Module 13 B2

Aircraft Structures and Systems

13.1 Aerodynamics and Flight Controls

13.2 Airframe Structures - General Concepts

13.3 Autoflight (ATA 22)

13.4 Communication / Navigation (ATA 23 / 34)

13.5 Electrical Power (ATA 24)

13.6 Equipment and Furnishings (ATA 25)

13.7 Flight Controls (ATA 27)

13.8 Instrument Systems (ATA 31)

13.9 Lights (ATA 33)

13.10 On Board Maintenance Systems (ATA 45)

13.1 Aerodynamics and Flight Controls

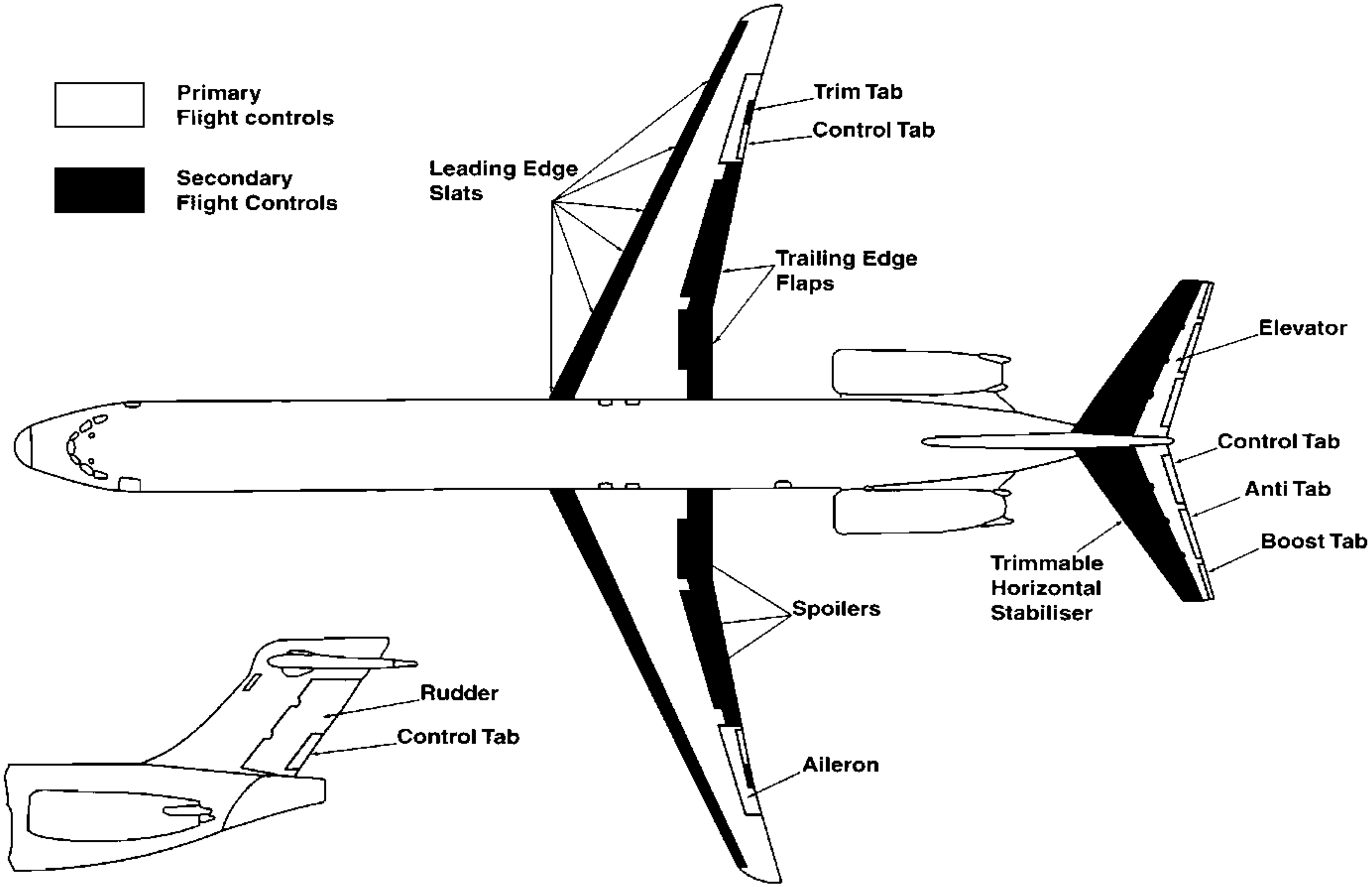
Operation an Effect of Flight Controls

The development of the aeroplane was delayed by two problems: how to achieve stability and how to achieve control. Before the Wright brothers' successful flight in 1903, others had flown, but none had their success in controlling their aircraft.

"Stability" relates to maintaining the desired flight attitude with a minimum of pilot effort, and "control" involves rotating the aeroplane about one or more of its three axes. On Figure 1 on page 3 are most of the control surfaces of an aeroplane shown.

Balanced aerodynamic forces cause a properly designed and trimmed aeroplane to fly straight and level with hands and feet off of the controls. The lift produced by the wings is equal.

Figure 1: Control Surfaces of a Jet Airliner (MD-80)

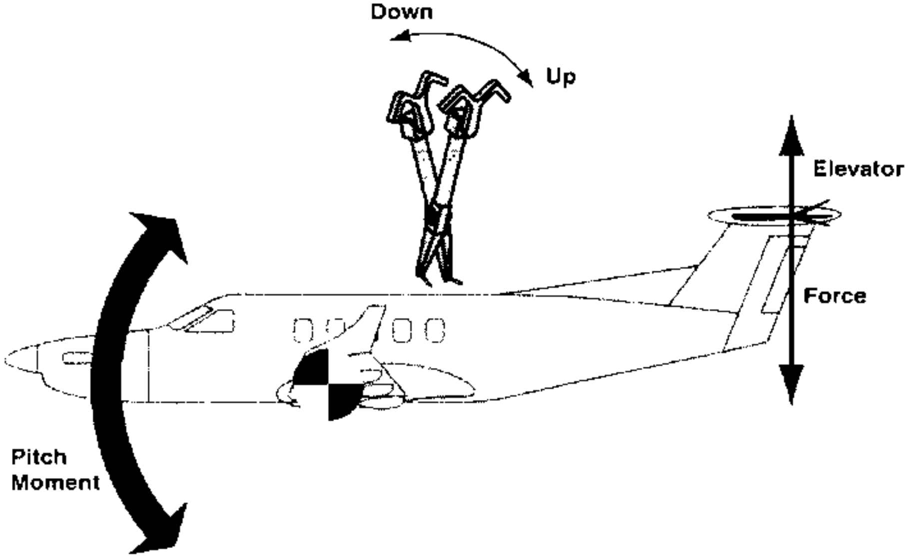


Longitudinal Control (Rotation About the Lateral Axis)

The aeroplane can be rotated nose upward about its lateral axis (pitch up) by increasing the downward tail load, or nose downward (pitch down) by decreasing the tail load.

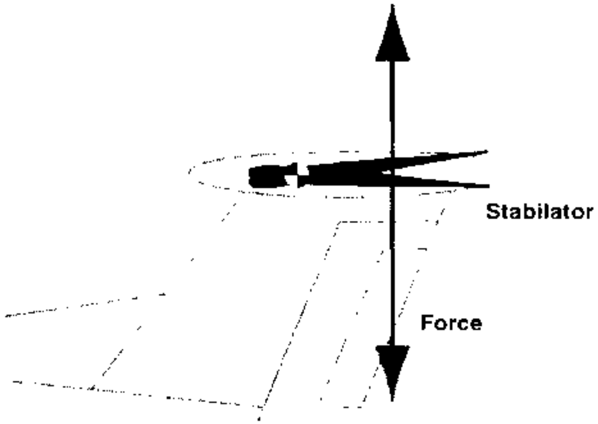
The most generally used pitch control for an aeroplane is the fixed horizontal stabiliser with a movable elevator hinged to its trailing edge. When the control wheel or stick is pulled back, the trailing edge of the elevator moves up and increases the down load on the horizontal tail surface. The tail moves down and rotates the aeroplane nose-up about its lateral axis.

Figure 2: Conventional Pitch Control



Some aeroplanes use a stabilator for pitch control.(see "Figure 3" on page 4). This is a single-piece horizontal surface that pivots about a point approximately one third of the way back from the leading edge. When the control wheel is pulled back, the leading edge of the stabilator moves down and increases the downward force produced by the tail. This rotates the nose up. When the wheel is pushed in, the nose of the stabilator moves up, decreasing the tail load, and the aeroplane rotates nose down.

Figure 3: Aeroplane with Stabilator



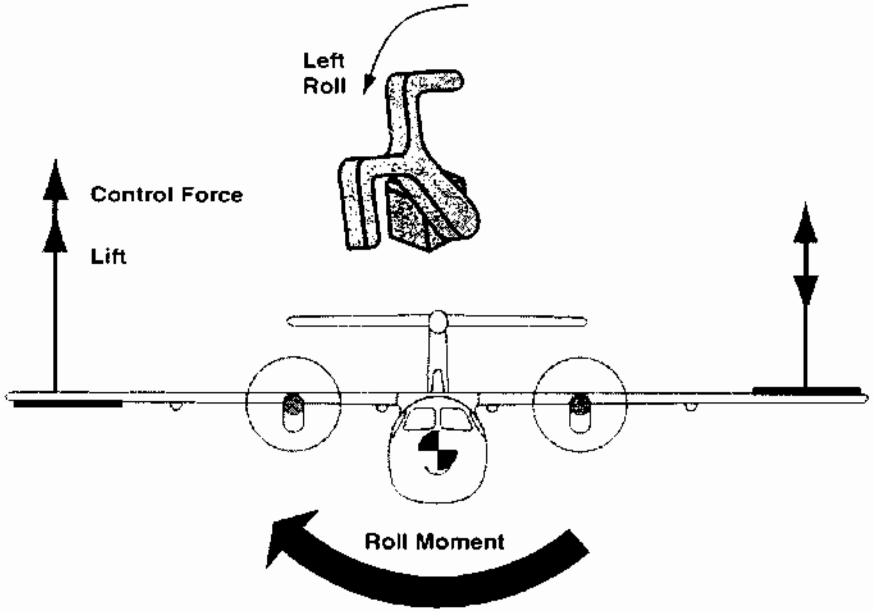
Any aeroplane that has the equivalent of two lifting surfaces, instead of the conventional horizontal stabiliser that provides a down load, can be classified as a canard. The canard is the forward surface, and frequently is also a control surface.

Figure 4: Canard Aeroplane

Lateral Control (Rotation About the Longitudinal Axis)

To roll the aeroplane to the left, the control wheel is turn to the left. The aileron on the left wing moves up, decreasing the camber, or curvature, of the left wing and decreasing the lift it produces. At the same time, the aileron on the right wing moves down, increasing the camber of the left wing and increasing the lift it produces. The difference in lift produced by the two wings rolls the aeroplane to the left.

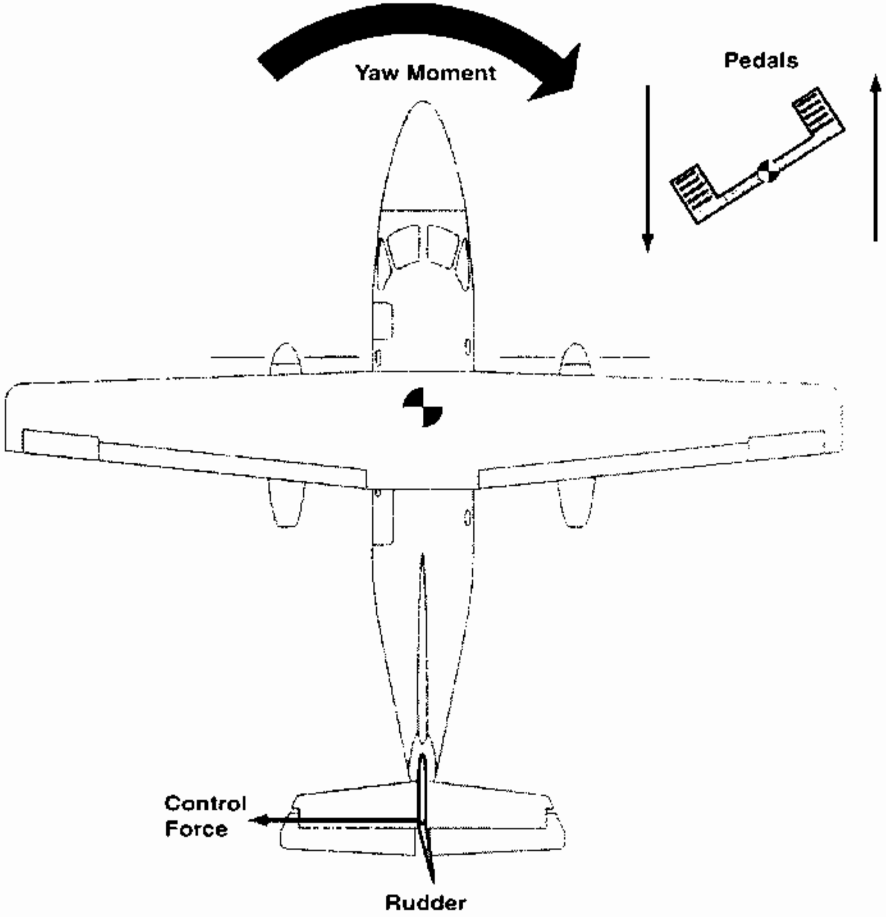
Figure 5: Roll Movement with Ailerons



Directional Control (Rotation About the Vertical Axis)

The rudder is used on an aeroplane only to rotate it about its vertical axis. An aeroplane is turned by tilting the lift vector with the ailerons and not by using the rudder. The rudder is used only at the beginning of the turn to overcome the adverse yaw and start the nose moving in the correct direction and for such flight conditions as crosswind and one engine off operation.

Figure 6: Yaw Movement with Rudder



The movement of the rudder is controlled by rudder pedals operated by the feet of the pilot. When the right pedal is pressed, the rudder swings to the right, thus creating an aerodynamic force that pulls the tail to the left.

Trim Systems

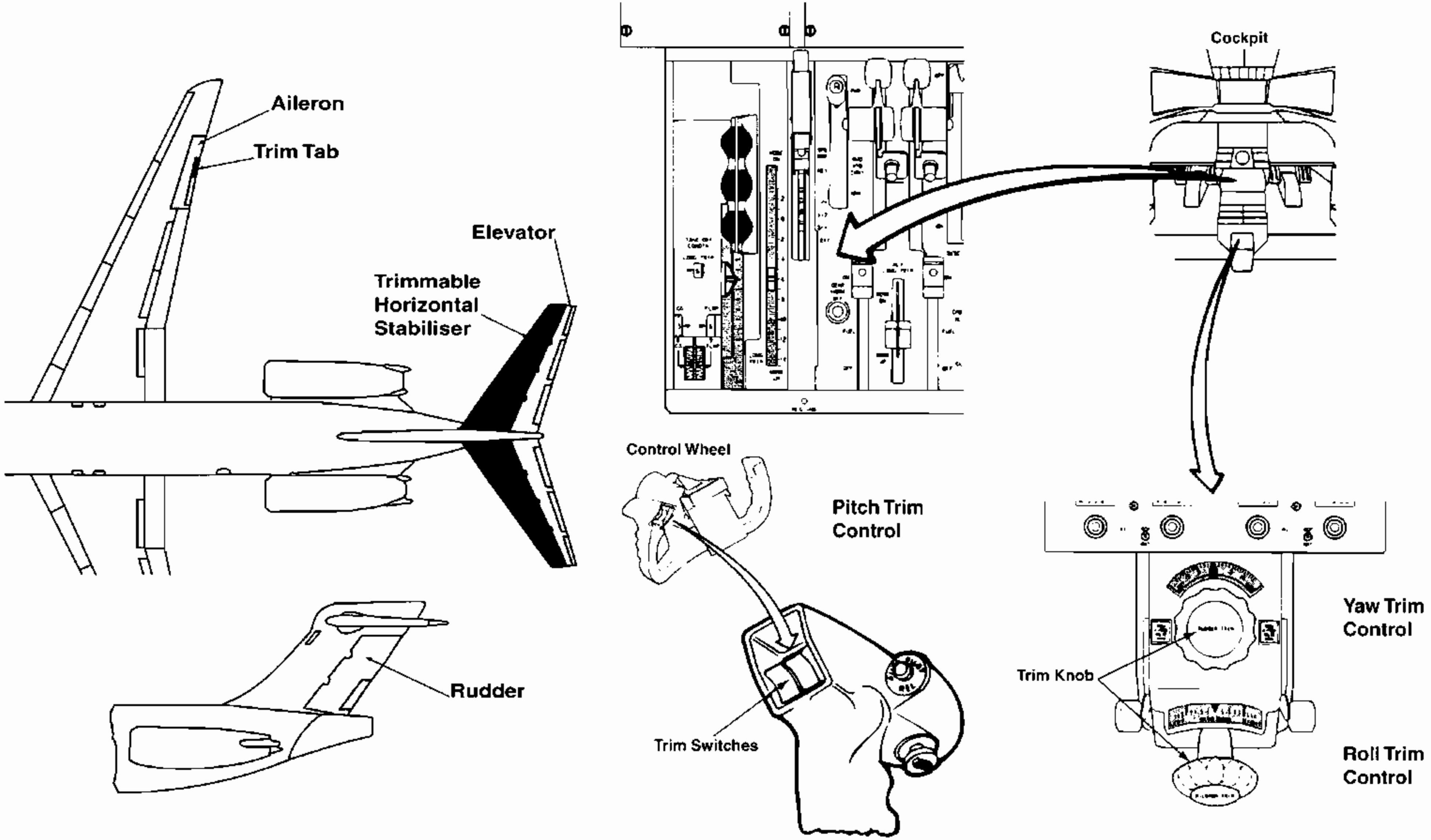
In aviation, trimming means maintaining the equilibrium of an aircraft during flight without having to use steering force. For this reason, the following are installed in the aircraft:

- an adjustable horizontal stabiliser (stabilizer) for trimming the pitch axis (pitch trim);
- adjustable trim surfaces in rudders and ailerons;
- electrical actuators which are included in the cable system.

(see "Figure 1" on page 3)

The adjustable trim surfaces and the actuators give trim possibilities for the longitudinal axis and the yaw axis.

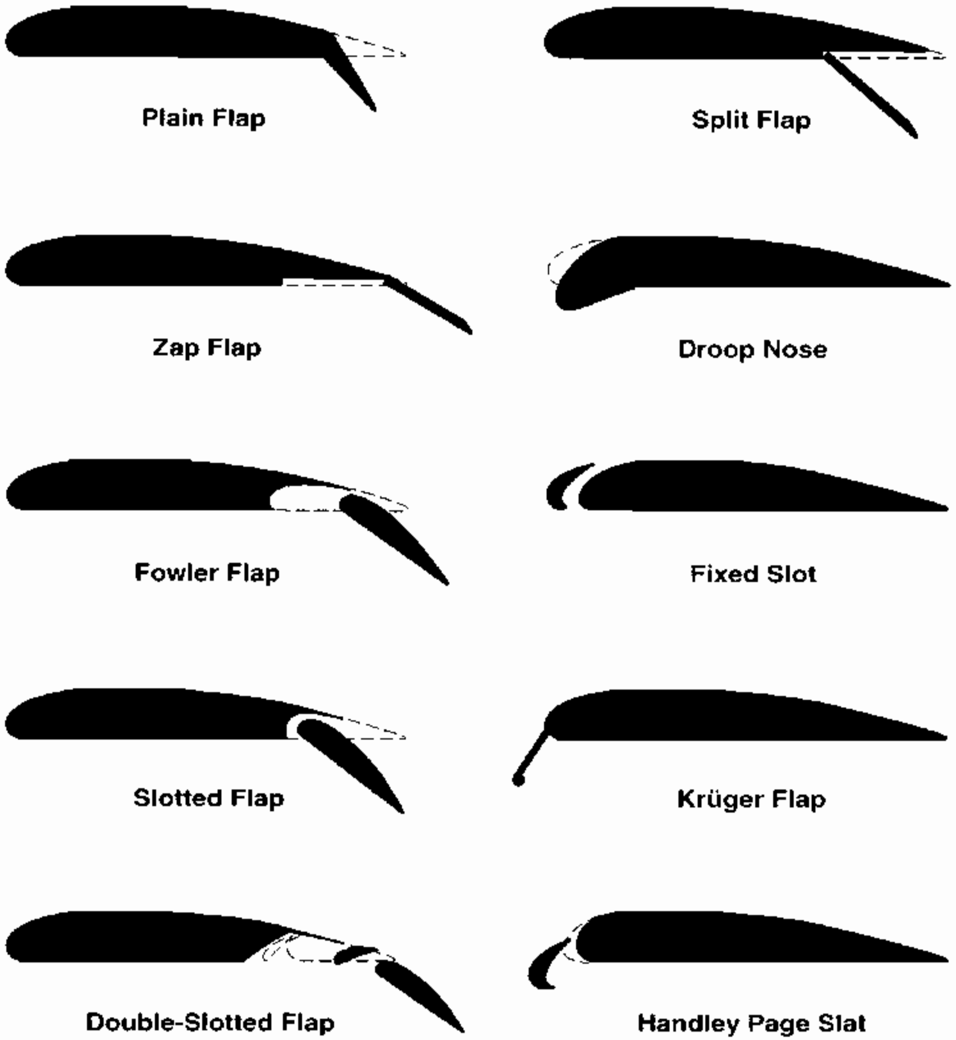
Figure 7: Example of Trim System Layout



High Lift Devices

An aeroplane is a series of engineering compromises. We must choose between stability and manoeuvrability and between high cruising speed and low landing speed, as well as between high utility and low cost. Lift-modifying devices give us some good compromises between high cruising speed and low landing speed, because they may be extended only when they are needed and then tucked away into the structure when they are no longer needed.

Figure 8: Most Used High Lift Devices



Plain Flap

Split Flap

Zap Flap

Droop Nose

Fowler Flap

Fixed Slot

Slotted Flap

Krüger Flap

Double-Slotted Flap

Handley Page Slat

Slots

Slots are nozzle-shaped passage through a wing, designed to improve the airflow conditions at high angles of attack and slow speeds. It is normally placed very near the leading edge and is built into the wing. As the angle of attack of the wing increases, more of the air is deflected through the slot, thus maintaining a streamline flow around the wing.

Slats

Since the slot is of use only at high angles of attack, at the normal angles its presence serves only to increase drag. This disadvantage can be overcome by making the slot movable so that when not in use it lies flush against the leading edge of the wing. In this case the slat is hinged on its supporting arms so that it can move to either the operating position at which it gives least drag. This type of slat is fully automatic in that its action needs no separate control.

Wing Flaps

A wing flap is defined by the NACA as a hinged, pivoted, or sliding airfoil, usually near the trailing edge of the wing. It is designed to increase the lift and drag, when deflected. Wing flaps are used for both take-off and landing phases of flight. For take-off, an intermediate setting is used. This gives an increase of lift with little increase in parasite drag, allowing a shorter take-off run and lower take-off speed. For landing, the flaps are lowered fully The increase in camber and in some cases surface area gives an increase of lift for any given speed. This allows a lower approach speed. At the same time parasite drag is increased significantly. This allows for a steep approach without an increase in speed. The advantages are that obstacles on the approach can be cleared easily and the landing run will be shorter with less wear on the landing gear.

Types of Flaps

The trailing edge flap has many variations, all of which serve to increase the C_L max. Some, however, are more efficient than others. The more efficient flaps are usually more complex mechanically and their use is restored to, only when the lowest possible stalling speed is essential.

Fowler Flap

This flap is constructed so that the lower part of the trailing edge of the wing rolls back on a track, thus increasing the effective area of the wing and at the same time lowering the trailing edge.

Slotted Flap

Have been developed to provide even more lift than the flaps described previously. When such flaps are extended, either partially or completely, one or more slots are formed near the trailing edge of the wing. The slots allow air from the bottom of the wing (high-energy air) to flow to the upper portion of the flaps and downward at the trailing edge of the wing. This aids in preventing the airflow from breaking away into turbulence. When lowered there is increased lift for similar angles of attack of the basic airfoil and the maximum lift coefficient is greatly increased.

Krüger Flap

Another method for providing the leading edge flap is to design an extendible surface that ordinarily fits smoothly into the lower part of the leading edge. When the flap is required, the surface extends forward and downward.

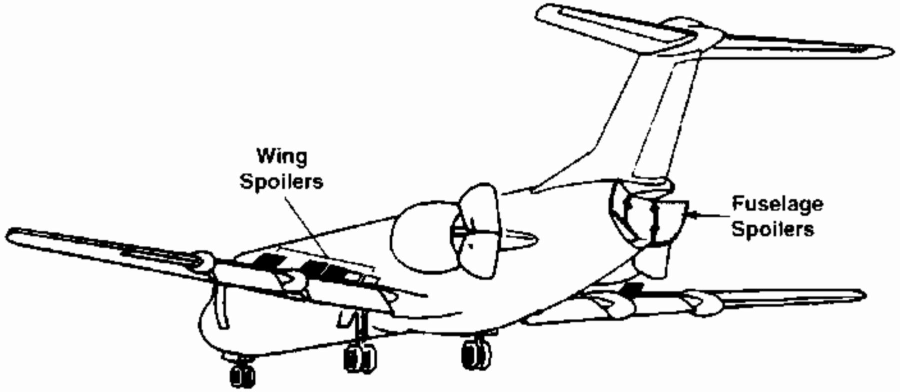
Drag Inducing Devices

Aerodynamic brakes are devices, which when deployed disturb the patterns of smooth airflow This produces an increasment of drag and also decreasment of lift, depending of the kind of device.

They are two kind of devices mainly in use:

- Wing installed (drag increasment and lift decreasment)
- Fuselage installed (drag increasment)

Figure 9: Different Aerodynamic Brakes



Spoilers

A spoiler is a control device that destroys lift over a part of the wing. The most common spoilers are used on sailplanes. They are "popped up" to allow a rapid rate of descent, while still retaining full control. This function of spoilers is normally named **"speed-brake"**. They can be retracted to regain full lift when the desired altitude is reached.

On the ground, spoilers can be raised to the maximum to help increase braking efficiency by increasing contact pressure of the tires with the ground and providing additional drag, thus becoming aerodynamic **ground spoilers**.

For aileron assistance, they act on the "down" wing through a mixer system and move in proportion to the aileron. The spoiler system can also act as a backup aileron system, should the primary system ever fail. This function of spoilers is named **"roll spoilers"**

Boundary Layer Control

As it is described in Sub Module 8.2 "Aerodynamics", separator of boundary layer is the cause of wing stall. Before this happens, it turns turbulent which cause an unwanted increasment of drag. Much study has been made to find ways of minimizing it.

Not only high angle of attack causes turbulent boundary layers, also shock waves along the wing upper surface, flying near speed of sound, cause turbulent boundary layers.

To retard separation during high angle of attack flying, slots and slats are used.

Swept wing is the most used method to retard shock waves from emerging. The movement of the air flow parallel to leading edge affects the boundary layer. This cause the boundary layer to lose energy, grow thicker and turbulent.

Vortex generators are low-aspect-ratio airflows arranged in pairs. The tip vortices of these pull high energy air down into the boundary layer and prevent the separation.

Fences and other devices like saw-cut or dog-tooth may also be used to prevent air from flowing toward wing tip (see "Figure 11" on page 12).

Figure 10: Air Flow over a Swept Wing

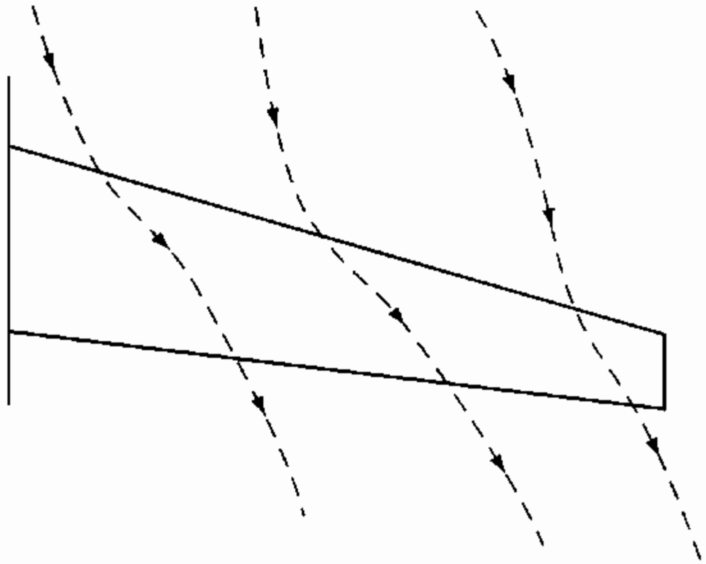
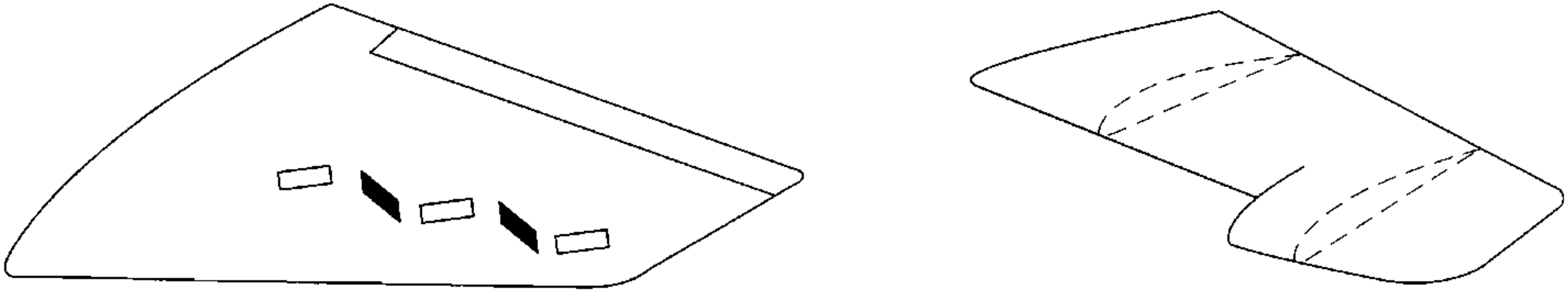


Figure 11: Examples of Boundary Layer Control

Fence

Saw Cut



Vortex Generator

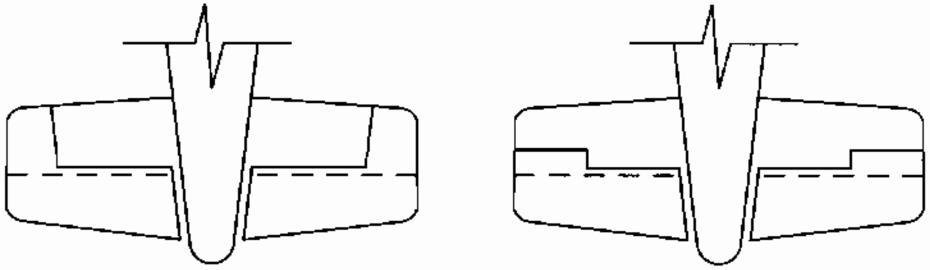
Dog-Tooth

Control Aids / Tabs

Balanced Control Surface

Even on small, light aeroplanes, aerodynamic assistance in the movement of the controls is used. The simplest form of this assistance is the balanced control surface. In the case of the rudder, the balance portion, or overhang, deflects to the opposite side of the fuselage from the main rudder surface to produce an aerodynamic force that aids the pilot in moving the surface. See Sub Module 11.1.2 "11.3.4 Flight Control Surfaces"

Figure 12: Balanced Control Panels

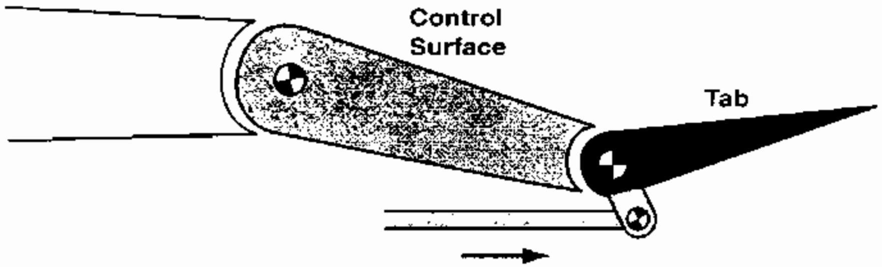


Unshielded **Shielded**

Control Tabs

Large aircraft are usually equipped with a power-operated irreversible flight control system. In these systems, the control surfaces are operated by hydraulic actuators controlled by valves moved by the control yoke and rudder pedals. An artificial feel system gives the pilot resistance that is proportional to the flight loads on the surfaces. The control forces are too great for the pilot to manually move the surfaces, so, In the event of a hydraulic system failure, they are controlled with control tabs. In the manual mode of operation, the flight control column moves the tab on the control surface, and the aerodynamic forces caused by the deflected tab move the main control surface.

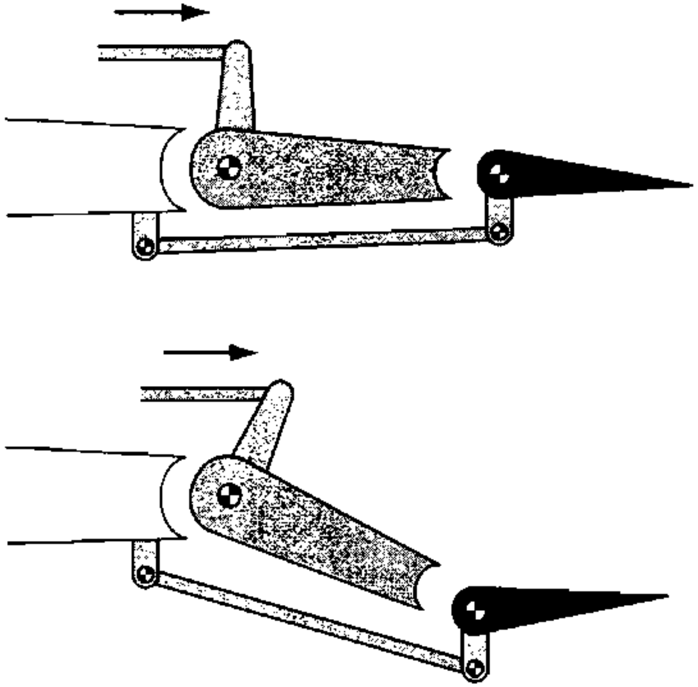
Figure 13: Servo Tab



Balance Tabs

The control forces may be excessively high in some aeroplanes, and in order to decrease them, the manufacturer may use a balance tab. This tab is located in the same place as a trim tab and in many installations one tab serves the function of both. The basic difference is that the control rod for the balance tab is connected to the fixed surface on the same side as the horn on the tab. In Figure 14 on page 14 we see the way a balance tab works.

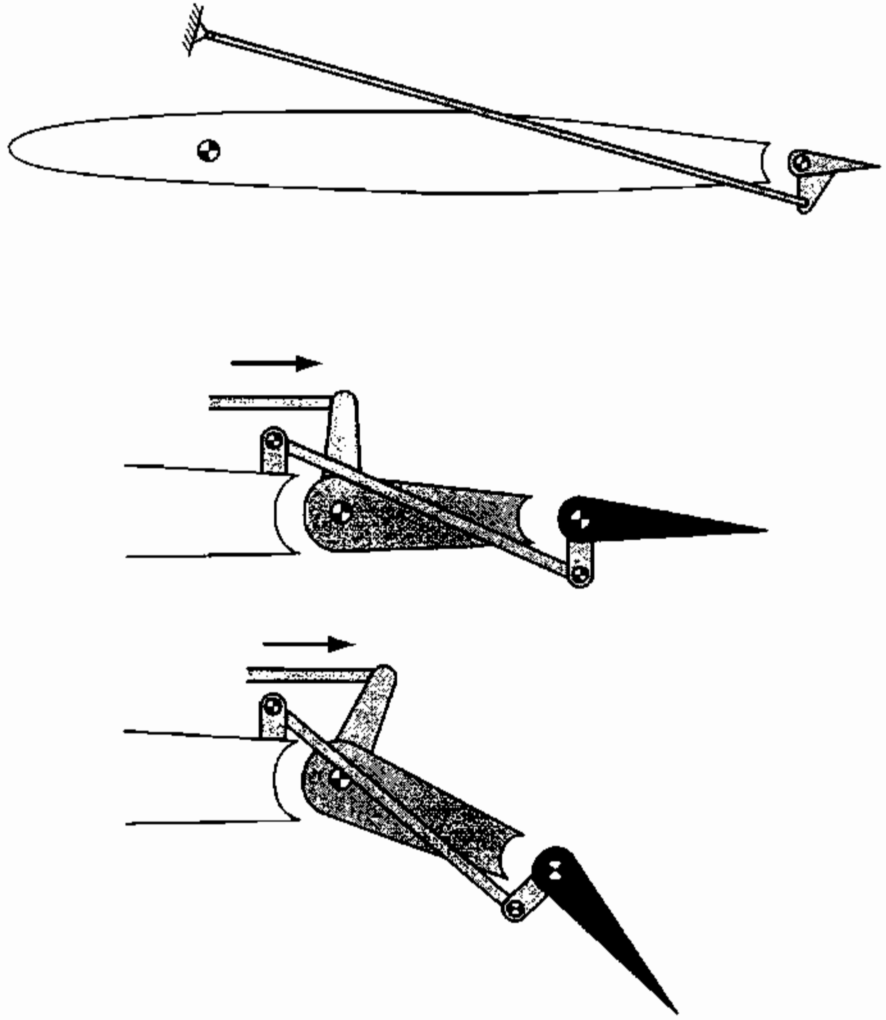
Figure 14: Balance Tab



Anti-Balance Tabs

Stabilator surfaces do not have fixed stabiliser in front of them, and the location of their pivot point makes them extremely sensitive. To decrease this sensitivity, a full length anti-servo tab may be installed on the trailing edge. This tab works in the same manner as the balance tab except that it moves in the opposite direction (see "Figure 15" on page 15).

Figure 15: Anti-Balance Tab

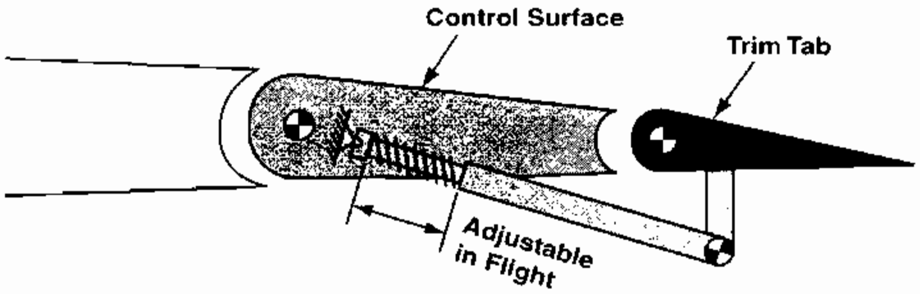


Trim Tabs

Trim tabs are small movable portions of the trailing edge of the control surface. These tabs are controlled from the cockpit to alter the camber of the surface and create an aerodynamic force that will hold the control surface deflected.

Trim tabs may be installed on any of the primary control surfaces. The tab has a variable linkage that is adjustable from the cockpit. Movement of the tab in one direction causes a deflection of the control surface in the opposite direction.

Figure 16: Trim Tabs



Spring Tabs

Another device for aiding the pilot of high-speed aircraft is the spring tab The control horn is free to pivot on the hinge axis of the surface, but it is restrained by a spring For normal operation when the control forces are light, the spring is not compressed and the horn acts as though it were rigidly attached to the surface. At high airspeeds when the control forces are too high for the pilot to properly operate, the spring collapses and the control horn deflects the tab in the direction to produce an aerodynamic force that aids the pilot in moving the surface.

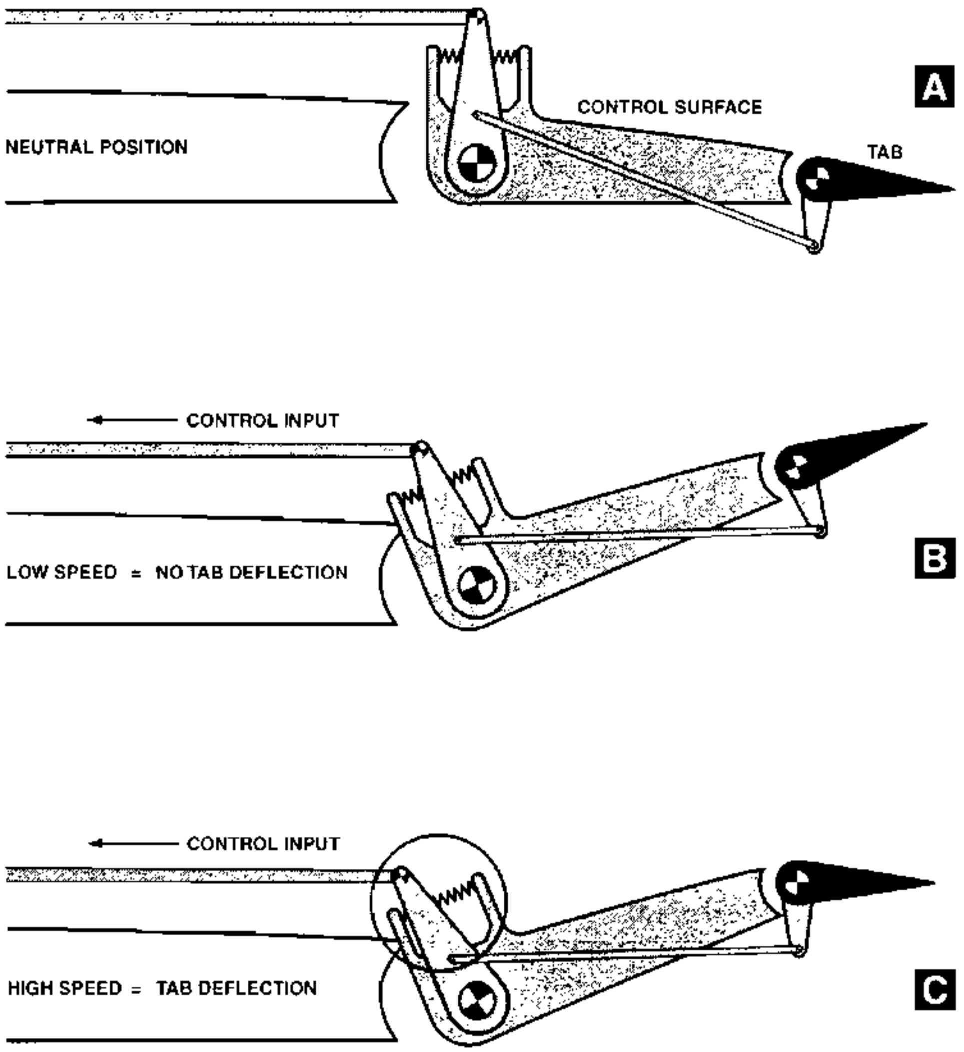
In Figure 17 on page 16, three situations are shown:

(A) illustrates no control input which means **no** deflection of the aileron and tab

(B) illustrates control input during low speed flight The spring is not compressed and therefore no tab deflection takes place

(C) illustrates control input during high speed flight where the required force to operate the control surface is high. The spring will compress and a deflection of the tab takes place, assisting the control surface to move in the demanded direction

Figure 17: Spring Tab



Control Surface Mass Balancing

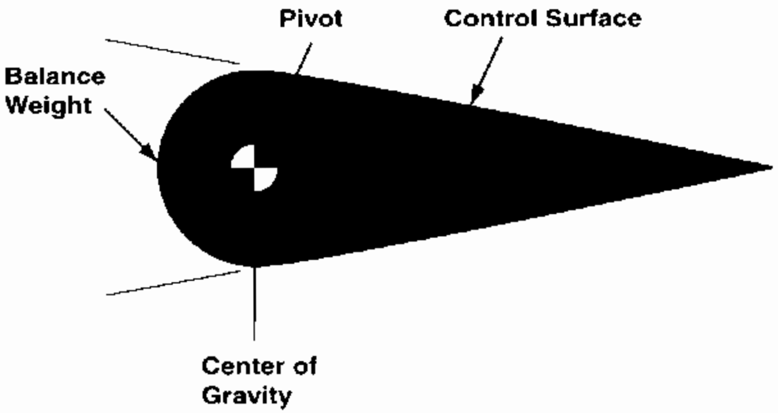
Most control surfaces are mass balanced. The purpose of this is to prevent control surface flutter.

Flutter is an oscillation of the control surface, which can occur due to the bending and twisting of the structure under load.

Flutter may be prevented by adding weight to the control surface in front of the hinge line, to bring the centre of gravity closer to the hinge.

⚠ **Note:** It is necessary that the control surface balance be checked whenever any operation is performed on a control surface, which can change the static balance.

Figure 18: Mass Balancing



The Speed of Sound

When air is disturbed, longitudinal waves are created that cause the air pressure to increase and decrease. The speed of sound is the speed at which this small pressure disturbances are able to move through the air. these pressure changes in the sound wave are caused by the movement of the molecules in the air, and as the temperature changes so does the molecular movement, as indicated in the chart:

Table 1: Standard Atmosphere

Altitude (m)	Temperature (°C)	Speed of sound (km/h)
Sea level	15.0	1224.1
1700	5.1	1203.5
3300	-4.8	1181.4
5000	-14.7	1159.4
6700	-24.6	1137.0
8300	-34.3	1114.1
10000	-44.4	1090.7
11700	-54.3	1066.7
13300	-56.5	1061.5
16700	-56.5	1061.5
20000	-56.5	1061.5

Mach Number

High-speed flight is measured in terms of Mach number, which is the ratio of the speed of the aircraft to the speed of sound. An aeroplane flying at a speed of Mach 1 at sea level is flying at the speed of sound, which, according to Table 1 on page 19 is 1224 km/h. When it is flying at a speed of Mach 0.75, it is flying at 75% of the speed of sound at the existing air temperature.

