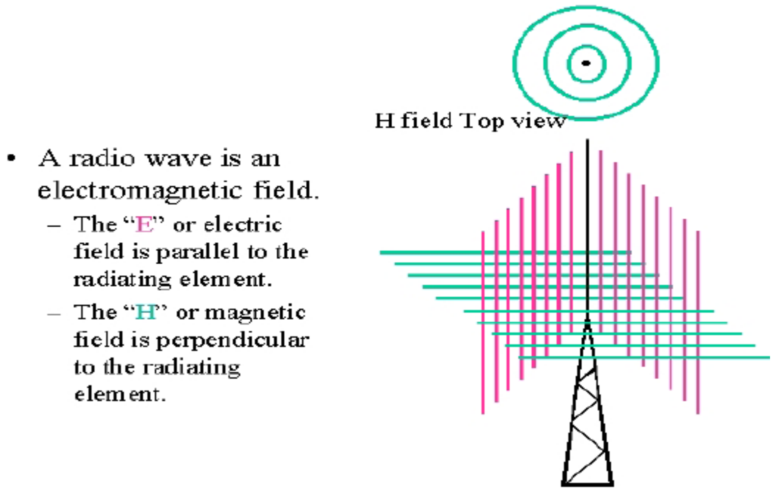


Figure 5.9 Radio wave transmission from an NDB

ADF Aircraft components

ADF aircraft components are Antennas, Receiver, Control head, Indicator.

ADF Antennas

Two antennas are used for ADF: (1) **Loop antenna** – It indicates the direction of the ground station. (2) **Sense antenna** – It indicates the sense of the station (if station is in front/back or to the right/left of the aircraft).

Loop antenna

It is a directional antenna. It indicates the direction of the station, but cannot determine if the station is in front/back or to the right/left of the aircraft. It is in the shape of rectangular or circular loop which is shown in figure 5.10 and 5.11. It uses magnetic field component of the radio wave.

Sense antenna

Its function is to indicate if the station is in front / back or to the left/right of the aircraft. It is a capacitive antenna. It couples only with the electrical component of the radio wave. It is an unidirectional antenna, its signal strength is the same all around.

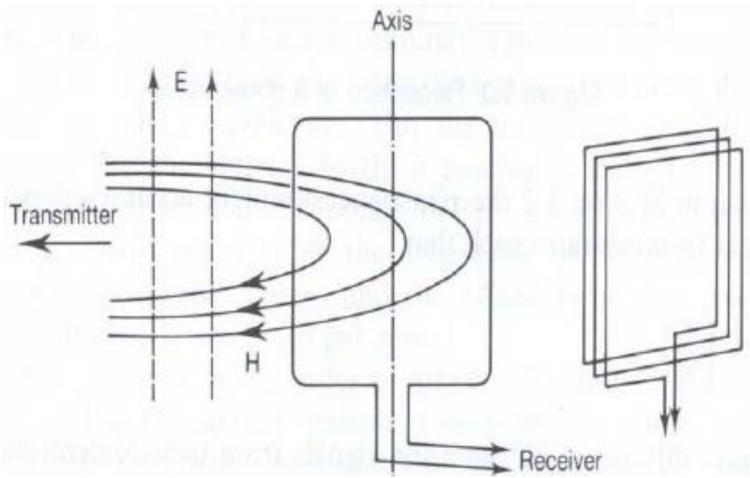


Figure 5.10 Rectangular Loop Antenna

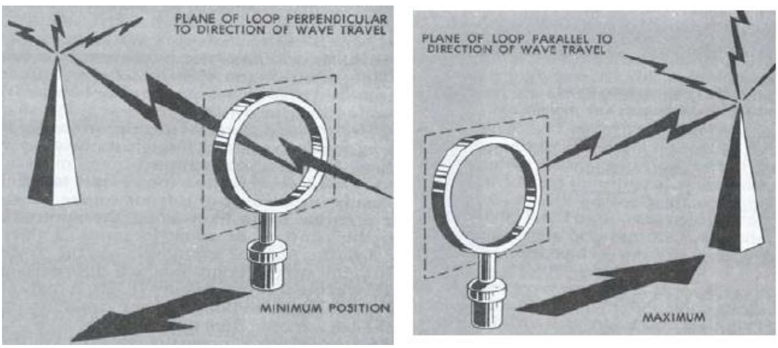


Figure 5.11 Circular loop antenna

Tactical Air Navigation (TACAN)

TACAN is a military system combining the bearing capability of VOR with the distance measuring capability of DME. TACAN is based on DME in that it uses the DME antenna shown in figure 5.12 and the DME pulse format.

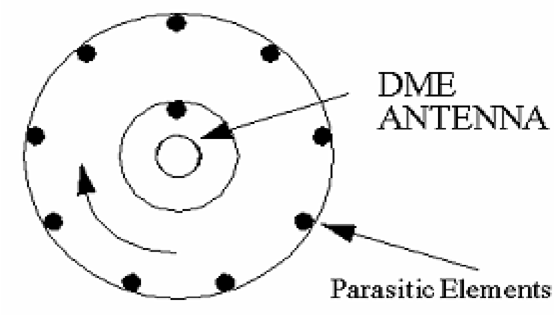


Figure 5.12 TACAN Antenna arrangement

TACAN bearing function

Two concentric drums are placed around the DME antenna. The parasitic elements distort the DME antenna pattern. The drum structure is rotated at 900 rpm (15 Hz). The resulting pattern has one main lobe caused by the inner parasitic element, and 9 secondary lobes caused by the outer elements. Thus the TACAN signal consists of 2700 pulse-pairs/second whose amplitude is modulated by a 15Hz signal and a 135 Hz signal.

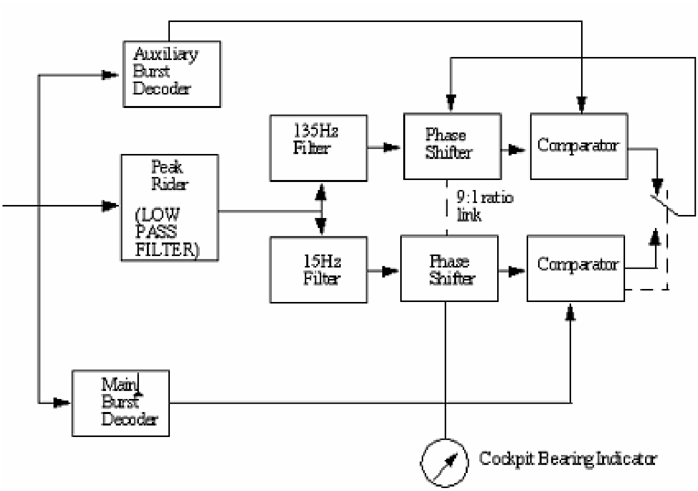


Figure 5.13 TACAN Receiver

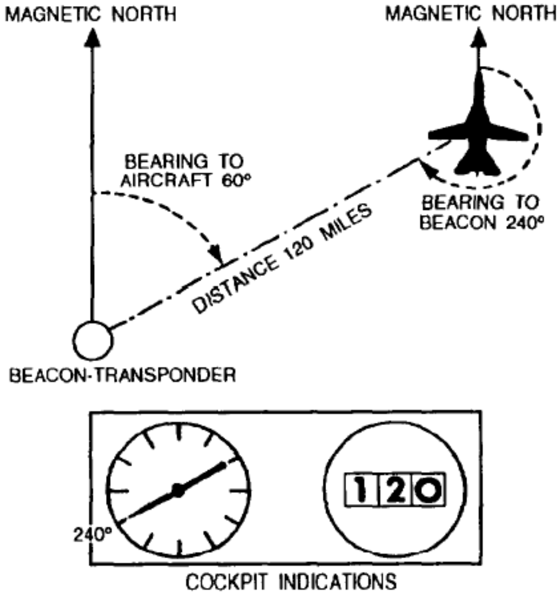


Figure 5.14 TACAN aircraft indication

The reference part of the TACAN signal consists of coded sets of pulses called reference groups (or bursts).