Critical Mach Number

The critical Mach number of an aeroplane is that flight Mach number at which there is the first indication of local sonic flow This means when a normal shock wave forms somewhere on the wing (see “Figure 2” on page 21).

Aeroplanes that fly at these speeds have Machmeters in the cockpit that automatically compensate airspeed for the air temperature and show the pilot the Mach number at which the aeroplane is flying.

Flight Speed Ranges

High-speed flight can be divided into four speed ranges:

- **Subsonic** - Below Mach 0.75

  All airflow is below the speed of sound.
- **Transonic** - Mach 0.75 to Mach 1.20

  Most of the airflow is subsonic, but in some areas, it is supersonic.
- **Super-sonic** - Mach 1.20 to Mach 5.00

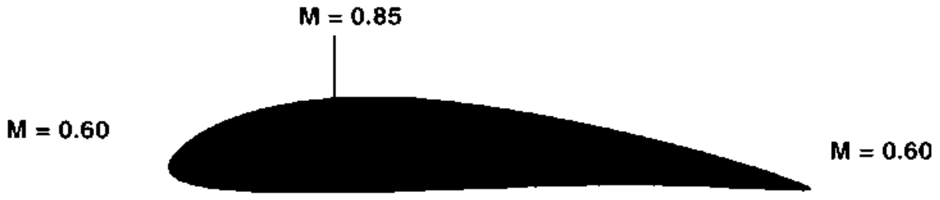
  All of the airflow is faster than the speed of sound.
- Hypersonic - Greater than Mach 5.00

Subsonic Flight

In low-speed flight, air is considered to be incompressible, and acts in much the same way as a liquid. It can undergo changes in pressure without any appreciable change in its density. But in high-speed flight the air acts as a compressible fluid, and its density changes with changes in its pressure and velocity. An aeroplane passing through the air creates pressure disturbances that surround it. When the aeroplane is flying at a speed below the speed of sound, these disturbances move out in all directions and the air immediately ahead of the aeroplane is affected and its direction changes before the air reaches the surface.

At speeds greater than the speed of sound, the disturbances do not spread out ahead of the aeroplane, and there is no change in flow direction ahead of the leading edge.

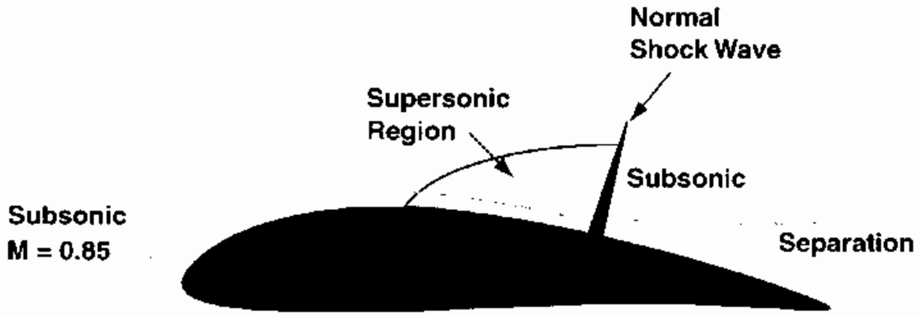
Figure 1: Subsonic Air Flow



Transonic Flight

When an aeroplane is flying below the speed of sound in the transonic range, some of the air flowing over the airfoil has accelerated until it is supersonic and a normal shock wave forms. Air passing through this normal shock wave slows to a subsonic speed without changing its direction. The shock wave can cause the air that passes through it to be turbulent, and to separate from the wing surface. Shock-induced separation can create serious drag and control problems.

Figure 2: Transonic Air Flow



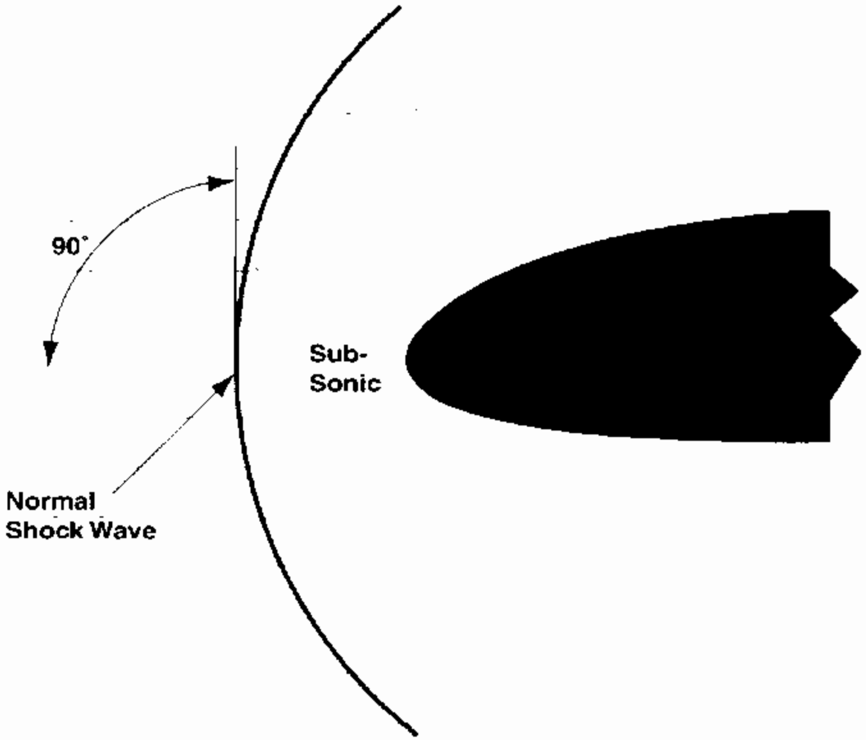
Supersonic Airflow

When air flows over a surface at a supersonic speed, pressure waves form. There are three types of pressure waves, normal and oblique shock waves, and expansion waves.

Normal Shock Waves

Air flowing over an airfoil acts in the same way it does as it flows through a converging and diverging duct. Figure 3 on page 21 shows that air approaching a relatively blunt-nose subsonic airfoil at a supersonic speed forms a normal shock wave, which wastes energy.

Figure 3: Normal shock wave



Oblique Shock Waves

When a supersonic airstream strikes a sharp-edged airfoil, the air is forced to turn, forming an oblique shock wave(see "Figure 4" on page 22).

Expansion Waves

When air flows at a supersonic speed over a double-wedge airfoil like that in Figure 4 on page 22, the air will turn to follow the surface and an expansion wave forms.

Figure 4: Expansion and Oblique shock wave

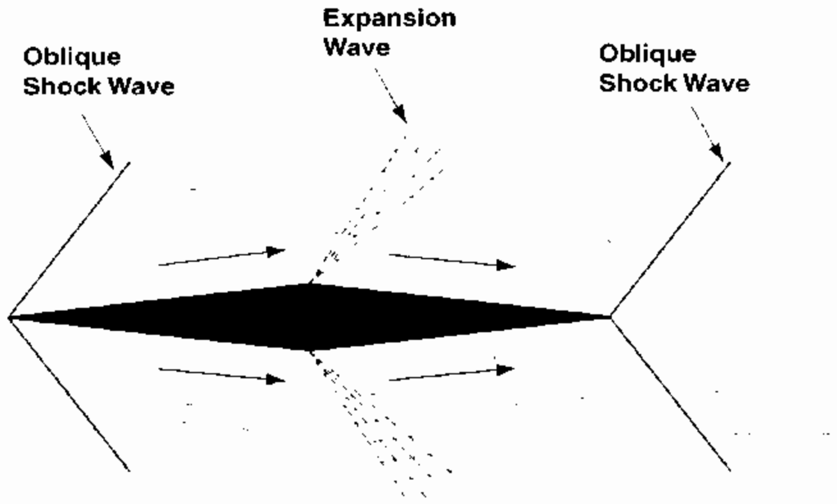
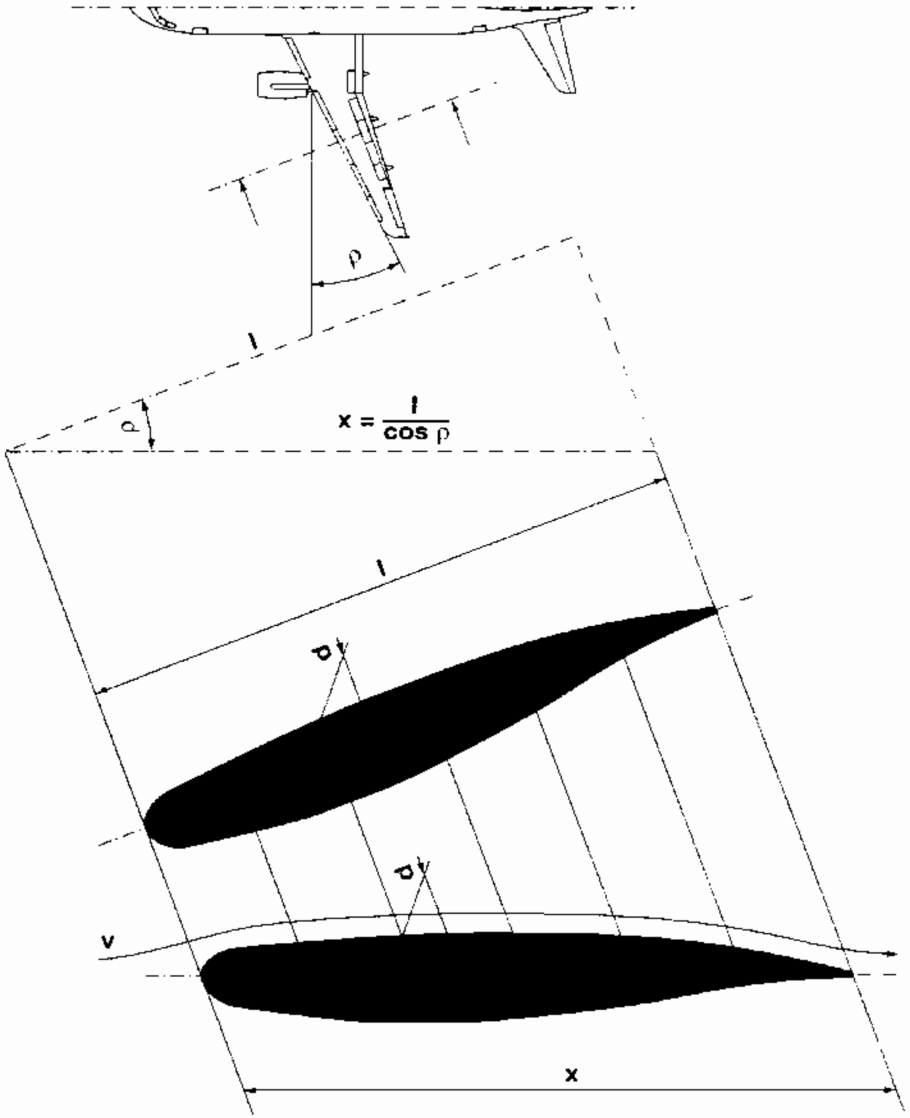


Figure 5: Supersonic Airflow on a swept wing



Effect of Sweepback

One of the most common ways to prevent drag rise and control problems with an aeroplane flying in the transonic range is to sweep the wings back. This will increase the critical Mach number by effectively decreasing the thickness ratio of the wing. In Figure 5 on page 22, its seen that the air flowing across the wing in the line of flight travels farther than the distance perpendicular to the leading edge. This longer travel for the same thickness has the same effect on the effect on the critical Mach number as making the wing thinner, yet it allows a thicker wing for structural strength

Figure 6:

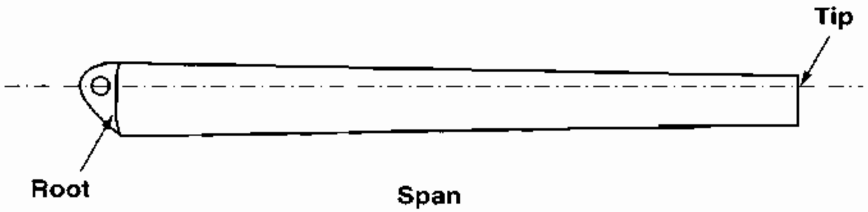
Notes:

Rotary Wings

Aerodynamics

Like fixed wing aircraft, the helicopter flies because of its airfoils. The airfoils of the fixed wings are primarily their wings. However, the tail surfaces and sometimes the fuselage, as well as the propeller may also be airfoils. The primary airfoil of the helicopter is the main rotor. For this reason the helicopter is often referred to as a rotary wing aircraft.

Figure 1: Rotor Blade

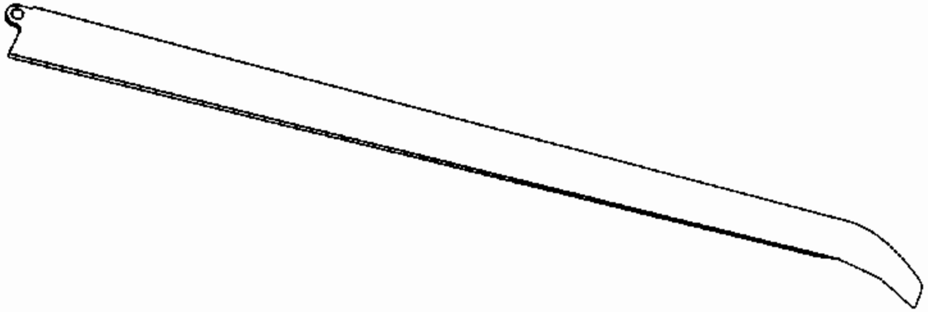


The span of the blade is the distance from the root of the blade to the tip of the blade, measured along the center line (see "Figure 1" on page 25).

The airfoils which are used for helicopters are usually reffered to as symmetrical airfoils. Some successful designs have been built with an unsymmetrical airfoil.

Some efforts are being made to change the airfoil shape along the span to achieve better flight characteristics in the blade (see "Figure 2" on page 25).

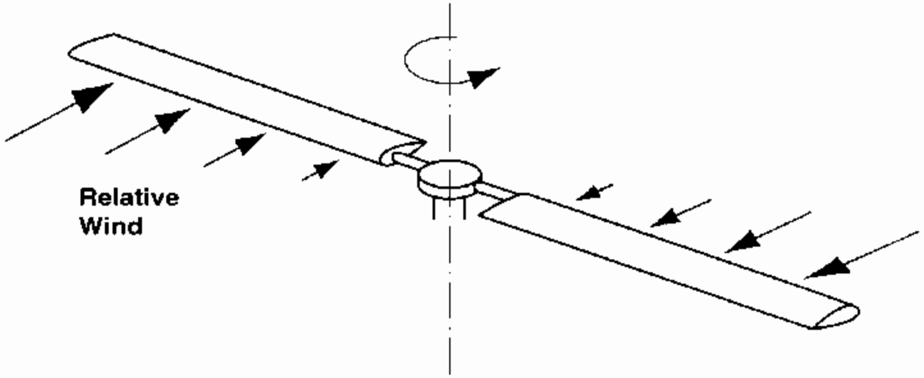
Figure 2: Actual Rotor Blade



Relative Wind

As the rotor blade moves, it is subjected to relative wind. This is always opposite the flight path of the blade.

Figure 3: Relative Wind on the Rotor

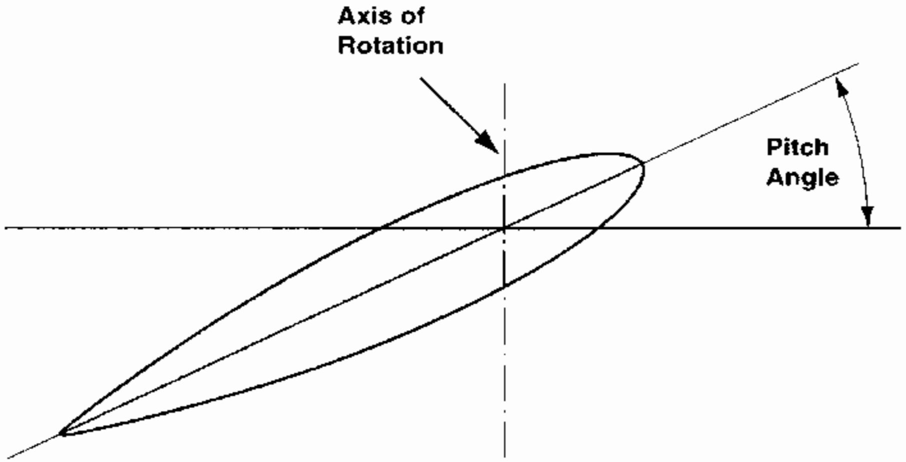


Relative wind is considered in relation to the nose of the helicopter. For this reason the forward moving blade is referred to as the advancing blade, while the backward blade is called the retreating blade. The relative wind may be affected by several factors such as movement of the rotor blades, horizontal movement of the helicopter, flapping of the rotor blade, wind speed, and direction. The relative wind of the helicopter is the flow of air with respect to the rotor blade. For example: when the rotor is stopped, the wind blowing over the rotor blades creates a relative wind. When the helicopter is hovering in a no-wind condition, the relative wind is created by the motion of the rotor blades. If the helicopter is hovering in a wind, the relative wind is a combination of the wind and the rotor blade movement. When the helicopter is in forward flight, the relative wind is created by the rotor blades, the movement of the helicopter, and possibly a wind factor

Pitch Angle

Pitch angle is the acute angle between the rotor blade chord and a reference plane The reference plane of the helicopter will be determined by the main rotor hub. The pitch angle is varied by movement of the collective control which will rotate the blade about the hub axis, increasing or decreasing the pitch (see "Figure 4" on page 26).

Figure 4: Pitch Angle

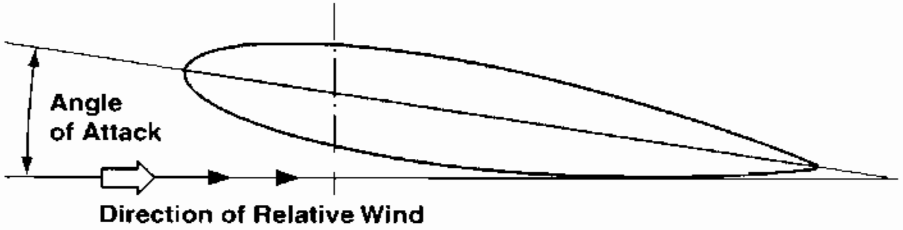


Angle of Attack

The angle of attack is the acute angle between the chord line of the airfoil and the relativ wind.

The pilot can increase or decrease the angle of attack by moving the pitch angle of the rotor. When the pitch angle is increased, the angle of attack is increased and when the pitch angle is decreased, the angle of attack is also decreased.

Figure 5: Angle of Attack



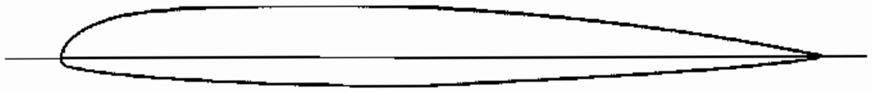
Center of Pressure

The center of pressure is an imaginary point where the result of all the aerodynamic forces of the airfoil are considered to be concentrated. This center of pressure can move as forces change.

On some unsymmetrical airfoils, this movement can cover a great distance of the chord of the airfoil.

On helicopters, because the rotor blades are moved from a fixed axis (the hub), this situation could lead to instability in the rotor, with the rotor blades constantly changing pitch. For this reason, the preferred airfoil is symmetrical where the center of pressure has very little movement. Accompanying lift and drag is stall.

Figure 6: Rotor Blade Airfoils



Unsymmetrical

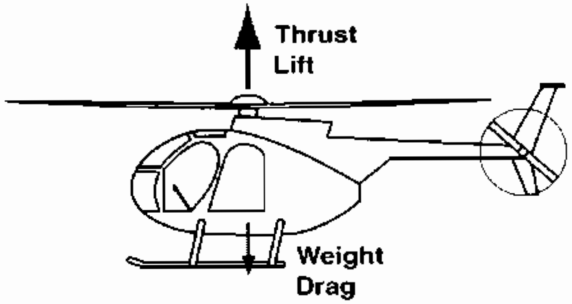
Symmetrical

Effects on Lift

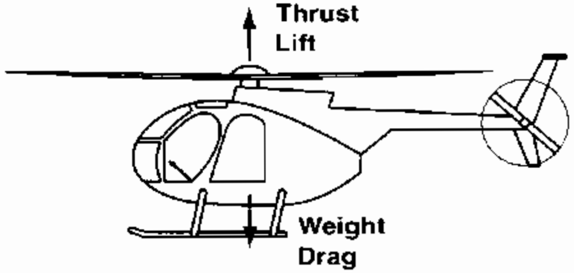
The lift development by the helicopter has to be sufficient to overcome the weight. The heavier the weight, the greater the pitch angle and power requirement to overcome the weight vs. lift action.

Also acting on the helicopter will be thrust and drag. Thrust is the force moving the helicopter in the desired direction, while drag is the force which tends to resist thrust. Therefore, before any movement may take place thrust must overcome drag (see “Figure 7” on page 27).

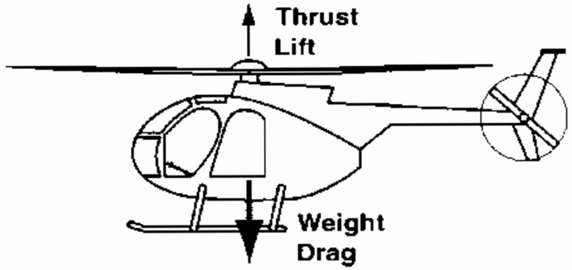
Figure 7: Relationship between Vertical Forces



Vertical Ascent



Hover



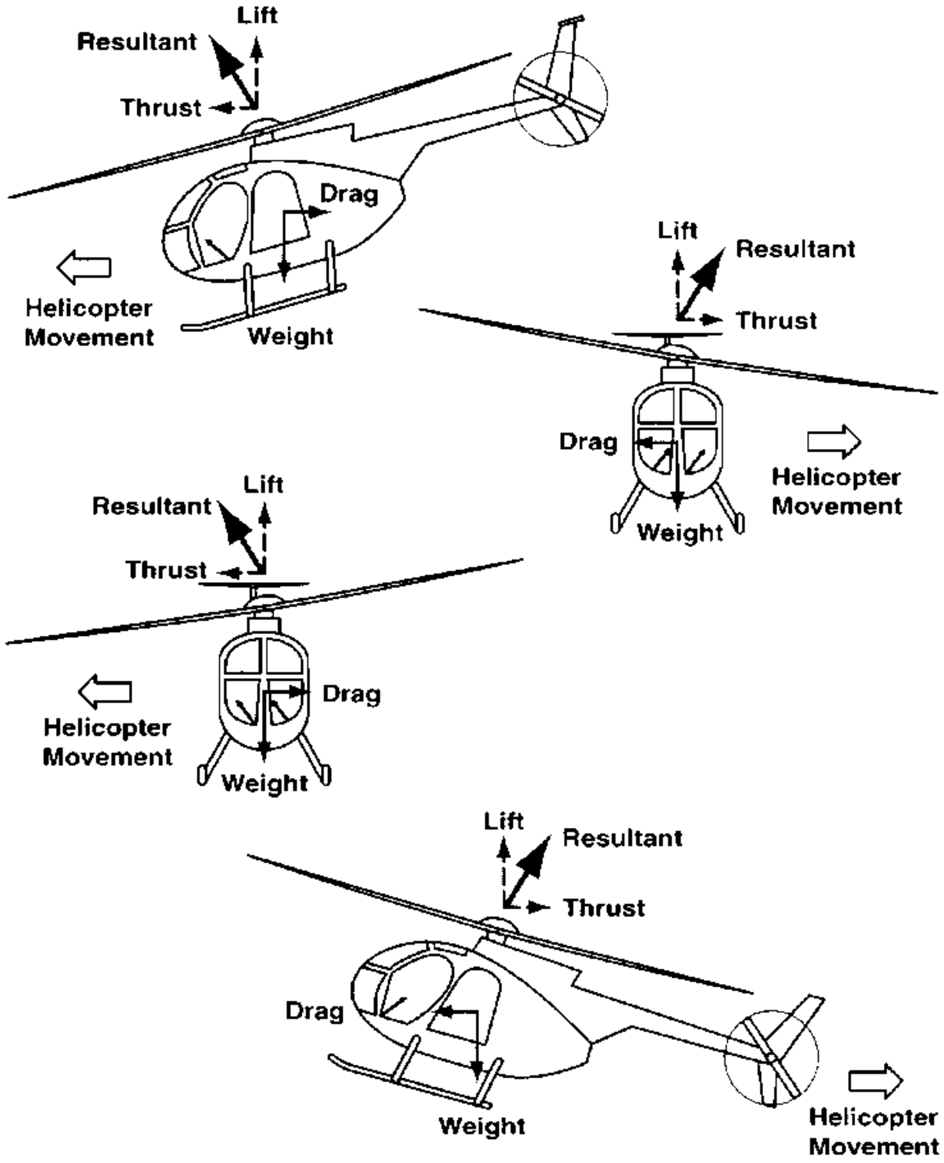
Vertical Descent

Thrust

Thus far we have discussed the flight of the helicopter only in regards to obtaining lift, with little mention of thrust. Since the rotor will produced lift force and at the same time propel the helicopter directionally, thrust is most important. It is thrust that gives this directional movement.

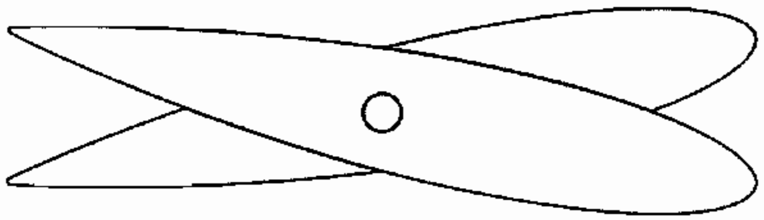
Thrust is obtained by movement of the tip path plane of the rotor or rotor disc. If the helicopter is ascending vertically or at a hover, lift and thrust are both in the same direction, vertical. However, in order to obtain forward, backward, or sideward directional flight, the rotor disc will be tilted in the direction of the movement desired. This will result in lift and thrust being perpendicular to each other, giving the helicopter the ability to maintain flight and move directionally (see "Figure 8" on page 28).

Figure 8: Thrust and Flight Directions



Movement of the tip path plane to change the direction of the helicopter is accomplished by changing the angle of attack of the individual blades as they pass along the disc. In order to accomplish this the hub must have provisions for a feathering axis, which simply allows the pitch to be moved as shown in Figure 9 on page 29.

Figure 9: Feathering Axis

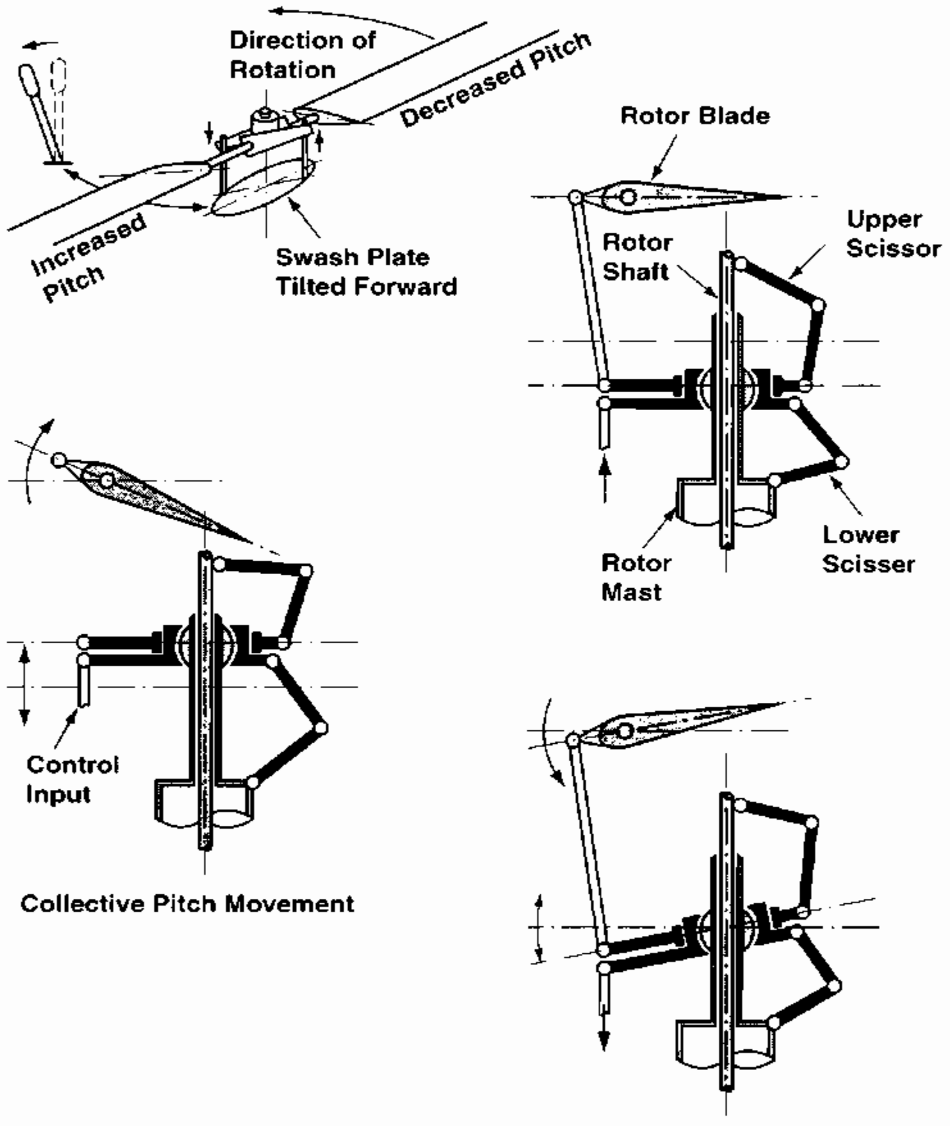


Feathering Axis

Collective and Cyclic Pitch

By changing the pitch angle of the blade, more or less lift will be created. This pitch change can be accomplished by the pilot by use of the collective to raise or lower the helicopter in the air. This raises or lowers the pitch angle of all the blades the same amount throughout the tip path plane. If this lift is increased at one point and decreased at another point 180° apart, the blades will climb and dive, thus moving the disc. This is accomplished as the pilot moves the cyclic control, which in turn moves each blade a predetermined and equal amount as shown in Figure 10 on page 29.

Figure 10: Swash Plate



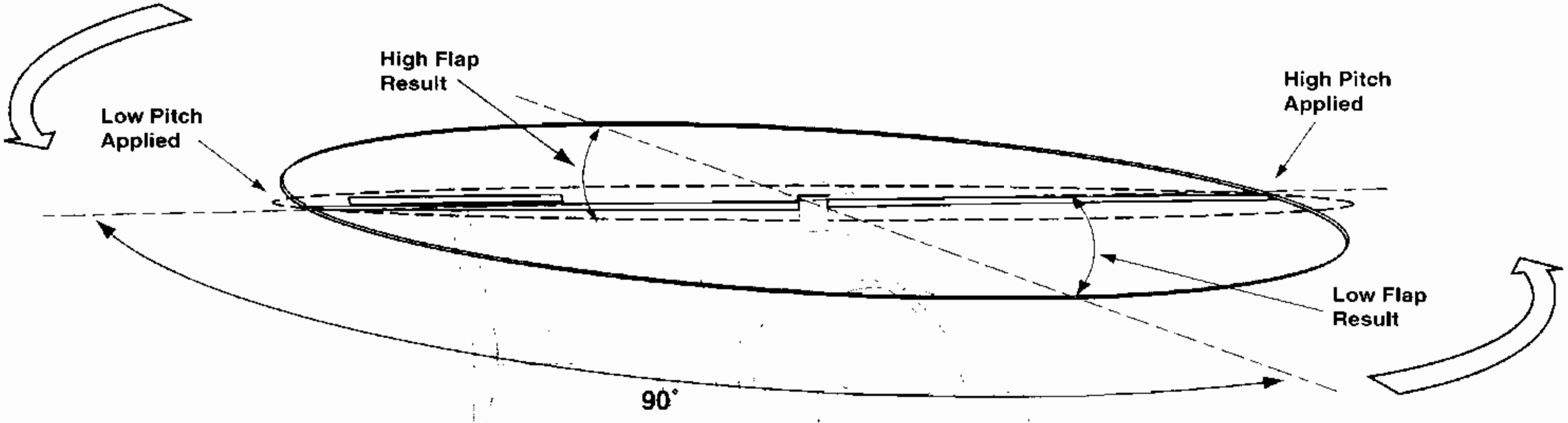
Collective Pitch Movement

Cyclic Pitch Movement

Gyroscopic Forces Precession

Another property of the rotor must be discussed before the total directional control can be understood. Since the rotor path is considered as a disc, it has the same properties as that of any other rotating mass. The property of most interest is gyroscopic precession which means that action occurs 90° from the force applied in the same direction as rotation. This means that the blades do not raise and lower the maximum deflection until a point 90° later than the input (see "Figure 11" on page 30). For this reason a device which is called a washplate or star assembly is used to place the input of the cyclic to main rotor at the location required for the movement of the helicopter in the desired direction.

Figure 11: Precession



Torque

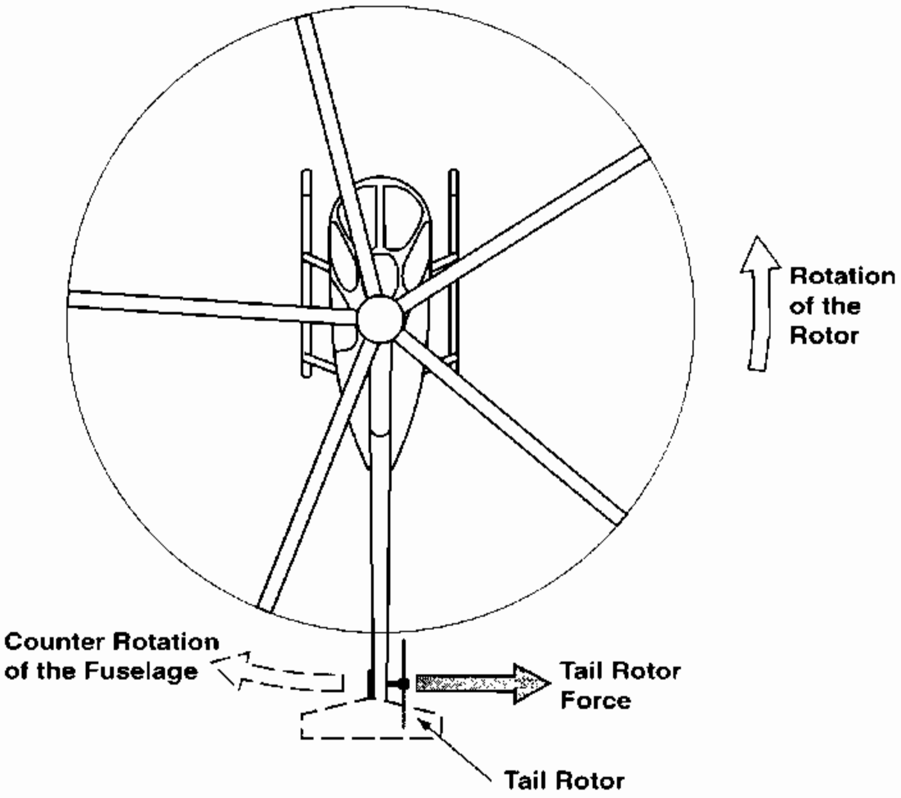
Newton's third law states that for every action there is an opposite and equal reaction. Therefore when power is applied to the rotor system the fuselage of the helicopter will tend to move in the opposite direction of the rotor. This tendency is referred to as torque. The torque problem has plagued designers since the inception of the helicopter. Several designs of rotor systems were tried to eliminate this problem.

One such design was the coaxial helicopter in which two main rotors were placed on top of each other rotating in opposite directions. Another design requires two main rotors placed side by side. Some of these designs actually used intermeshing rotors turning in opposite directions. Still other designs have used single rotors powered at the tip by ramjets or hot air passing through the blade and ejected through nozzles at the tip.

The disadvantages of these systems seem to outweigh the advantages to the point that most helicopters use one main rotor with an auxiliary rotor on the tail to counteract torque.

This system, however, absorbs a great percentage of the power available. To give the helicopter fuselage this directional control, a variable pitch rotor is vertically mounted on the tail. In order to keep the fuselage straight when increasing power, the pitch of the tail rotor is increased to counteract the torque. This is accomplished by foot pedals moved by the pilot (see "Figure 12" on page 31).

Figure 12: Principle of Tail Rotor



Many of the conventional helicopters using tail rotors have found methods to help reduce this power requirement in flight. One of these methods is a vertical fin, which is offset in order to keep the fuselage straight during forward flight. This in turn unloads the tail rotor.

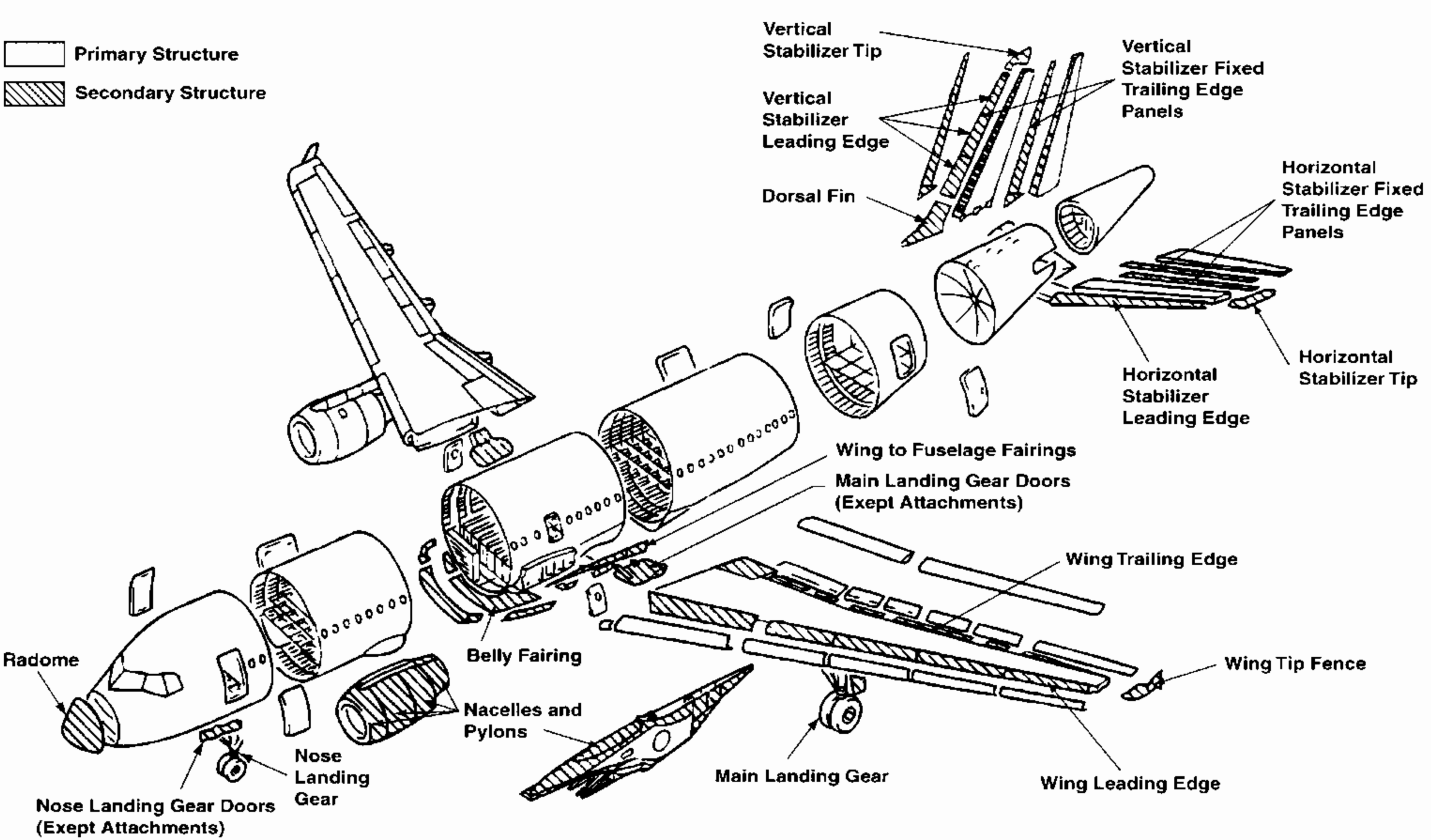
13.2 Airframe Structures - General Concepts

Structural Classification

When designing aeroplanes, loads to which the various parts are exposed must be taken into consideration. These loads are different for each part of the construction. A difference is made between primary and secondary constructions. When choosing materials for maintenance work, this must be taken into account.

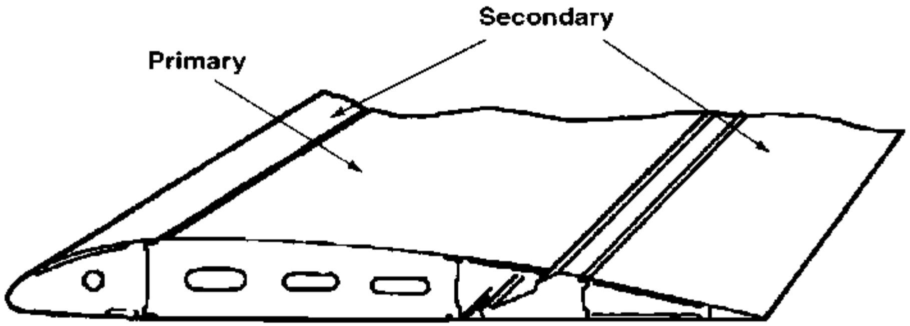
The primary construction consists of those parts of the aeroplane construction that bear the loads (see "Figure 1" on page 3).

Figure 1: Structural classification



The secondary construction generally gives the aerodynamic shape to the aeroplane construction. On the basis of the main sections, the difference between primary and secondary can be clearly illustrated. For example, a wing section consists of a primary part and a secondary part (see "Figure 2" on page 4).

Figure 2: Wing Structural classification

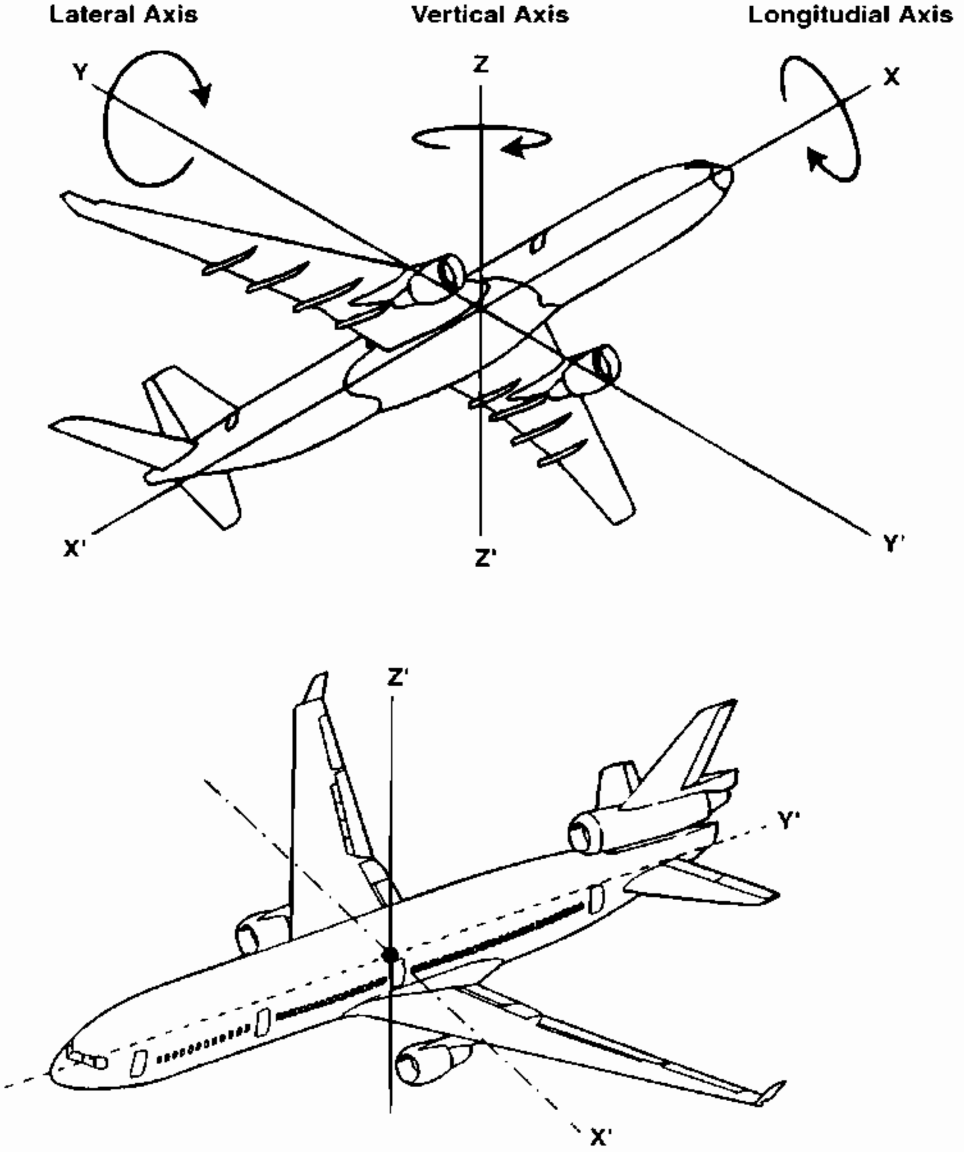


Dimensions and Locations

Station identification Systems

In order to determine a particular location in an aeroplane, it is divided into three (imaginary) planes that are at angle of 90° to each other. (see “Figure 3” on page 5).

Figure 3: Axle Systems



The first plane cuts the aeroplane horizontally (based on a cross section). These planes are called water lines or Z stations.

The second plane cuts the aeroplane vertically (based on a cross section). These planes are called buttock lines or X stations.

The third plane cuts the aeroplane vertically (based on a side view). These are called body stations or Y (X) stations. By means of these three planes, any and every point in the aeroplane can be given an X, a Y and a Z coordinate. Some aeroplane manufacturers use abbreviations for these coordinates as follows:

- B.L. (buttock lines) - the X (Y) coordinate;
- Sta. (body stations) - the Y (X) coordinate;
- W.L. (water lines) - the Z coordinate.

Other manufacturers use the following abbreviations:

- X Sta. (X Stations) - the X coordinate;
- Y Sta. (Y Stations) - the Y coordinate;
- Z Sta. (Z Stations) - the Z coordinate.

There is a number behind these abbreviations which indicates the distance of the part from the zero point. For aeroplanes built by Being, these distances are given in inches. For aeroplanes built by Airbus, in cm.

The zero point of the Sta. (Y Sta.) is in front of, behind or on the point of the fuselage nose (Figure 4 on page 6). In cases where the station number 0 is behind the point of the nose, the station number that are in front of the zero point have a minus sign, for instance: Sta. -60.4.

Figure 4: Zero Point of Stations

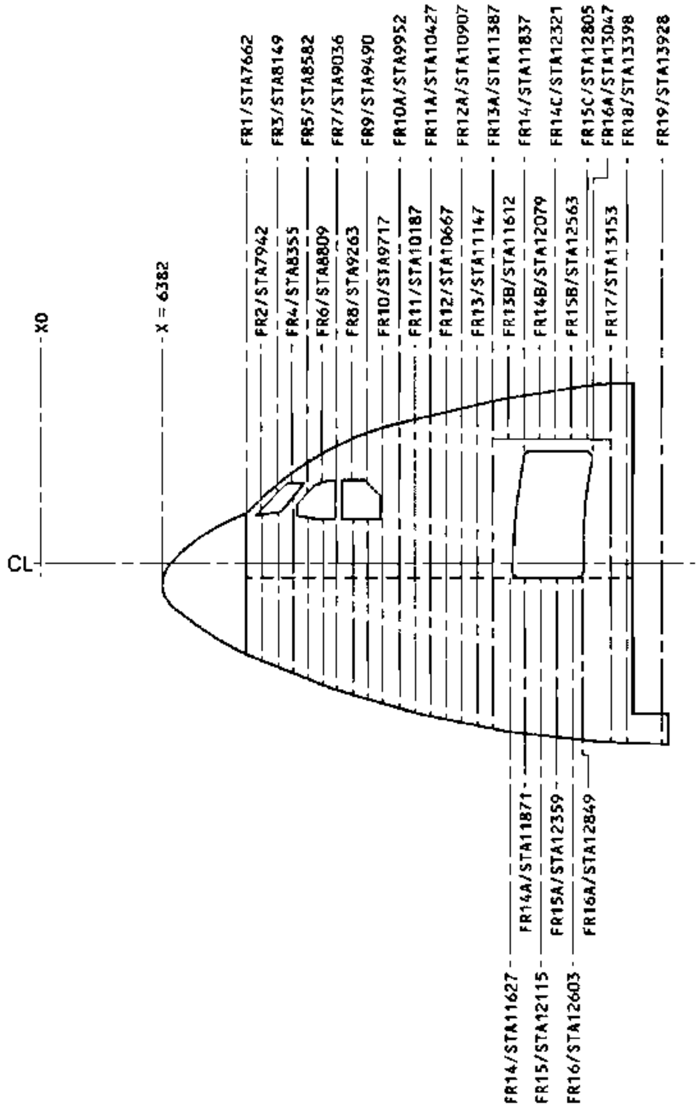
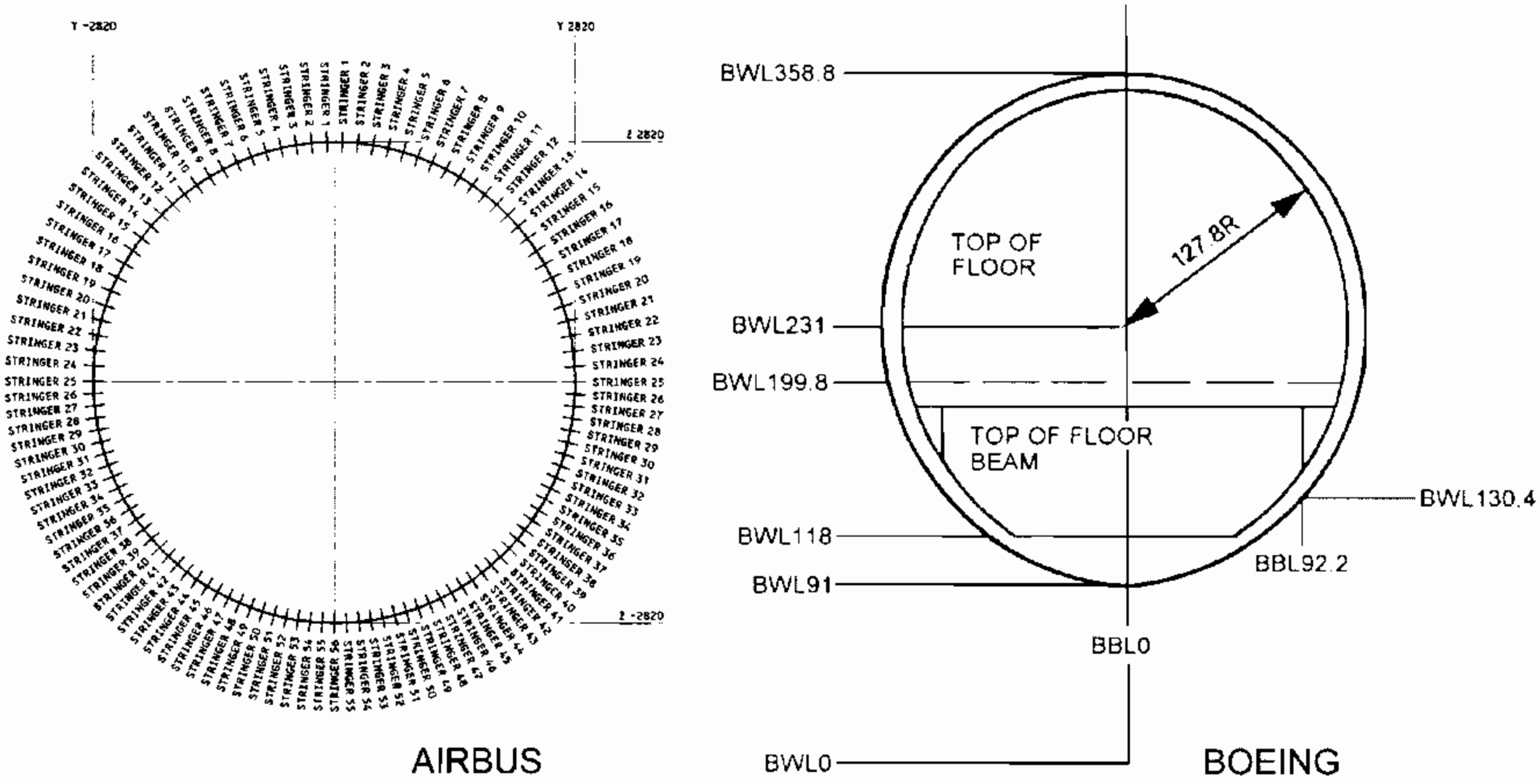


Figure 5: Station Examples



AIRBUS

BOEING

The zero point of the W.L. (Z Sta.) depends on the type of airplane.The zero point of the W.L. in a B-747 is 91 inches below the lowest point of the fuselage. Every aeroplane has a different zero point.

The zero point of the B.L. (X Sta.) is the centre line of the aeroplane (see "Figure 5" on page 7). Looking in the direction of flight, there are left-hand and right-hand buttock lines. The left- hand buttock lines are indicated by a minus sign and the right-hand ones with a plus sign.

The wings, horizontal and vertical stabilizers, and powerplants of most aeroplane types have their own location identification system.

Zonal Identification Systems

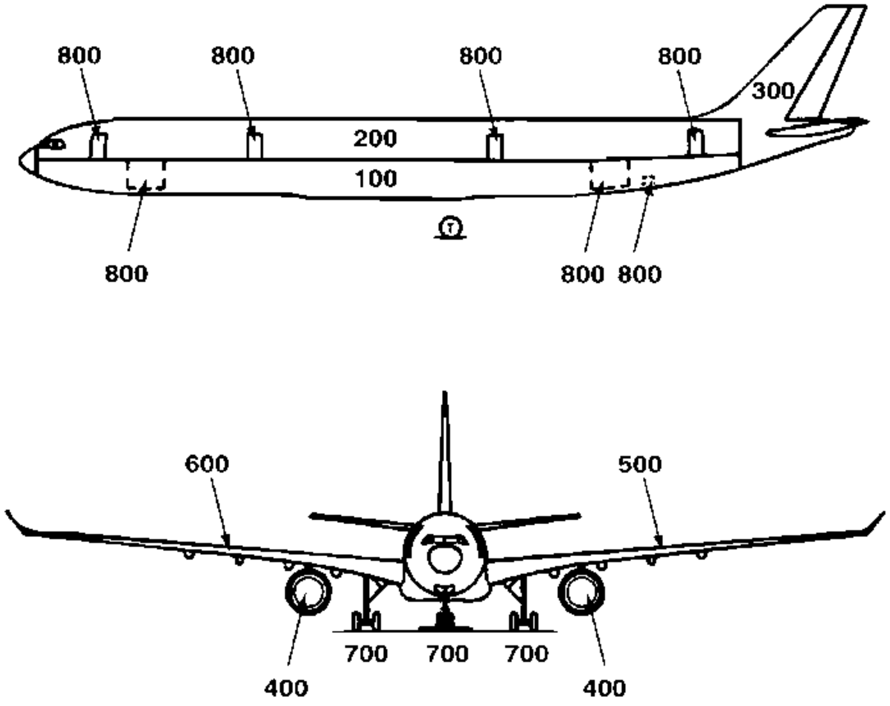
The location identification system is used to pinpoint the various locations in an airplane. The station numbers make it possible to indicate the location of the centre of gravity, the distribution of the load, the location of the compartments and of parts. To localize parts more easily and to localize where work must be done, the aeroplane is divided into:

- Major zones
- Major sub-zones
- Unit zones

Major zones are identified by hundred as follows:

- 100 FUSELAGE LOWER SECTION
- 200 FUSELAGE TOP SECTION
- 300 STABILIZERS
- 400 NACELLES
- 500 LEFT WING
- 600 RIGHT WING
- 700 LANDING GEAR
- 800 DOORS

Figure 6: Major Zones (Example)



Major sub-zones are identified by the ten of the majors zones.

Figure 7: Major Sub Zones (Example)

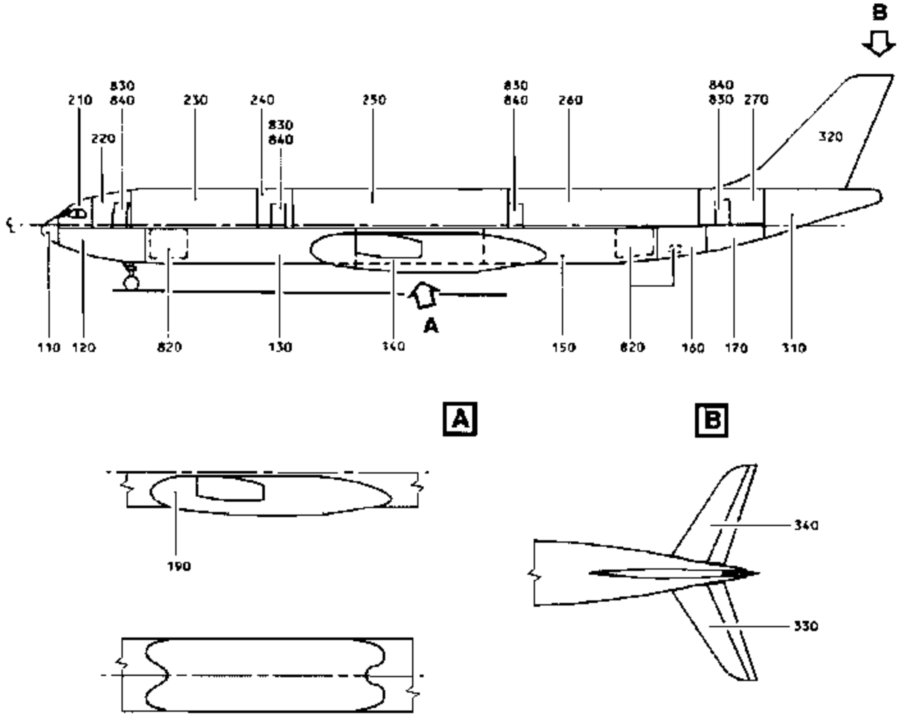
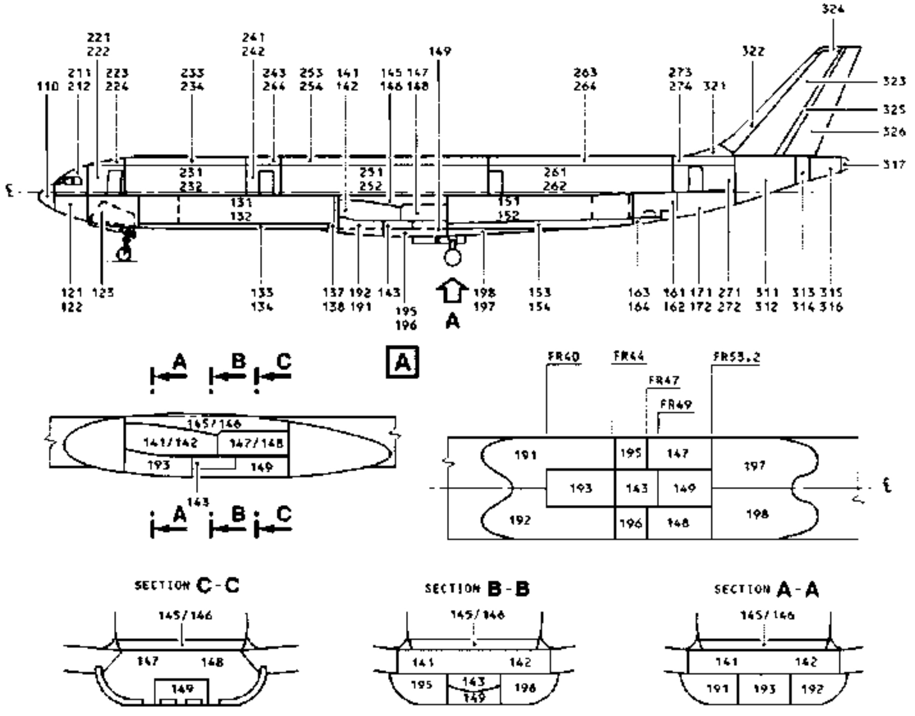


Figure 8: Unit Zones (Example)



Unit zones are identified by a three digit number. An example of a location identification system is 212:

- 200: upper half of body (major zone)
- 10: Cockpit (major sub-zone)
- 2: zone number on the right-hand side (unit zone)

Where necessary, the uneven zone number refers to the left-hand zone, and an even number indicates a right- hand zone. Large construction sections, including doors and control surfaces, have their own zone numbers.

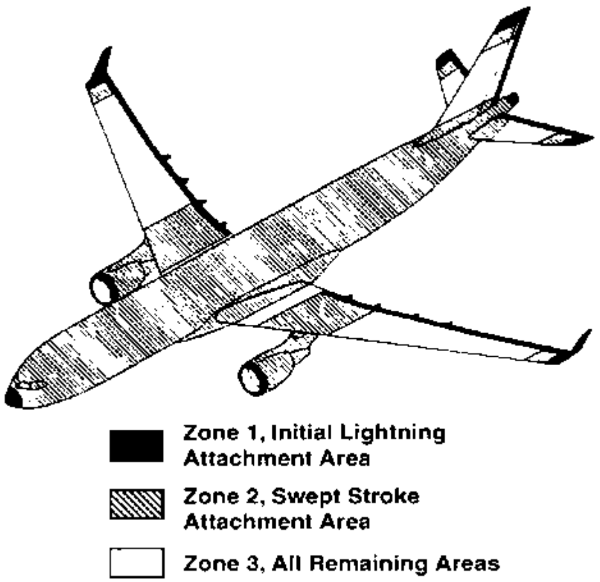
Lightning Strike Protection

Aircraft require electrical contact between all metallic and composite parts in order to prevent arcing or fiber damage. Aluminum is used to provide a conductive path for the dissipation of the electrical energy. The aluminium may be provided in a number of ways depending on the manufacture of the aircraft.

No matter whether an aircraft is aluminum or composite, when lightning hits an aircraft it needs a path for the electricity to flow through. On an aluminium skin, the electricity will flow through the skin and discharge out the static wicks. Since composites do not conduct electricity, lightning protection has to be built into the component.

If there is no lightning protection in the composite and the lightning exits through the composite component, the resins in the composite will evaporate, leaving bare cloth. Carbon/graphite composite was at first believed to conduct enough electricity to dissipate the electrical charge, but this was later found not to be true. Aluminium lightning protection may be found in carbon/graphite parts. A barrier, such as a layer of fiber glass, should be used to prevent a galvanic potential between the carbon/graphite and aluminium.

Figure 9: Lightning Attachment Zones



Electrical Bonding

Normally the structure of an aircraft consists of metallic assemblies which ensure an excellent electric conductibility; however certain insulating intermediate parts stop the continuity in large zones. The continuity is restored by means of strips, screws or grounding lugs fitted between metallic assemblies. Hinged parts (control surfaces, doors, hatches, etc....), removable parts (unhinged inspection doors, etc....), are provided with one or several bonding means shunting each part where conductibility may be interrupted. For particular zones such as fuel tanks, engines and APU, the bondings provide an efficient circulation of static potential; bonding strips and screws are connected to the main structure

External protruding parts, metallic or not, are provided with electrical lead connected to the main structure. Antennas and other equipment are not bonded due to the fact that flash of lightning could damage only the element struck without endangering the other parts of the aircraft.

Different manufacturers use different methods to dissipate the electrical charge on composite structures. These are a few different methods:

- Aluminium wires may be woven into the top layer of composite fabric. This is usually done with fiber glass or Kevlar and not with carbon/graphite.
- A fine aluminium screen may be laminated under the top layer of fabric. If this method is used on a carbon/graphite component, it is usually sandwiched between two layers of fiber glass to prevent a galvanic potential.
- A thin aluminium foil sheet may be bonded to the outer layer of composite during the manufacturing process.
- Aluminium may be flame sprayed onto the component. This is molten aluminium that is sprayed on like a paint. Some companies will just paint the component with an aluminised paint.
- In some structures, a piece of metal is bonded to the composite to allow the dissipation of the electrical charge out to another metal component or static wick.

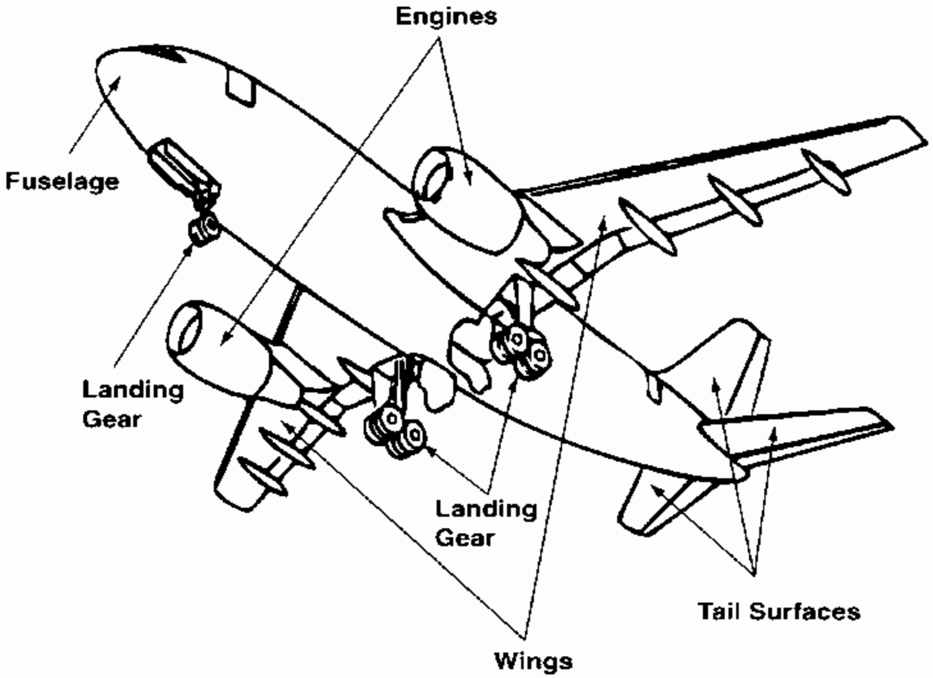
Construction Methods of Aeroplanes

Maintenance and repairs to aeroplanes must be done well, fast and at the right location. That's why the aeroplane maintenance mechanic must know where the part to be repaired or replaced is.

When constructing an aeroplane, a distinction is made between the main sections and the subsections. The main sections are connected to each other in a particular order in various ways. The main sections of the aeroplane construction as shown in Figure 10 on page 11 are:

- the fuselage
- the wings
- the landing gears
- the empennage (consisting of the vertical and horizontal stabilisers, rudder and elevator)
- the propulsion systems (powerplants, also referred to as engines).

Figure 10: Main Sections of an Aircraft



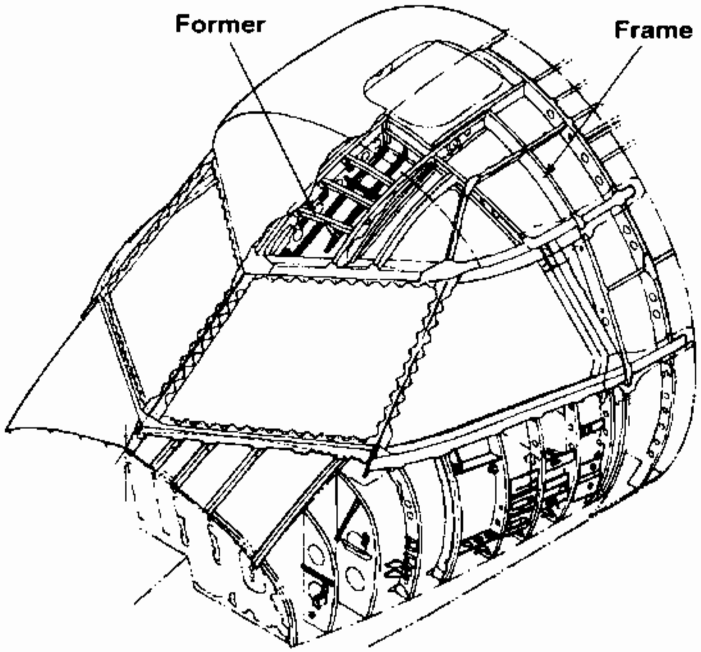
Stressed Skin Construction Method

To take the maximum advantage of metal, most aircraft structure is of the stressed skin. A type of aircraft structure in which all or most of the stresses are carried in the outside skin. A stressed skin structure has a minimum of internal structure. There are two types of metal stressed skin: monocoque and semimonocoque.

Monocoque Structure

The name monocoque means single shell, and in a true monocoque structure, all the strength of the structure is carried in the outside skin. Figure 11 on page 12 shows a view of a monocoque structure. The formers give the structure its shape, but the thin metal skin riveted to them carries all the flight loads.

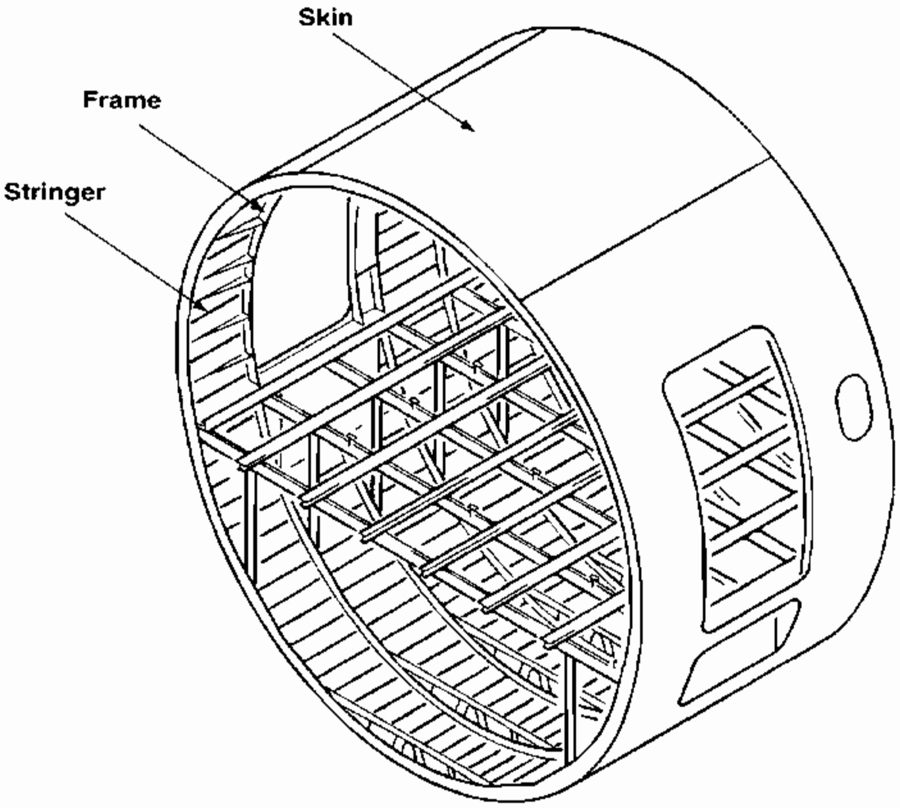
Figure 11: Monocoque Structure



Semi-monocoque Structure

Pure monocoque structure has the serious drawback that any dent or deformation will decrease its ability to carry the flight loads. To overcome this limitation, semimonocoque structure as seen in Figure 12 is widely used. In this type of structure, formers not only provide the shape, they carry the majority of the flight loads.

Figure 12: Semi-Monocoque Structure



13.3 Autoflight (ATA 22)

Automatic Flight Fundamentals

Introduction

Early automatic pilots were primarily pilot relief devices, which did little more than hold the aircraft straight and level. The introduction of transistorized electronics permitted dramatic changes in the size, weight, and power requirements of automatic pilots. The automatic pilot has grown to become a system that is utilized in all phases of flight and has, as such, acquired its more modern identification as an Automatic Flight Control System.

Commercial Aircrafts

The Automatic Flight Control Systems or AFCS, in modern jet transports, are all uniquely tailored to the specific aircraft, but all share common features. For example, the flight aerodynamics of a MD-11 are different from those of a A380; however, both aircraft would most likely require an "attitude hold" mode of operation. In this case, the attitude hold feature is common to both autopilot designs, but gains in the two autopilots will differ to accommodate the differences in the aerodynamics of each aircraft. Each AFCS receives attitude and heading signals from a vertical and directional gyro and has its own rate gyro/accelerometer system to develop attitude and flight path stabilization signals. The AFCS computers comprise an electronic "brain" that receives signals from its "senses" to compute the proper responses and provides outputs to electric and/or hydraulic actuators that are then "muscles" which move the aircraft's control surfaces.

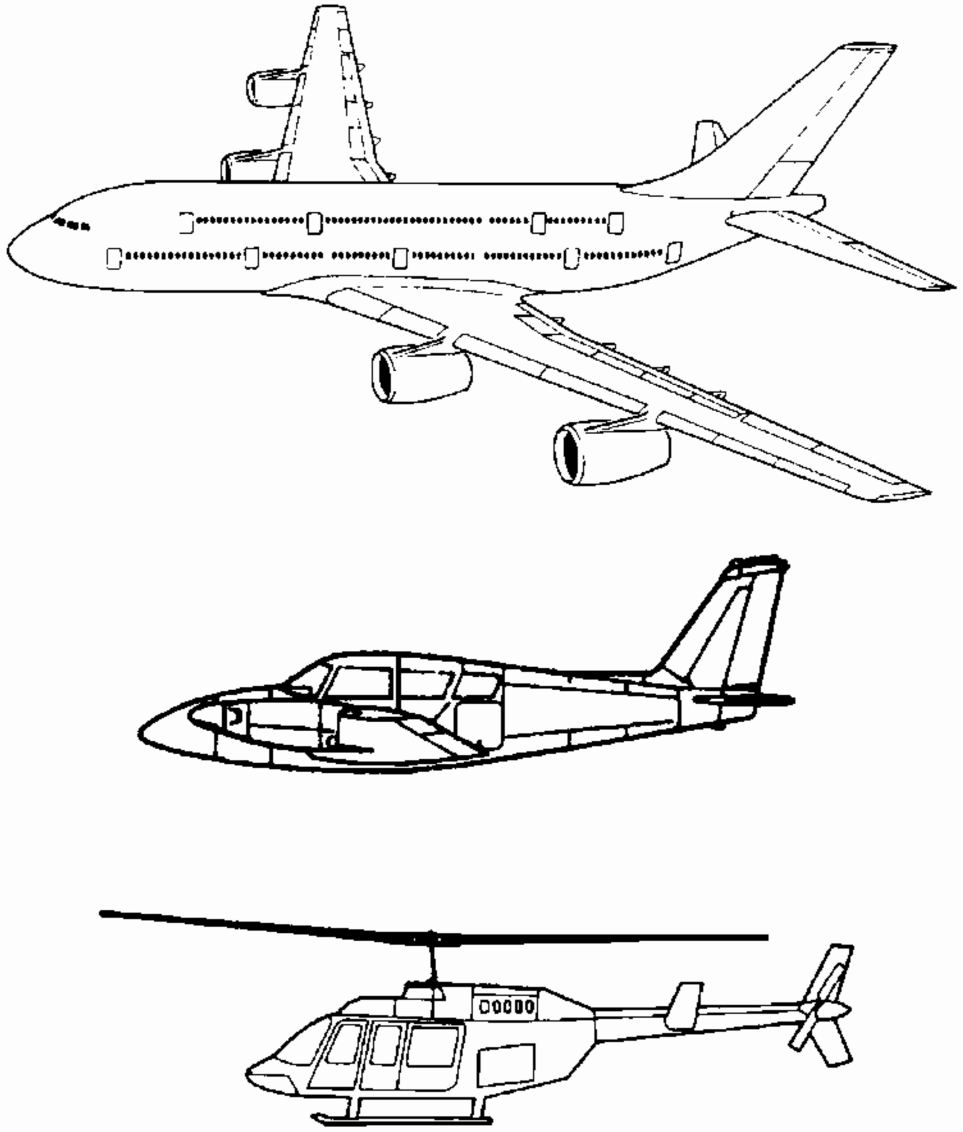
Smaller Aircraft

The need for Automatic Flight Control in smaller aircraft has produced autopilots with varying degrees of complexity; from simple single-axis "wing levelers" in small single engine aircraft, all the way up to three-axis systems for corporate jet aircraft that have as many features and functions as those systems found on jet transport aircraft. Autopilots, from the simple to the complex, have undoubtedly reduced pilot workload and mental fatigue throughout all areas of the flight envelope.

Helicopters

Helicopters are relatively unstable aircraft requiring constant attention of the pilot even under smooth flight conditions. Helicopters must be controlled from zero forward speed to speeds approaching 200 miles per hour. Additionally, since they can fly sideways and backwards as well, a completely new design approach was required.

Figure 1: Various Types of Aircrafts with Autoflight Systems



Aircraft Axes and Movements

Movements of an aircraft occurs along and around the known axes.

X - Axis

Longitudinal axis

Roll axis

Y - Axis

Lateral axis

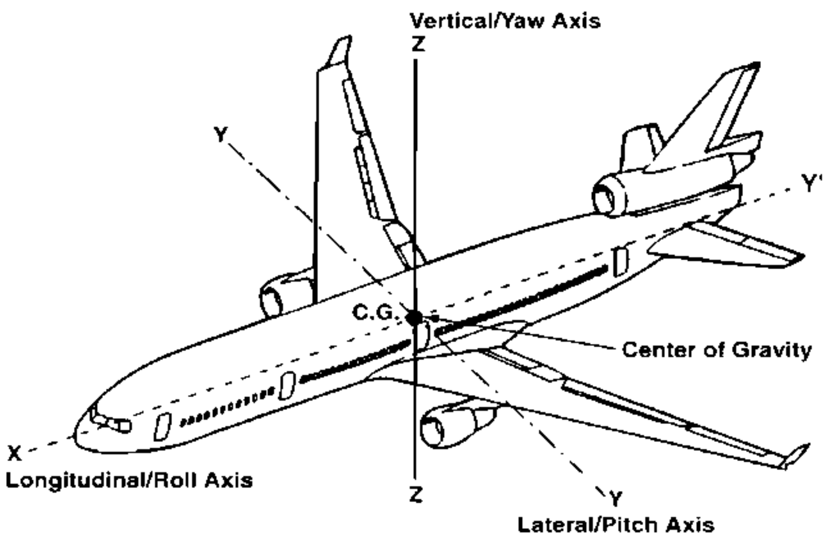
Pitch axis

Z - Axis

Vertical axis

Yaw axis

Figure 2: Axes



Aircraft Movements

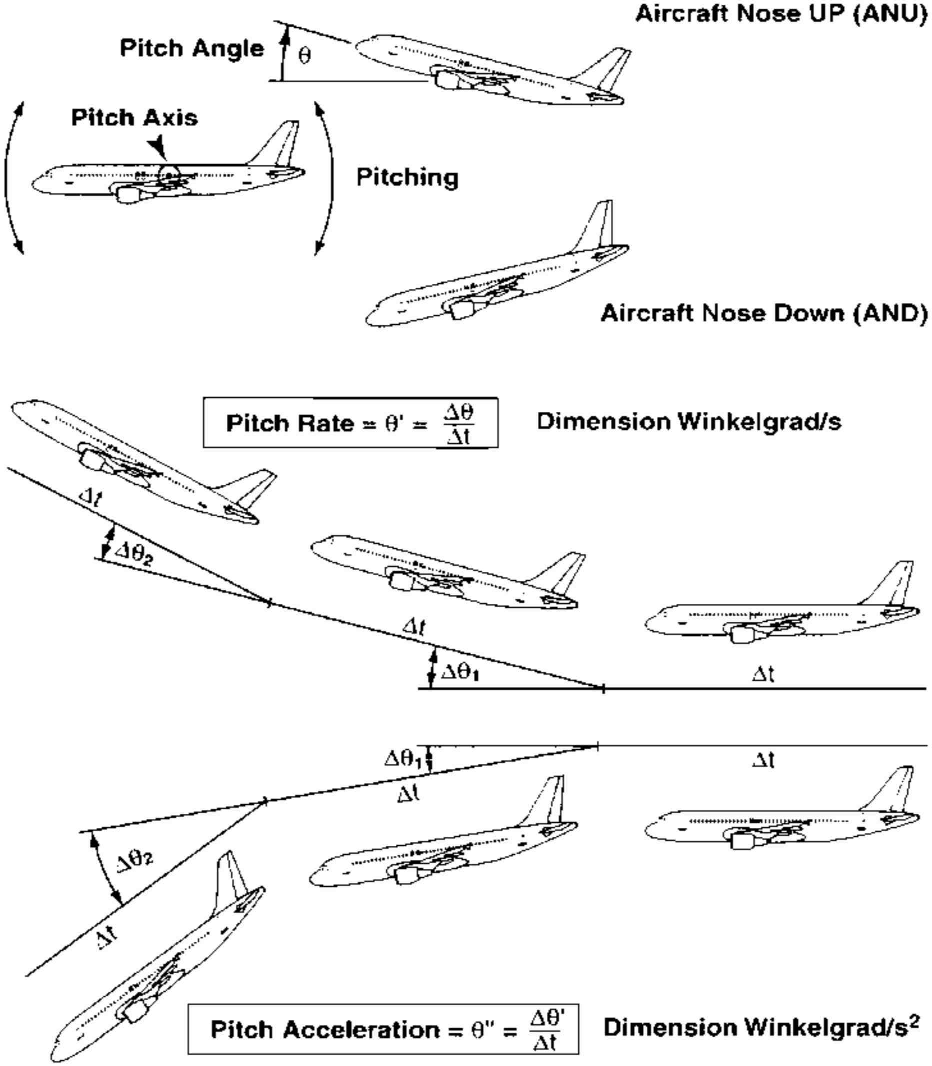
Movements around the aircraft axes are named according following drawing:

Pitch Movements

Movements around lateral axis:

- Attitude
- Rate
- Acceleration

Figure 3: Movements Pitch

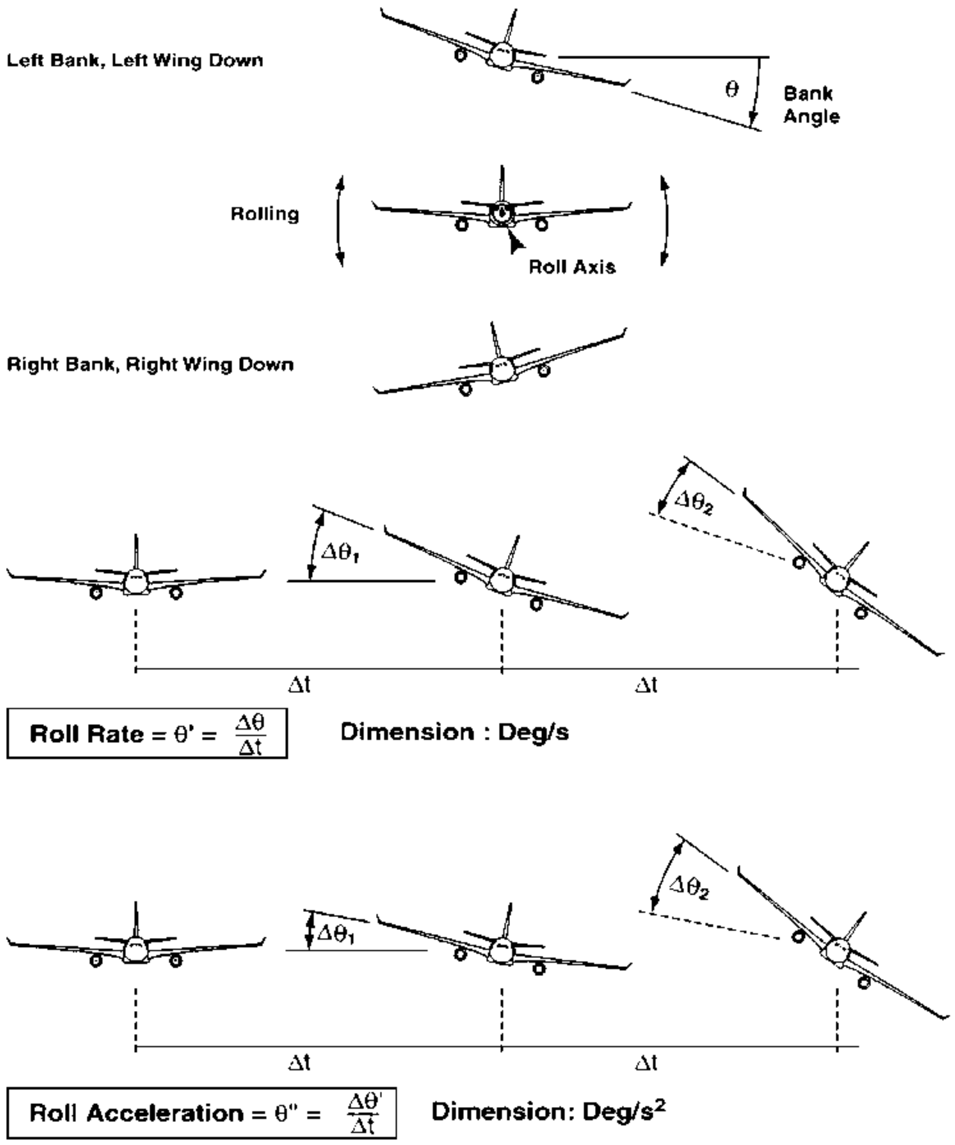


Bank or Roll Movements

Movements around longitudinal axis:

- Attitude
- Rate
- Acceleration

Figure 4: Movements Roll

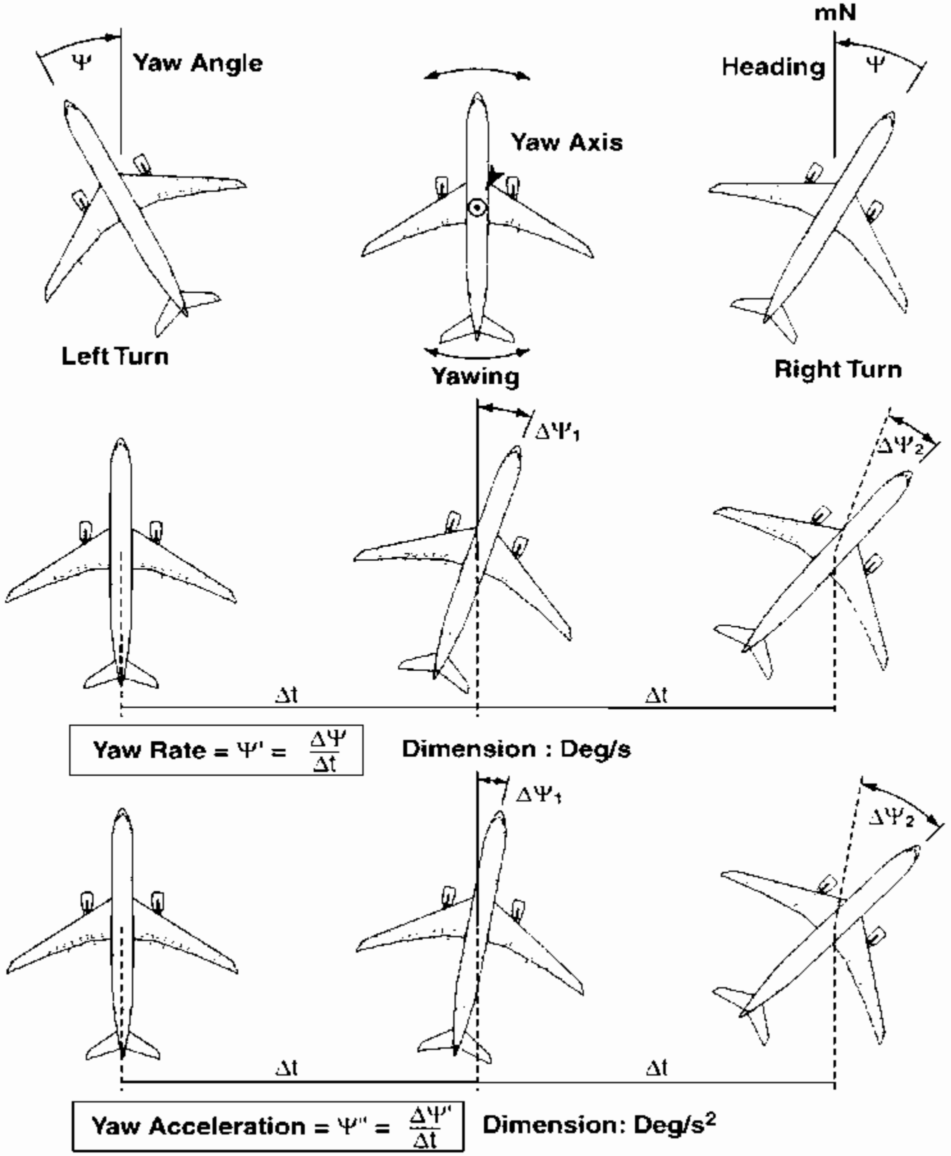


Yaw Movements

Movements around vertical axis:

- Attitude (Heading)
- Rate
- Acceleration

Figure 5: Movements Yaw



Integrating and Differentiating

are mathematical functions. In graphs the functions are easier understandable.

Integrating

The output is the sum of all inputs.

Acceleration > Rate > Displacement

Differentiating

The output is proportional to the rate of change of the input.