The Main Reference Group (MRG) consists of 24 pulses with alternate spacings of 12 and 18µs. This is transmitted when the antenna pattern main lobe reference point passes the North reference.

The Auxiliary Reference Group (ARG) consists of 12 pulses with of 30 µs spacing. This is transmitted when each of the auxiliary lobe reference points passes the North reference.

Since TACAN is not a civilian system it does not have to conform to normal aviation requirements. However, since military aircraft use the same airway structure as civilian aircraft, there are TACANS co-located with VORs on most airways and these conform to the civilian standards for VORs. These facilities are called **VORTACs**.

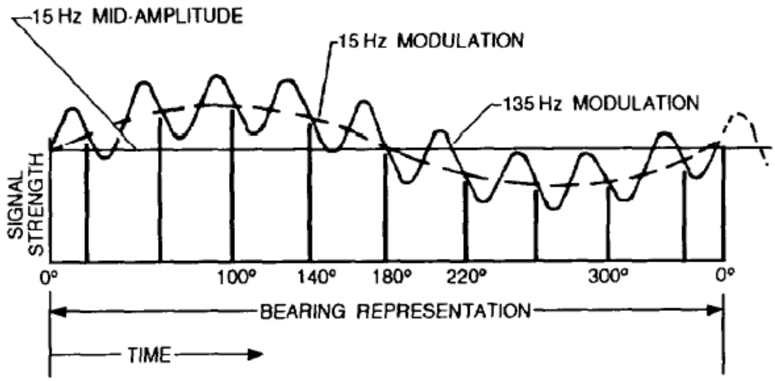


Figure 5.15 TACAN modulation envelope

Inertial Navigation System (INS)

INS which relies on knowing your initial position, velocity, and attitude (orientation) and thereafter measuring your attitude rates and accelerations. The operation of INS depends upon Newton's laws of classical mechanics. It is the only form of navigation that does not rely on external references (ground stations, satellites etc).

Basic principle of inertial navigation

Inertial navigation is accomplished by integrating the output of a set of sensors to compute position, velocity, and attitude. The sensors used are gyros and accelerometers **(Inertial Sensors)**. Gyros measure angular rate (rotation) with respect to **inertial space**, and accelerometers measure linear acceleration, again with respect to an inertial frame. Integration is a simple process, complexities arise due to the **various coordinate frames** encountered, sensor errors, and noise in the system.

Given the ability to measure the acceleration of vehicle it would be possible to calculate the change in velocity and position by performing successive mathematical integrations of the acceleration with respect to time.

In order to navigate with respect to our inertial reference frame, it is necessary to keep track of the direction in which the accelerometers are pointing.

Rotational motion of the body with respect to inertial reference frame may be sensed using gyroscopic sensors that are used to determine the orientation of the accelerometers at all times. Given this information it is possible to resolve the accelerations into the reference frame before the integration process takes place.

The main problem in INS is that the accelerometer cannot tell the difference between vehicle acceleration and gravity. We therefore have to find a way of separating the effect of gravity and the effect of acceleration. This problem is solved in one of the two ways:

(1) Keep the accelerometers horizontal so that they do not sense the gravity vector. This is the stable platform (Gimbal) mechanization shown in figure 5.16.
(2) Somehow keep track of the angle between the accelerometer axis and the gravity vector and subtract out the gravity component. This is the strap down mechanization.

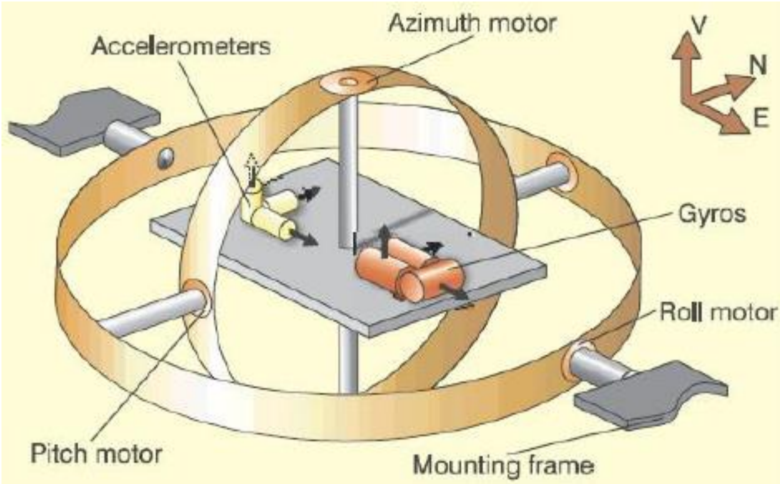


Figure 5.16 Stable platform mechanization

Gimbal platform mechanization

A gimbal is a rigid with rotation bearings for isolating the inside of the frame from external rotations about the bearing axes. At least three gimbals are required to isolate a subsystem from host vehicle rotations about three axes, typically labelled roll, pitch, and yaw axes.

The gimbals in an INS are mounted inside one another. Gimbals and torque servos are used to null out the rotation of stable platform on which the inertial sensors are mounted.

The gyros of a type known as "integrating gyros" give an output proportional to the angle through which they have been rotated. Output of each gyro connected to a servo-motor driving the appropriate gimbal, thus keeping the gambling a constant orientation in inertial space.

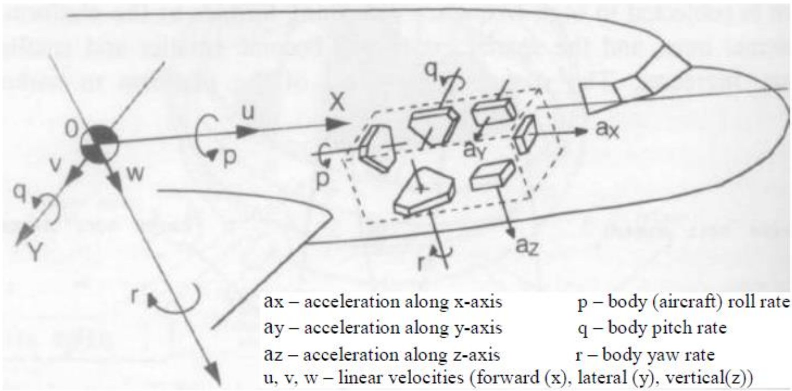


Figure 5.17 Strapdown mechanization

Strapdown mechanization

In Strapdown INS concept, Accelerometers are mounted directly to airframe (Strapdown) and measure "body" acceleration which is illustrated in figure 5.17.

Horizontal/vertical accelerations computed analytically using direction cosine matrix (DCM) relating body coordinated and local level navigation coordinates (North (N), East (E), Down (D).