Displacement > Rate > Acceleration

Figure 6: Resistor and Capacitor as Integrator and Differentiator

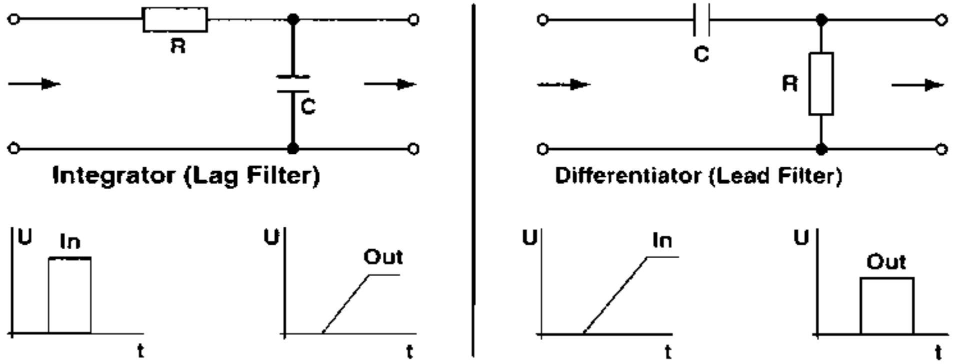


Figure 7: Integrator and Differentiator with Operation-Amplifier

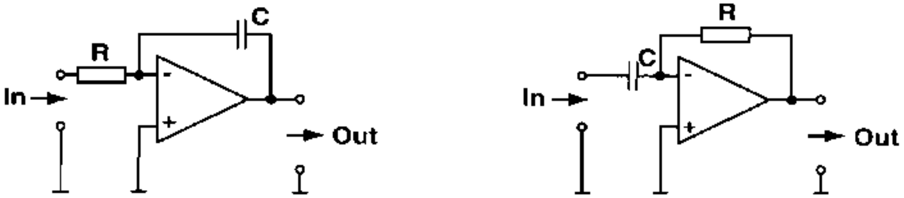
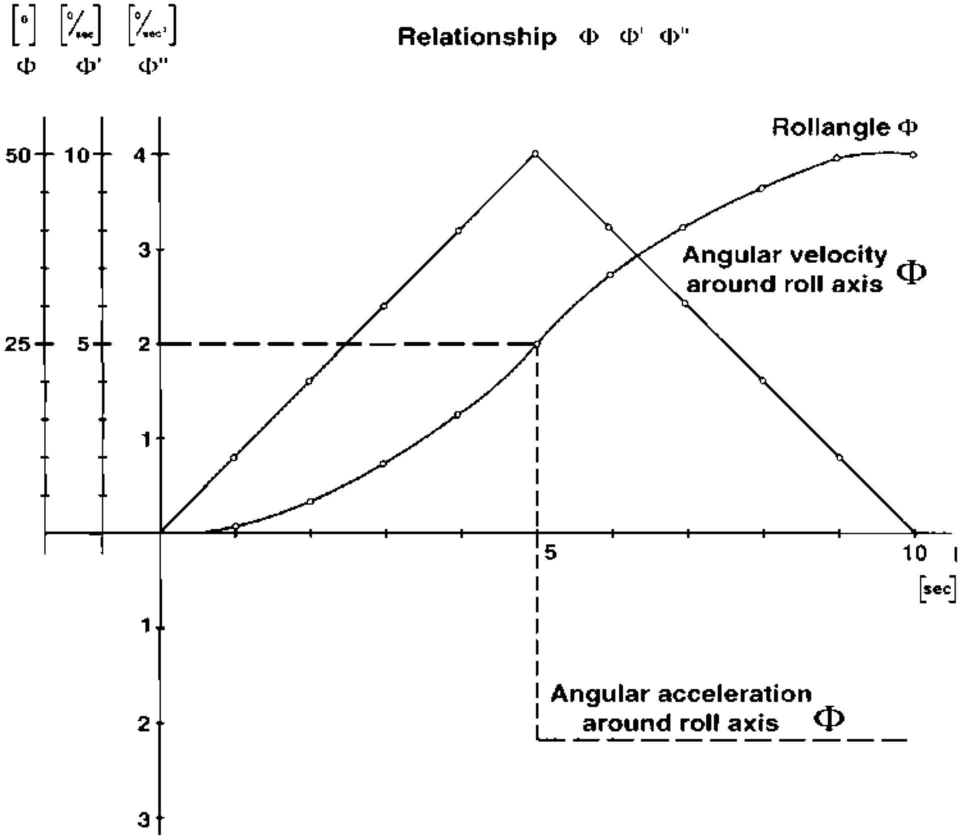


Figure 8: Relations between displacement rate and acceleration



Operation Principle of Flight Controls

Primary flight controls

Aileron > steers around Roll axis, causing a heading change

Elevator > steers around Pitch axis, causing a altitude rate change

Rudder > steers around Yaw axis, causing a heading change

Secondary flight controls

Flaps > controls lift and drag

Slats > controls lift and drag

Spoiler > assisting aileron and spoiling of lift

Flight manoeuvres

The primary flight controls must be deflected to initiate or terminate an attitude change.

During climb for example the attitude is nose up and the elevators are centered. To initiate and terminate a climb, the elevators must be shortly deflected.

During heading change the left wing is up or down, the ailerons are nearly centered. To initiate and terminate a curve, the ailerons must be shortly deflected. The ailerons may be assisted by spoilers and rudder.

Figure 9: Deflections of Flight Control

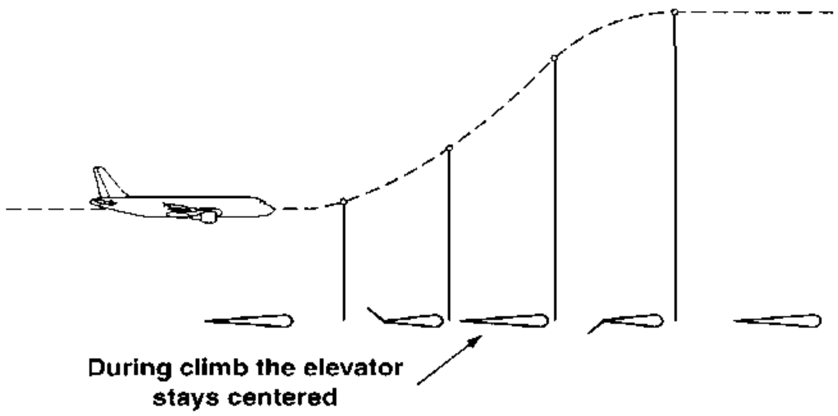
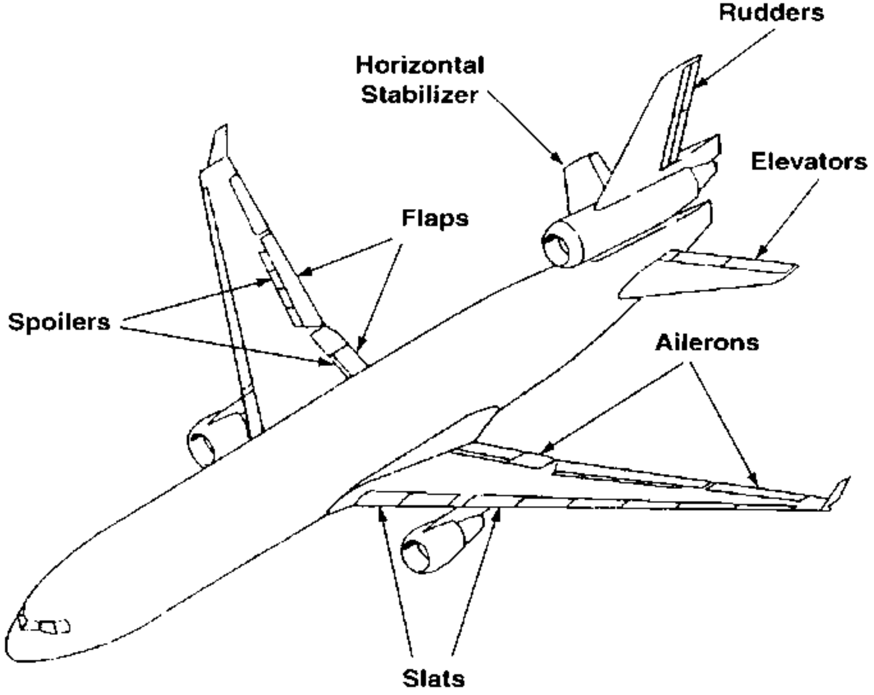


Figure 10: Flight Controls



Feedback Controls

Feedback controls are widely used in modern automated systems. A feedback control system consists of five basic components:

1 input
2. process being controlled
3. output
4. sensing elements
5. controller and actuating devices

The input to the system is the reference value, or set point, for the system output. This represents the desired operating value of the output. Using in example a heating system, the input is the desired temperature setting for a room. The process being controlled is the heater. In other feedback systems, the process might be a steering system or the engines of a aircraft. Also the automobile engine in cruise control, or any of a variety of other processes to which power is applied. The output is the variable of the process that is being measured and compared to the input; in the above example, it is room temperature.

Sensing elements

The sensing elements are the measuring devices used in the feedback loop to monitor the value of the output variable. In the heating system example, this function is normally accomplished using a temperature sensor. There are many different kinds of sensors used in feedback control systems for automation.

Controller and actuating device

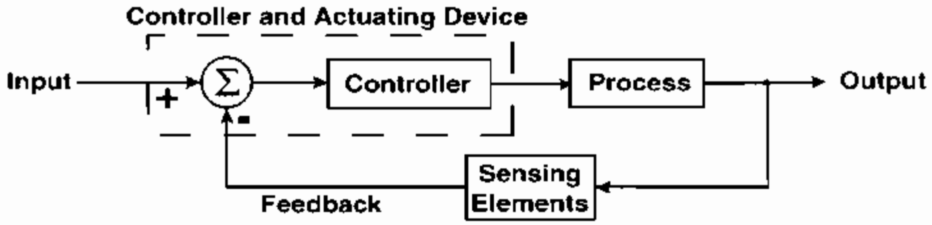
The purpose of the Controller and actuating device in the feedback system is to compare the measured output value with the reference input value and to reduce the difference between them. In general, the controller and actuator of the system are the mechanisms by which changes in the process are accomplished to influence the output variable. These mechanisms are usually designed specifically for the system and consist of devices such as motors, valves, solenoid switches, piston cylinders, gears, power screws, pulley systems, chain drives, and other mechanical and electrical components. When the output (room temperature) is below the set point, the controller turns on the heater. When the temperature exceeds the set point, the heater is turned off.

Hunting and damping

The stability of a control system is determined to a large extent by its response to a suddenly applied signal, or transient. If such a signal causes the system to overcorrect itself, a phenomenon called hunting may occur in which the system first overcorrects itself in one direction and then overcorrects itself in the opposite direction. Because hunting is undesirable, measures are usually taken to correct it.

The most common corrective measure is the addition of damping somewhere in the system. Damping slows down system response and avoids excessive overshoots or overcorrections. Damping can be in the form of electrical resistance in an electronic circuit, the application of a brake in a mechanical circuit, or forcing oil through a small orifice as in shock-absorber damping. Signals proportionally of the actuating device rate or process rate are also commonly used for dampening.

Figure 11: Control Loop



Control Loops

The autopilot represents two different control loops.

Inner loop

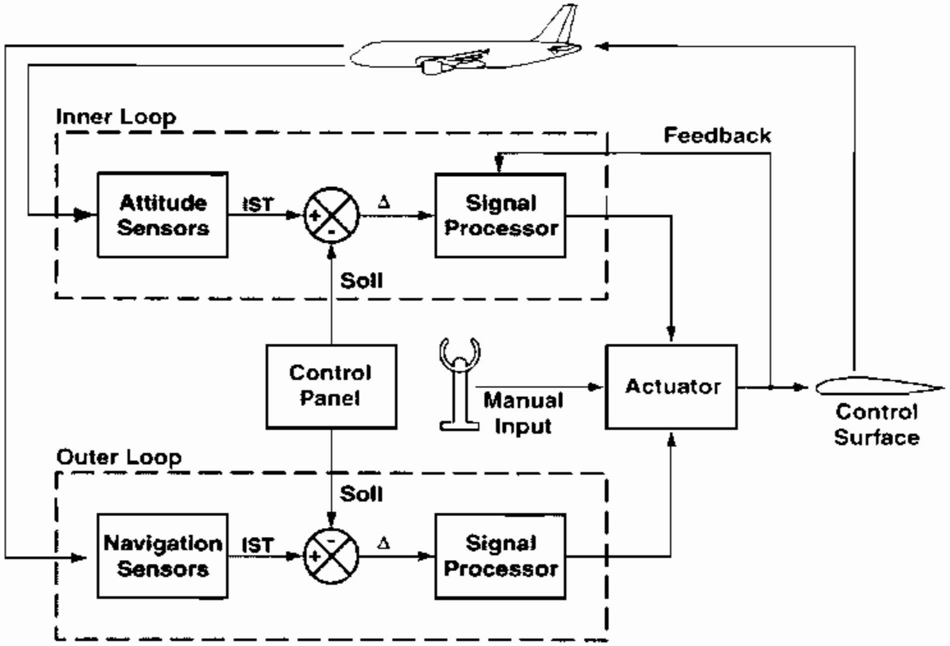
Stabilizes the aircraft attitude around the pitch or roll axis.

Outer loop

Controls the aircraft in lateral and vertical direction.

(i. e. airspeed, altitude, track, intersception of radio beam etc.)

Figure 12: Inner- and Outer Loop



Synchronisation

Autopilot not engaged

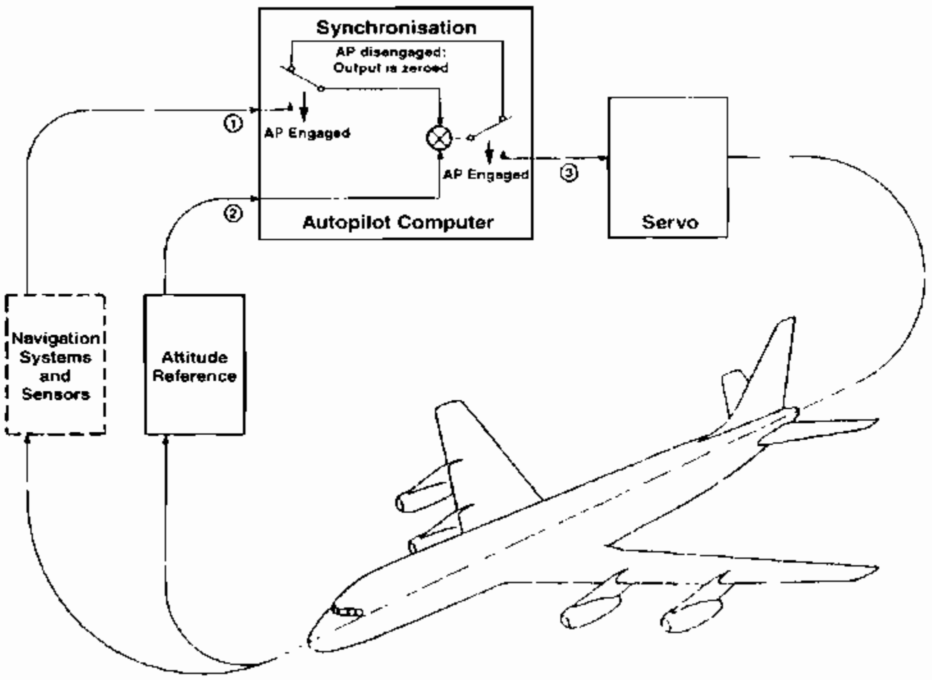
During the time, when the human pilot steers manually the aircraft, the attitude reference provides the actual attitude information (2) to the autopilot computer. The output of the internal summing point is feeded back instead of input (1) to wash out any builded up signal to the servo.

- This mode is called synchronisation. The synchronisation is necessary to prevent any jerks of the flight controls at the moment of autopilot engagement.
- A disengaged autopilot synchronizes with the actual aircraft attitude, therefore the autopilot must be always electrically powered and functional operative.

Autopilot engaged

The navigation system and sensors provides a steering command (1) to the autopilot computer. The summing point feeds the steering order (3) to the servo. The aircraft reaction is sensed by the attitude reference and acts as feedback (2) to the summing point.

Figure 13: Loop, Autopilot disengaged and engaged



Terms and Definitions

The following explanations covering the autoflight system are held in a general level covering mainly commercial airplanes. Detailed instructions are covered in aircraft type courses.

The therm „Automatic Flight Control System" (AFCS) is to understand as a complex system, with the purpose to increase the comfort for the passengers, to relief the pilots routine workload and to increase the stability of the airplane.

Depending of the aircraft model, different devices or integrated into one computer unit will perform following functions:

Take-off
Today there is no aircraft certificated for an automatic take-off certified. Some functions like yaw damper, pitch trim, auto trust etc. must or may be activated.

Cruise
The AFCS controls the aircraft around and along all three axes.

Landing
The AFCS lands the aircraft automatically, including align, flare, nose lowering and roll out.

Roll out
The AFCS steers and maintains the airplane along the runway centerline.

Yaw damper YD
The YD is damping dutch rolling, assisting the lateral steering by turn coordination and eliminates gusty wind effects close the ground. The electronic controlled active rudder compensates every small distortion around the aircrafts yaw axis.

Control wheel steering CWS
With no autopilot engaged, ailerons and elevators are deflected via electro-hydraulic servos manually controlled by force sensors installed at the control wheel and column.

Automatic pitch trim APT
If the elevator is deflected over a longer time, the AFCS trims the horizontal stabilizer to eliminate the elevator deflection load.

Longitudinal stability augmentation system LSAS
Large aircrafts with reduced size of horizontal stabilizers needing an electronic controlled active elevator compensating every small distortion around the aircrafts pitch axis.

Center of gravity control
Controls the center of gravity (CG) within the allowable limits by transferring fuel from-to regular fuel tanks and tanks located in tail or inside the horizontal stabilizer

Mach pitch trim
With increasing aircraft speed, the outer wing produces more lift. This results in a nose-down effect. The mach pitch trim counteracts this effect.

Flight director FD
The AFCS calculates „How to fly" that means the aileron, elevator and rudder command. This commands are shown at a flight director horizon instrument or EFIS display. Pilots has to follow the steering orders to reach and maintain the correct flight path. The FD can be used to monitor AP reactions.

Mode annunciation
Armed (preselected but momentary not active) and active AFCS operation modes are displayed at the PFD or a separate flight mode annunciator.

Flight envelope protection
According the aircraft configuration (landing gear, flap, slat, weight and angle of attack) the AFCS calculates and displays the minimum and maximum operating airspeeds.

Engine thrust Limit (N1/EPR)
Depending of the environment condition (temperature and air pressure) and the selected mode of operation, the AFCS calculates the maximum thrust limit. The limits are displayed and applied to the engine thrust control system.

Auto Throttle AT
The AFCS thrust control circuit moves the power levers with a servo motor to get the desired engine thrust or a signal is directly applied to the electronic engine control (EEC) without moving the thrust levers. The AT operates in speed or thrust mode.

Stall warning
The AFCS triggers the warning if the aerodynamic lift get lost (increasing angle of attack)
The engine thrust is increased and a safe attitude (aircraft nose down) will be established)

Failure monitoring and logging
The AFCS stores failure conditions for analysis and troubleshooting. Tests can be initiated for maintenance purposes.

Definitions of System Layouts

Fail safe
The crew is part of the monitoring.

Redundant
To have extra equipment:

- flight control computers
- calculations
- sensors
- servos

Redundant modes
In these modes the extra equipment is really in use:

- Take Off
- Land
- Go Around

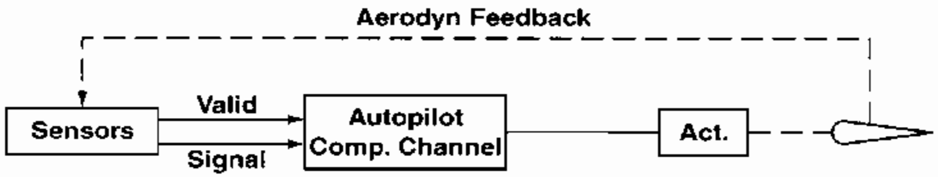
All other modes are non redundant.

Fail Safe System

The crew is part of the monitoring.

When only one sensor of one kind is available (one RA, one ILS)

Figure 14: Single Channel System



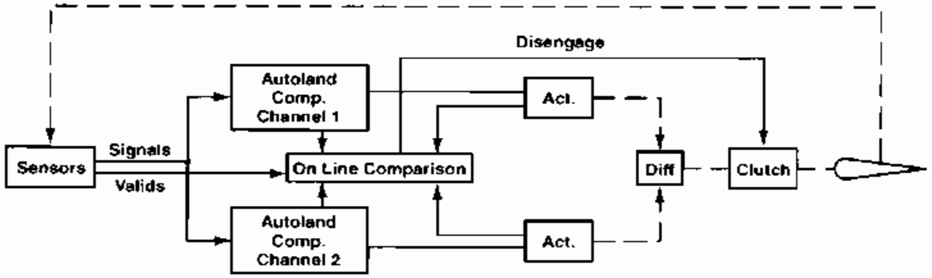
Fail Passive System

The system monitor will disconnect a system **before** a dangerous situation occurs.

A system becomes fail passive by using:

- 2 different computers for monitoring
- multiple channels
- multiple feedback

Figure 15: Dual Channel System



Fail Operational System

After a single failure the system continues its operation but degrades to fail passive.

When you give more redundancy by adding a third or a fourth channel, the autoflight system becomes a fail operational status. This is used in critical modes like Take-off, Land and Go-around.

Triple configuration

Example: Boeing 747, Fokker-100

Quadruple configuration

Example: MD-11, Airbus A320, A330, A340

Figure 16: Failsafe Tripple Channel System

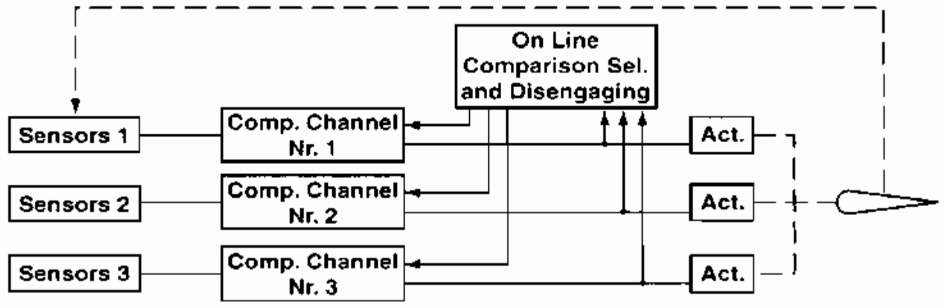
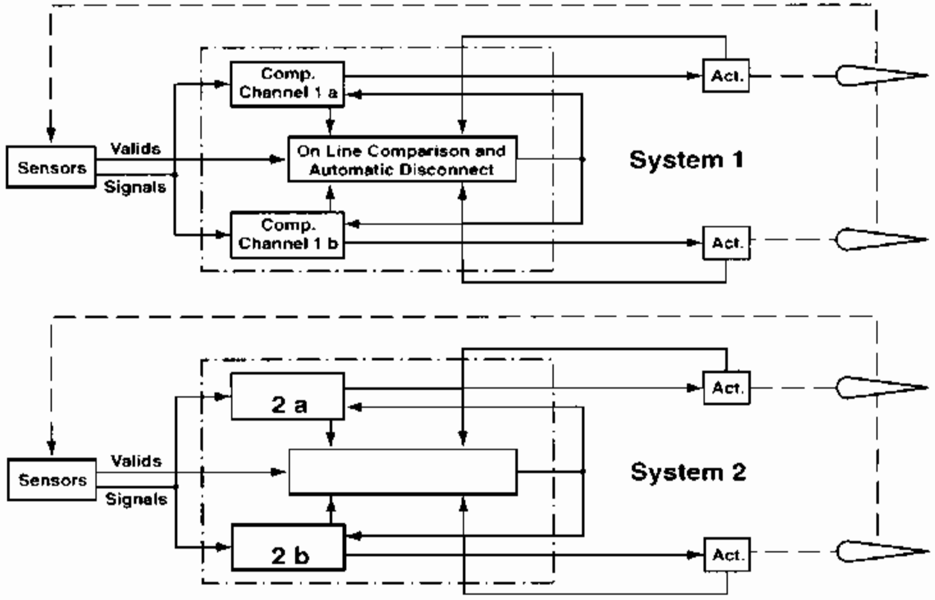


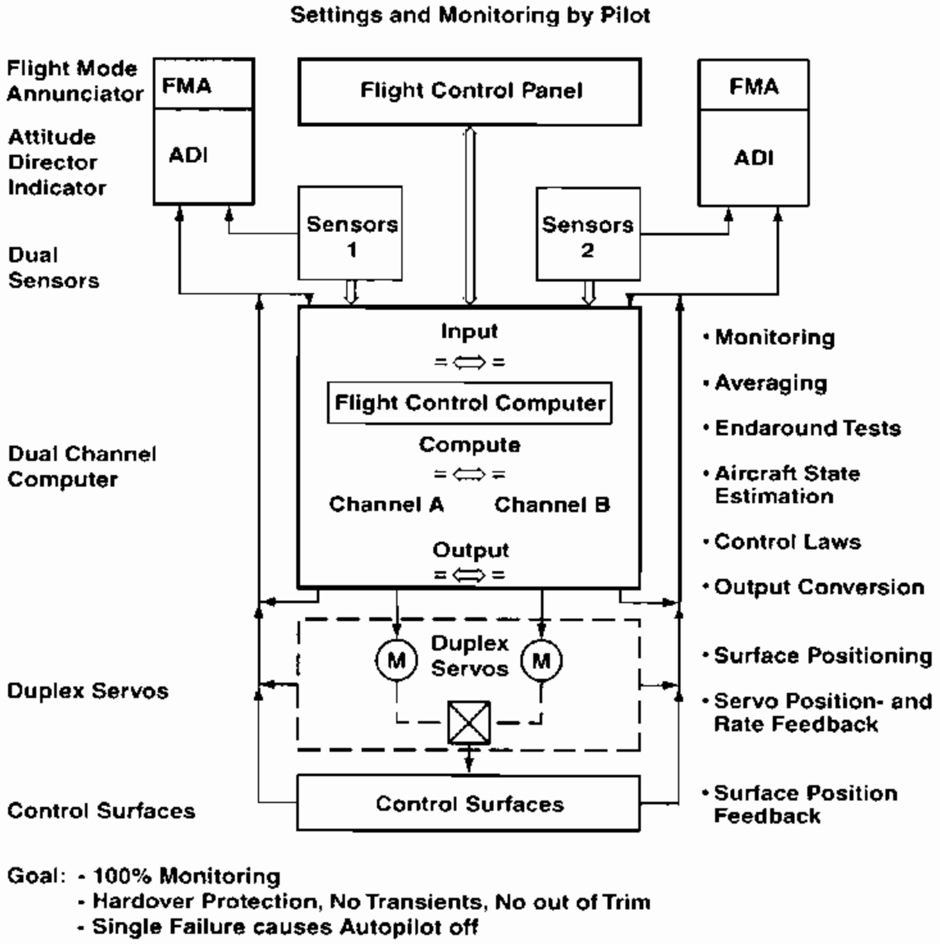
Figure 17: Failsafe Quadruple Channel System



Dual Channel Fail Passive System

One dual channel flight control computer with duplex servo actuators are active. If a failure occurs system disengages and if available, the second autopilot must be manually selected.

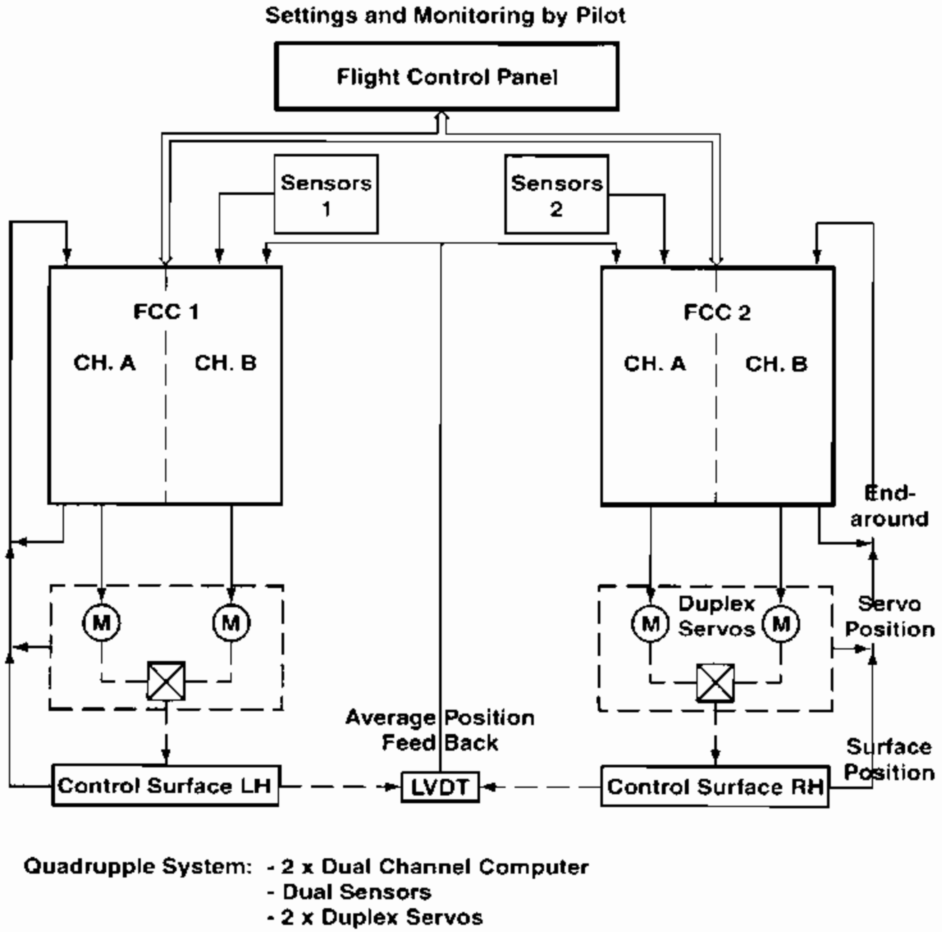
Figure 18: Dual Channel



Quadruple Channel Fail Operational System

Two dual flight control computers with two duplex servo actuators are active. If a failure occurs system remains engaged and continues the flight with the healthy system.

Figure 19: Quadruple Channel



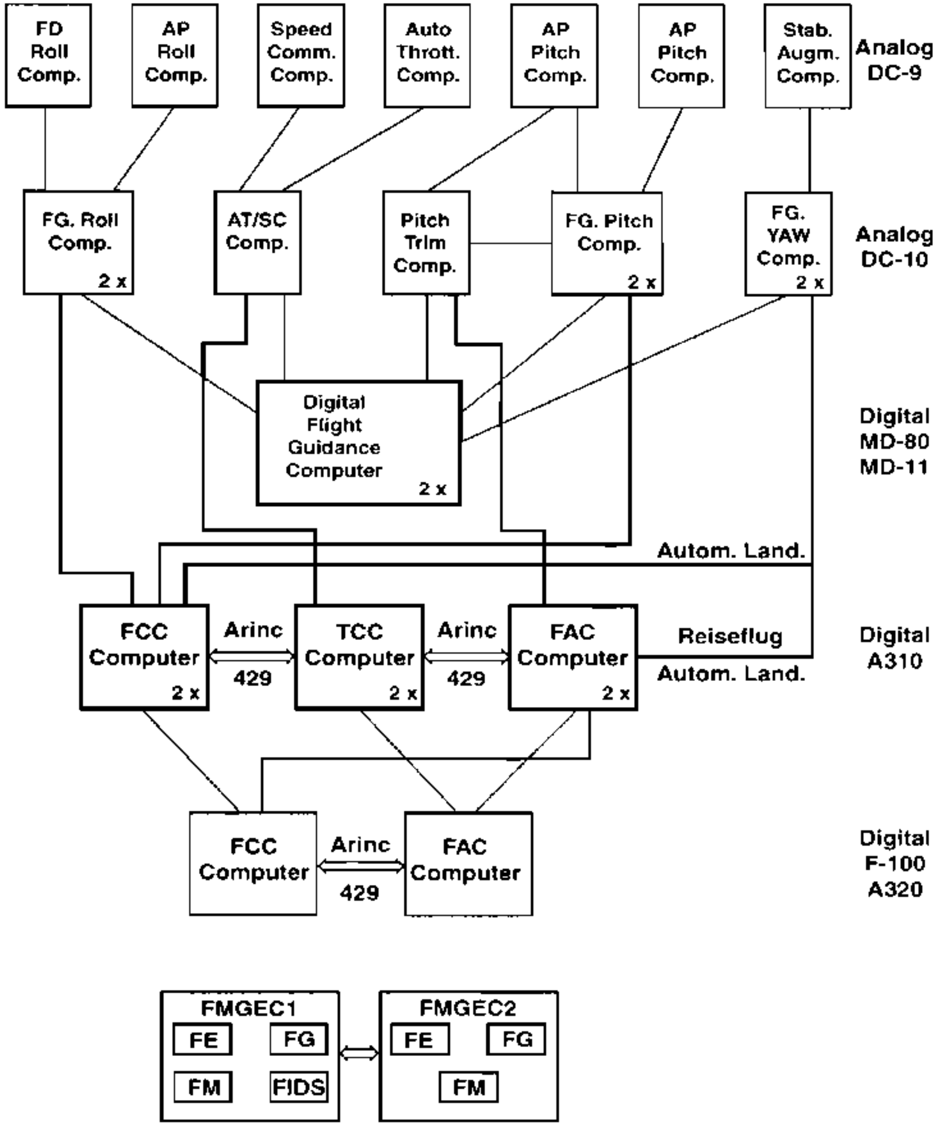
System Layout

Development of autopilot and flight director system in different aircrafts models 1960's-2000

Different stand alone system are today integrated today in modern systems.

AP	Autopilot
FD	Flight Director
AT/SC	Auto throttle/Speed Command Computer
FCC	Flight Control Computer
TCC	Thrust Control Computer
FAC	Flight Augmentation Computer
FMGC	Flight Management Guidance Computer
FMGEC	Flight Management Guidance Envelope Computer FE - Flight Envelope FG - Flight Guidance FM- Flight Management FIDS - Fault Isolation Detection System

Figure 20: Progress of System Layout

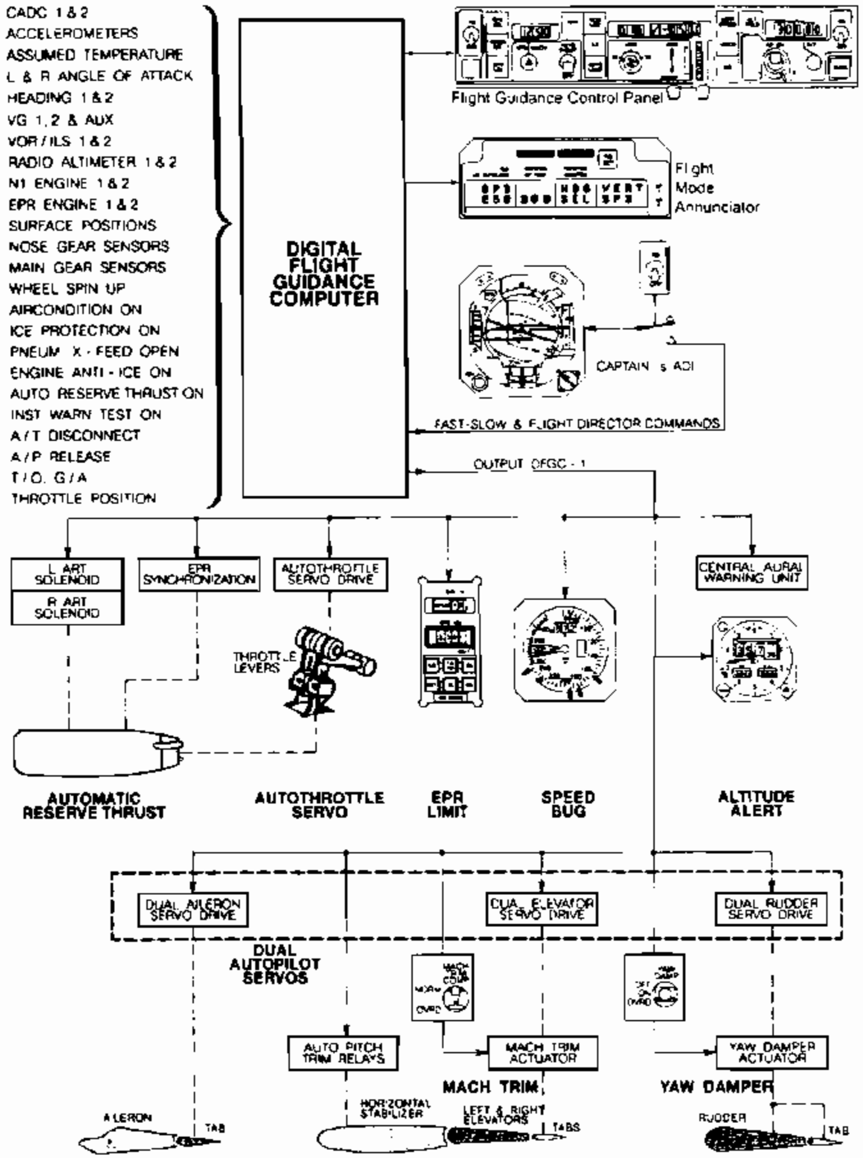


Example MD80

The Digital Flight Guidance Computer is a dual channel unit. It receives all necessary inputs to calculate outputs which are send to all users.

- Flight Guidance Control Panel: Engagement and mode selection of Autopilot, Flight-Director and Auto throttle.
- Flight Mode Annunciator: Displays the preselected and active operational mode.
- Attitude Direction Indicator (ADI) shows deviation of the actual speed against optimum or preselected speed and Flight Director commands.
- Automatic Reserve Trust increases engine power if one engine fails during take off.
- EPR Synchronisation controls both engines to keep identical trust.
- Auto throttle Servo moves both power levers to reach and maintain the desired trust or speed.
- Engine Pressure (EPR) Limit is the limiting parameter for the engine. The limit depends from outside temperature, bleed air consumption, air pressure and flight phase.
- Speed Bug shows the selected speed at the airspeed indicator. It also represents the auto throttle desired speed.
- Altitude Alert Light and sound reminding the crew to maintain the correct flight level.
- Aileron Servo steers the aircraft around roll (x) axis with ailerons.
- Elevator Servo steers the aircraft around pitch (y) axis with elevators.
- Auto Pitch Trim controls stabilizer to eliminate a durable elevator deflection.
- Mach Trim counteracts the nose down tendency of the aircraft when flying a high Mach number.
- Rudder Servo steers around yaw (z) axis at low airspeed with great rudder deflections. For roll out guidance, the nose wheel steering system is driven by rudder servo.
- Yaw Damper counteracts dutch rolling and performs the turn coordination function.

Figure 21: Flight Guidance System (MD-80)



Example A320

The interactive Flight Management and Guidance System (FMGS) provides predictions of flight time, mileage, speed, economy profiles and altitude. It reduces cockpit workload, improves efficiency and eliminates many routine operations normally performed by the pilots.

During cockpit preparation, the pilot inserts a planned route from origin to destination via the Multifunction Control and Display Units (MCDUs). This route includes the departure, enroute waypoints, arrival, approach, missed approach and alternate routes as selected from the NAV data base. The system generates optimum vertical and lateral flight profiles and predicted progress along the entire flight path. Either FMGC performs all operations if one FMGC fails.

The pilot may modify any flight parameter on a short term basis (SPD, V/S, HDG...and the FMGS will guide the aircraft to the manually selected target.

The FM part provides following functions:

- Navigation.
- Performance prediction and optimization.
- Flight planning management
- Managed guidance computation.
- Information display.

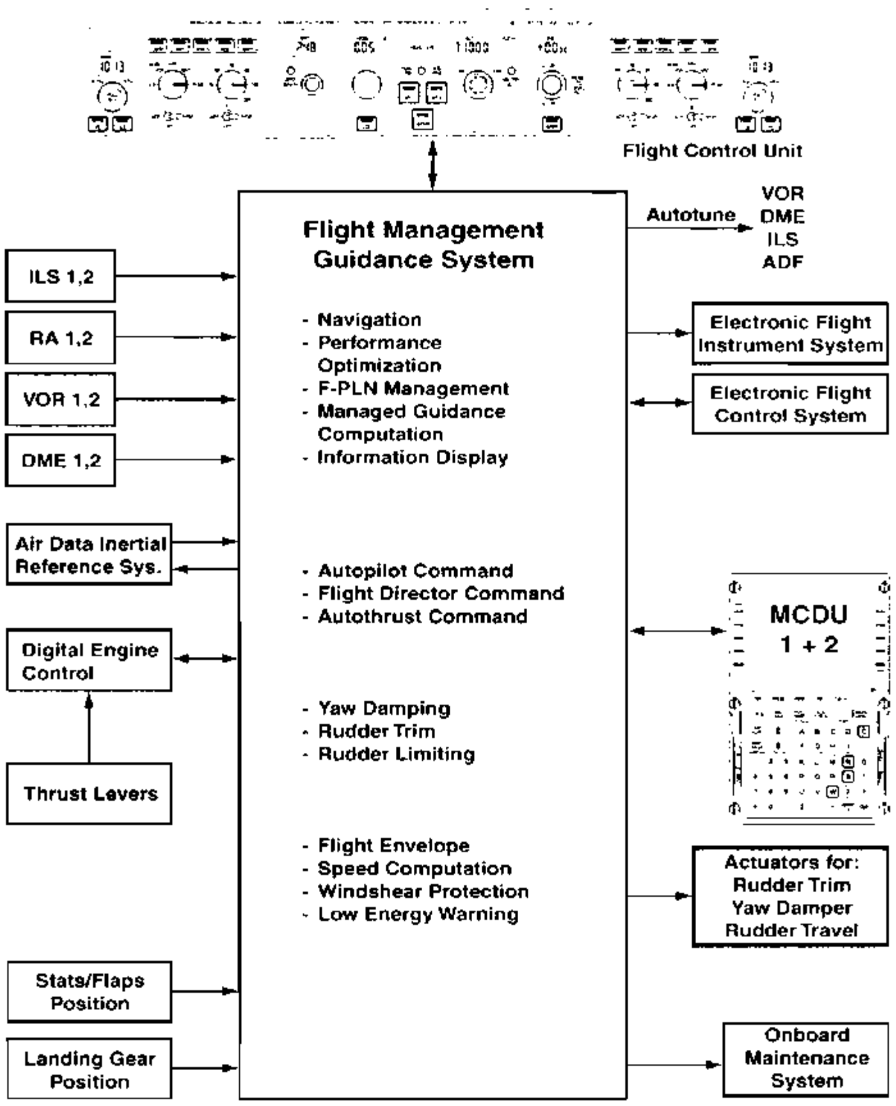
The FG part provides following functions:

- Autopilot command (AP).
- Flight director command (FD).
- Auto thrust command (A/THR).

The Flight Augmentation part provides following functions:

- Yaw functions.
- Flight envelope functions.
- Windshear protection.
- Low energy warning.

Figure 22: Flight Guidance System (A320)



Example MD-11 Automatic Flight System

The aircraft is equipped with an automatic flight system (AFS). The AFS supplies automatic flight control and flight crew guidance during the full flight envelope (from takeoff above 100 feet through ground roll out after landing).

The AFS Provides the following functions:

- Automatic ILS approach.
- Longitudinal stability augmentation system (LSAS).
- Speed envelope limiting (Auto throttle and LSAS).
- Dual autopilot (AP), flight director (FD).
- Auto throttle system (ATS) / engine trim control.
- Automatic pitch trim in AP and LSAS.
- Full-time parallel actuation roll control wheel steering (CWS) with roll attitude hold when the AP is not engaged.
- Windshear warning with AP FD, and ATS compensation.
- Yaw damping / turn coordination.
- Elevator load feel (ELF) control and flap limiting (FL).
- Automatic ground spoiler (AGS).
- Stall warning with stick shaker and auto slat extend.
- Altitude alerting with visual and aural warnings.

Figure 23: Flight Guidance System (MD-11)

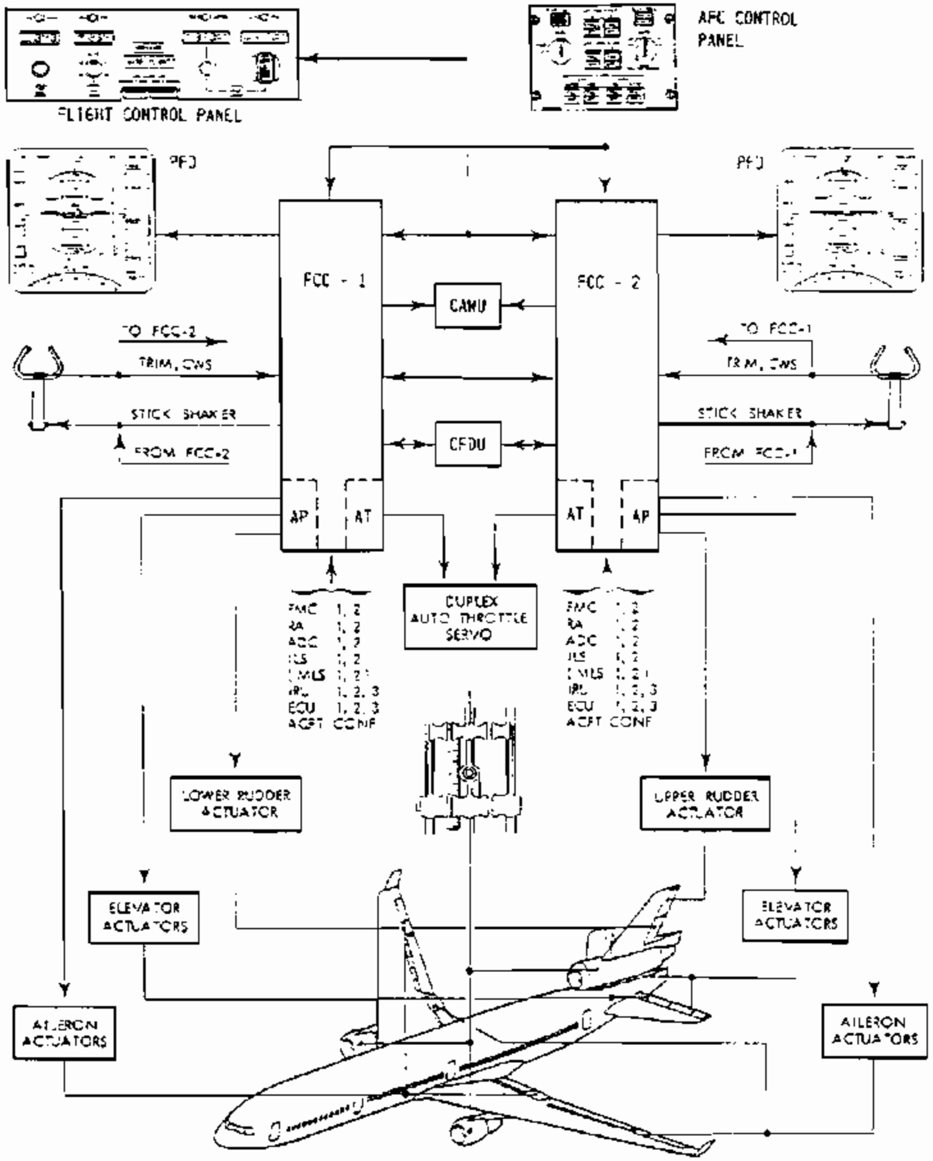
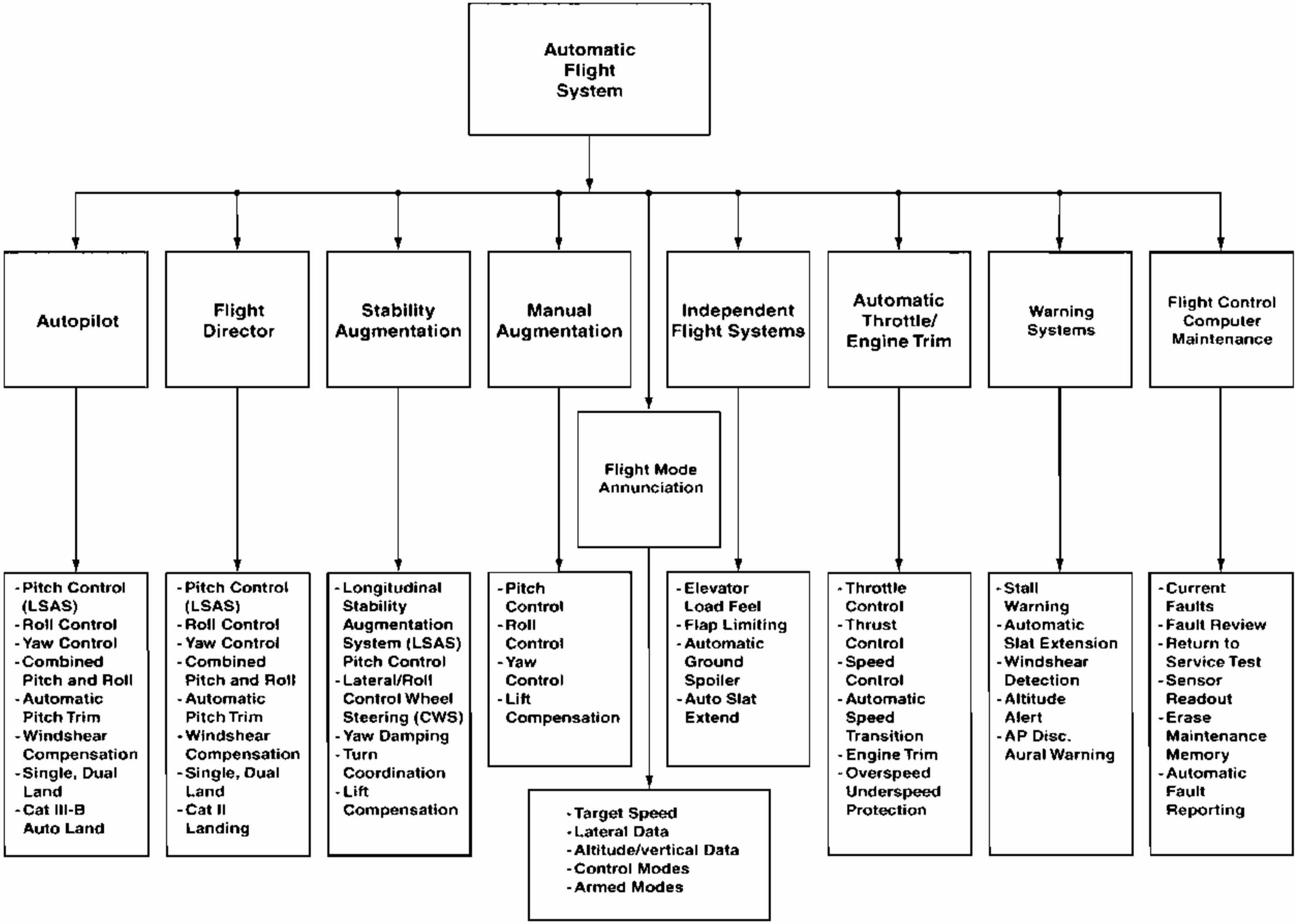


Figure 24: Function Hierarchy (MD-11)



Autopilot

General

The autopilot represents a closed control loop. The autopilot controls the aircraft via the associated servos in the right order to fly.