DCM computed using Strapdown body mounted gyro outputs.

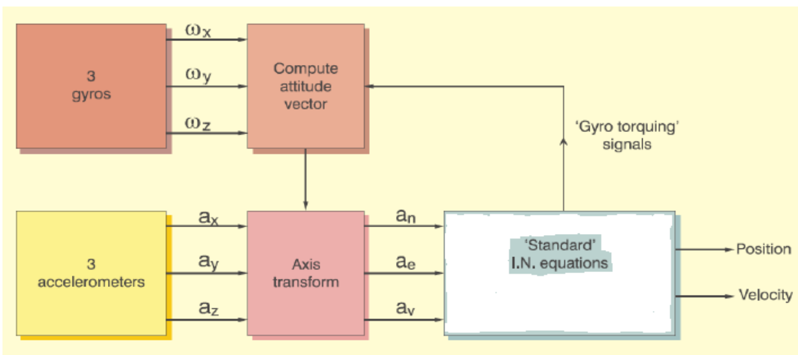


Figure 5.18 Basic Strapdown INS block diagram

Advantages of INS

- It is autonomous and does not rely on any external aids or visibility conditions. It can operate in tunnels or underwater as well as anywhere else.
- It is immune to jamming and inherently stealthy. It neither receives nor emits detectable radiation and requires no external antenna that might be detectable by radar.
- Provides both translational and rotational data.
- Data outputs from INS available at faster rates.

Disadvantages of INS

- Position errors accumulate with time.
- Knowledge of gravity required.
- Inertial sensors cost are high for accurate navigation.

Global Positioning System (GPS)

The Global Positioning System (GPS) is part of a satellite-based navigation system developed by the U.S. Department of Defence under its NAVSTAR satellite program.

GPS Satellites orbits

The fully operational GPS includes 24 or more (28 in March 2006) active satellites approximately uniformly dispersed around six circular orbits with four or more satellites each. The orbits are inclined at an angle of 55° relative to the equator and are separated from each other by multiples of 60° right ascension. The orbits are non-geostationary and approximately circular, with radii of 26,560 km and orbital periods of one-half sidereal day

(≈11.967 h). Theoretically, three or more GPS satellites will always be visible from most points on the earth's surface, and **four or more GPS satellites** can be used to determine an observer's position anywhere on the earth's surface 24 hour per day.

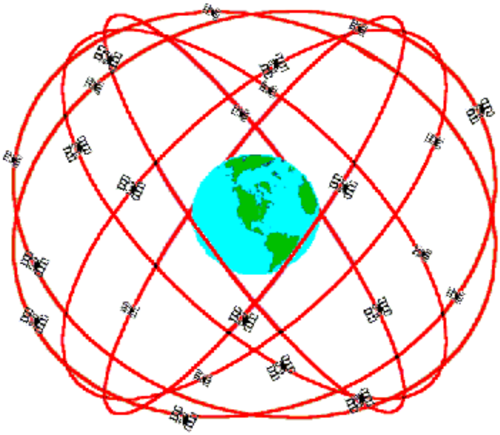


Figure 5.19 GPS orbits

GPS Satellite Signals

Each GPS satellite carries a atomic clock to provide timing information for the signals transmitted by the satellites. Internal clock correction is provided for each satellite clock. Each GPS satellite transmits two spread spectrum, L-band carrier signals – an L1 signal with carrier frequency $f1$ **= 1575.42 MHz** and an L2 signal with carrier frequency $f2$ **= 1227.6 MHz**. These two frequencies are integral multiples $f1 = 1540 \times f0$ and $f2 = 1200 \times f0$ of a base frequency $f0$ **= 1.023 MHz**.

The L1 signal from each satellite uses *binary phase-shift keying* (BPSK), modulated by two *pseudorandom noise*

(PRN) codes in phase quadrature, designated as the **C/A** or Clear Acquisition (or Coarse Acquisition) code and **P** or Precise or Protected code. The L2 signal from each satellite is BPSK modulated by only the P-code.

The Navigation Message also modulates the L1-C/A code signal. The **Navigation Message** is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters.

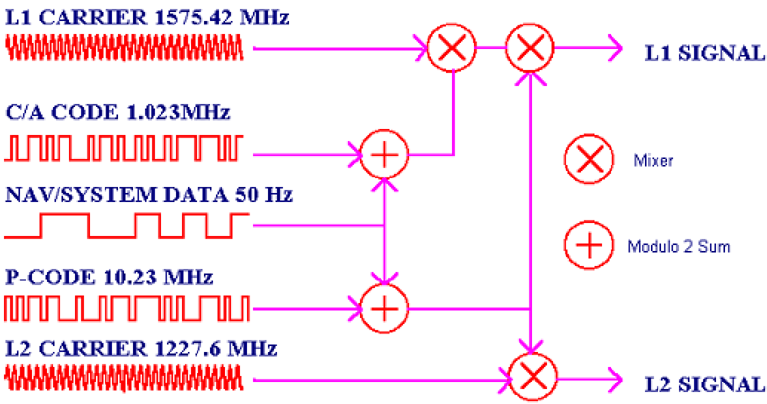


Figure 5.20 GPS Satellite signals

The GPS system comprises of three major segments: Space, Control and User segments which is given in figure 5.21.

Space Segment

The fully operational space segment was planned to have a constellation of 21 satellites, plus 3 operational spares, in six planes with four satellites per plane. Their orbits are nominally circular with an inclination of about 55 degrees and have a period of 12 hours. Orbital height is approximately 20200 km.

Control Segment

The Control Segment consists of a system of tracking stations located around the world. The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado. These monitor stations measure signals from the satellites which are incorporated into orbital models for each satellite. The models compute precise orbital data (ephemeris) and clock corrections for each satellite. The Master Control station uploads ephemeris and clock data to the satellites. The satellites then send subsets of the orbital ephemeris data to GPS receivers over radio signals.

User Segment

Two methods are used to lower the accuracy of the system:

Selective Availability (SA)

SA mainly affects single receiver usage and is achieved primarily by dithering the satellite clock frequency.

The transmitted navigation message can also be truncated which denies the user the ability to accurately compute the coordinates of the satellites.

Anti-Spoofing (AS)

This feature is invoked randomly to negate potential spoofing (hostile imitation) of Precise Positioning Service (PPS) users. This ability essentially turns off the P-code or turns on an encrypted Y-code.

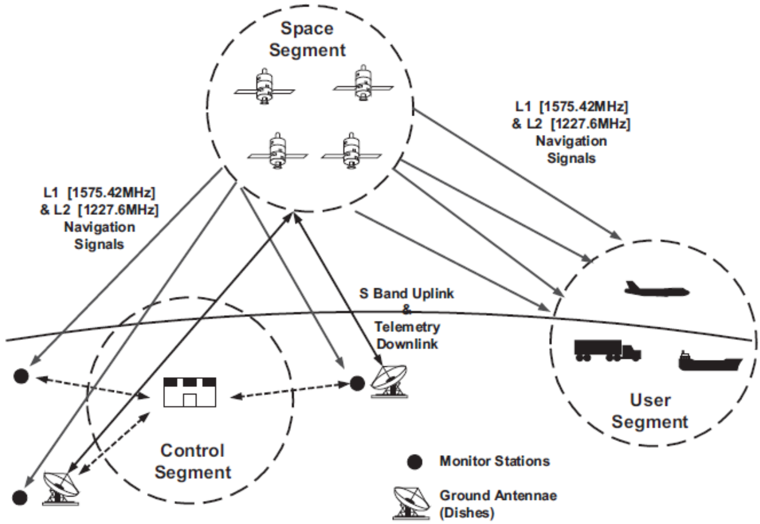


Figure 5.21 GPS Space segment, control segment and user segment

GPS levels of service for users

There are two basic levels of service provided by GPS:

Precise Positioning Service (PPS)

Authorized users with cryptographic equipment and keys and specially equipped receivers use the Precise Positioning System. U.S and Allied military, certain U.S Government agencies, and selected civil users specifically approved by the U.S Government, can use the PPS.