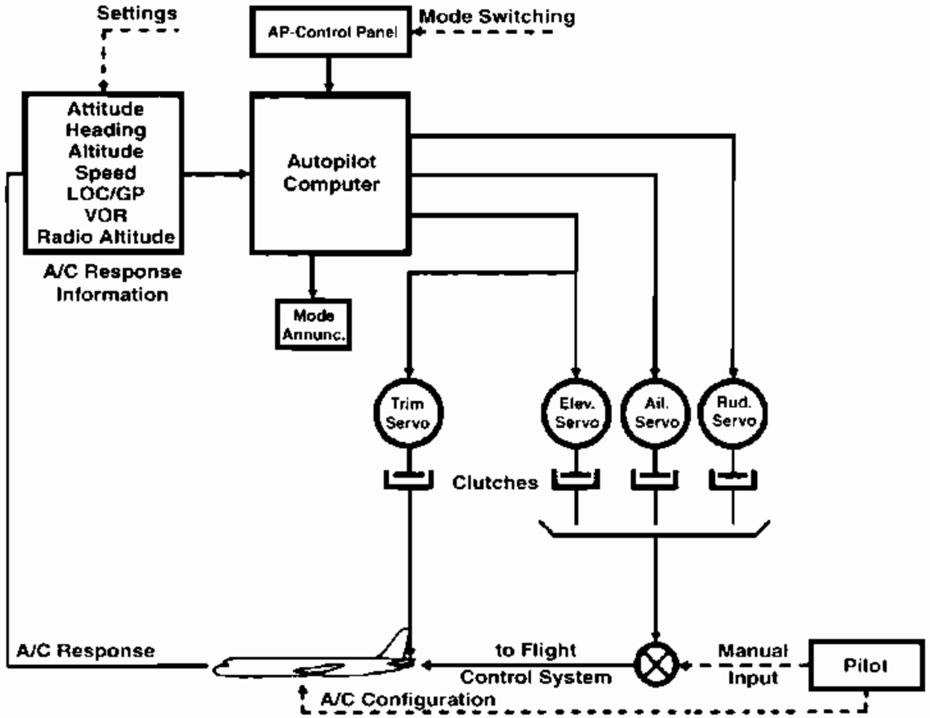
If the autopilot is not engaged, clutches are open so the pilot has to control the plane. Then the autopilot is synchronizing during this time the output of the servos to zero, so the autopilot can be engaged at any time with no jerking aircraft movements.

The aircraft response is sensed by different sensors and applied as response information back to the autopilot.

The pilot task are:

- Mode selection and switching
- Setting of different navigation parameter like speeds, altitude, radio frequencies.
- Selection of aircraft configurations such as flaps, slats, landing gear, trim.

Figure 25: Autopilot operational loop

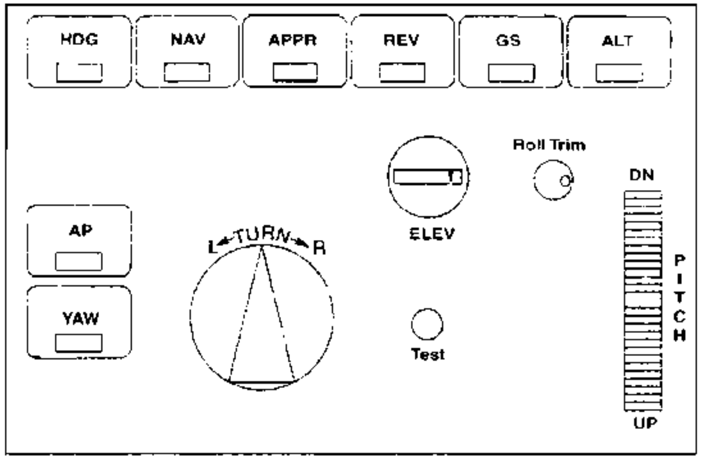


Control Panel

are used to engage the autopilot, presetting the parameters and mode selection.

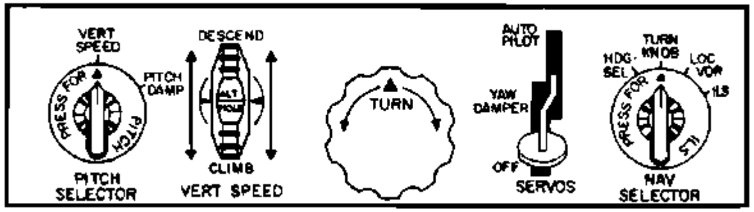
General aviation aircraft

Figure 26: Various Autopilot Control Panels 1/2



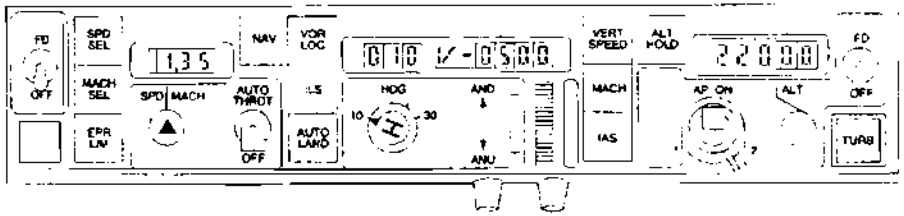
DC-9

Analog



MD-80

Digital flight guidance system



Boeing 747

Triple autopilot system

MD-11

Dual autopilot system

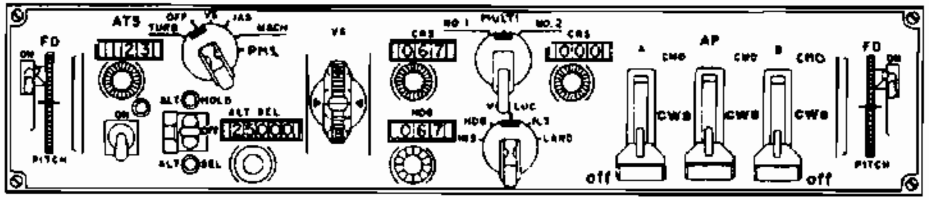
Each autopilot has two channels

Airbus A320, 330, 340

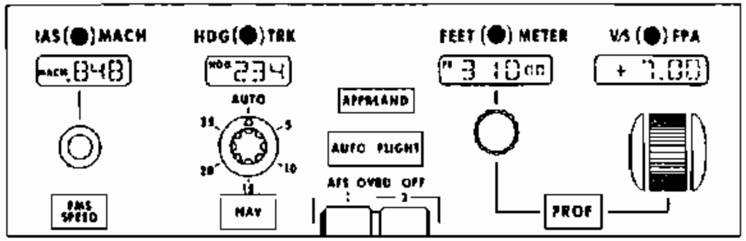
Dual autopilot system

Each autopilot has two channels

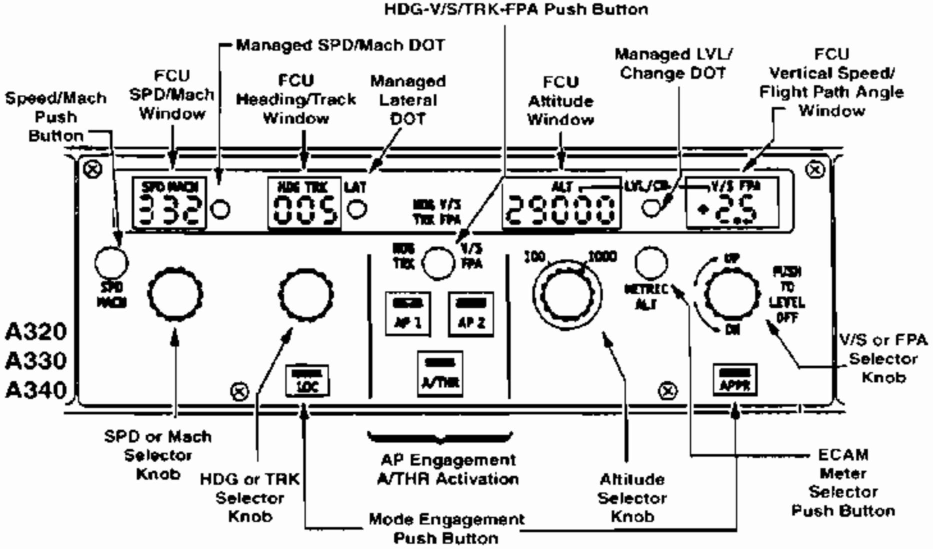
Figure 27: Various Autopilot Control Panels 2/2



B747-300



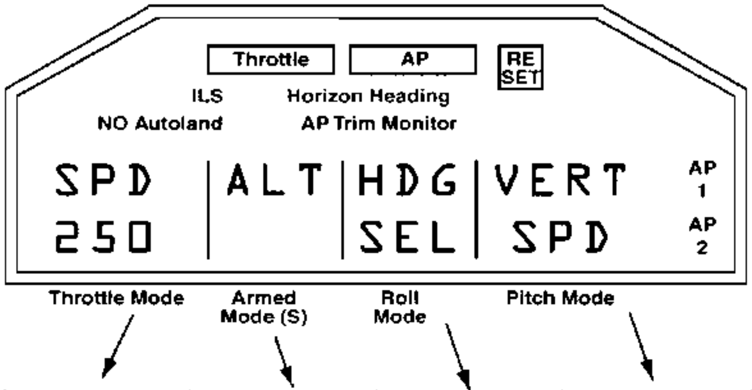
MD-11



Flight Mode Annunciation

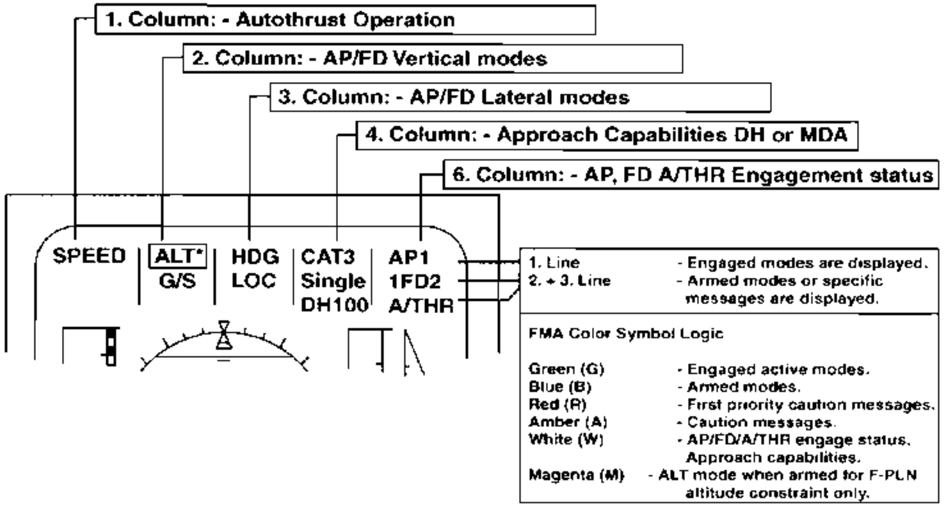
The autothrottle/autothrust, autopilot and flight director operational modes are displayed at the specified flight mode annunciator or integrated in the primary flight display.

Figure 28: Flight Mode Anunciator



Throttle Mode		Armed Mode (S)		Roll Mode		Pitch Mode	
RET	EPR T/O	VOR	LND	VOR CAP	TAK OFF	VERT SPD	TAK OFF
CLMP	EPR G/A	VOR ALT	LND ALT	VOR TRK	GO RND	ALT HLD	GO RND
MACH ***	EPR MCT	ALT		VOR CRS	HDG HLD	ALT CAP	FLAR
SPD ***	EPR CL	NAV	AUT G/A		HDG SEL	MACH	NO FLR
ALFA SPD	EPR CR	LOC	F/D G/A		AUT LND	IAS	AUT LND
FLAP LIM	EPR **	LOC ALT	MAN G/A	LOC CAP	ALN	GS CAP	
SLAT LIM	LOW LIM	ILS		LOC TRK	ROL OUT	GS TRK	OUT
SPD ATL	VMO LIM	ILS ALT		WNG LVL	NAV CAP	TURB	
MACH ATL	MMO LIM				NAV TRK	SPD LOW	

Figure 29: Primary Flight Display



1. Line - Engaged modes are displayed.
2. + 3. Line - Armed modes or specific messages are displayed.

FMA Color Symbol Logic

Green (G) - Engaged active modes.
Blue (B) - Armed modes.
Red (R) - First priority caution messages.
Amber (A) - Caution messages.
White (W) - AP/FD/A/THR engage status, Approach capabilities.
Magenta (M) - ALT mode when armed for F-PLN altitude constraint only.

Actuators

Servos vary in complexity with the size of the aircraft in which they are installed, and with the aerodynamic forces they must control.

Pneumatic Servo

The simplest servo is pneumatic and uses a diaphragm moved by either suction or a positive air pressure from the gyro pickoff. This diaphragm is attached to the control cable by a clamp and it pulls on the cable at the command of the autopilot.

Electric Servo Actuators

Electric servos may use either a reversible DC or AC motor driving a capstan through a reduction gear. If the autopilot is engaged, the servo motor gear train is mechanically clutched to the control cables which connect the cockpit control to the control surface actuator. The clutch is operated by an electric solenoid. The servo motor drives a tachometer generator to provide inverse feedback to the amplifier for speed limiting and smoothing.

A sine winding follow-up synchro is driven by the servo motor to a null prior to engaging the autopilot. The null results because there is no command signal to the amplifier while the autopilot is disengaged.

If the autopilot computer determines that the control surface should be moved up, the computed command calls for control surface movement up. The signal from the follow-up synchro is of a phase opposite to that of the computed command. Therefore, control surface movement will stop when the follow-up signal equals the computed command.

Figure 30: Vacuum driven servo

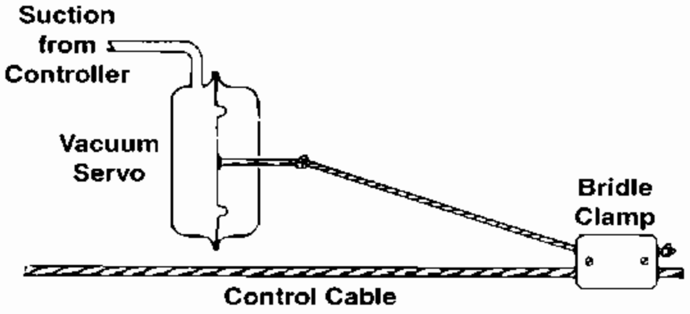
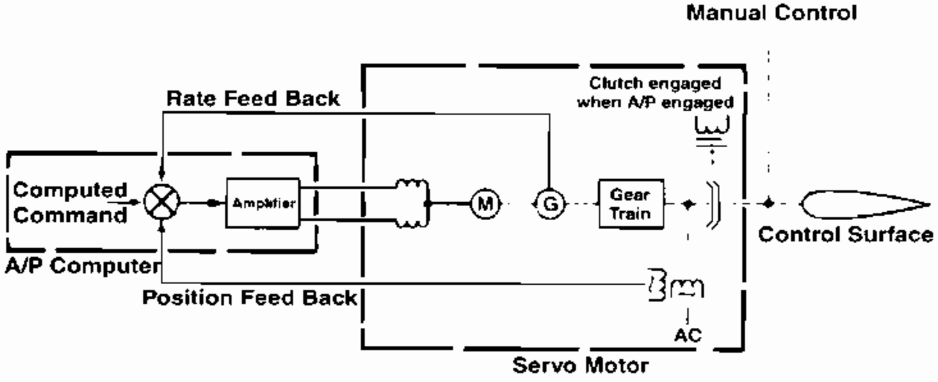


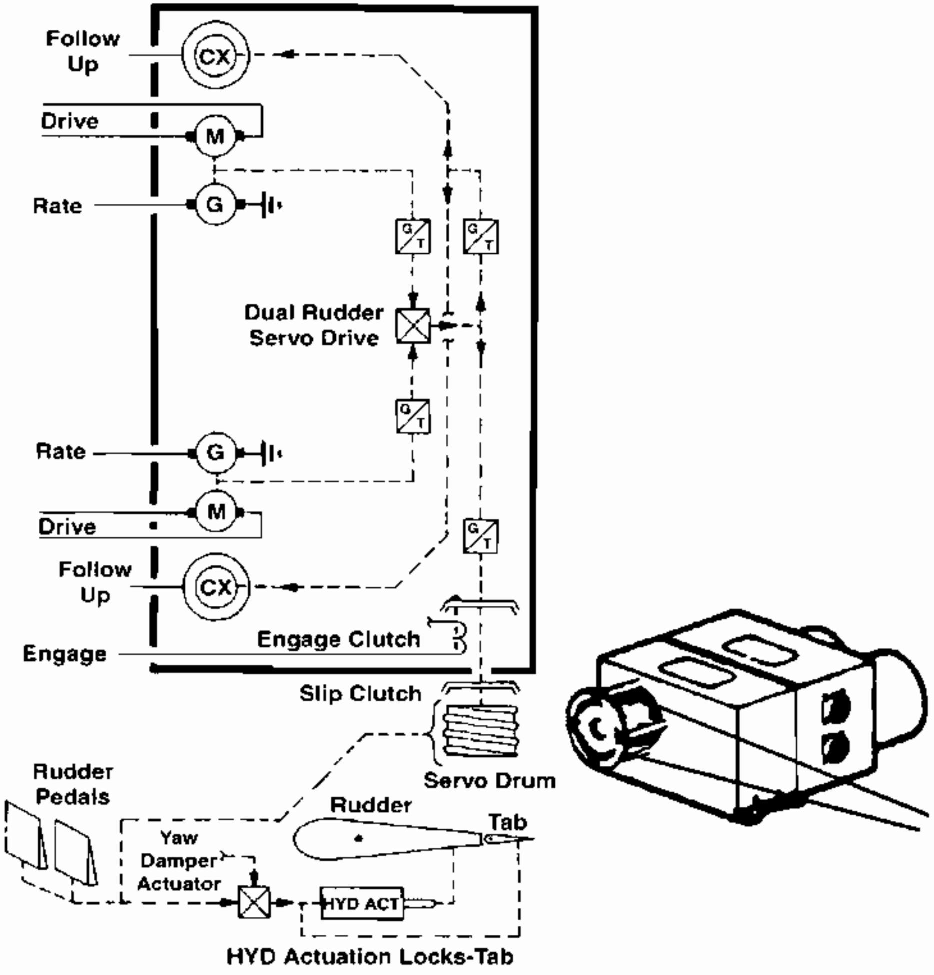
Figure 31: Electric motor driven servo



Rudder Servo

This actuator rotates the cable drum. For system redundancy motors are used. The actuator operates in parallel mode. The rudder pedals are moving with rudder movements. The deflection of the rudder is +/- 25°.

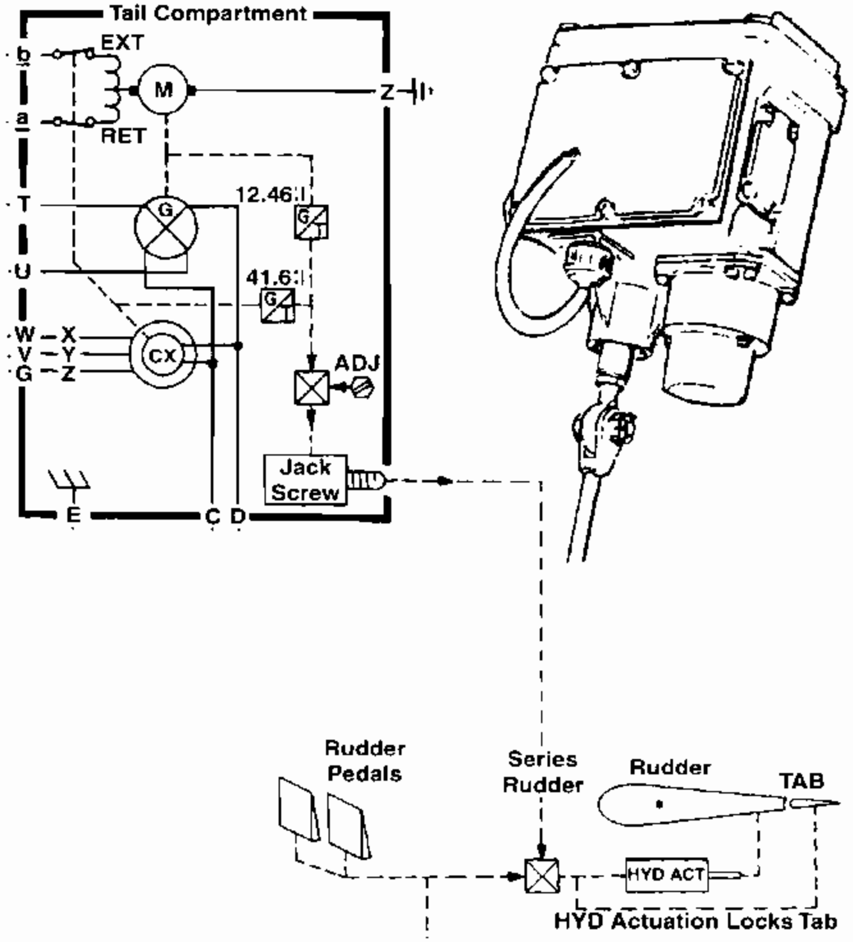
Figure 32: Servo rotary type



Yaw Damper Servo

This actuator moves the output rod in linear direction. The input to the rudder system is in serie mode. No movements at the rudder pedals are existent. The rudder deflection is +/- 3-6°.

Figure 33: Servo linear type



Hydraulic Servo

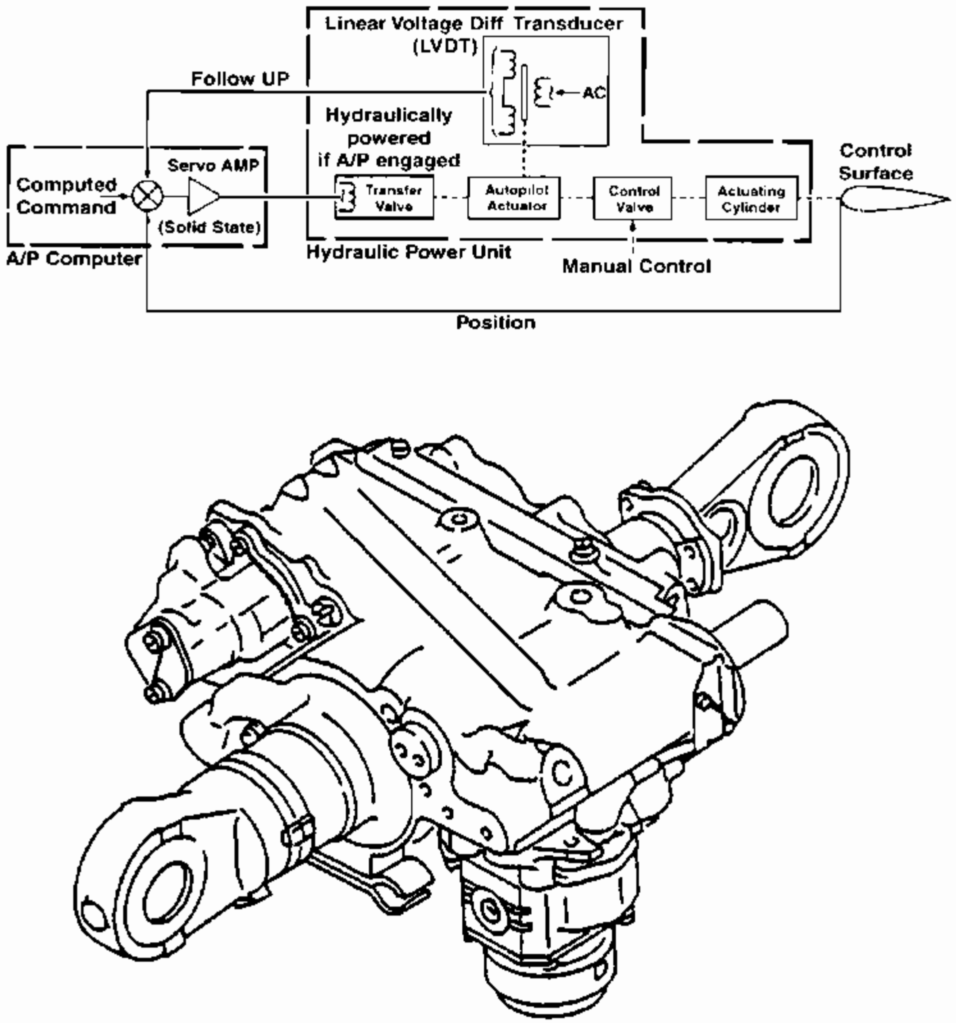
The next figure illustrates a hydraulic power unit which can be operated directly by the autopilot. The servo amplifier has a low power output on the order of 100 millivolts or 8 mA.

The transfer valve is an electrically controlled hydraulic valve which operates a piston assembly called the autopilot actuator, which in turn operates the main control valve for the actuating cylinder.

The amount of movement of the autopilot actuator is indicated by the output of the linear variable differential transformer, abbreviated LVDT. An LVDT is a cylindrical E-pickoff. This becomes the follow-up signal to the computed command.

The control surface position may also be used as a follow-up signal. Direct operation of the hydraulic power unit by the autopilot has two main advantages. One is the very low power computer output. The other is that control is effected directly at the hydraulic power unit, bypassing cable slack, stretch and drag. The control is therefore more sensitive and more accurate.

Figure 34: Hydraulic Servo



Manual input from the cockpit

The cockpit control cables move the quadrant at the top of the drawing. Assume that it rotates clockwise. As it turns, it moves the arm attached to it to the left. That moves the autopilot actuator to the left, compressing the left springs. This is of no consequence since the autopilot is not engaged. The long lower arm then pivots around the ball at its lower end.

As the top end of the long lower arm moves to the left, it moves the control valve to the left. This connects the left side of the main actuator piston to pressure. The right side of the main actuator piston is, at the same time, connected to return.

The main actuator piston then moves to the right, carrying the bottom end of the long arm to the right, and moving the control valve back toward its neutral, or shut-off position. The main actuator piston will move the control surface until the control valve has closed off its ports.

Further movement of the cockpit control in the same direction would again move the control valve to the left, causing the main actuator piston to move to the right until the control valve is once again shut off. The amount of control surface movement is a function of the amount of movement of the cockpit control. The direction of control surface movement is a function of the direction of cockpit control movement.

Autopilot input

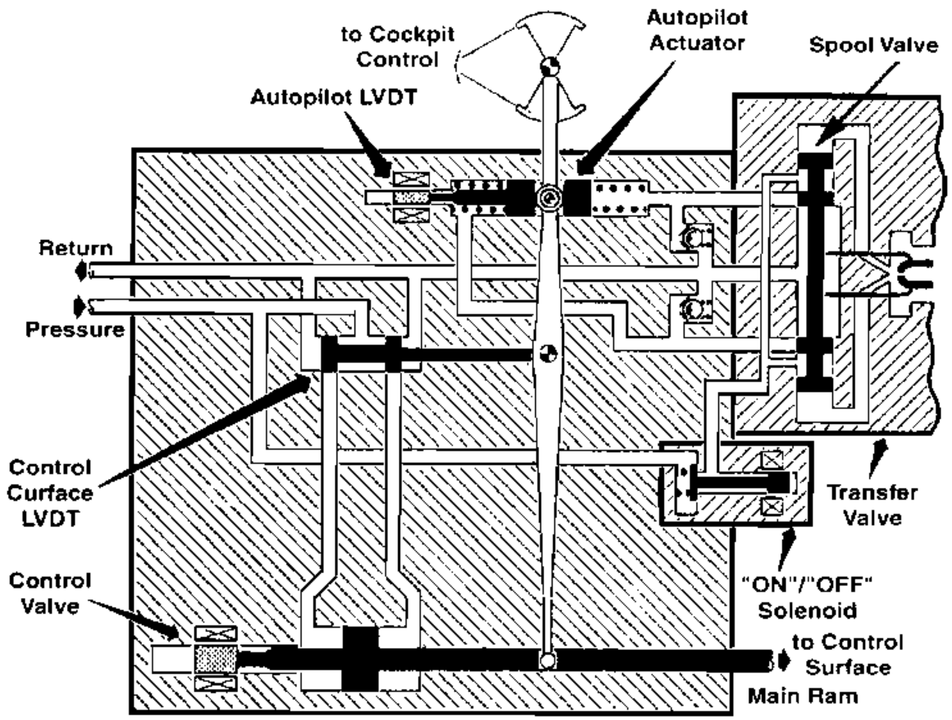
The autopilot is capable of performing the same operation. If the transfer valve has a signal, the black vertical spool on the right moves in one direction or the other. Hydraulic system pressure is then ported to the right side of the autopilot actuator, and return is ported to the left. As long as the transfer valve ports remain open, the autopilot actuator continues to move to the left.

As it moves to the left, however, it develops a follow-up signal in the autopilot LVDT This will cause the transfer valve signal to become null when the computed command has been equaled by the follow-up signal.

As the autopilot actuator moves to the left, rotating the quadrant to which the cables are attached, and moving the associated cockpit control. This could be either the control wheel rotating for aileron movement, or the control column moving for elevator movement.

The amount of movement developed in the autopilot actuator determines how far the control surface moves. When the control surface moves, an aerodynamic follow-up signal shows up in the autopilot as a changed attitude signal.

Figure 35: Hydraulic Actuator



Transfer Valve

If the "C" core is magnetized by a signal to the electric coil, it can move the permanent magnet armature up or down about its pivot point. Hydraulic fluid comes in at the lower right, passes through the flex tube and splits across the pointed divider just under the flex tube. This fluid flows all the time that the autopilot is engaged.

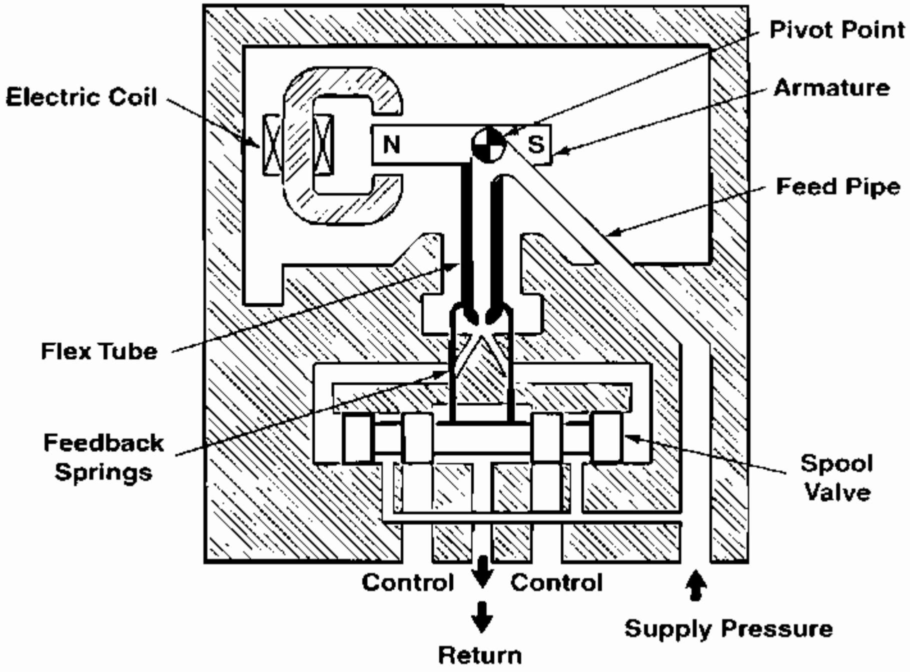
If there is no electric signal to the coil, the flex tube is spring-loaded to the neutral position. In this position, the combination spool valve, against whose ends the hydraulic flow is directed, sees equal pressures at both ends. It, therefore, takes up the neutral position. In this position, both of the control ports are closed off by the spool valve.

If the autopilot develops a command signal calling for control surface movement, the first action is the electrical signal in the coil windings polarizing the core, causing the permanent magnet to rotate slightly in one direction or the other.

If the signal develops a north pole at the top and a south pole at the bottom of the core ends, the permanent magnet will rotate slightly counter clockwise, moving the bottom of the flex tube to the right. That causes greater pressure at the right end of the spool valve than at the left end. The spool will therefore move toward the left. It moves to the left until the force from the feedback springs is sufficient to bring the flex tube back almost to the neutral position.

A stronger signal from the autopilot would cause a greater movement of the spool to the left in order to develop a greater force from the feedback spring to overcome the greater magnetic force on the permanent magnet. With the spool moved to the left, the right control port is connected to hydraulic pressure, and the left control port is connected to return, moving the autopilot actuator. If the electrical signal is of the opposite polarity, the spool will move right instead of left, reversing the hydraulic connections to the control ports.

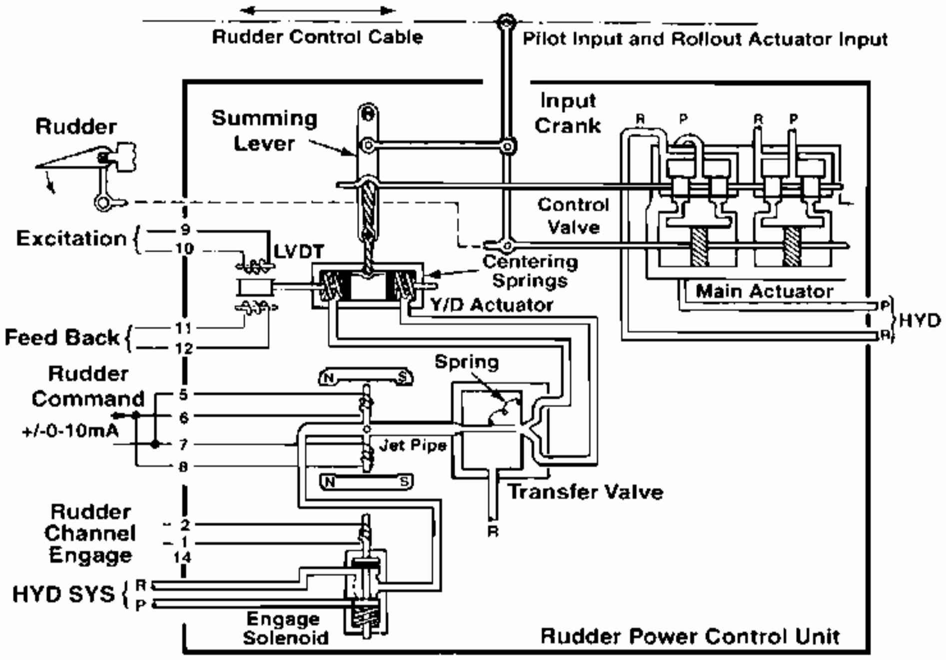
Figure 36: Electro Hydraulic Transfer Valve



Rudder Power Control Unit

Example 747

Figure 37: Rudder Actuator (Hydraulic)



Serie - Parallel Mode

The mechanical output of autopilot servos are applied in two different manners to the flight control system:

- Serie Mode
- Parallel Mode.

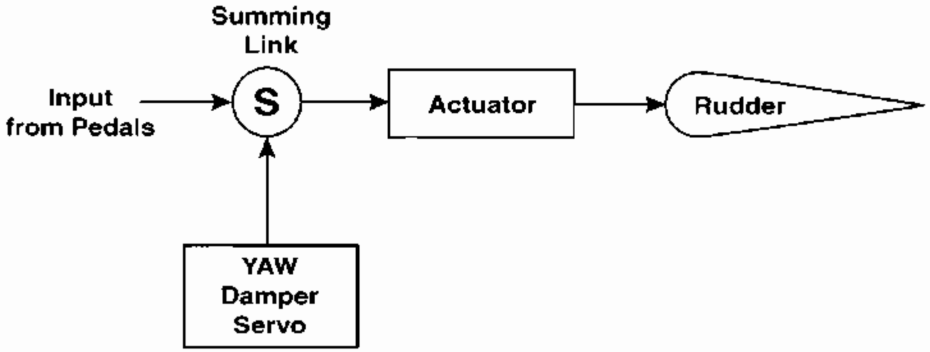
Following example is shown for the rudder function.

Serie Mode

The Yaw Damper servo movement is added (in serie) to the input from the pedals. There is no feedback to the pedals feelable. The rudder deflections are small. (up to +/- 6°)

This mode is used for yaw damper function during cruise.

Figure 38: Serie - Mode

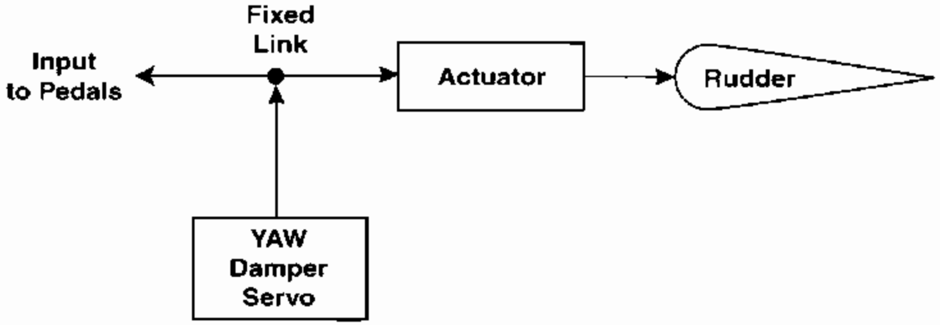


Parallel Mode

In critical modes like Take-off, Land, Go-around and Engine-failure, the servo movement is directly (parallel) applied to the pedal input. The pedals will move accordingly. The rudder deflection authority can be large. (up to 25°)

This mode is active during take-off, approach, landing and go-around.

Figure 39: Parallel Mode



Control Wheel Steering

Force sensors are installed in the mechanical steering links or directly inside the control wheel hub. If the pilot is manually steering, sensors takes the applied force from the control wheel to the autopilot computer. The output is electrically send to the servo actuator The movement of the control surface is mechanically feed back to the control column and wheel.

The control wheel steering provides lateral and vertical stability through electronic control of ailerons and elevators when the AP is not engaged

With no force on the control wheel the aircraft holds the current attitude. Forces on the control wheel command an aircraft roll and pitch rate proportional to the applied force so that when the force is removed from the control wheel the aircraft holds the new attitude. This simplifies the steering of the airplane and is also a protection against excessive steering commands by the pilots.

CWS is available when the flight control computer is operational but not engaged.

Figure 40: System Layout

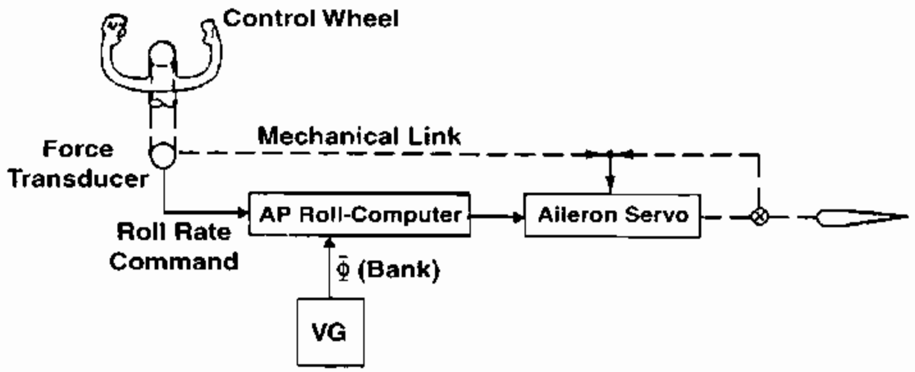


Figure 41: Force Tranducer (E - Pick-off Transformer Type)

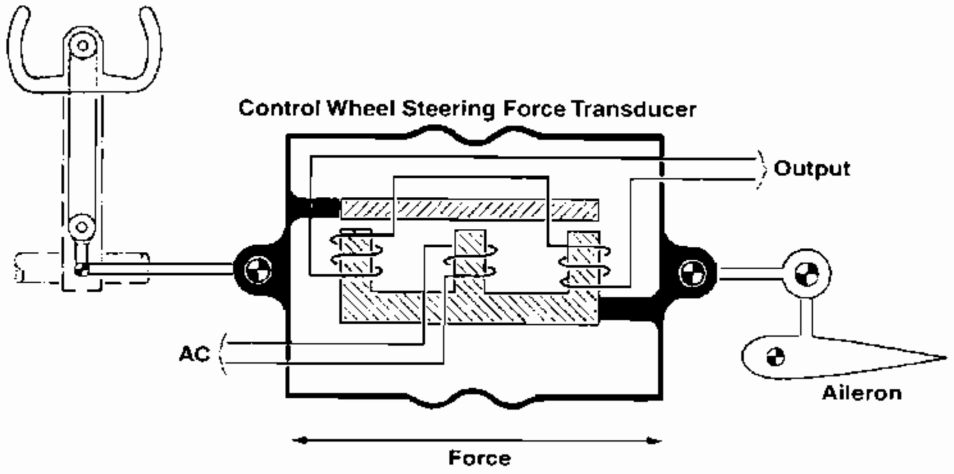
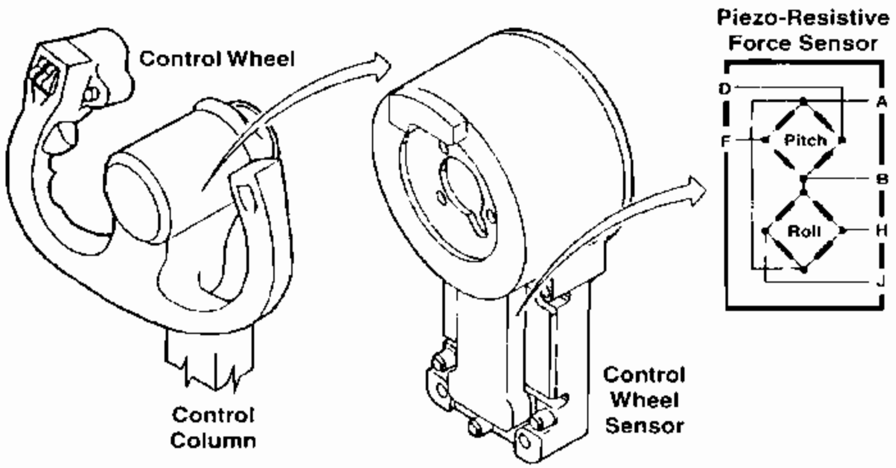


Figure 42: Force Transducer (Piezo-Resistive Type)



Fly By Wire

Sidesticks are used to fly the aircraft in pitch and roll. The pilot inputs are interpreted by the computers and move the flight controls as necessary to achieve the desired flight path. However, regardless of the pilot's input the computers will prevent excessive manoeuvres and exceeding of the safe flight envelope. The flight control surfaces are all electrically controlled and hydraulically actuated. One of the advantages of fly by wire is that the aircraft is simpler to fly than a conventional aircraft.

If the sidestick is centered the aircraft will maintain its attitude. Deflection of the sidestick represents a pitch or roll attitude change with a predetermined rate.

The autopilot will provide the commands directly in to the flight control computers of the fly by wire system instead of the side stick signal.

Figure 43: System Layout

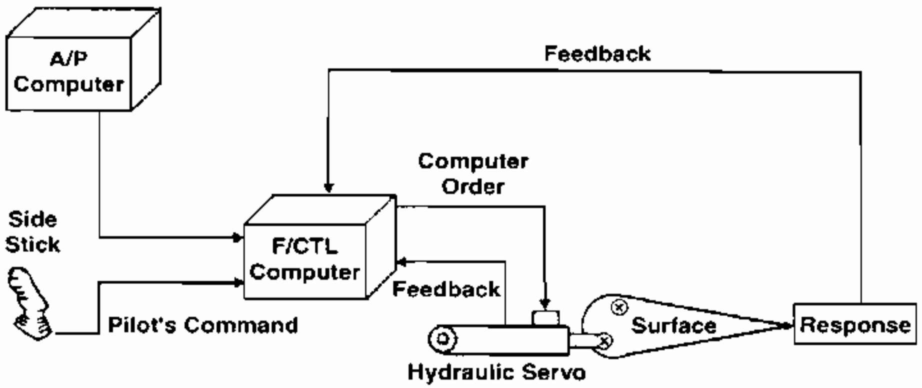
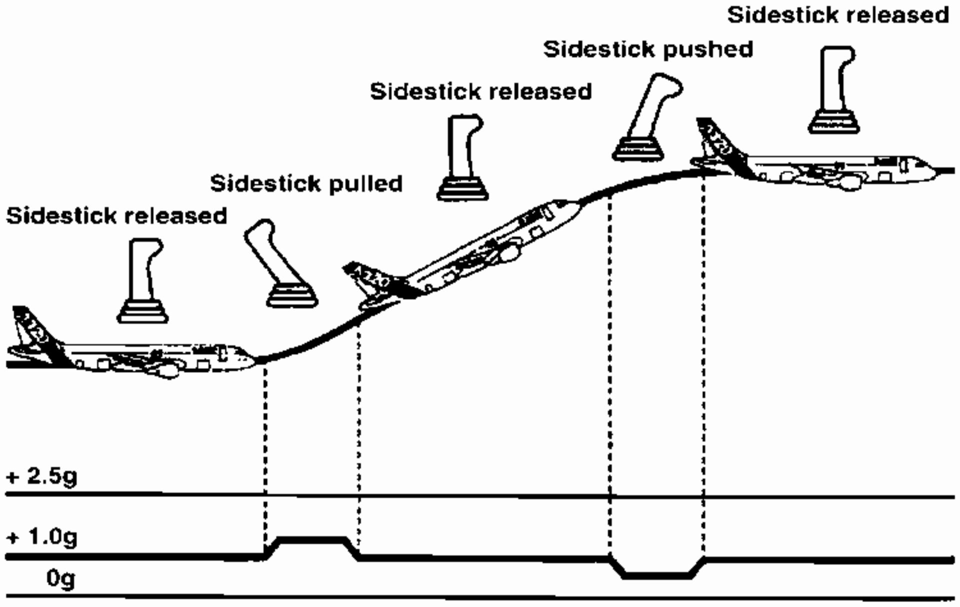


Figure 44: Aircraft Control Characteristic



Operational Modes

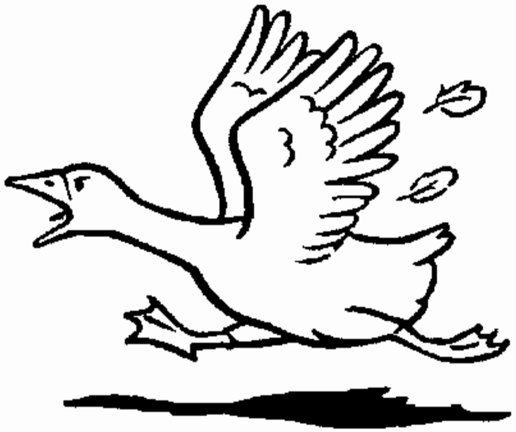
Take Off

This is the mode in which the system powers-up on the ground. In the take-off mode the auto flight system gives steering signals for the ground roll, rotation, lift-off and climb-out segments of the take-off.

Aircraft on the ground and up to 35 - 100 feet of radio altitude:
The AFS gives flight director commands only.

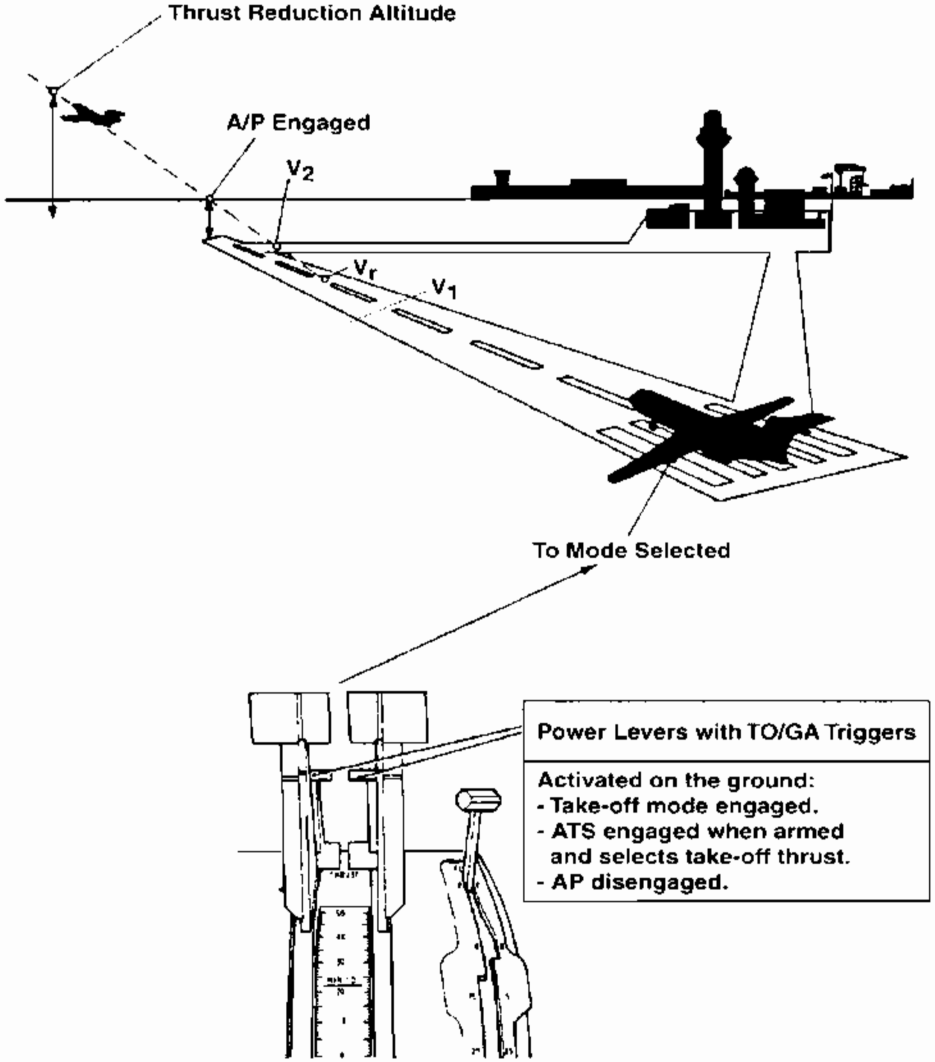
Above 35 - 100 feet:
it is allowed to engage the autopilot.

Figure 45: Take Off Run



- V_1 Decision Speed
- V_R Rotation Speed
- V_2 Take Off Safety Speed

Figure 46: Take Off situation



Power Levers with TO/GA Triggers

Activated on the ground:
- Take-off mode engaged.
- ATS engaged when armed and selects take-off thrust.
- AP disengaged.

Take off

The autopilot can be engaged **after** lift off

The pitch attitude is controlled to reach and maintain take off reference speed V_2 +10 Kts and wings level or heading hold.

Pitch control

The take off reference speed can be determined according aircraft weight, ambient temperature and airport elevation with tables specified in the aircraft operators manual or booklet.

The modern solution is the automatic determination of the automated computation of the alfa speed α with the help of the computer.

Roll control

After lift off the autopilot steers for wings level, after reaching a safe height the airplane is controlled to steer heading hold. After selection by the pilot the mode is changed to heading select or navigation.

Yaw control

In take-off the rudder channel stabilizes the airplane around the yaw axis. If one engine fails, the rudder immediate deflects to compensate the asymmetric thrust.

Go around

After a missed approach, an automatic go around can be initiated. For pitch control the angle of attack speed α_0 + a safe margin of 10 kts is applied. The roll control is identical of take off.

Figure 47: Pitch Control

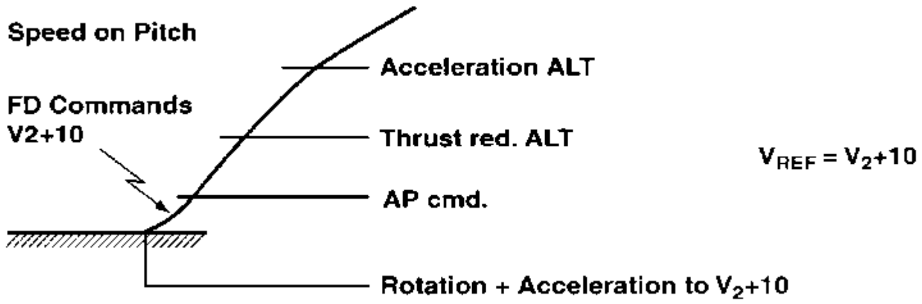
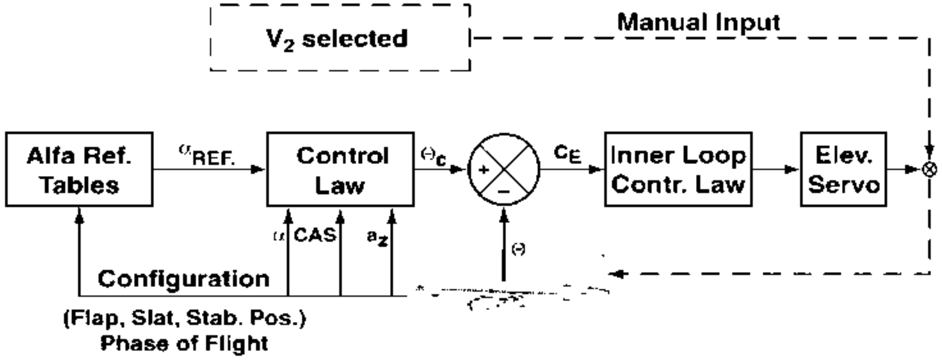


Figure 48: Control Loop



Sensors:
ADC (CAS), Angle of Attck (α), Accelerometer (a_z), VGPitch (Θ),
Flaps-, Slats-Position Tx, Stabilizer Pos. Tx
Radio Altimeter
Ground Sensing

Θ_c = Pitch Command
C_E = Command Error

Landing

This mode provides the capture and track of the ILS beam (LOC and GLIDE) and ensures the following functions: alignment, flare and roll out.

This mode is available for AP and FD. It enables landings to be performed in CAT2/ CAT3 operation. Therefore, the selection of the LAND mode authorizes the engagement of a second AP.

The arming of the LAND mode enables the LOC and GLIDE modes to be armed on the lateral and longitudinal axes. When the aircraft is stabilized on the LOC and GLIDE beams: the AP/ FD guides the aircraft along the ILS beam to 30 ft. At this altitude, the LAND mode provides the alignment on the runway center line on the yaw axis and flare on the pitch axis.

The ROLLOUT submode is engaged at touch down and provides guidance on the runway center line. As the LAND mode is latched below 400 ft. it can be deactivated only by engaging the GO AROUND mode. Actions on the FCU are no longer taken into account.

Figure 49:

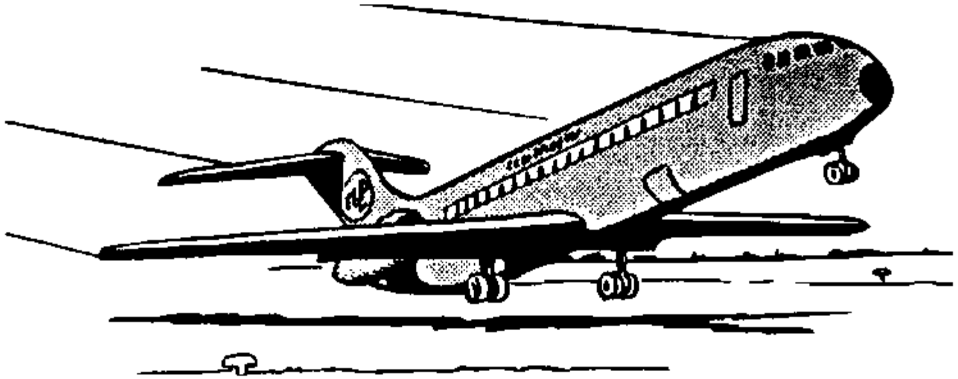
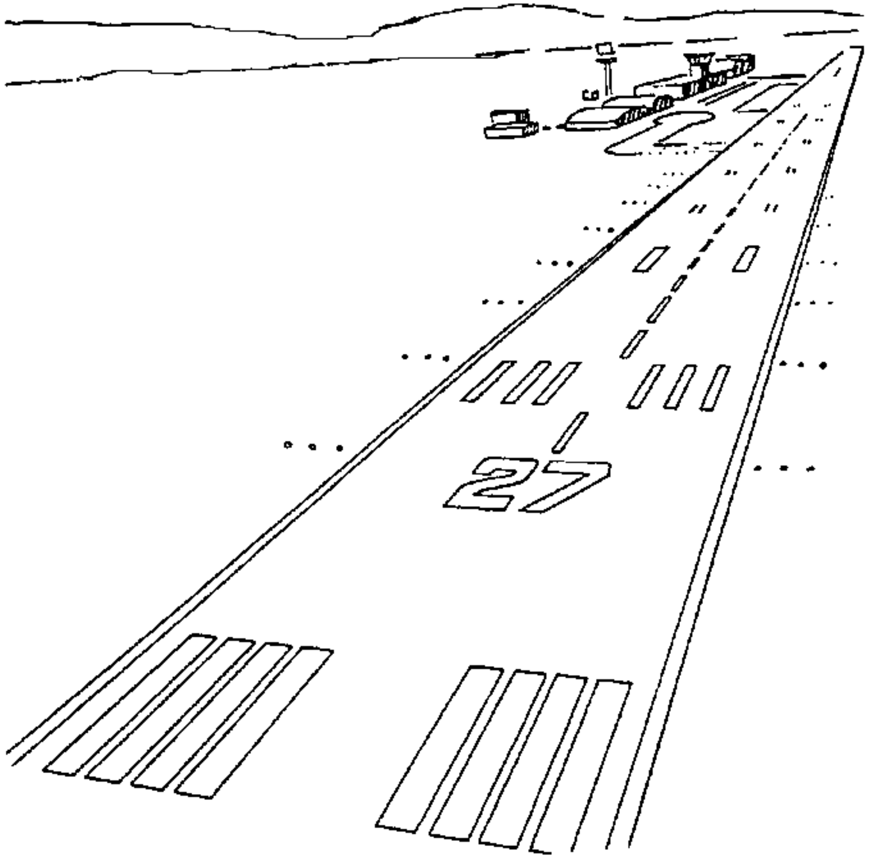


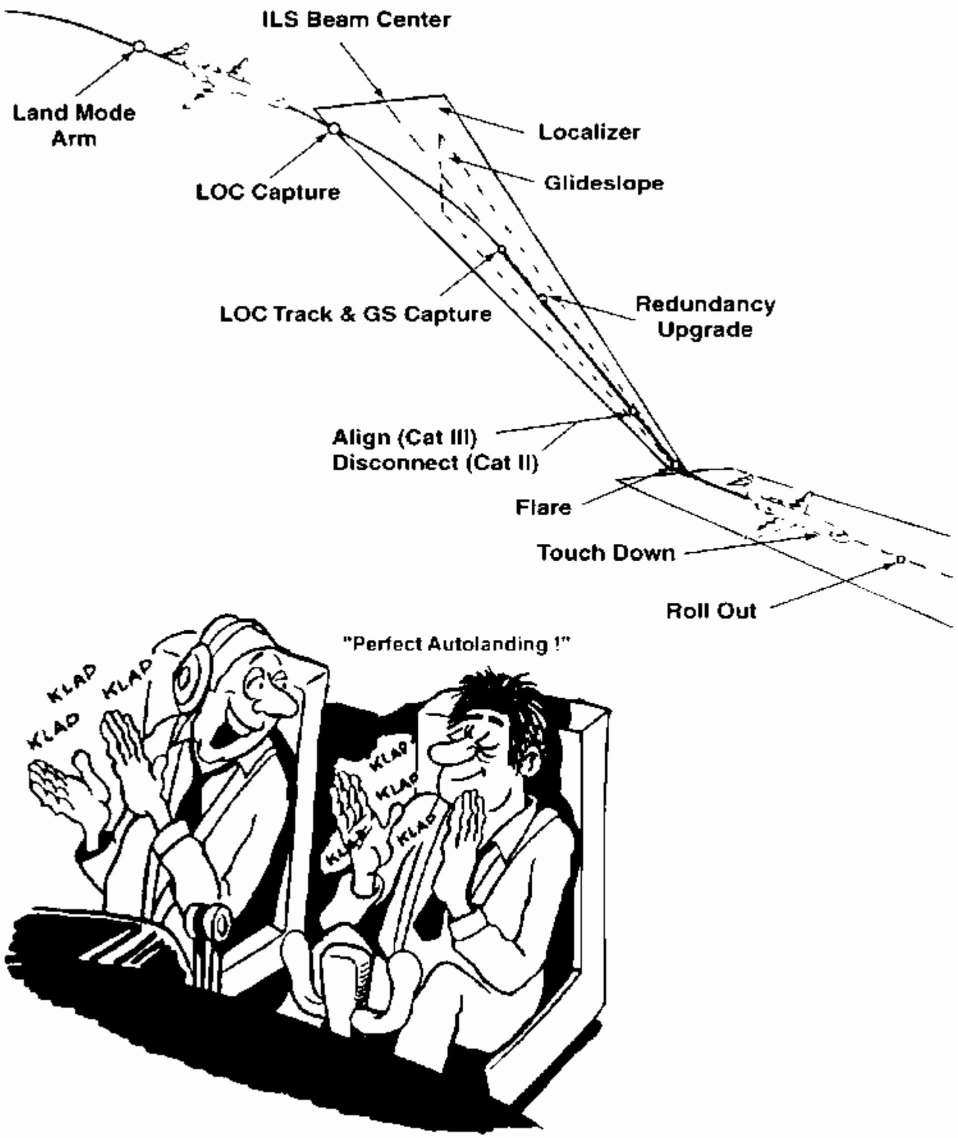
Figure 50: Before Touch Down



Approach and Landing

- CAPTURE PHASE - This phase is when the aircraft captures the localizer or glideslope beams for guidance during an automatic landing. The localizer and glideslope beams supply the guidance references to keep the aircraft on an optimum flight path.
- LOCALIZER CAPTURE is smooth and stable at ranges from four nautical miles up to 40 nautical miles from the runway threshold and at airspeeds up to 1.5 Vs (Minimum steady-flight speed). The localizer beam is captured at any intercept angle up to 90 degrees from the selected runway heading. This is done from either side of the beam.
- GLIDESLOPE CAPTURE is done within the performance limits from above or below the glideslope centerline. This is done at any intercept angle up to plus or minus three degrees. The capture is smooth and does not overshoot the beam center.
- ALIGN PHASE - The align mode is engaged automatically at 150 feet radio altitude. The autopilot commands an align manuever to bring the aircraft heading to the runway heading.
- FLARE PHASE - The flare mode is engaged automatically at about 50 feet radio altitude. The autopilot commands a flare path and the auto throttles control to reduce thrust to the idle stop. Autothrottle retard is engaged at approximately the same point as autopilot flare, but is independent of the autopilot engage status. All changes in the rate of descent are smooth. When the flare mode is engaged a nose-up control column motion is supplied by the autopilot.
- NOSE LOWERING - Nose lowering is initiated immediately after touchdown of the main landing gear The autopilot decreases the current nose up attitude at main landing gear touchdown to a minimum pitch rate of two degrees per second. After the nose gear has touched down the autopilot continuously sends a nose down command (to make sure there is always firm contact with the runway) during the landing rollout phase.
- ROLLOUT - The AFS supplies a ground rollout mode which controls the aircraft to stay on the runway centerline.

Figure 51: Automatic Landing Sequence



Automatic Landing Categories

Landing in low visibility is perhaps one of the most exciting ways to operate an aircraft but is certainly the most demanding. Such progress in civil aviation was made possible by huge improvements in aircraft control systems over the last 30 years coupled with stringent requirements for airfield equipment and crew qualification. In Category III, pilots see the runway lights only a few seconds (about 5 seconds) before touch down, therefore there is no margin for error. The basis for Category II/III operations, such as aircraft certification or airline operational demonstration, ensures a high level of safety. Moreover, approach success rate in actual in-line services is now nearly 100%.

A Brief History

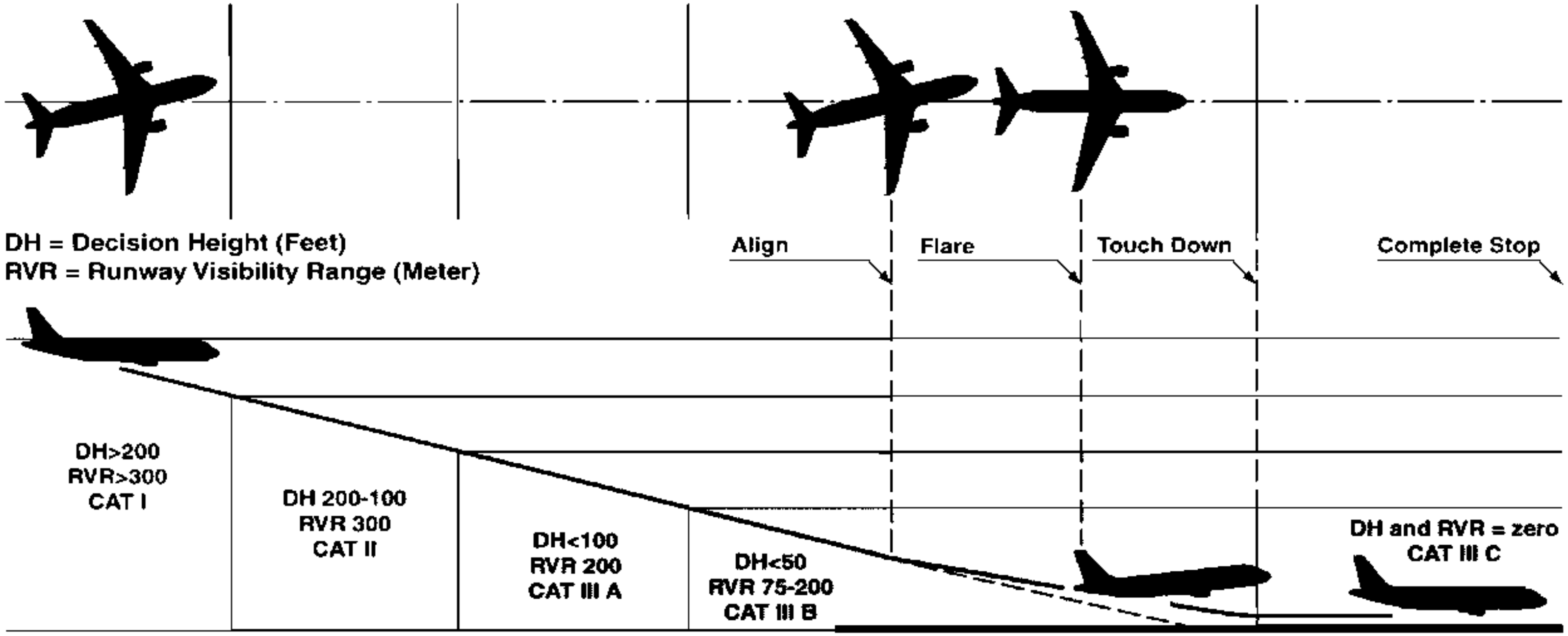
The 9th of January, 1969, an Air Inter Caravelle became the first aircraft in the history of civil aviation to land in actual Category III A conditions during a commercial flight (Lyon-Paris). This approval was the direct result of successful flight tests made since 1962.

Since then, many aircraft were granted approval for Category III A, such as the Trident, the B747 (1971) or the Concorde (1975). In 1974, the A300 was certified for Category III B, followed by the A310 (1983) and also the A300-600 (1984). Fail-operational automatic landing was first used for these type of operations, but it was found useful to develop fail-passive capability in order to satisfy airline requests. Currently, Airbus Industrie Aircraft are certified both with fail-passive (limited to DH =50 ft.) and fail-operational landing systems.

Economic Aspects

CAT II/III equipment represents a significant cost for an airline. However, it is the only way to keep in-line services during the whole year without any diversion. Weather conditions mainly depend on the airfield location, nevertheless actual CAT II or CAT III conditions may occur at any airfield during some periods of the year. Diversions are expensive for an airline: directly by passenger compensation costs but also by the resulting bad 'image'. For these reasons, getting operational approval for CAT II and CAT III approaches may be considered as a necessary step in the evolution of a modern airline.

Figure 52: Auto Land Categories



Decision Height and Alert Height

In CAT II/CAT III regulations, two different heights are defined:

- Decision Height (DH)
- Alert Height (AH).

Decision Height Definition

Decision height is the wheel height above the runway elevation by which go around must be initiated unless adequate visual reference has been established and the aircraft position and approach path have been assessed as satisfactory to continue the approach and landing in safety.

A pilot may not continue the approach below DH unless a visual reference containing not less than a 3 light segment of the centre line of the approach lights or runway centre line or touchdown zone lights or runway edge lights is obtained.

Alert Height Deftition

An Alert Height is a height above the runway based on the characteristics of the aircraft and its fail-operational automatic landing system, above which a Category III approach would be discontinued and a missed approach initiated if a failure occurred in one of the redundant parts of the automatic landing system, or in the relevant ground equipment.

It is generally stated that if a failure occurred below the Alert Height, it would be ignored and the approach continued

Decision Height and Alert Height Concept

Decision height is a specified point in space at which a pilot must make an operational decision. The pilot must decide if the visual references, adequate to safely continue the approach, have been established:

- If the visual references have not been established, a go around must be executed.
- If the visual references have been established, the approach can be continued. However, the pilot may always decide to execute a go around if sudden degradations in the visual references or a sudden flight path deviation occur.

Runway Visual Range

Runway Visual Range (RVR) is the range over which a pilot of an aircraft on the center line of the runway can see the runway surface markings or the lights delineating the runway or identifying its center line (ICAO).

Fail-Passive Automatic Landing System

An automatic landing system is fail-passive if, in the event of a failure, there is no significant out of trim condition or deviation of flight path or attitude but the landing is not completed automatically. For a fail-passive automatic landing system the pilot assumes control of the aircraft after a failure.

On Airbus Industrie aircraft since the A320, fail-passive capability is announced by the display of CAT 3 SINGLE on the PFD.

Fail-Operational Automatic Landing System

An automatic landing system is fail-operational if, in the event of a failure below alert height, the approach, the flare and landing can be completed by the remaining part of the automatic system. In the event of failure, the automatic landing system will operate as a fail-passive system.

On Airbus Industrie aircraft since the A320, fail-operational capability is announced by the display of CAT 3 DUAL on the PFD.

Table 1: Categories

Landing Category	**RVR (Meter)**	**DH (feet)**
CAT II	300	100 - 200
CAT III A	200	< 100
CAT III B	75 - 200	0 - 50
CAT III C	zero	zero

Automatic Landing

The automatic approach contains different phases of operation in all 3 axes pitch, roll and yaw.

Flare: the vertical speed will be reduced, acceptable for the landing.

Align: the aircraft's heading must be identical with the runway's heading.

Roll-out: the aircraft is steered along the centerline of the runway with the help of localizer signal.

Figure 53: Approach

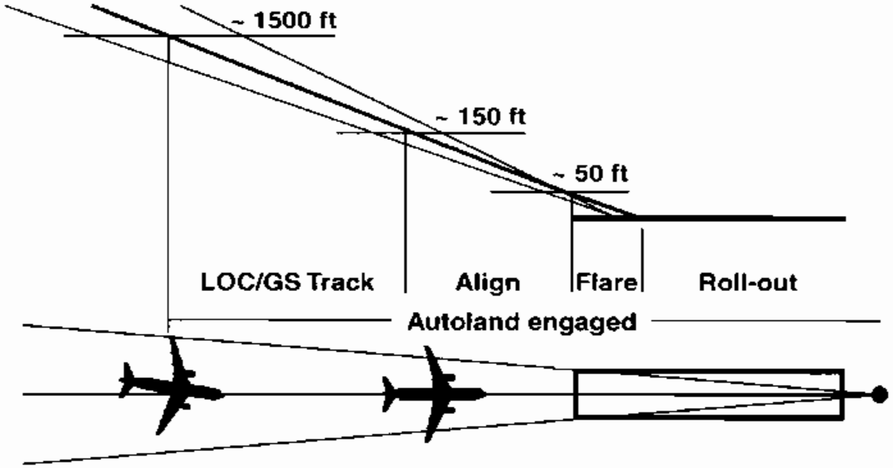


Figure 54: Pitch Control

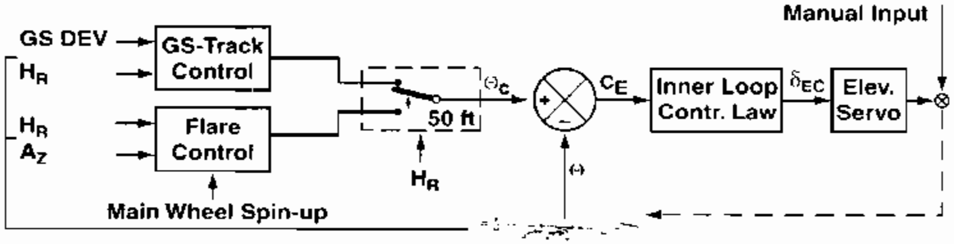
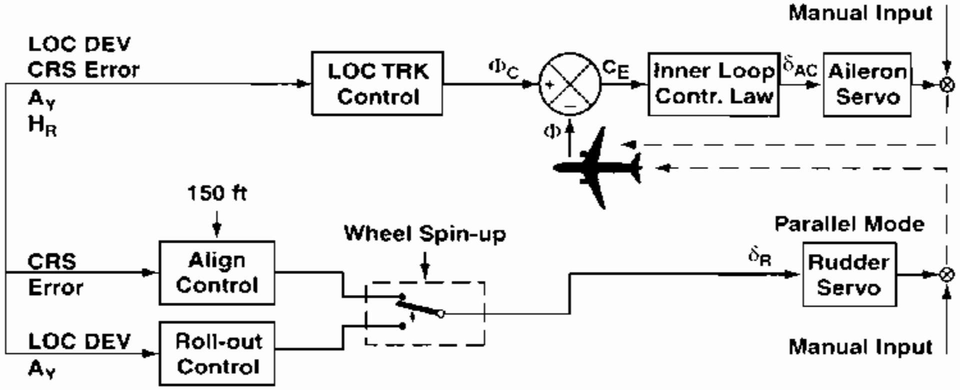


Figure 55: Roll Control



Sensors:
LOC/GS Receiver (ILS)
Vert. Gyro (Θ = Pitch, Φ = Bank)
Compass System (ψ) = Heading)
Course Select. (Runway Inbnd. HDG)
Radio Altimeter (H_R)
Accelerometer (lat. = A_Y, vert. = A_Z)
Wheel Spin-up / Weight on Wheel
Surface Position
Configuration
Stabilizer Position

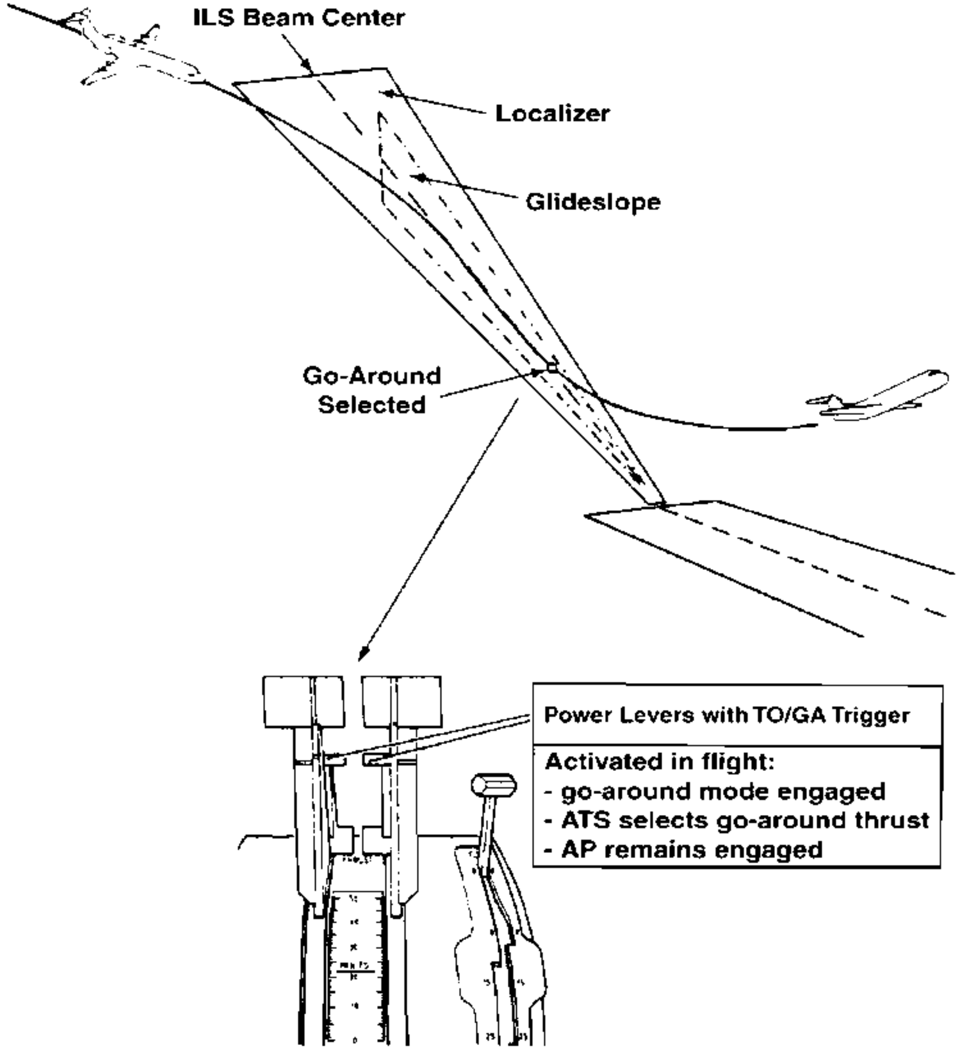
Go-Around

In the go-around mode the autoflight system gives pitch, roll, and thrust steering signals to control the aircraft on a safe climb-out from an unsuccessful approach.

There are switches on the thrust levers to select the go-around mode. The GA selection automatically engages the ATS, selects HDG hold mode on, and a safe speed in the speed display.

On other aircraft types the throttles must be manually moved to fully forward position. The Go-around thrust will be demanded from the engine and automatically a positive safe climb is initiated. The wings are leveled and at a safe altitude heading hold or heading select mode is initiated.

Figure 56: Missed Approach Go Around



Power Levers with TO/GA Trigger

Activated in flight:
- **go-around mode engaged**
- **ATS selects go-around thrust**
- **AP remains engaged**

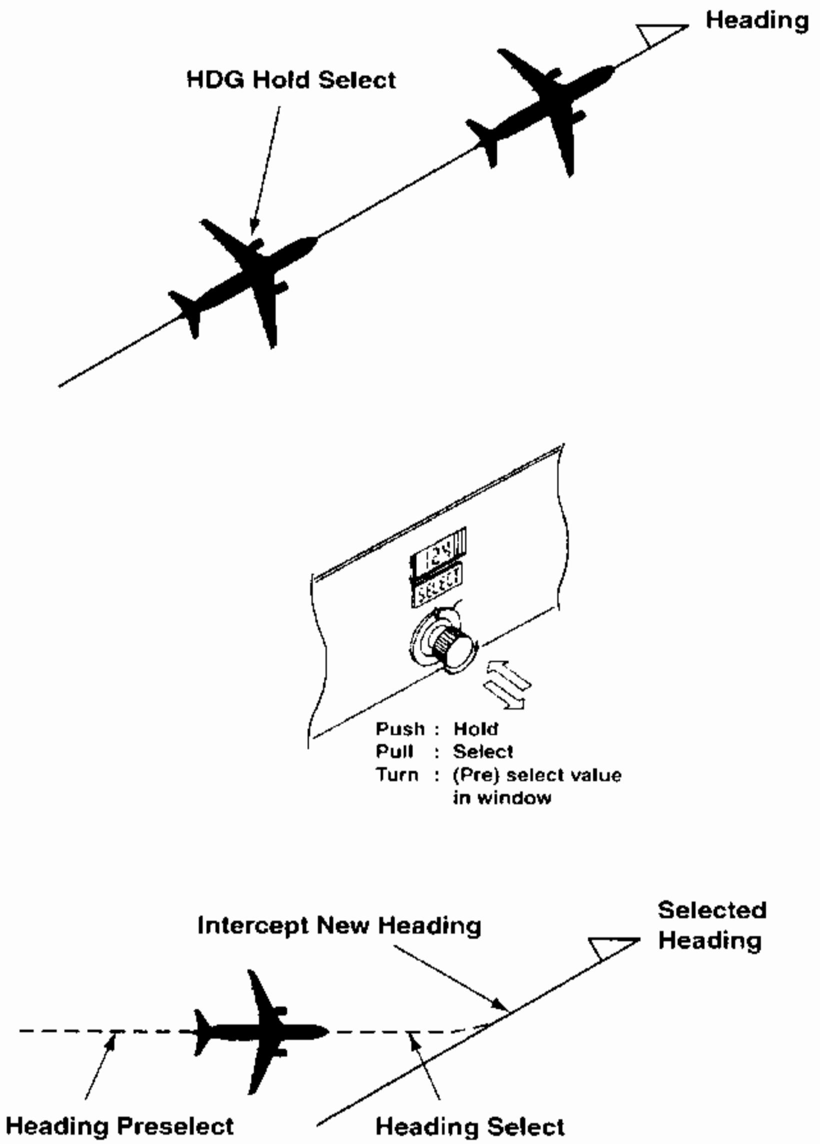
Heading Hold

In the heading hold mode the autopilot makes steering signals to hold the aircraft's existing heading. When the crew selects the HDG hold mode while the aircraft is in a roll, the AFCS first levels the aircraft off. The heading hold mode is the basic roll mode.

Heading Select

In the heading select mode the AFCS controls the aircraft to capture and hold the heading which the crew selects on the flight mode panel.

Figure 57: Heading Hold and Heading Select Mode



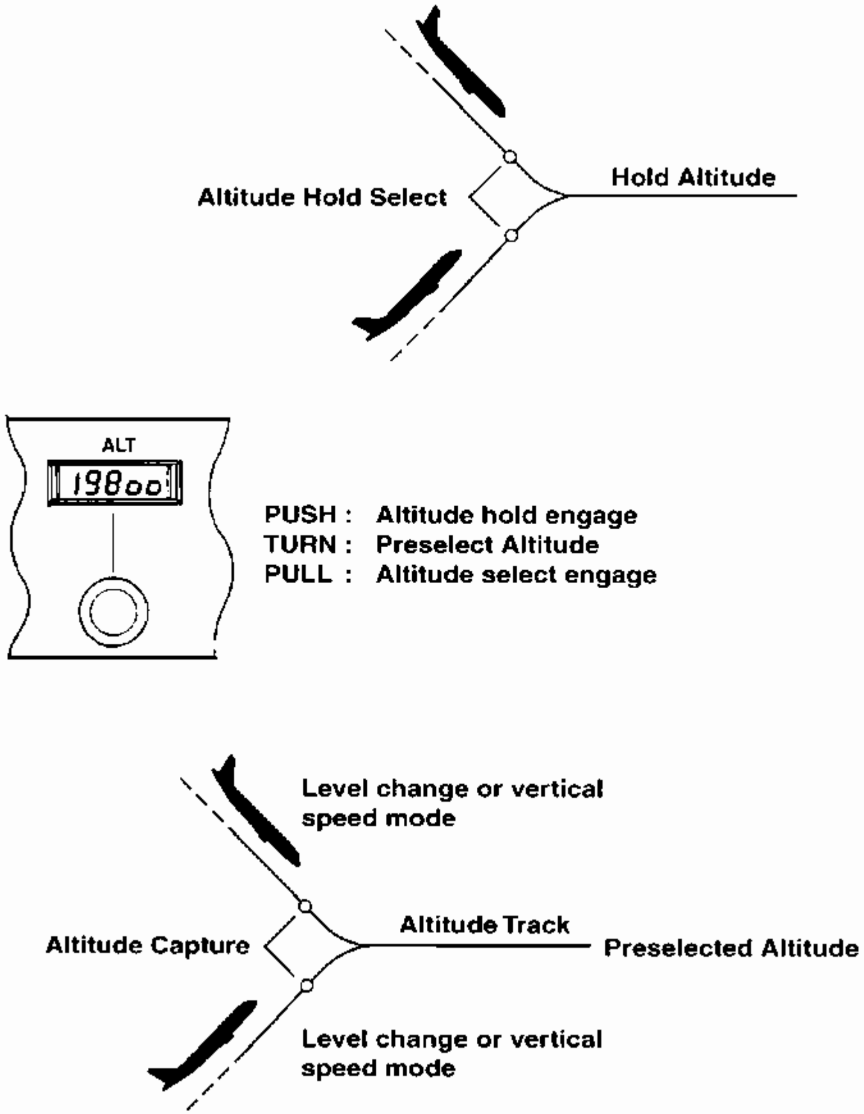
Altitude Hold

In the altitude hold mode the auto flight system makes steering signals to level the aircraft off and it then holds the altitude at which the aircraft was flying when the altitude hold mode was initiated by pressing the selector knob momentary in.

Altitude Select

The auto flight system makes steering signals to level the aircraft off at a preselected altitude and then it holds the altitude. The aircraft was climbing or descending with a preselected vertical speed or in the level change mode.

Figure 58: Altitude Hold and Altitude Select Mode



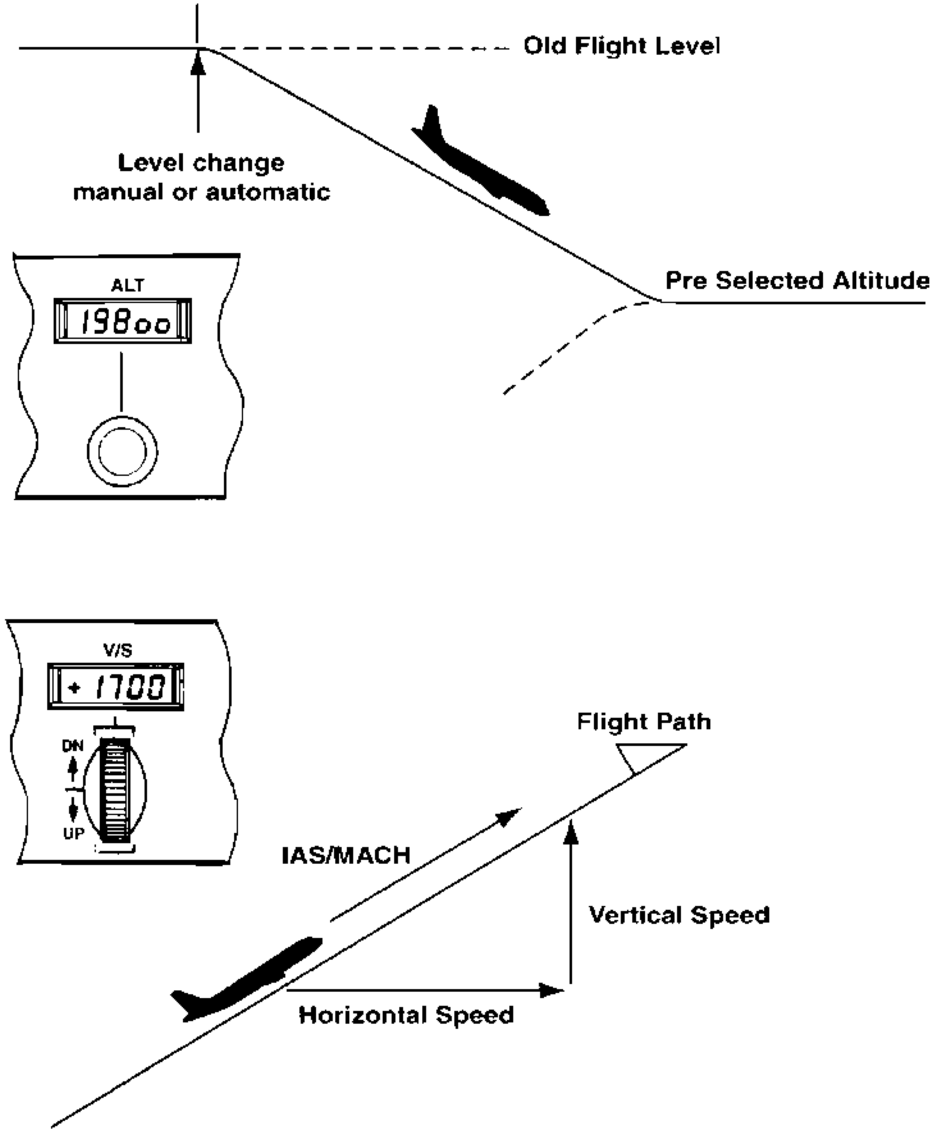
Level Change

The level change mode is a combination of an speed mode and a thrust mode (when AT is engaged). With this combination AFCS flies the aircraft from an old flight level to a new preselected altitude. in the level change mode the AFCS makes steering signals to control the speed of the aircraft with the elevator (IAS or M select mode). Auto throttle controls the engines to the upper limit in level change climb or the lower limit in descent. The vertical speed in this mode depends on aircraft weight etc. The AFCS stays in the level change mode until the aircraft is at the preselected altitude and then it goes to altitude capture/hold.