Standard Positioning Service (SPS)

Civil users worldwide use the SPS without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the U.S Department of Defence (DOD) by the use of Selective Availability.

Instrument Landing System (ILS)

The ILS is an approach and landing aid that has been in widespread use since the 1960s and 1970s.

The main elements of ILS include:

A **localizer antenna** centred on the runway to provide lateral guidance. A total of 40 operating channels are available within the band 108.112 MHz. The localizer provides left and right lobe signals that are modulated by different frequencies **(90 and 150 Hz)** so that one signal or other will dominate when the aircraft is off the runway centre-line. The beams are arranged such that the 90 Hz modulated signal will predominate when the aircraft is to the left, while the 150 Hz signal will be strongest to the right. The difference in signal is used to drive a cross-pointer deviation needle so that the pilot is instructed to 'fly right' when the 90 Hz signal is strongest, and 'fly left' when the 150 Hz signal dominates. When the aircraft is on the centre-line, the cross-pointer deviation needle is positioned in the central position. This deviation signal is proportional to azimuth out to ±5° of the centre-line.

A **glide slope antenna** located beside the runway threshold to provide lateral guidance. Forty operating channels are available within the frequency band 329.335 MHz. As for the localizer, two beams are located such that the null position is aligned with the desired glide slope, usually set at a nominal 3°. In the case of the glide slope, the 150 Hz modulated signal predominates below the glide slope and the 90 Hz signal is stronger above. When the signals are balanced, the aircraft is correctly positioned on the glide slope and the glide slope deviation needle is positioned in a central position. As for the localizer needle, the pilot is provided with ‘fly up’ or ‘fly down’ guidance to help him or her acquires and maintains the glide slope. Figure 5.22 shows the general arrangement of ILS. Figure 5.23 illustrates how guidance information is portrayed for the pilot according to the aircraft position relative to the desired approach path. On older aircraft this would be shown on the compass display, but on modern aircraft, with digital cockpits, this information is displayed on the Primary Flight Display (PFD). The ILS localizer, glide slope, and DME channels are paired such that only the localizer channel needs to be tuned for all three channels to be correctly tuned.

Marker beacons are located at various points down the approach path to give the pilot information as to what stage on the approach has been reached. These are the **outer, middle, and inner markers**. Location of the marker beacons are:

- outer marker approximately 4.7 nautical miles from the runway threshold,
- middle marker ~3000 ft from touchdown,
- inner marker ~1000 ft from touchdown.

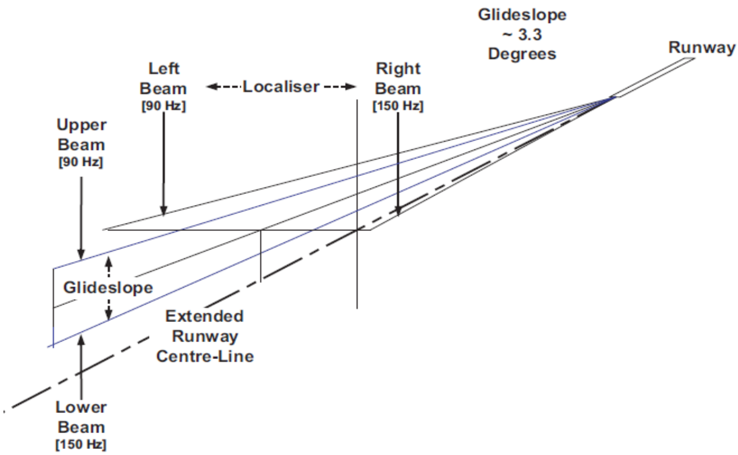


Figure 5.22 ILS glide slope and localizer

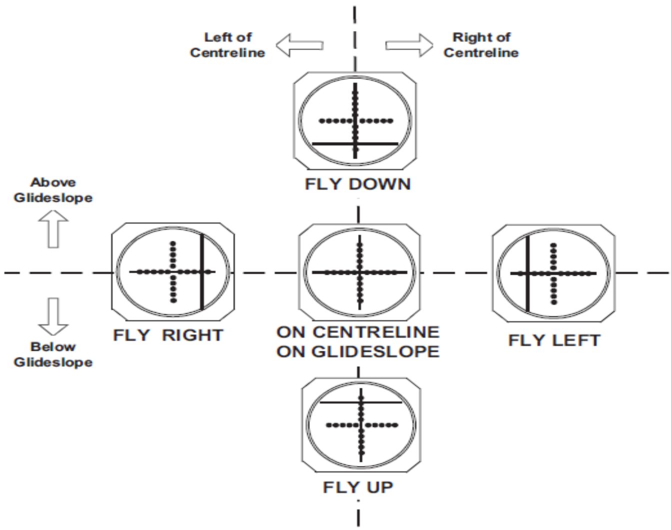


Figure 5.23 ILS guidance display

The marker beacons are all fan beams radiating on 75 MHz and provide different Morse code modulation tones that can be heard through the pilot's headset. The layout of the marker beacons with respect to the runway is shown in

Figure 5.24. The beam pattern is ±40º along track and ±85º across track. The overall audio effect of the marker beacons is to convey an increasing sense of urgency to the pilot as the aircraft nears the runway threshold.

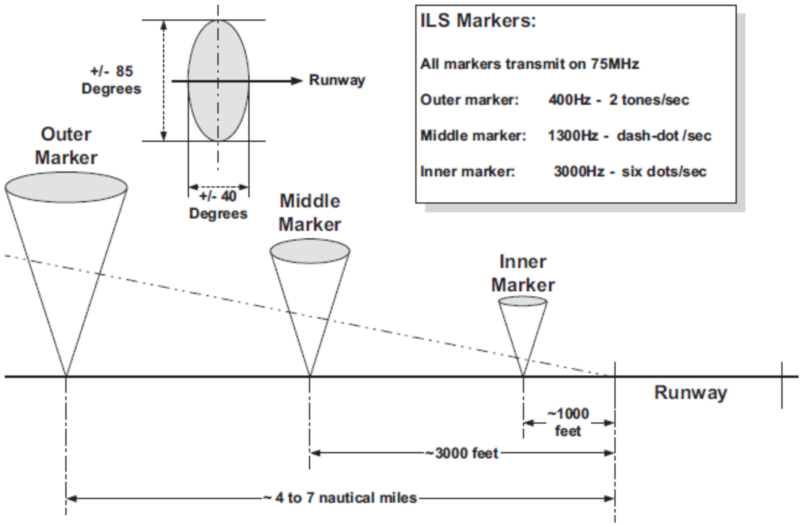


Figure 5.24 ILS marker beacons

Microwave Landing System (MLS)

The specification of a Time-Reference Scanning Beam (TRSB) MLS was developed through the late 1970s/early 1980s, and a transition to MLS was envisaged to begin in 1998.

MLS operates in the frequency band 5031.0 – 5190.7 MHz and offers some 200 channels of operation. It has a wider field of view than ILS, covering ±40º in azimuth and up to 20º in elevation, with 15º useful range coverage. Coverage is out to 20 nm for a normal approach and up to

7 nm for back azimuth/go-around. The co-location of a DME beacon permits three-dimensional positioning with regard to the runway, and the combination of higher data rates means that curved arc approaches may be made, as opposed to the straightforward linear approach offered by ILS. This offers advantages when operating into airfields with confined approach geometry and tactical approaches favoured by the military. For safe operation during go-around, precision DME (PDME) is required for a precise back azimuth signal. Typical coverage in azimuth and elevation for an MLS installation is shown in Figure 5.25.

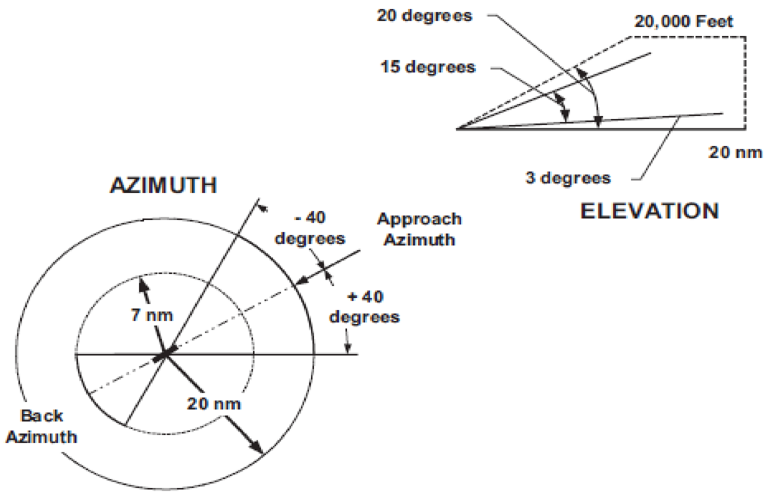


Figure 5.25 Microwave landing system coverage

The TRSB-MLS is based on the principle of converting the angular position of the receiver (in aircraft) into a time difference between two received pulses. It uses two narrow beams which are scanned in an oscillatory manner in the azimuth and elevation sectors. At every position within the scan sector, an aircraft will receive two pulses from each beam corresponding to the 'to' and 'fro' scans. The aircraft derives its position within the coverage volume by measuring the time difference between these pulses pair wise.

The azimuth scan uses a fan beam broad in the vertical plane and narrow in the horizontal plane. Similarly, the elevation beam scans up and down using a fan beam broad in the horizontal plane and narrow in the vertical plane. Each beam scans its assigned sector (azimuth or elevation) at a constant sweep rate.

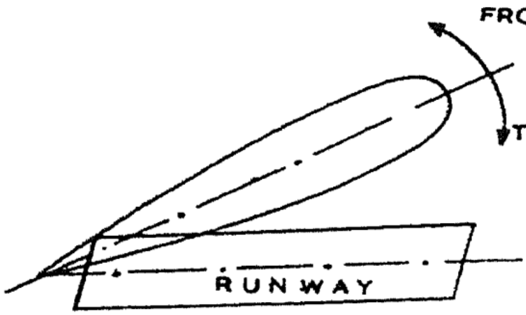


Figure 5.26 ***MLS 'to' and 'fro' scans***

For a given scanning speed and pause time, the elevation angle can be calculated from the equation.

$\theta = (t_0 - t)\ V/2$

where

θ = angular position of aircraft in degrees

V = angular speed of the scanning beam (0.02 degrees per microsecond)

t = actual time interval between pulses received from 'to' and 'fro' scans in microseconds

t_0 = value of ***t*** in microseconds.

Aircraft Flight Control Systems

Introduction

Flight controls have advanced considerably throughout the years.

In the earliest biplanes flown by the pioneers flight control was achieved by warping wings and control surfaces by means of wires attached to the flying controls in the cockpit.

When top speeds advanced into the transonic region the need for more complex and sophisticated methods became obvious.

They were needed first for high-speed fighter aircraft & then with larger aircraft when the jet propulsion became more wide spread.

The higher speeds resulted in the higher loads on the flight control surfaces, which made the aircraft very difficult to fly physically.

To overcome the higher loads powered surfaces began to be used with hydraulically powered actuators boosting the efforts of the pilot.

Principles of Flight Control

All aircrafts are governed by the same basic principles of flight control, whether the vehicle is the most sophisticated high performance fighter or the simplest model aircraft.

The following figure shows the direction of the aircraft velocity in relation to the pitch, roll and yaw axes.

For most of the flight the aircraft will be flying straight and level and the velocity vector will be parallel with the surface of the earth and proceeding upon a heading that the pilot has chosen.

Types of Flight Control Systems

1. Conventional system.
2. Power assisted flight controls.
3. Fully powered flight controls.
4. Power actuated systems.

Conventional System

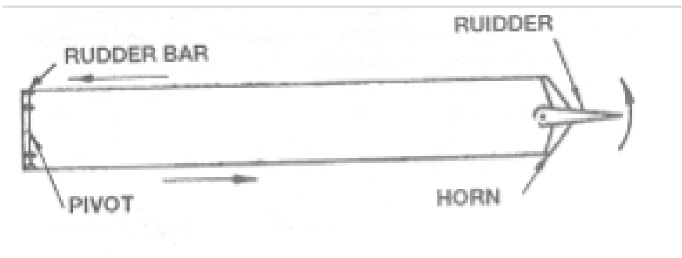


Figure 5.27 Cable Rudder Control

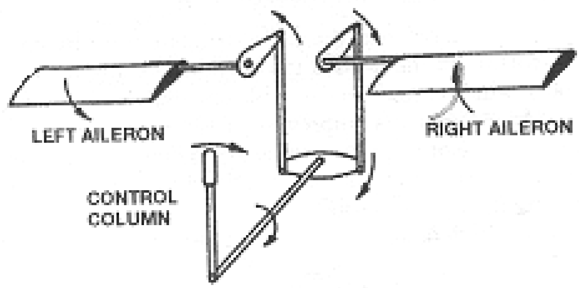


Figure 5.28 Torque Tube Aileron Control

Figure 5.29 Push Pull Rod Control.

Power Assisted Control

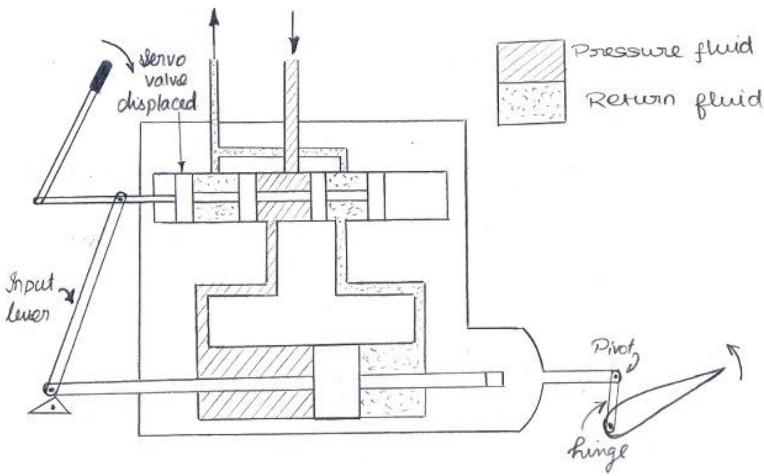


Figure 5.30 Power Assisted Control.