Vertical Speed Select

You select the vertical speed mode with the VS selector. The read-out shows the current vertical speed on the display and selects the VS mode. Rotating the knob update the display and the AFCAS adjusts the vertical speed of the aircraft to the displayed value.

Figure 59: Level Change and Vertical Speed Select Mode



Flight Path Angle Select

This mode allows a preselection of a desired climb- or descent- path angle. The aircraft is guided along the desired flight path.

The selector is combined for:

- Vertical speed selection (4 digits in the read-out are shown ending with oo)
- Flight path angle selection (2 digits are shown with a decimal point in between)

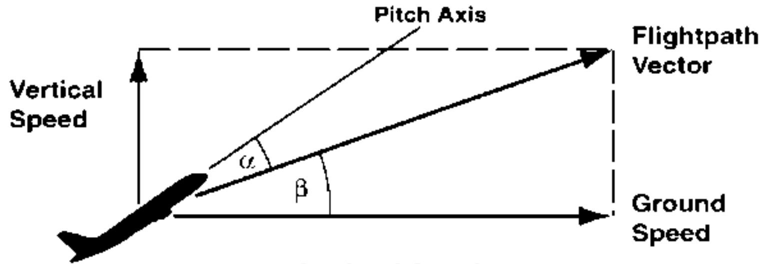
α = Angle of attack

β = Flight path vector angle

tg β = vertical speed / groundspeed

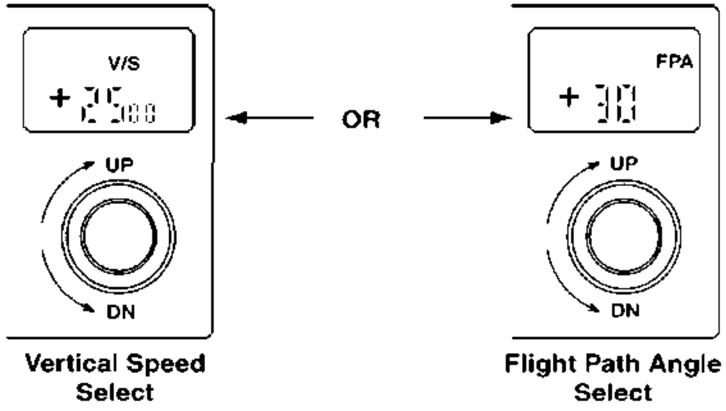
$\alpha + \beta$ = Pitch angle

Figure 60: Flight Path Vector



α = **Angle of Attack**
β = **Flight Path Angle**

Figure 61: VS / FPA Selector



Vertical Speed / Flight Path Angle Selector Knob (Autoflight Control Panel)

Lateral Navigation

In the navigation mode the flight management computer gives steering signals to the flight control computers to control the heading of the aircraft.

Figure 62: Lateral

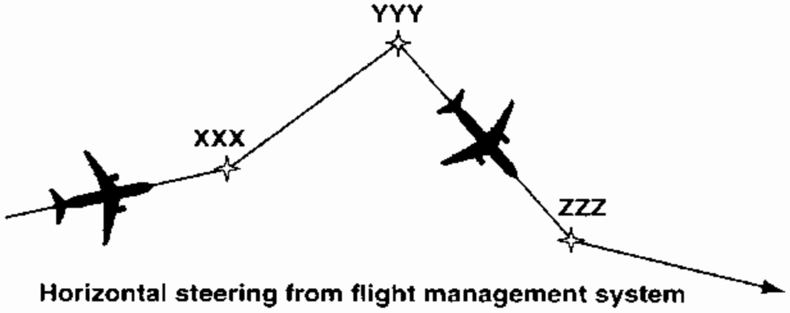


Figure 63: Profile

Profile Navigation

Profile mode. In the profile mode the FMS gives vertical steering and thrust commands to the flight control computers. The flight management system does all the altitude changes, altitude captures, and altitude holds when the AFCS is in the profile mode.

VOR or LOC

In the VOR or localizer mode the flight control computers use VOR or LOC signals to make roll steering signals.

Figure 64: VOR

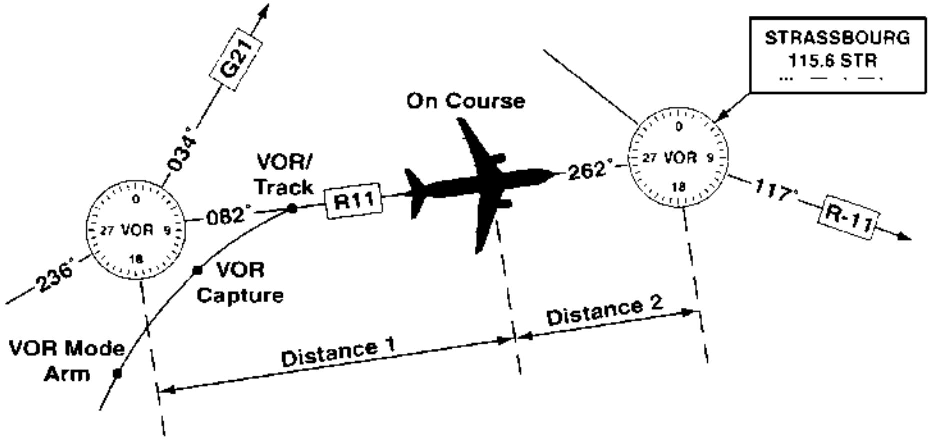
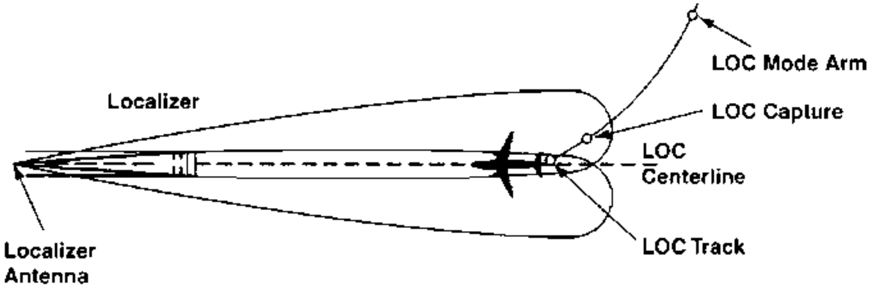


Figure 65: LOC



Pitch Trim

Function

The horizontal stabilizer is automatically positioned to off-load any steady state elevator deflections of more than 3 seconds. The trim rate is varied with airspeed and altitude to provide best performance for all flight conditions.

Automatic pitch trim (APT) function is contained in auto flight system.

Out-of-trim conditions that could result in unacceptable trim function causes to disengage and are annunciated to the flight crew.

Aircraft flies in stable condition

The Lift A + the Weight G + the negative Lift S = Zero

A x l_A = S x l_s

Lift attachment moved backward

Induced by increased lift of the wing tips at high speed flight.

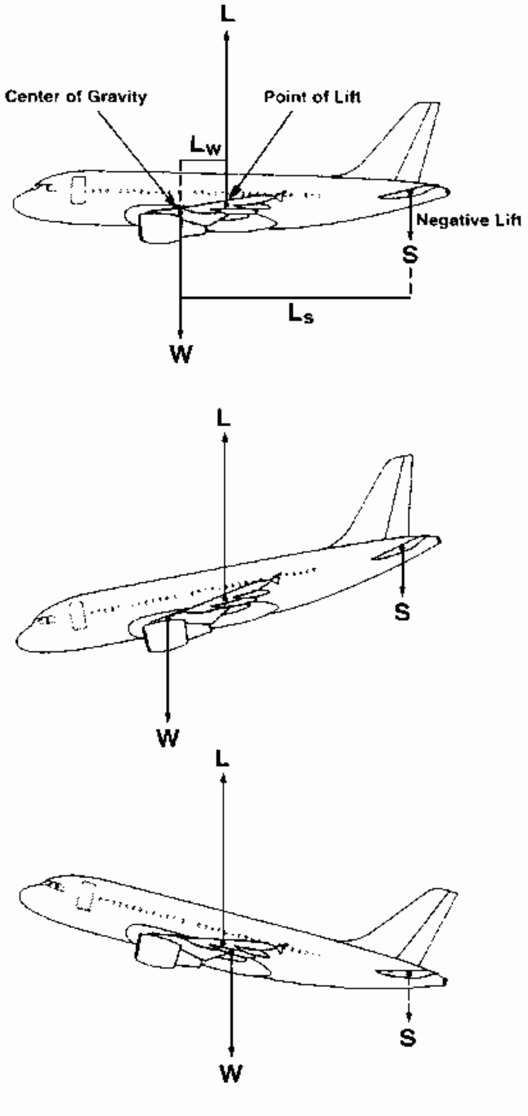
- The aircraft lowers the nose.
- Correction with horizontal stabilizer toward aircraft nose up direction (ANU).

Center of gravity moved backward

Due of fuel usage of the inner tanks.

- The aircraft rises the nose.
- Correction with horizontal stabilizer toward aircraft nose down direction (AND).

Figure 66: Lift, Weight and Center Of Gravity



Automatic Stabilizer Trim System

The motor on the right drives a jackscrew whose nut is attached to the forward spar of the stabilizer. The stabilizer is pivoted on the aft spar. Turning the jackscrew one way or the other raises or lowers the nose of the stabilizer. The motor itself could be hydraulically operated and electrically controlled, or it could be a threephase electric motor. Shown is a DC electric motor.

There are always at least two stabilizer motors, and usually, both can drive into the same differential gear box. If both are driving, the rate of operation is greater than that of only one motor. If there are two electric motors, one is typically smaller and drives through a lower ratio gear train for slow speed operation. There might be one hydraulic motor used for the fast operation, and an electric motor used for the slow operation. Fast is used during takeoff and approach, and slow is used for cruise. The slow operation is used by the autopilot system.

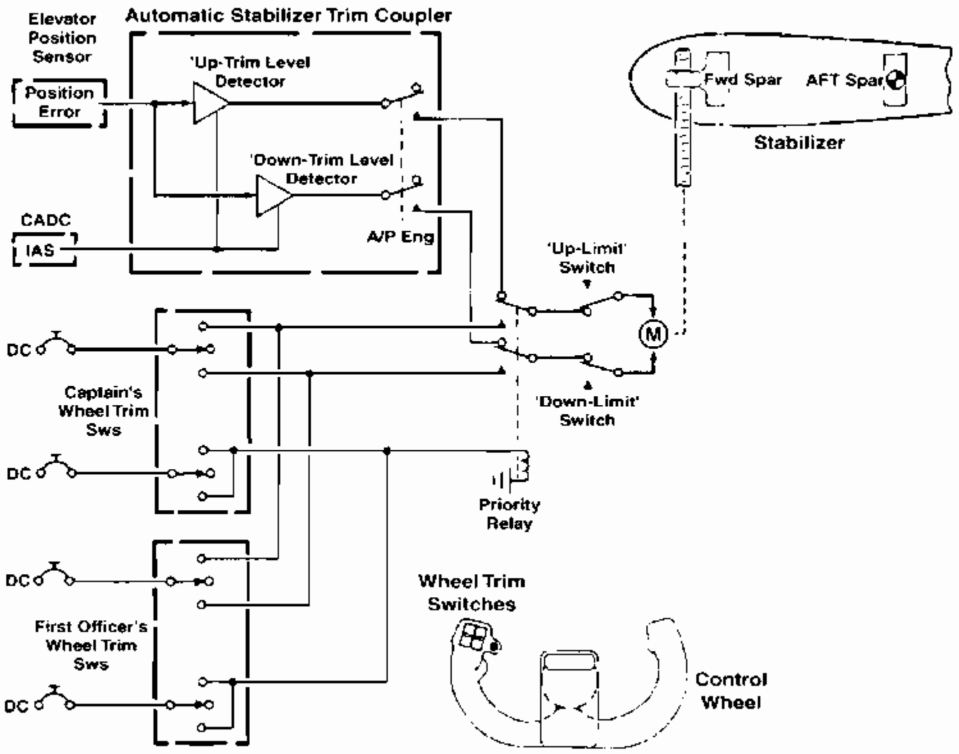
On the outboard horns of the cockpit control wheels are two switches mounted close together which can be operated by one thumb.

Generally, the manual operation of the stabilizer trim system by the pilot disconnects his autopilot. The reasoning behind this arrangement is that, if the pilot needs to trim the stabilizer, the autopilot is not doing its job correctly. Operation of either the captain's or first officer's wheel trim switches operates a priority relay which disconnects from the motor any signals that might be generated by the automatic stabilizer trim coupler. The trim coupler is part of the automatic flight guidance system.

The basic control signal for automatic stabilizer trim is the elevator position. If the level detectors see an elevator too far away from the faired position for several seconds, one of them will operate the servo motor to trim the stabilizer up or down as needed. When the elevators get close enough to the faired position, the level detectors stop their operation of the servo motor.

An airspeed function usually controls the sensitivity of the level detectors. At cruise speeds, if the elevator is held perhaps as little as 1/4° away from the faired position, the stabilizer trim system operates. At approach or takeoff speeds, automatic stabilizer trimming is not initiated unless the elevator is held much farther away from the faired position.

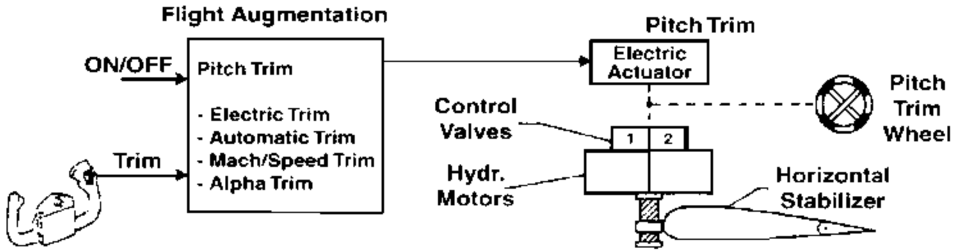
Figure 67: System



Pitch Trim Functions

- **Electric trim** This basic function provides pitch axis stabilizing and enables loads applied to the control column in manual flight to be overridden by means of the pitch trim control switches located on the control wheels.
- **Automatic trim or autotrim** Without any action on the pitch trim control switch, permanently stabilizes the pitch axis and overcomes out-of-trim conditions
- **Mach/Speed Trim** compensates aerodynamic pitch down tendency at high Mach number or speed.
- **Alpha trim** (angle of attack trim) applies forward trim to improve aircraft resistance to stall at high angle of attack.

Figure 68: Functions

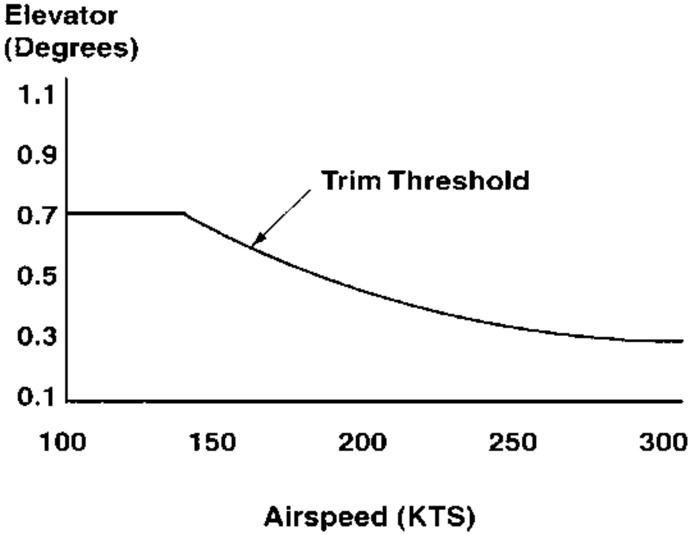


Automatic Pitch Trim Threshold

When the system is engaged it provides automatic pitch trim. The horizontal stabilizer automatically moves to trim out steady state elevator commands. If elevator position exceeds threshold during more than 3 seconds the trim coupler will trim horizontal stabilizer until elevator position is 10% below the threshold.

Out of trim condition is met if the elevator position exceeds 3 times the trim threshold. This causes a warning to the pilots.

Figure 69: Trim Threshold



Yaw Damping

Introduction

Many of the high-speed jet aircraft with swept-back wings have the undesirable problem of Dutch Roll flight characteristics. This is an oscillatory flight condition that can be very uncomfortable for the passengers and, to counteract it, these aircraft are equipped with yaw dampers.

A rate gyro senses the rate of yaw of the aircraft and sends a signal to the rudder servo that provides just exactly the correct amount of rudder deflection to cancel the Dutch Roll before it gets enough amplitude to be disturbing.

The yaw damper system provides the following functions:

- Dutch roll damping
- Turn coordination in low speed manual flight to reduce the sideslip induced by the turn.
- Engine failure compensation. A command is generated to the rudder to counteract sideslip during the transient induced by a engine failure.

The block diagram shows a yaw damper. The complete rudder channel may or may not perform other functions, but this is its most important one. The dutch roll is only dampened, it is not eliminated.

In the signal source on the left of the block diagram, yaw rate or yaw acceleration is called out. This signal is typically supplied by the inertial reference system, a yaw rate gyro or yaw accelerometers.

The shaper/processor accomplishes whatever is necessary in the way of conversion, smoothing, dampening, limiting, and gain control. Its output goes to the dutch roll filter.

The dutch roll filter attenuates all signals which are not at the frequency of the dutch roll. Its output is a continuously changing command for left rudder, then right rudder, then back to left rudder and so on.

The servo amplifier amplifies this signal as required to control the servo and operate the rudder the correct amount to eliminate most of the dutch roll.

The small amount of dutch roll that is not eliminated is represented with a dashed line coupling the airplane to the signal source.

Figure 70: Dutch Rolling

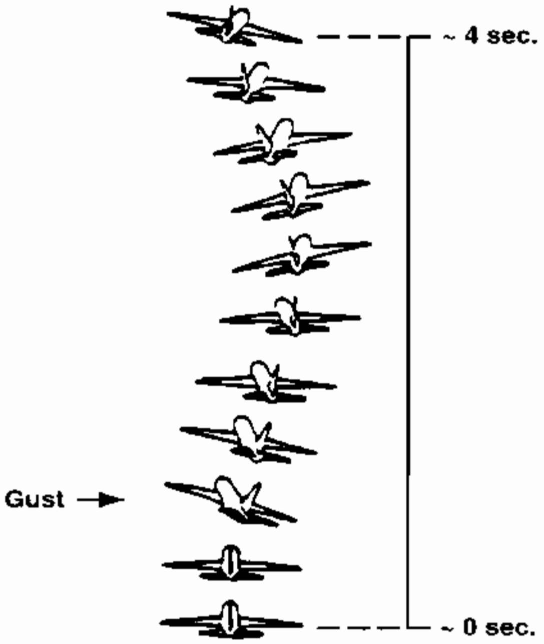
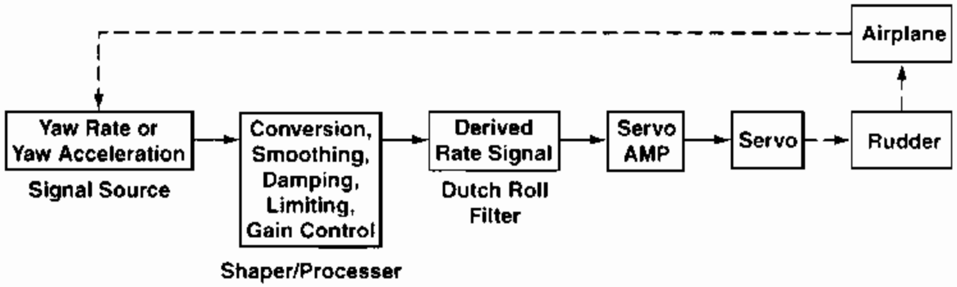


Figure 71: Block Diagramm



Yaw Damper

The yaw rate gyro senses the oscillations around the yaw (Z) axis.The oscillation frequency named "Dutch Roll" is about 0.25 Hz. The air data computer provides the computed airspeed for gain programming to the yaw damper computer. At high CAS the correction is smoother than at low CAS.

The Y/D servo output is applied to the rudder actuator to control the rudder. The steering signal will not be feel able at the pilots pedal input.

Figure 72: Control Loop

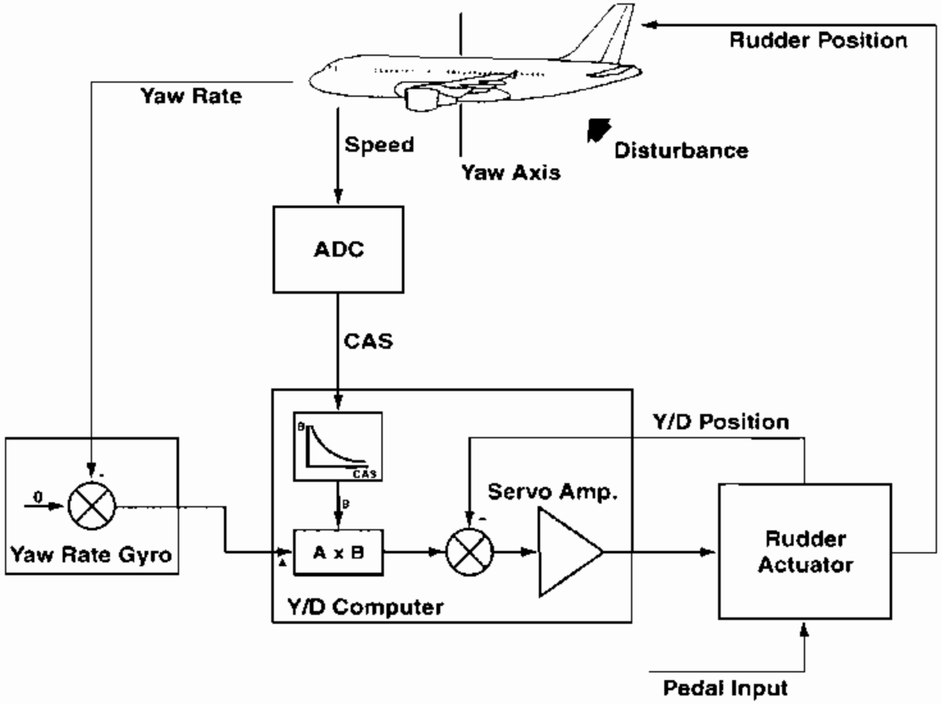
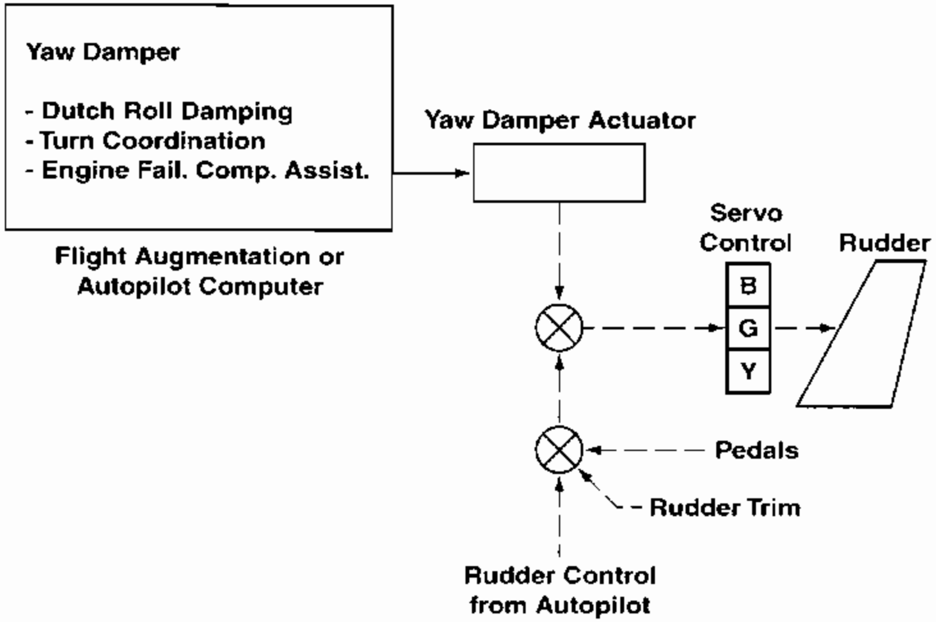


Figure 73: Rudder Functions



Signals

The left figure illustrates an airplane flight path beginning at the left with a straight path. It soon changes to a constant rate of turn to the right. Near the end it resumes a straight path.

The rate gyro output represents the 400 Hertz synchro signal developed by the rate gyro during this flight path. When the airplane is flying straight ahead there is no output from the synchro. During the time it is making a constant rate of turn, the output is of a particular phase with a constant amplitude.

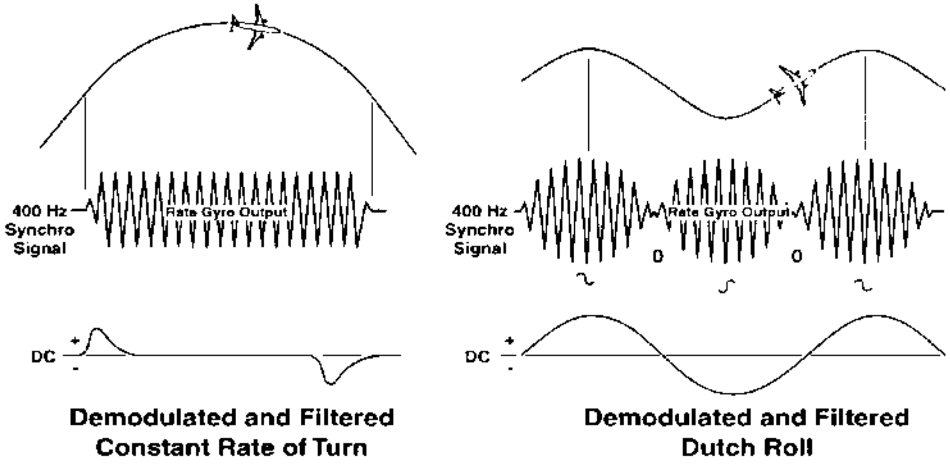
The DC graph shows the demodulated and filtered output of a dutch roll filter. Only during the time that the rate of turn is changing is there an output from the dutch roll filter.

The right figure shows the flight path and the changing turns that occur during a dutch roll. In a dutch roll manoeuvre the rate of turn is constantly changing. Since the rate of turn is constantly changing, the output of the rate gyro is constantly changing.

The DC graph is the dutch roll filter output resulting from the rate gyro input. The DC polarities are greatest when the rate of turn is greatest, and reverse when the direction of turn (phase of gyro signal) reverses.

The dutch roll filter is a narrow band pass filter designed to pass only signals which change at the frequency of the dutch roll, which range from 1/5 Hz to 1/3 Hz. The rate gyro produces outputs for all turns, but only those related to dutch roll will appear at the input to the servo amplifier driving the rudder servo motor.

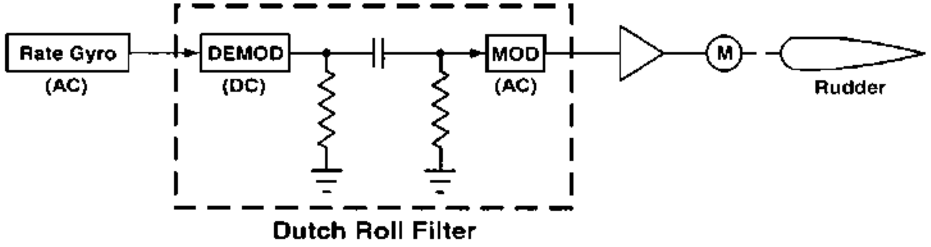
Figure 74: Dutch Roll detected by Yaw Rate Signals



Demodulated and Filtered Constant Rate of Turn

Demodulated and Filtered Dutch Roll

Figure 75: Yaw Damper Dutch Roll dampening Function



Stability Augmentation Systems in Helicopters

Stability and control are among the most important aspects in the design and analysis of rotary wing aircraft. It is interesting to note that no civil fixed wing transport aircraft with inherent static instabilities, has ever received fight certification. Helicopters on the other hand, routinely receive light certification despite being naturally unstable. The deficiencies in the helicopter's stability and control characteristics have become an acceptable part of the vehicle over the years providing that a good Automatic Stabilisation Equipment (ASE) or Stability Augmentation System (SAS) is installed.

When a helicopter operates at hover or low speed (up to approximately 45 knots), it exhibits poor handling qualities and is difficult to fly. Interactions between the logitudinal and lateral axes, coupling of the control inputs, and inherent low frequency instabilities are undesirable characteristics typical of a helicopter when flying at low speeds. As most unaugmented helicopter will not meet the handling quality specifications, **S**tability **A**ugmentation **S**ystem (SAS) is necessary to improve handling qualities so that safe operation close to the ground in poor weather conditions and/or at night is possible.

The correction movements are mostly relative fast and small (constant regulation). There is **no** correction movement feedback to steering column.

ⓘ These days, stability augmentation is a function of the automatic flight control system. This means that the autopilot also takes care about stability at lower level. Therefore we only discuss about a typical autopilot system used in modern helicopters.

Basic Principles of flying an Helicopter

A helicopter has four main controls for creating movement. They consist of the cyclic, collective, yaw pedals, and throttle. Only three of these are used to create movement. The throttle is used primarily to control power output of the engine.

For creating forward movement the cyclic is moved forward. This tilts the rotor blades forward. The resulting thrust vector now has a vertical and forward component. For the same reasons, moving the cyclic back, right, left cause overall movement in the helicopter backwards, to the right, to the left respectively. During forward flight the cyclic is moved laterally in order to produce turns. The yaw pedals are not used.

The collective is used to change the thrust of the helicopter by changing the collective pitch of the blades. Hence, increasing the collective pitch increases the thrust and decreasing the collective pitch decreases the thrust. In order to effect an increase in height above ground, the collective pitch must be increased. Since this increases the thrust vector, any lateral or longitudinal movement of the helicopter will see a increase in speed. For example, if the helicopter is traveling forward while the collective is increased, the helicopter will see an increase in forward speed and height. In order to correct the increase in forward speed, the cyclic must be pulled back to lower the forward component of the thrust vector. This can be applied in the other directions as well.

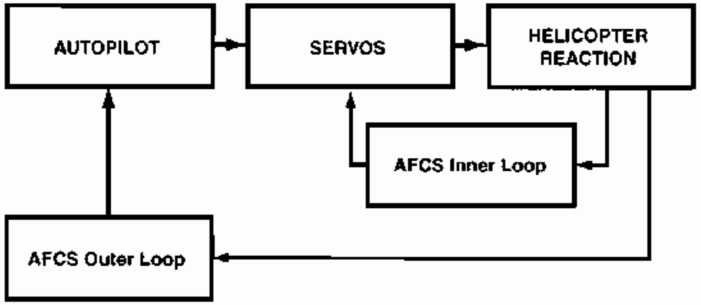
The yaw pedals are used to counter the rotational effect of the main rotors. The pedals themselves alter the collective pitch of the tail rotor. It must be kept in mind that the main and tail rotors are using the same power source. Increasing one will have a direct effect on the amount of power used on the other. This leads into the reasons why the throttle is used primarily to control power output. In turbine and certain piston helicopters, the pilot doesn't have a throttle control, but the rpm is controlled by a governor. A governor on the engine simplifies the task of controlling a helicopter. It eliminates one more variable to adjust during flight since the governor maintains constant engine rpm.

Automatic Flight Control System

The structure of the control system for the helicopter is called AFCS (Automatic Flight Control System). It consists of a hierarchy that builds from vehicle stability to an operational autopilot. Each inner level builds on the previous which will make it easier to develop. We will start at the inner most level and develop each one step by step.

The overall hierarchy of an AFCS is shown in Figure 77 on page 56. The overall system can be divided into an inner and outer loop. The inner loop primarily deals with internal conditions from sensors directly related to the helicopter. For example, pitch, roll, and yaw attitudes, rates and accelerations. Consequently, the outer loop deals with conditions external to the helicopter such as air speed, altitude, and other navigational information. See Figure 76 on page 55.

Figure 76: Relationships between inner and outer loops of AFCS



Level Description

The inner most level, called SAS (Stability Augmentation System), provides rate damping for the helicopter. This makes the helicopter stable in flight. Stability is important in a helicopter since it is an inherently unstable vehicle. If left alone, a helicopter will diverge and become unstable. Sensors in the helicopter, rate gyros or attitude gyros with a differentiator, will detect a disturbance. In this case, we will assume it is a gust of wind. Once the disturbance is detected the AFCS sends a control signal to cancel the movement generated by the disturbance. Note that this does not mean the helicopter is returned to its original state e.g. nose down attitude, but only that the resulting movement from the disturbance is stopped.

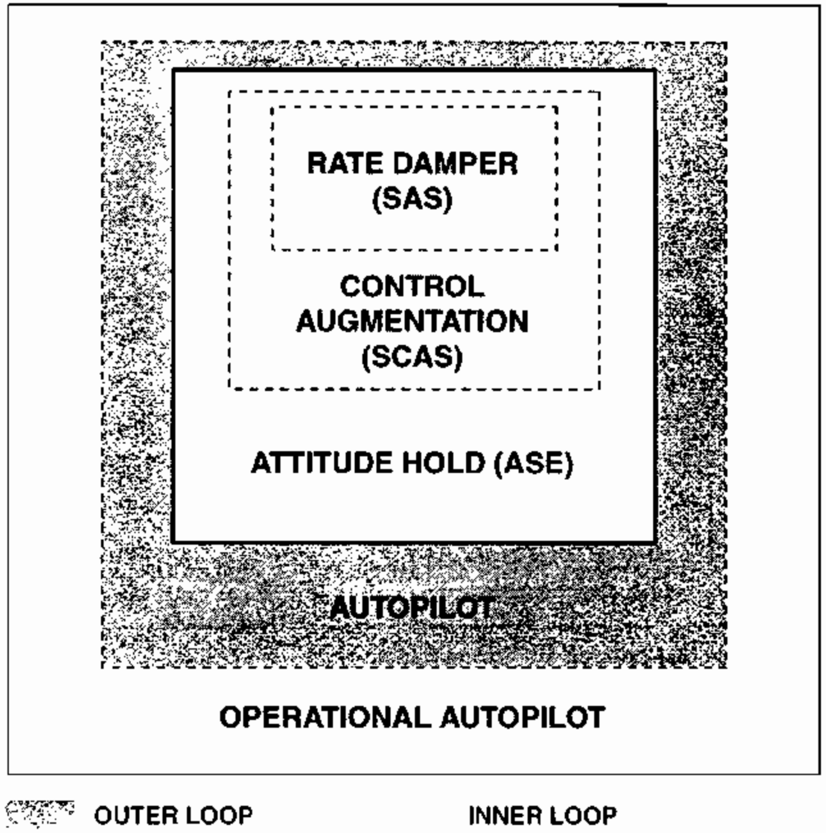
The next level in the hierarchy is the SCAS (Stability Control Augmentation System). The purpose of this system is to provide control of the helicopter. If this system is not present the SAS would sense any disturbance in the helicopter from a control input, i.e. pilot or auto-pilot command, and damp it. Instead, the SCAS "feeds the signal forward" which results in a delay of the damping. Without the SCAS the damping would take place immediately and the responsiveness of the helicopter would be slow at best.

The last level in the inner loop is the ASE (Attitude Stabilization System). As the name suggests this system maintains the attitude of the helicopter. It works with either a rate gyro or attitude gyro The signal from a rate gyro must be integrated over time to provide a displacement. If a displacement exists, the system will apply a corrective movement until the previous attitude is attained.

The lowest level of the outer loop consists of an autopilot. This autopilot works to maintain airspeed, altitude, and sideslip. While the helicopter is traveling forward there is some inherent sideslip which means the helicopter is not traveling in a straight line but at a slight diagonal. This system will maintain the height and sideslip according to the levels set by the operational autopilot

The outer most system is an operational autopilot. It carries out higher level functions. The operational autopilot works to coordinate maneuvers such as the transition from hovering to forward flight. Navigation from point to point is also carried out by this system. This is the highest level of the control system which in the final implementation will take commands and execute them. Commands given to the operational autopilot will be similar to "goto point (x,y,z)".

Figure 77: Architecture of Automatic Flight Control System



Common Parts of an Autoflight System

The common parts of a typical auto flight system are:

- Autopilot Computer
  (Regulator of the Flight Position, Calculator / Amplifier) Processor of the Analog and/or Digital Signals.
- Autopilot Control Unit
  A unit for access system function to the Autopilot System.
- ADI Attitude Direction Indicator (Artificial Horizon)
- Rate Gyro's for sensing fast turn movements with a pick up to send correction signals to the Autopilot Computer.
- Accelerometers for sensing accelerations in each directions with a pick up to send correction signals to the Autopilot Computer.
- Servomotor, Actuators
  There are servomotors in each of the primary controls: The roll-, pitch-, yaw- and collective (power axis) axis. The automatic pilot senses when a flight correction is needed, and it sends current of the correct polarity to turn the servomotor in the proper direction to make the correction.

Figure 78: Auto Flight Control Component Overview

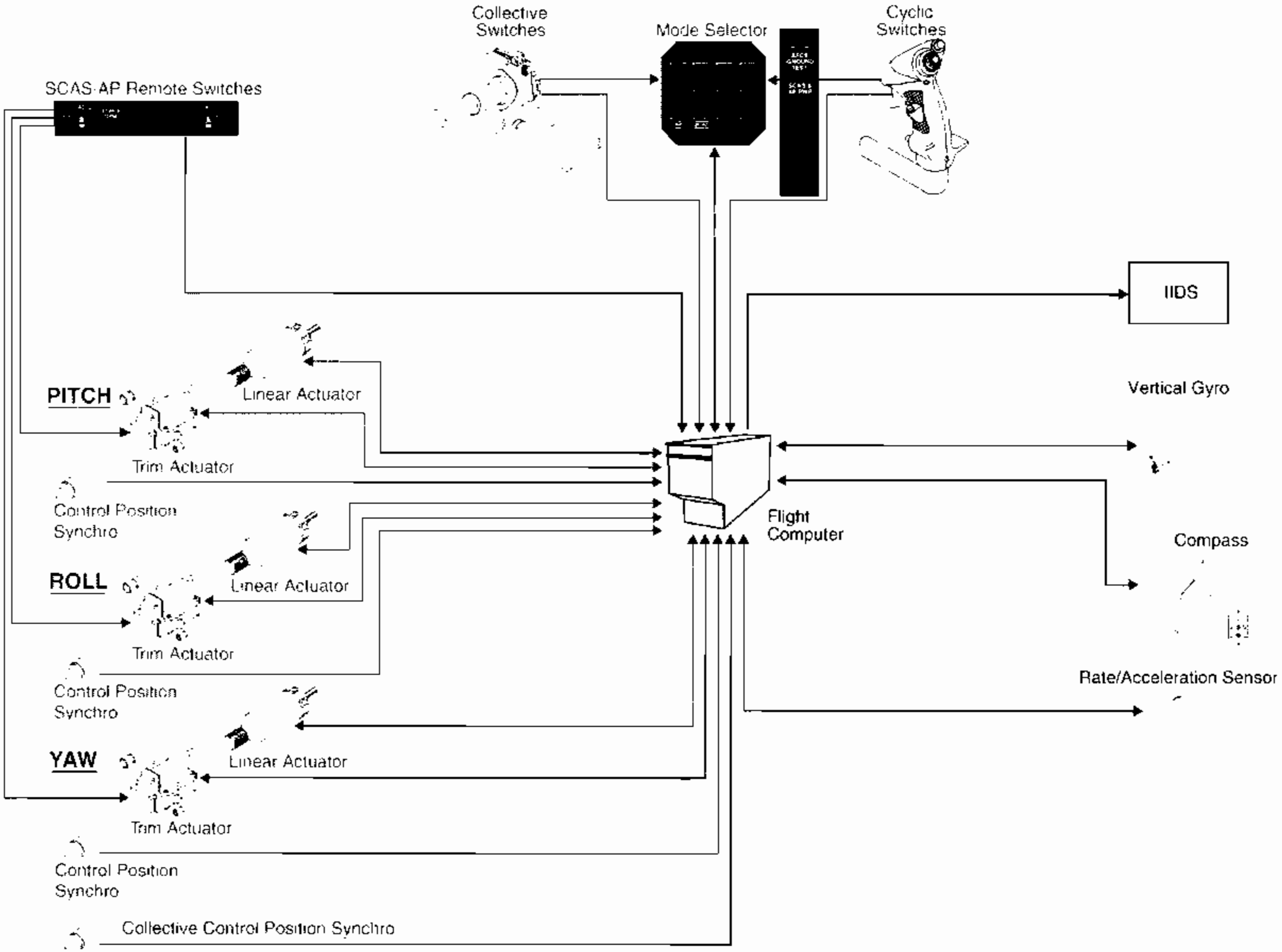


Figure 79: Component Location Example Augusta 109K2

1	Autopilot Computer
2	Autopilot Controller
3	Actuator Display
4	Attitude Director Indicator
5	Airspeed Sensor
6	Airspeed Switch
7	Yaw Axis Linear Actuator
8	Pitch & Roll Axis Linear Actuators
9	Pitch, Roll & Yaw Axis Artificial Feel & Trim Units
10	Collective Artificial Feel & Trim Units
11	Flight Director Computer
12	Barometric Sensor
13	Vertical Accelerometer
14	Longitudinal & Lateral Accelerometer