In a power assisted control system the pilot is assisted in the operation of the control surface in the real sense that the majority of the work of the moving the control surface is done by the actuator and a small proportion by the pilot.

This is shown by the examples illustrated in the figure. In powered control system the actuator does all the work and pilot's contribution of effort is zero.

In a power assisted installation the pilot feels a proportion of the load on the control surface and therefore can be said to have "feel" or "sense of feel".

This achieved by proportional feedback in that whilst most of the load acting on the control surface is transmitted via the actuator body, fluid, piston and ram back into the airframe through the input lever and control run to the cockpit control and will be felt by the pilot.

If at high speed the control surface is progressively deflected, the load on the control surface will progressively increase and so the feel experienced by the pilot will be progressive increase.

Power Operated Flying control System

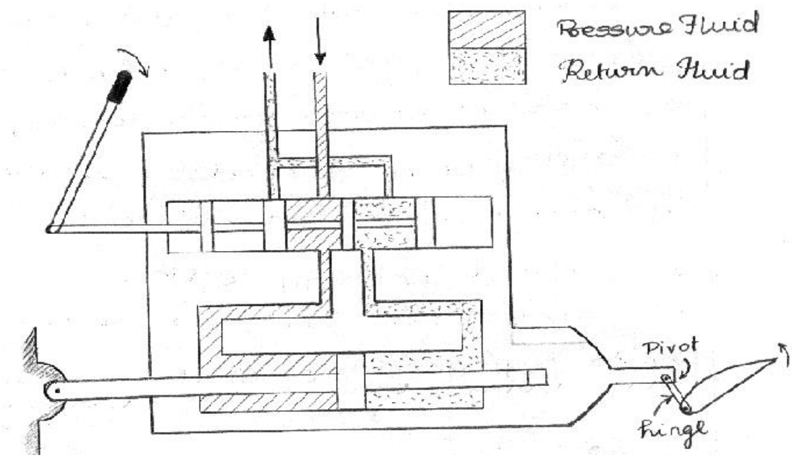


Figure 5.31 Power Operated Flying control system.

The PFCU normally consists of two essential elements in the form of an actuator, or jack to which is attached a selector valve or a servo valve inlet.

- ❖ The selector or servo valve is activated by the pilot when movement of the control column or rudder pedals are made.
- ❖ Figure indicates the simple example of a PFCU movement of the cock-pit control moves the servo valve input via cables or rods which determines the direction of the fluid flow from one side to the other of the piston.
- ❖ The fluid cannot move the piston as the piston rod or the ram is connected to the aircraft structure and the result is that the unit body moves and through linkage, moves the control surface.
- ❖ This action creates a flow up motion. So that, when a small input is made, the body will move until the ports close.
- ❖ In this way the movement of the unit is always related to the movement of the cockpit control.
- ❖ Each time an input made to the servo valve, the body will move until the parts are closed, when the servo valve is in neutral, return valve is also controlled and directed by the servo valve and when allowed to flow is directed back to the common return.
- ❖ When the servo is in the neutral, a hydraulic lock is formed so that, the control surface is held rigidly in the selected position.

Control Configured Vehicle

Aircrafts are made statically and dynamically stable. In other words, longitudinally and laterally stable.

The stable aircraft possess problem for manoeuvrability.

By making the aircraft longitudinally unstable say by keeping the C.G., aft of left center, the higher roll rates can be obtained.

But, controlling the aircraft becomes very difficult for the pilot.

The improvement of electronics, the present day aircraft helps in applying the controls 40 times per second, which is impractical for a human pilot.

Controlling of the aircraft by the present day electronics is called “Active Control Technology” [ACT].

ACT takes into account of all the safety factors and limitations of the particular aircraft and controls the aircraft in pitch, roll and yaw, taking into consideration of the pilot inputs, through control column and rudder pedal.

The pilot makes nightmare of the load factor control [‘g’ control], roll rate control [‘p’ control], Angle of Attack [AOA] control are fully taken care by ACT.

This is accomplished by having its own sensors, to sense pitch rate, roll rate, yaw rate, longitudinal acceleration, lateral acceleration, vertical acceleration etc. In addition, the applications of the controls are modified as per altitude & Mach number.

This is done by sensing the Pitot pressure and static pressure.

This information is vorted out to have redundancy of the information. [vorting- means comparing information from 3 to 4 sources taking average of this information and comparing with each input not compatible with the average value is vorted out].

Mechanical Flight Control System

It is generally used on small aircraft. The primary flight control surfaces are moved manually by using push-pull rods.

Push Pull Rod Type

In this a sequence of rods are used to link the control surfaces to the cabin input.

Bell crank lever is used to alter the direction of the force and to obtain the coupling between stick movement and the control surface deflection.

This is used to transfer either tension or compression loads.

Cable Pulley Type

The cable pulley system requires large no of pulleys, brackets and guards. So this system becomes more complex and heavier. In this system we are using the cables instead of rods.

Pulleys – Used to alter the direction of lines

Quadrant is employed at the base of the control column to impact force and motion to the cable system. A torque tube is attached to the control surface, which changes linear motion of the cable into rotary motion. For large aircrafts this type is preferable, because more flexible.

Fly By Wire Basic Concepts and Features

1. Total elimination of all the complex mechanical control runs and linkages. All commands and signals are transmitted electrically along wires.
2. The interposition of a computer between the pilot's commands and the control surface actuators.
3. The aircraft motion sensors which feed back the components of the aircraft's angular and linear motion to the computer.
4. The air data sensors which supply height and airspeed information to the computer.

The pilot thus controls the aircraft through the flight control computer and the computer determines the control surface movement for the aircraft to respond to the pilot's command.

Modern FBW systems use a serial digital data transmission system with TDM, through a digital data bus. Military FBW system uses the MIL STD 1553 B data bus system. It has a data rate of 1 Mbps and a word length of 20 bits, so can receive or transmit upto 50000 data words/ second. The Boeing 777 uses the ARINC 629 data bus system which operates at 2 Mbps.

The FBW system without motion sensor is called as direct electric link system. The motion sensors comprise rate gyros for angular rates and linear accelerometers for linear rates.

Fly By Wire

In this control system the control inputs from the pilot are transmitted to the control surfaces by electronic signals. In this system, the control columns are having electronic transducers which sense the position of the control column and sends that information to independent computers. This information is used to adjust the position of control surfaces. The control signals are transmitted by wires to hydraulic unit. The hydraulic power is used to move the control surfaces.

In this flight control system the actuators are operated by electro – hydraulic servo valves. The electro – hydraulic servo valve is used to convert electric voltages into hydraulic power.

Linear Variable Differential Transformation

LVDT are used to translate linear motion into electrical signal.

RVDT are used to translate angular displacements into electrical signal.

The pilot's demand is compared with the feedback from LVDT/RVDT. When the feedback signal is equal to the command signal from the cockpit the movement of control surface stops.

In this system primary and secondary flight control computers are used for calculations concern with aircraft control and sending signals to the actuators. So this system is having less amount of common errors.

In this system the following data are processed,

a) Pitch, Roll, Yaw rate and Linear Accelerations
b) Angle of Attack
c) Airspeed, Altimeter, Mach meter, Pressure gauge Indications.
d) Stick and pedal demands.

Fly By Light

It uses the optic cables for transmitting the control signals. It uses the electro – optic converters for converting light signals into electrical signals for actuating the hydraulic control valves.

Advantages

1. Fibre Optic cables are light weight
2. Fibre optic cables are having high band width
3. Fibre optic cables are having immunity to EMI
4. Special shielding is not required.

Autopilot System

Autopilots are used to reduce the work, strain of controlling the aircraft during long flights. It provides control for one, two or three axis. The three axis system contains ailerons, elevators and rudders.

Autopilot system contains,

1. Gyros (to sense the aircraft's position)
2. Servos (to move the control surfaces)
3. Amplifier (to increase the strength of gyro signals)

The Gyro sensing units are connected to flight instruments which indicates direction, rate of turn, bank or pitch. If the flight attitude is changed electrical signals are developed in the gyros, and this is transmitted to the servo unit. And this servo unit is used to convert the electrical signals into mechanical force, which is used to move the control surfaces.

Basic Autopilot Components

1. The sensing elements
2. Command elements
3. Output elements
4. Computing elements

The command unit is manually operated to produce signals which cause the aircraft to climb, dive or turns.

Sensing Elements

1. Directional Gyro
2. Turn & Bank Gyro
3. Attitude Gyro
4. Altitude control and Navigation signals
5. Heading Selector

Computing Elements

This is used to process the signal and passes that one to the control surfaces.

Output Elements

Servos – 1) Electric Motors
2) Electro/Pneumatic servos

Servos is used to actuate the control surfaces.

A single axis autopilot control an aircraft in the roll axis only.

A two axis autopilot controls the pitch and roll axis.

A three axis autopilots controls the yaw, pitch and roll axis.

Modern autopilots use computer software to control the vehicle. The software reads the vehicle's current position and then controls a flight control system to guide the vehicle. Besides classic flight controls many autopilots incorporate thrust control capabilities that can control throttles to optimize the speed.

The modern autopilots reads the vehicle's position and attitude from an inertial guidance system, which uses a six dimensional kalman filter. The six dimensions are Roll, Pitch, Yaw, Altitude, Latitude and Longitude.

Types

Longitudinal Autopilot Systems (Displacement Autopilot)
Lateral Autopilot Systems (Roll attitude Autopilot)
Self-adaptive Autopilot

Electronic Warfare (EW)

- EW is any military action involving the use of the Electromagnetic (EM) spectrum to include directed energy (DE) to control the EM spectrum or to attack an enemy. This is not limited to radio or radar frequencies but includes IR, visible, ultraviolet, and other less used portions of the EM spectrum.
- EW assists air and space forces in gaining access to the battle space and operating free from interference from adversary threat systems.
- Control of the EM spectrum is an **essential and critical objective** in the success of today's military operations and is applicable at all levels of conflict.
- The three major components of EW are **electronic attack** (EA), **electronic protection** (EP), and **electronic warfare support** (ES). **Figure 5.32** illustrates this concept, and the relationship between them.

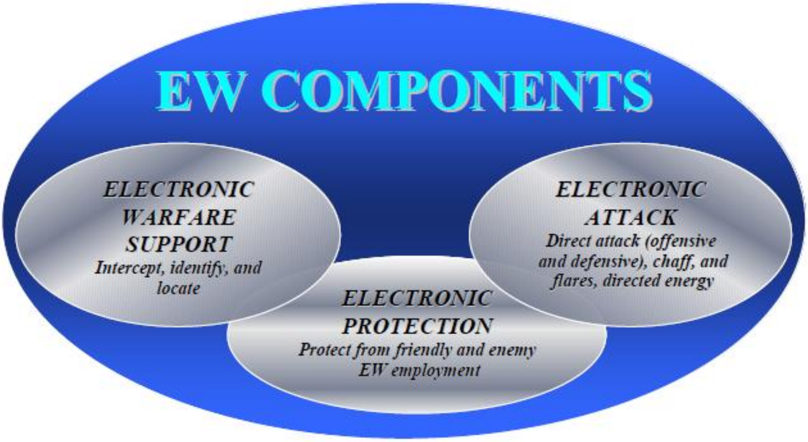


Figure 5.32 ***EW Components***

Electronic Attack (EA)

- EA is the component of EW involving the use of electromagnetic, directed energy, or antiradiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability. EA also prevents or reduces an enemy's use of the electromagnetic spectrum. It can be accomplished through detection, denial, disruption, deception, and destruction. EA includes direct attack with High-speed Anti Radiation Missiles (HARMs); active applications such as decoys, noise jamming, deceptive jamming, and expendable miniature jamming decoys; and employs EM or DE weapons (lasers, radio frequency weapons, particle beams, etc.). Electronic Emission Control (EMCON) and low observable technologies are passive applications of EA.

- **Electromagnetic jamming** and the **Suppression of Enemy Air Defences** (SEAD) are also applications of EA.
- **Electromagnetic Jamming:** Electromagnetic jamming is the deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing an enemy's effective use of the electromagnetic spectrum, with the intent of degrading or neutralizing the enemy's combat capability.
- **Suppression of Enemy Air Defences (SEAD):** SEAD is that activity which neutralizes, destroys, or temporarily degrades surface-based enemy air defences by destructive and/or disruptive means. The goal of SEAD operations is to provide a favourable situation in which friendly tactical forces can perform their missions effectively without interference from enemy air defences.

Electronic Protection (EP)

- EP includes the actions taken to protect personnel, facilities, and equipment from any EW employment that may degrade, neutralize, or destroy friendly combat capability. Examples of EP include frequency agility, changing Pulse Repetition Frequency (PRF), etc.

Electronic Support (ES)

- ES responds to tasking to search for, intercept, identify, and locate sources of intentional and unintentional radiated electromagnetic energy for the purpose of threat recognition.

Commanders, aircrews, and operators use ES to provide near-real-time information to supplement information from other intelligence sources.

Electronic Warfare effects

- **Detection** — Assesses the electromagnetic environment to include radar/radio frequency, electro-optics/laser, and infrared spectrums using active and passive means.
- **Denial** — Controls the information an adversary receives and prevents the adversary from gaining accurate information about friendly forces.
- **Deception** — Utilizes the electromagnetic spectrum to confuse or mislead an adversary.
- **Disruption** — Degrades or interferes with the enemy's control of it's forces in order to limit attacks on friendly forces.
- **Destruction** — Eliminates some or all of an adversary's electronic defences.

Electronic Counter Measures (ECM)

- ECM are a subsection of electronic warfare which includes any sort of electrical or electronic device designed to trick or deceive radar, sonar, or other detection systems like IR (infrared) and Laser. It may be used both offensively or defensively in any method to deny targeting information to an enemy. The system may make many separate targets appear to the enemy, or make the real target appear to disappear or move about randomly.

- It is used effectively to protect aircraft from guided missiles. Most air forces use ECM to protect their aircraft from attack. That is also true for military ships and recently on some advanced tanks to fool laser/IR guided missiles. It is frequently coupled with stealth advances so that the ECM system has an easier job. **Offensive ECM** often takes the form of jamming. **Defensive ECM** includes using blip enhancement and jamming of missile terminal homers.

- **RADAR ECM**

  Basic RADAR ECM strategies are (1) RADAR interference, (2) target modifications, and (3) changing the electrical properties of air. Interference techniques include jamming and deception. Jamming is accomplished by a friendly platform transmitting signals on the RADAR frequency to produce a noise level sufficient to hide echos. The jammer's continuous transmissions will provide a clear direction to the enemy RADAR, but no range information. Deception may use a transponder to mimic the RADAR echo with a delay to indicate incorrect range. Transponders may alternatively increase return echo strength to make a small decoy appear to be a larger target. Target modifications include RADAR absorbing coatings and modifications of the surface shape to either "stealth" a high-value target or enhance reflections from a decoy. Dispersal of small aluminum strips called chaff is a common method of changing the electromagnetic properties of air to provide confusing RADAR echoes.

- **Aircraft ECM**

  ECM is practiced by nearly all modern military units—land, sea or air. Aircraft, however, are the primary weapons in the ECM battle because they can "see" a larger patch of earth than a sea or land-based unit. When employed effectively, ECM can keep aircraft from being tracked by search radars, or targeted by surface-to-air missiles or air-to-air missiles. On aircraft ECM can take the form of an attachable under wing pod or could be embedded in the airframe. Active Electronically Scanned Array (AESA) radars like those mounted on the F-22, MiG-35, Su-35BM or the F-35 can also act as an ECM device to track, locate and eventually jam enemy radar. Previous radar types were not capable of performing these activities due to: the inability of the antenna to use suboptimal frequencies the processing power needed the impossibility to practically intermix or segment antenna usages.

Fire Control System

A **fire-control system** is a number of components working together, usually a gun data computer, a director, and radar, which is designed to assist a weapon system in hitting its target. It performs the same task as a human gunner firing a weapon, but attempts to do so faster and more accurately.

The original fire-control systems were developed for ships. The early history of naval fire control was dominated by the engagement of targets within visual range. Moreover, in naval engagements both the firing guns and target are moving and it is also necessary to control the firing of several guns at once.

Naval gun fire control potentially involves three levels of complexity. Local control originated with primitive gun installations aimed by the individual gun crews. Director control aims all guns on the ship at a single target. Coordinated gunfire from a formation of ships at a single target was a focus of battleship fleet operations. Corrections are made for surface wind velocity, firing ship roll and pitch, powder magazine temperature, drift of rifled projectiles, individual gun bore diameter adjusted for shot-to-shot enlargement, and rate of change of range with additional modifications to the firing solution based upon the observation of preceding shots.

The resulting directions, known as a firing solution, would then be fed back out to the turrets for laying. If the rounds missed, an observer could work out how far they missed by and in which direction, and this information could be fed back into the computer along with any changes in the rest of the information and another shot attempted.

There were also procedural improvements, like the use of plotting boards to manually predict the position of a ship during an engagement. Then increasingly sophisticated mechanical calculators were employed for proper gun laying, typically with various spotters and distance measures being sent to a central plotting station deep within the ship. There the fire direction teams fed in the location, speed and direction of the ship and its target, as well as various adjustments for Coriolis effect, weather effects on the air, and other adjustments.

Anti-aircraft fire control

By the start of World War II, aircraft altitude performance had increased so much that anti-aircraft guns had similar predictive problems, and were increasingly equipped with fire-control computers. The main difference between these systems and the ones on ships was size and speed. The early versions of the High Angle Control System, or HACS, of Britain's Royal Navy were examples of a system that predicted based upon the assumption that target speed, direction, and altitude would remain constant during the prediction cycle, which consisted of the time to fuze the shell and the time of flight of the shell to the target. The USN Mk 37 system made similar assumptions except that it could predict assuming a constant rate of altitude change. The Kerrison Predictor is an example of a system that was built to solve laying in "real time", simply by pointing the director at the target and then aiming the gun at a pointer it directed. It was also deliberately designed to be small and light, in order to allow it to be easily moved along with the guns it served.

UK radar-based M-9/SCR-584 Anti-Aircraft System was used to direct air defense artillery since 1943. It made a particularly good account of itself against the V-1 flying bombs

Modern fire control systems

Modern fire-control computers, like all high-performance computers, are digital. The added performance allows basically any input to be added, from air density and wind, to wear on the barrels and distortion due to heating. These sorts of effects are noticeable for any sort of gun, and fire-control computers have started appearing on smaller and smaller platforms. Tanks were one early use that automated gun laying using a laser rangefinder and a barrel-distortion meter. Fire-control computers are not just useful for large cannons. They can be used to aim machine guns, cannons, guided missiles, rifles, grenades, rockets.

They are typically installed on ships, submarines, aircraft, tanks and even on some small arms. Fire-control computers have gone through all the stages of technology that computers have, with some designs based upon analogue technology and later vacuum tubes which were later replaced with transistors.

Fire-control systems are often interfaced with sensors (such as sonar, radar, infra-red search and track, laser range-finders, anemometers, wind vanes, thermometers, etc.) in order to cut down or eliminate the amount of information that must be manually entered in order to calculate an effective solution. Sonar, radar and range-finders can give the system the direction to and/or distance of the target. Alternatively, an optical sight can be provided that an operator can simply point at the target, which is easier than having someone input the range using other methods and gives the target less warning that it is being tracked. Typically, weapons fired over long ranges need environmental information, the farther a munition travels, the more the wind, temperature, etc. will affect its trajectory, so having accurate information is essential for a good solution. Sometimes, for very long-range rockets, environmental data has to be obtained at high altitudes or in between the launching point and the target. Often, satellites or balloons are used to gather this information.

Once the firing solution is calculated, many modern fire-control systems are also able to aim and fire the weapon(s).. Even if the system is unable to aim the weapon itself, it is able to give the operator cues on how to aim. Typically, the cannon points straight ahead and the pilot must maneuver the aircraft so that it oriented correctly before firing. In most aircraft the aiming cue takes the form of a "pipper" which is projected on the heads-up display (HUD). The pipper shows the pilot where the target must be relative to the aircraft in order to hit it. Once the pilot maneuvers the aircraft so that the target and pipper are superimposed, he or she fires the weapon, or on some aircraft the weapon will fire automatically at this point, in order to overcome the delay of the pilot. In the case of a missile launch, the fire-control computer may give the pilot feedback about whether the target is in range of the missile and how likely the missile is to hit if launched at any particular moment. The pilot will then wait until the probability reading is satisfactorily high before launching the weapon.

Questions

Part – A

1. Give details about avionics equipment fit.
2. Write brief description about electrical data bus.
3. Provide details on fire control system.
4. Write notes on avionics system architecture.
5. Define: EA and EP.

Part – B

1. Describe about the aircraft navigation systems.
2. With clear illustration describe about mechanical flight control systems.
3. Write detail notes on radar electronic warfare.
4. Describe about the communication and fire control system.
5. With neat diagram explain about modern flight control system.

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