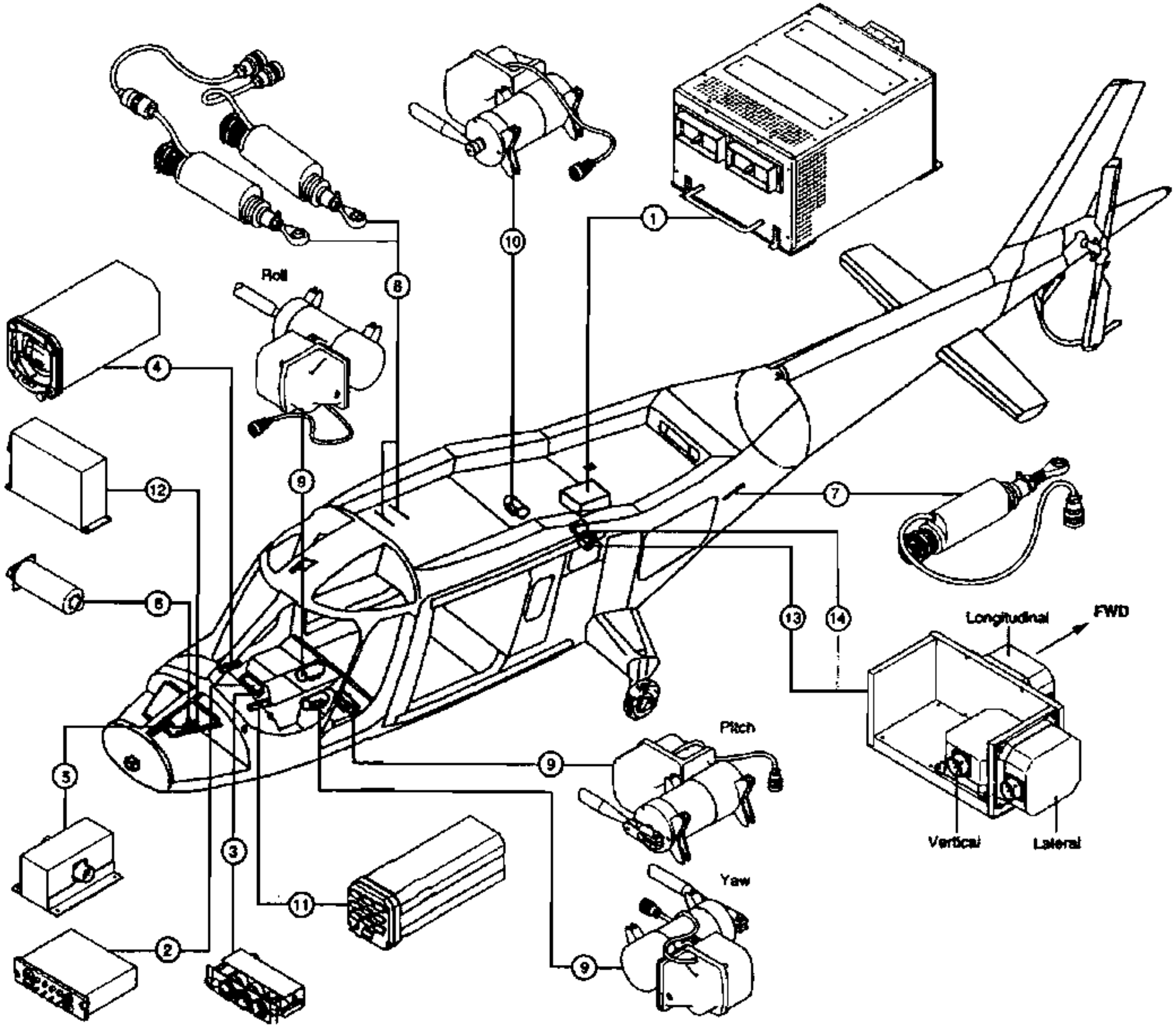
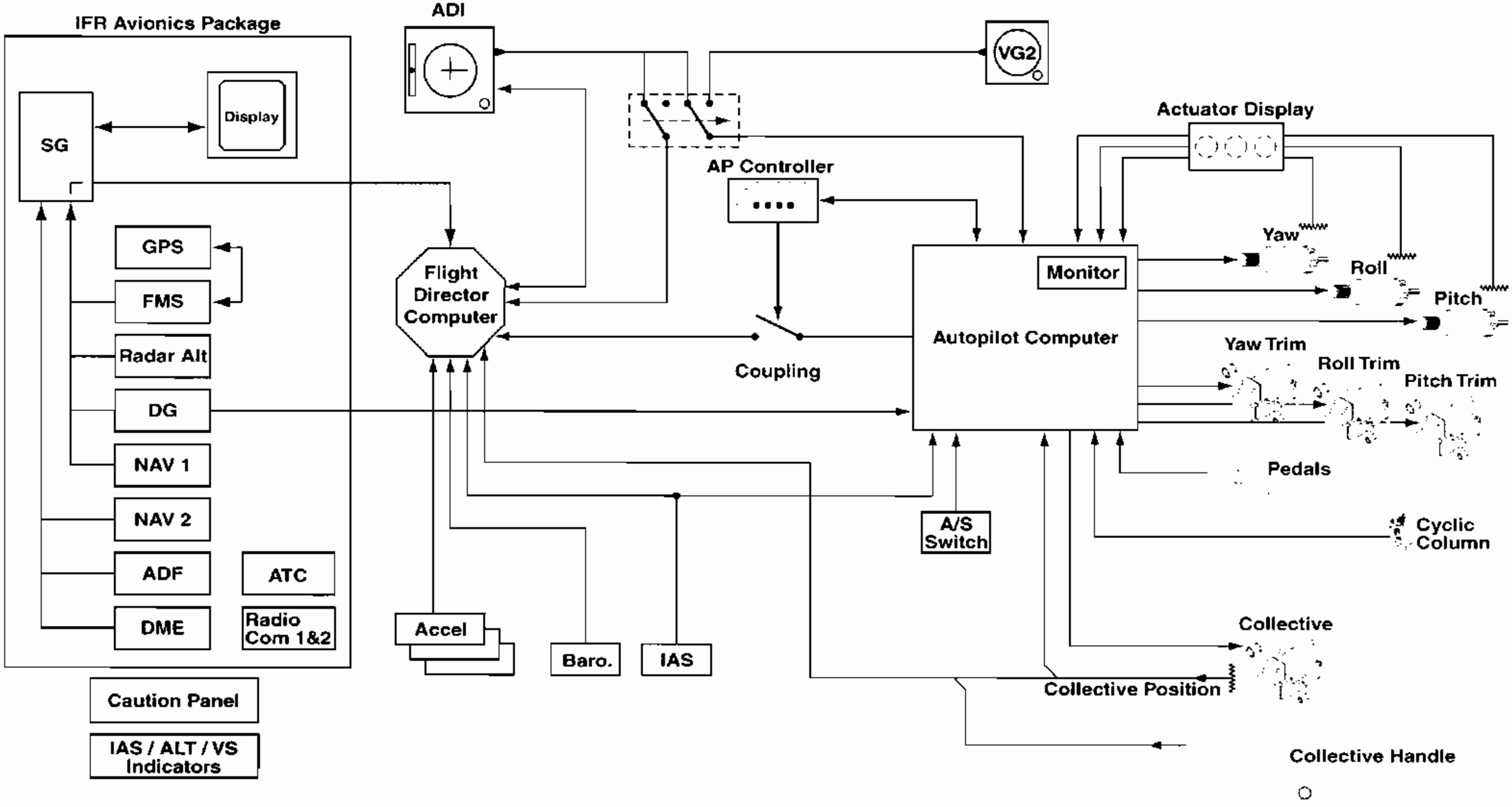
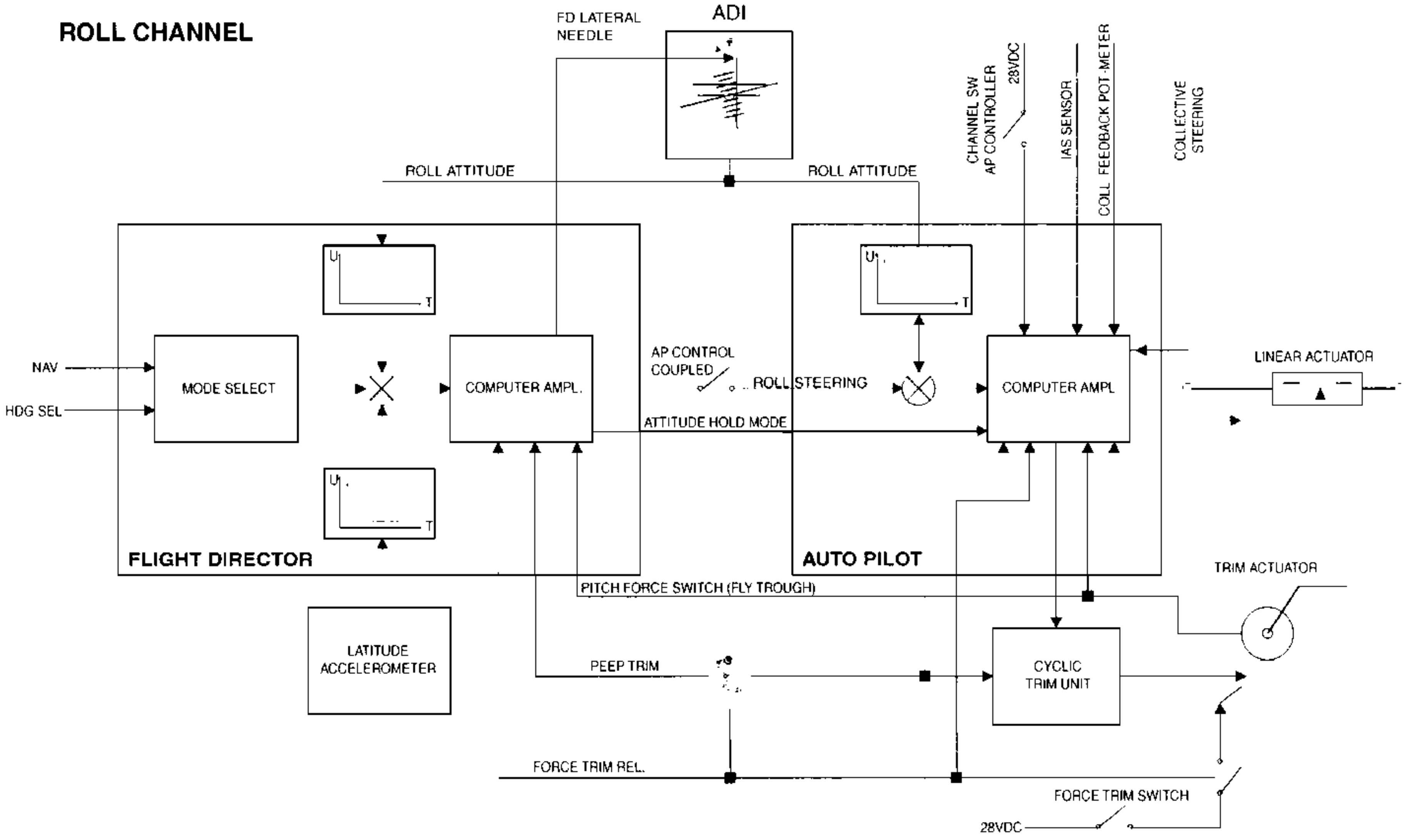


Figure 80: Block Diagram Autopilot (Example Augusta A109)



Schematic of a Control Channel

The following figure shows a schematic diagram of a roll channel. Pitch and Yaw channels are almost identical in design.



Airworthiness Criteria for Helicopter Instrument Flight

Stability Augmentation System (SAS)

1. If a SAS is used, the reliability of the SAS must be related to the effects of its failure. The occurrence of any failure condition which would prevent continued safe flight and landing must be extremely improbable. For any failure condition of the SAS which is not shown to be extremely improbable:
    a) The helicopter must be safely controllable and capable of prolonged instrument flight without undue pilot effort. Additional unrelated probable failures affecting the control system must be considered.
    b) The flight characteristics requirements in Subpart B of Part 27 must be met throughout a practical flight envelope.
2. The SAS must be designed so that it cannot create a hazardous deviation in flight path or produce hazardous loads on the helicopter during normal operation or in the event of malfunction or failure, assuming corrective action begins within an appropriate period of time. Where multiple systems are installed, subsequent malfunction conditions must be considered in sequence unless their occurrence is shown to be improbable.]

Auto Throttle/Thrust

Introduction

The auto throttle system controls the power setting of the engines to reach and maintain a preselected speed or thrust limit. A servo moves the thrust levers or an electronic signal commands the engine power via the engine control unit

The ATS operates in the following modes:

IAS HOLD Provides control of throttles to hold the current airspeed.

IAS SELECT Provides control of throttles to capture and hold the selected reference airspeed.

MACH HOLD Provides control of throttles to hold the current MACH number.

MACH SELECT Provides control of throttles to capture and hold the selected reference MACH number

THRUST LIMIT/TARGET Provides control of throttles to capture and hold thrust at the thrust limit/target.

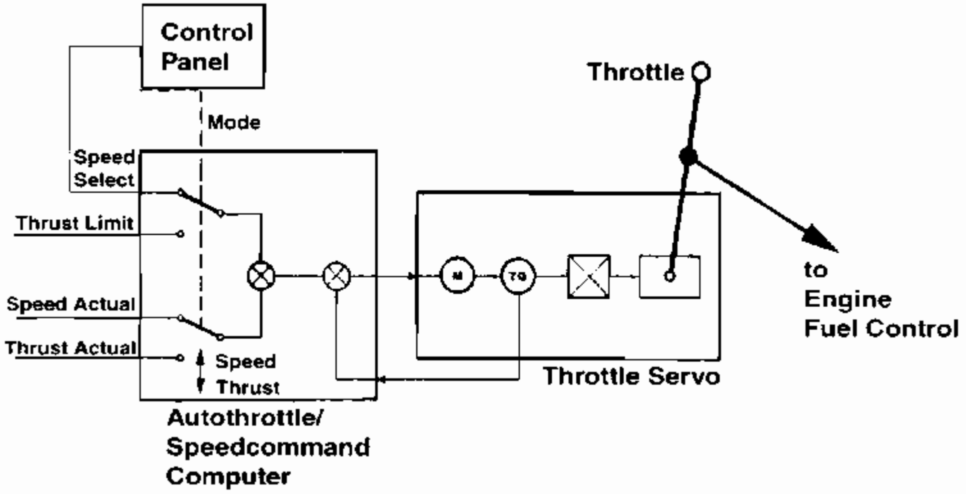
RETARD Provides control of throttles to reduce thrust at the appropriate radio altitude during the landing flare mode.

CLAMP Inhibits ATS control during takeoff at approximately 80 knots without causing disengagement of the ATS. Full manual throttle is available during this mode.

Engine Thrust Trim

The engine thrust trim system is available during both, manual and automatic throttle operation. It is engaged any time, when two or more engines are operating above an EPR/N1 threshold. The engine thrust trim system will maintain the engines at a common thrust setting to eliminate the need for throttle adjustments. Automatic engine trim is independent of air/ground operations.

Figure 81: Auto Throttle Principle



Auto Throttle MD-11

A single or duplex throttle system is used to provide a drive to the aircraft throttle quadrant. The motor drives via the thrust control slip clutch to move all thrust control (throttle) levers. Manually operation of the throttle levers is any time possible. The throttle-position is transmitted as thrust demand to the Full Authority Digital Engine Control (FADEC) to the engines.

Pressing the auto throttle disconnect switches disconnects the auto throttle function.

Pressing the Go-around switch will:

- Aircraft on ground:
  Throttles will move to maximum thrust limit if they are manually moved over a certain limit.
- Aircraft in flight land-approach:
  the levers moves forward to reach GA thrust.

Figure 82: Throttles with GA and Disconnect switches

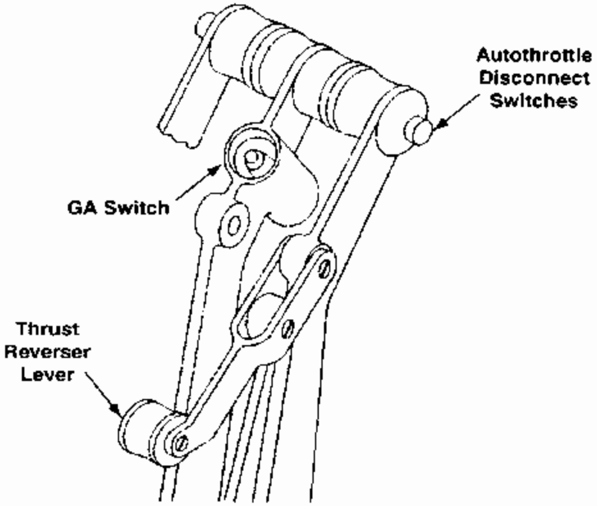
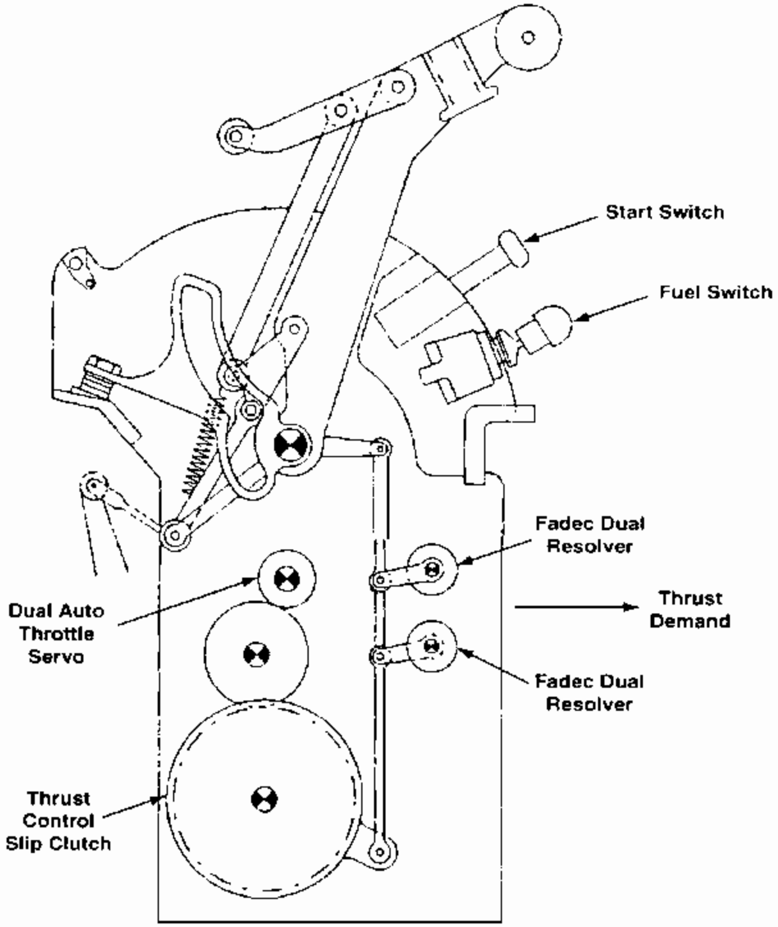


Figure 83: Throttle Module



Auto Thrust A320 A330 A340 A380

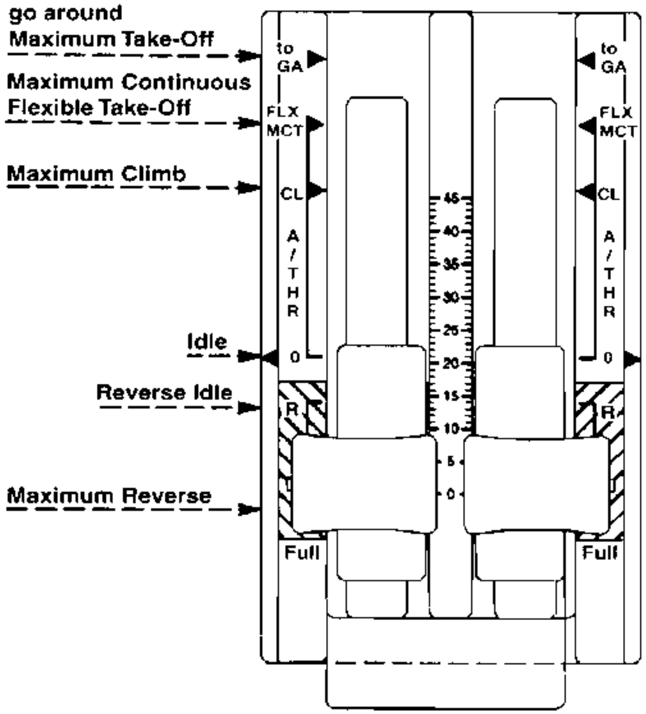
Thrust Control

Thrust control is provided by the Electronic Engine Control dedicated to each engine. Thrust selection is achieved by means of the thrust levers when in manual mode or automatic mode. Thrust rating limit is provided by the Auto Flight System according to the thrust lever position both for manual and automatic thrust control.

Thrust Levers

The thrust levers can only be moved manually. They move over a sector which is divided into 4 operating segments. There are 5 positions defined by detents or stops. Thrust lever position is transmitted to the Electronic Engine Control which displays the position of the Thrust Lever Angle (TLA) as the commanded (predicted) N1.

Figure 84: Thrust Levers



Thrust Limit

The maximum allowable engine thrust is a function of:

- Selected Flight mode like:
  - Take off
  - Take-off flexible for a derated take off
  - Go around
  - Maximum continuous thrust
  - Climb thrust
  - Cruise thrust
- Ambient condition like:
  - Ram air temperature RAT or TAT
  - Airspeed CAS
  - Altitude
- Bleed-air demand from engine for:
  - Anti ice and airconditioning.

The thrust limit is shown as EPR-Limit or N_1 Limit depending of the engine model. The limit is shown at a dedicated indicator: Thrust rating indicator, EPR indicator.

The auto throttle servo controls the engine thrust to the limit.

The assumed temperature is used for a derated take off thrust limit computation. This temperature is assumed to be higher than the actual outside air temperature.
TAT = Total Air Temperature, RAT = Ram Air Temperature.
TO-Flexible is used for noise abatement, environment and engine protection.

Figure 85: MD 80 Thrust Rating

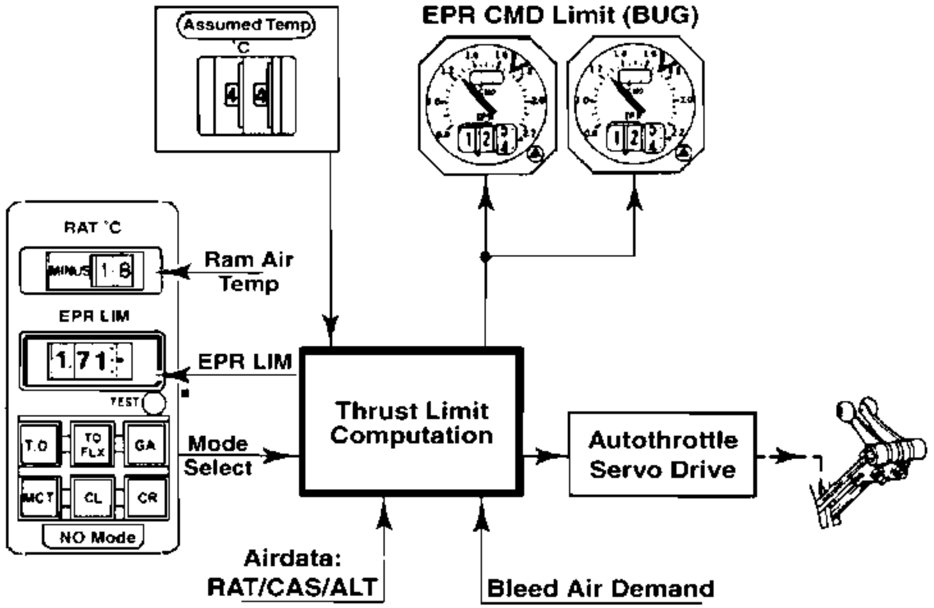
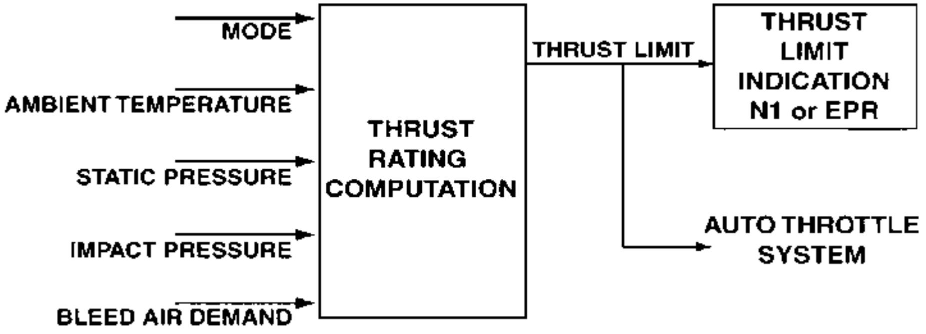


Figure 86: Thrust Rating Computation



Thrust Rate Limit Computation

Thrust rating limit is computed according to the thrust lever position. If the thrust lever is set in a detent the Electronic Engine Control will select the rating limit corresponding to this detent.

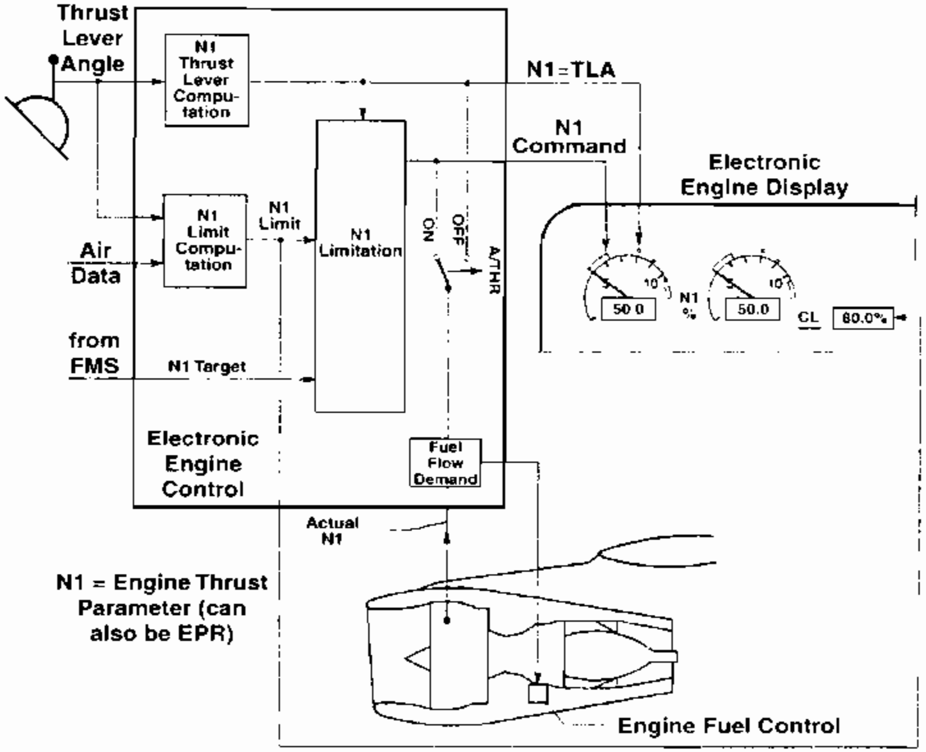
Thrust lever computation. Thrust selection is achieved according thrust lever position. In manual thrust mode the selected thrust is applied as the fuel flow demand.

The limit computation is computing the engine thrust limit according ambient temperature, airspeed, altitude thrust lever position and bleed air demand.

The thrust limitation is limiting the thrust to the limit or target trust.

When auto thrust is engaged the target thrust from flight management system is lower than the limit thrust computed in the electronic engine control. So the flight is more economical

Figure 87: Thrust Control (Airbus)



Warnings

Overview

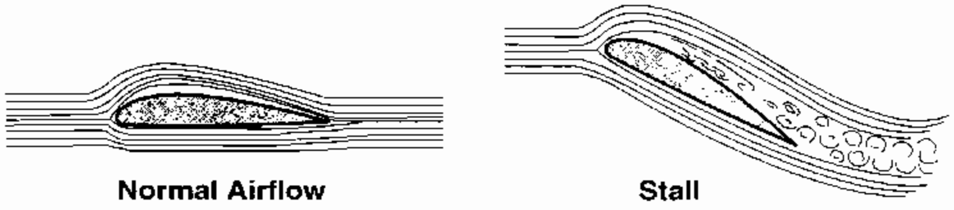
Different warnings are covered in a modern flight guidance system:

- Stall
- Altitude alert
- Wind shear
- Flight envelope protection
- Autopilot failure/disengage

Stall

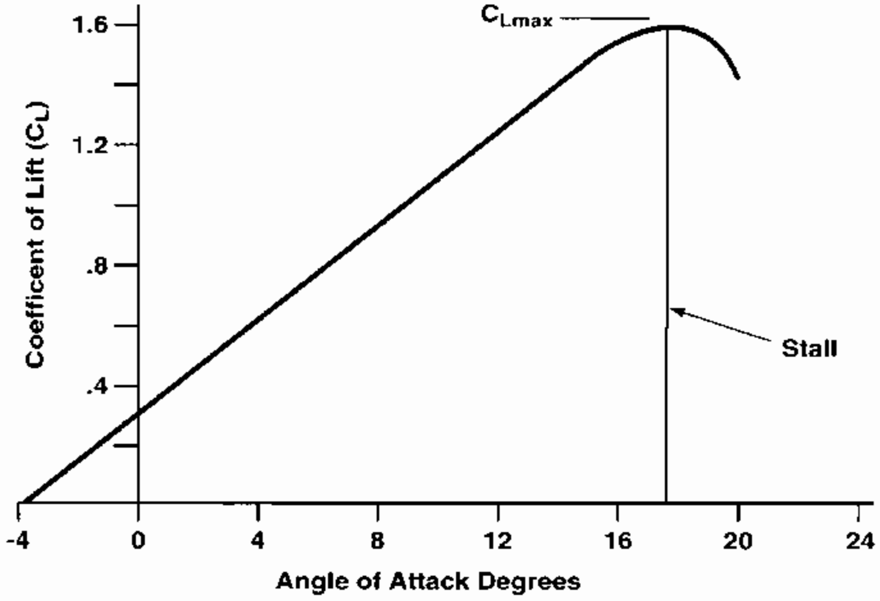
A stall is caused by the separation of airflow from the wings upper surface. This results in a rapid decrease in lift. For a given airplane, a stall always occurs at the same angle, regardless of airspeed, flight attitude or weight.

Figure 88: Wing



As angle of attack increases, the coefficient of lift also increases. this continues to a point where C_L peaks. The point of maximum lift is called C_{Lmax}. If the maximum lift angle is exceeded, lift decreases rapidly and the wing stalls.

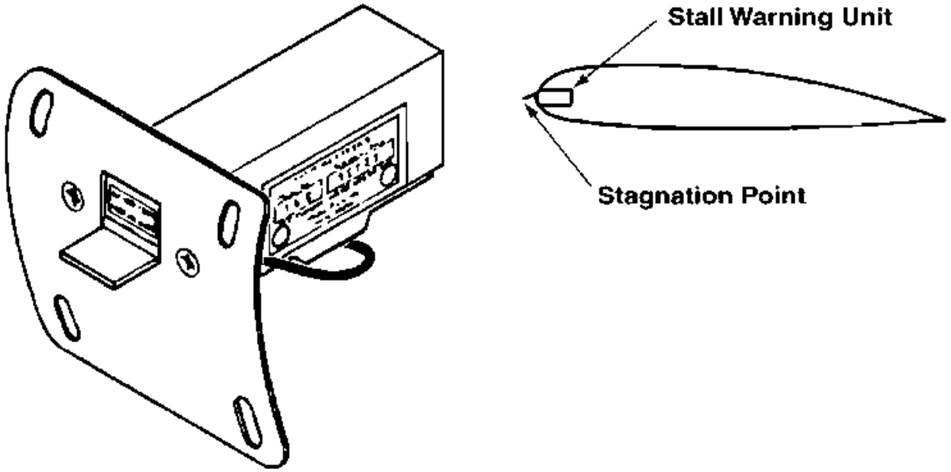
Figure 89: Lift vs. Angle of Attack



Stall Sensor

An electrically operated stall warning system uses a small vane mounted near the stagnation point in the leading edge of the wing. At flights above the stall speed, the airflow over the vane is downward and the vane is held down. An electrical switch connected to the vane is open when the vane is down. As the angle of attack increases to the extent that a stall is impending, the stagnation point moves down until the airflow over the vane is upward When the vane is blown up, the switch is closed and either a red light is turned on or a warning horn is sounded, or both.

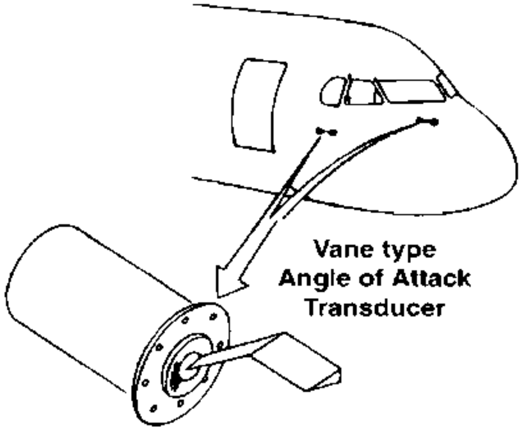
Figure 90: Stall Warn Switch



Angle of Attack Sensor AOA

The vane is used to sense the angle between the airflow and the longitudinal axis of the airplane. The angle of attack is used for static source error correction, stall warning/protection and other avionics system.

Figure 91: Vane Type Sensor

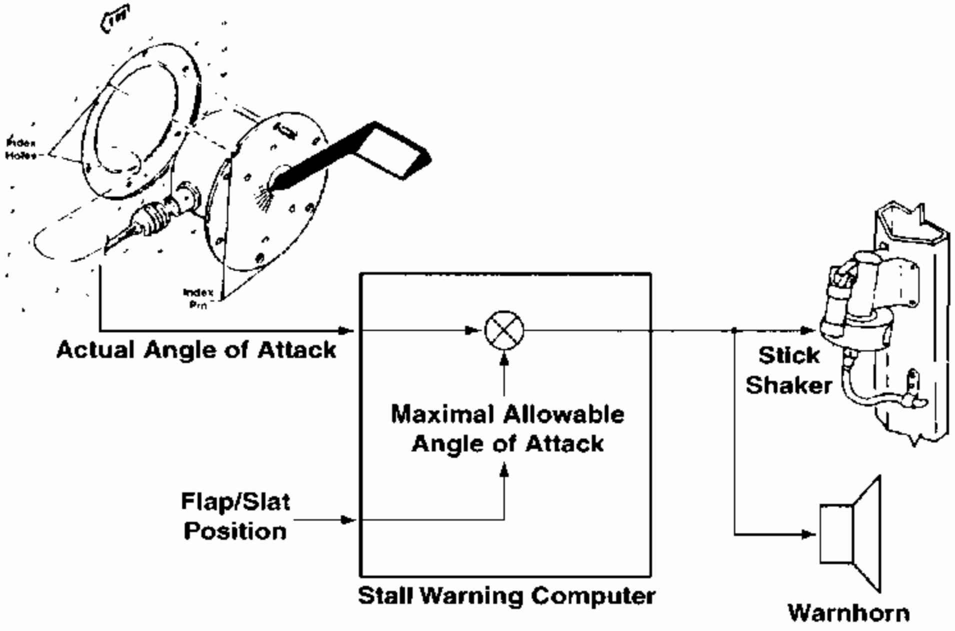


Stall Warning

System activation occurs as a function of angle of attack and flaps, slats and horizontal stabilizer position.

Increasing the angle of attack will activate stick shakers at captain's and copilot's control column to indicate a pre-stall condition. At stall an aural warning is heard and visual indication (STALL-light or -indication at PFD) is shown.

Figure 92: Stall Warning System

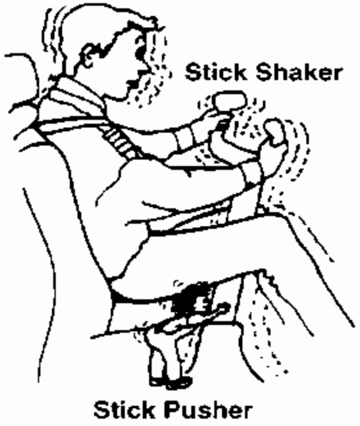


Stall Prevention

Stick Pusher will be activated which pushes the control column forward. The stick pusher remains active until either stall warning conditions are no longer fulfilled, or manually disengaged via a dedicated switch.

Autoslat Extension controls the slats automatically to the correct position, to have the correct wing geometry to prevent a deep stall.

Figure 93: Stick Pusher



Altitude Alert

The altitude alerting functions give visual and aural alerts when the aircraft deviates from, or comes close to, a selected altitude. The altitude alert function makes altitude entry and exit alerts. To make the alerts the function compares a selected altitude with the current altitude from the air data computer or the altitude hold reference altitude.

The altitude entry alert is a visual and an optional aural alert. The visual alert comes on the EFIS or warning light. The aural alert is a "C" chord from the flight warning system, when the program pin for this option is enabled.The entry alert resets when the aircraft comes outside the entry alert area or when the crew selects a new target or alert altitude. Refer to the illustration for the alert areas.

The altitude exit alert is visual and aural.The exit alert resets when the aircraft is back within the alert area or when the crew selects a new altitude.

Figure 94: Altitude Alert System

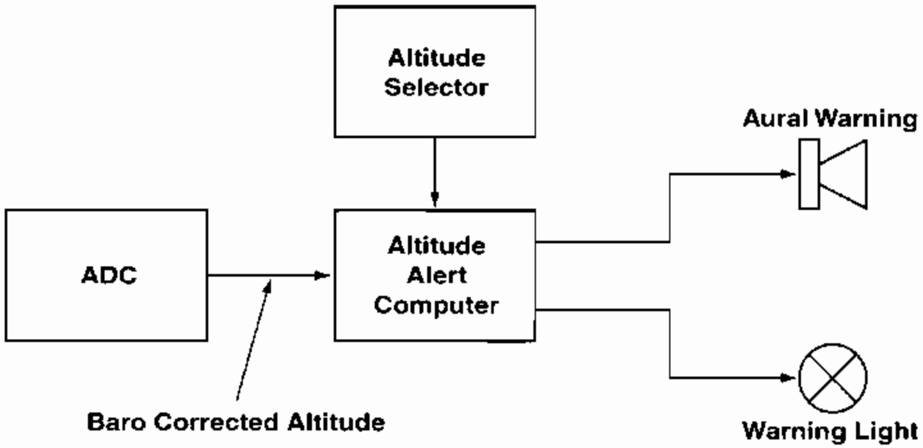
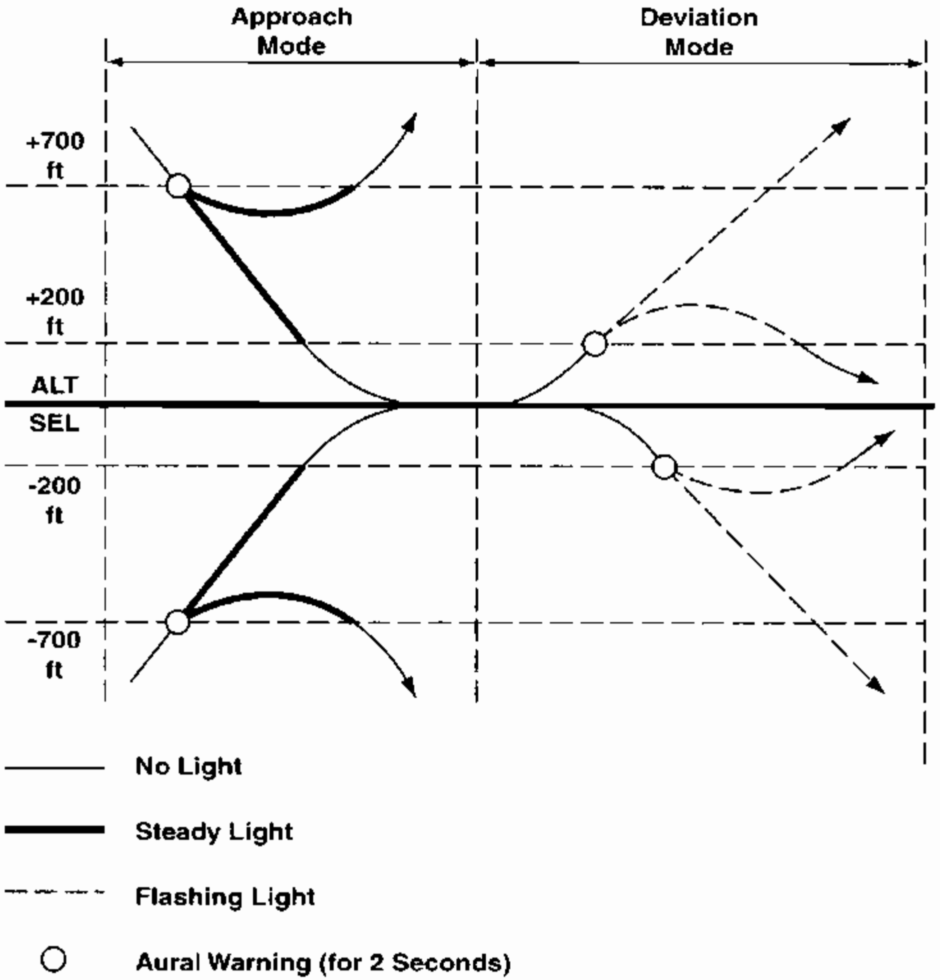


Figure 95: Altitude Alert Thresholds



Wind Shear

Windshear means a strong horizontal or vertical windshift that acts at right angles to the direction the wind is blowing. Wind shear, normally associated with the passage of a front, can be dangerous if an aircraft flies through one when slowed for landing or immediately after takeoff.

Microburst is a localized, extremely high-intensity column of descending air. They have such extreme downward velocity that any aircraft, when flying slow near the ground, as during takeoff and landing, can be slammed into the ground before it is able to fly out of it.

Comparing the airspeed from Airdata-Computer with groundspeed from Inertial reference system gives the information about the wind to the aircraft. Any change of the wind means windshear.

The windshear alert and guidance system (WAGS) provides detection, alerting, and guidance through windshear The categories of headwind shears and tailwind shears are formed based on the wind change direction with respect to the aircraft.

Updrafts are categorized as Headwind Shears-Increasing Performance
Downdrafts are categorized as Tailwind Shears Decreasing Performance

On takeoff the WAGS is available from 80 kts to 1500 feet RA.
On landing the WAGS is available from 1500 feet RA to 50 feet RA.

The WAGS gets data from the air data computers ADC, the inertial reference system (IRS), and other AFS components. The windshear detection circuits which compare inertial and airspeed rate are integrated in the dual-channel FCCs. The WAGS will provide visual warnings on the PFD / FMA and aural warnings through the CAWS. FD and AP are provided through the AFS.

The flight director and /or autopilot pitch guidance during takeoff, landing and go-around is provided for best flight path relative to the ground.

Figure 96: Windshear

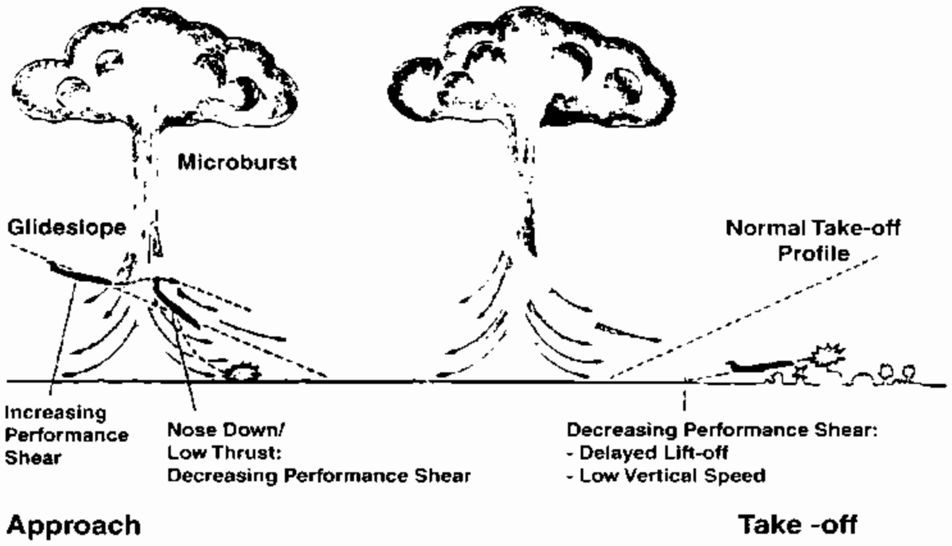
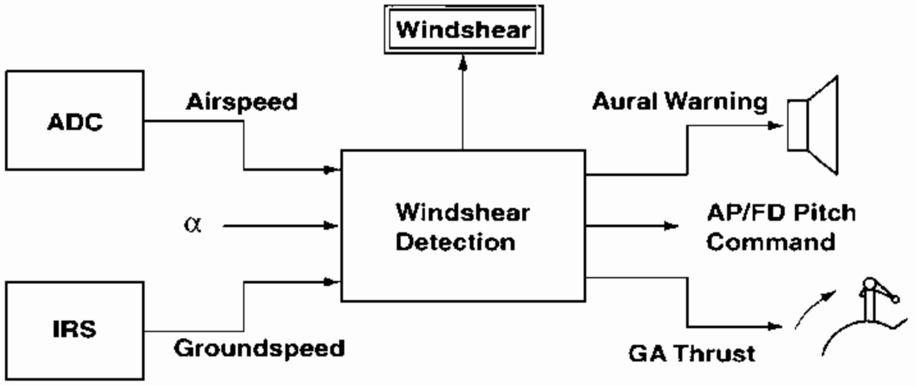


Figure 97: Warning and Recovery System



Flight Envelope Protection

The Flight Envelope (FE) part detects aircraft configurations outside the normal flight envelope such as:

Aircraft weight computation

Center of gravity computation

Aft center of gravity out of tolerated limit

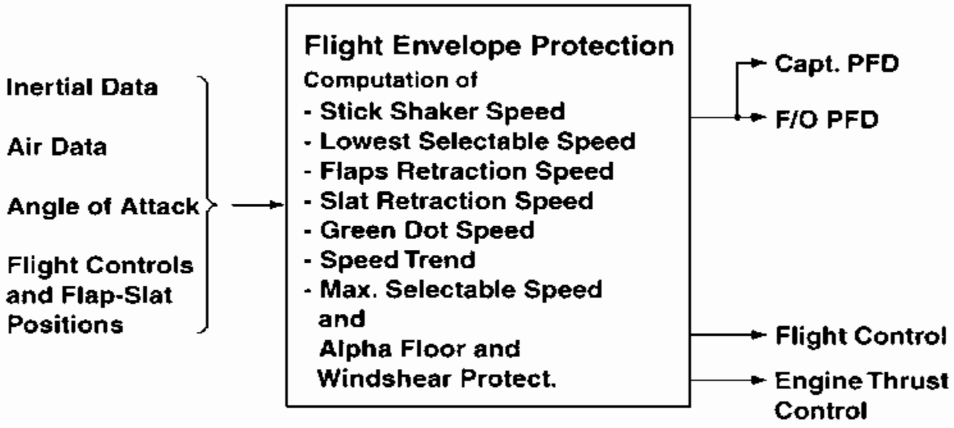
Alpha floor acquisition

Wind shear conditions

Operational Speed computation

Lateral asymmetry due of engine failure

Figure 98: Envelope Protection



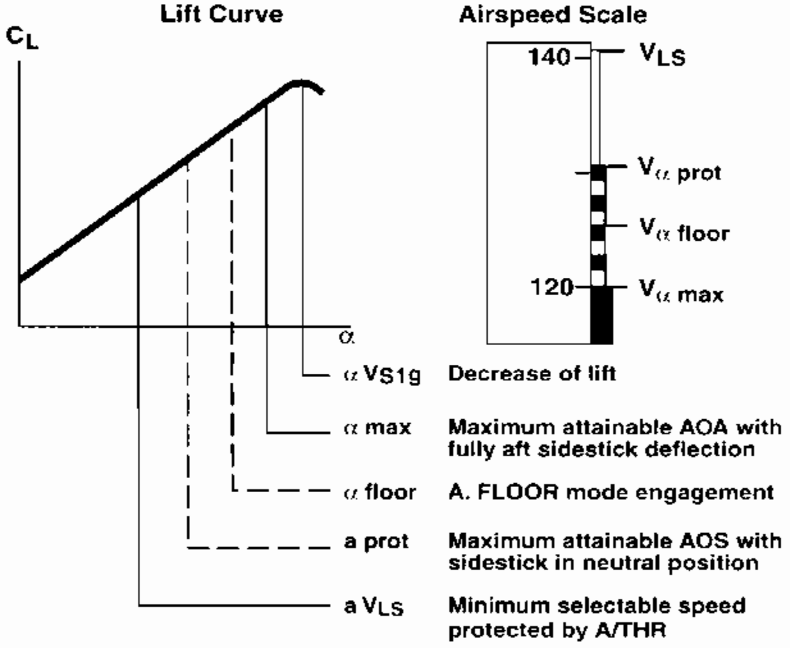
Speed Protection

Following speeds are generated in the Flight Augmentation Computer (FAC) and displayed on the speed scale of the PFD:

- Maximum selectable speed
- speed trend
- slat retraction speed
- flap retraction speed
- lowest selectable speed
- Stall warning speed

Alpha-floor signal for protection against high angle-of-attack.

Figure 99: Various Speeds



Operational Speed Computation and Display

The Flight Envelope function computes the limit and manoeuvring speeds which are displayed on the speed scale of the Primary Flight Display.

F Speed is a manoeuvring speed which means minimum flap retraction speed and corresponds to the speed at which flaps can be retracted.

S Speed is a manoeuvring speed which means minimum slat retraction speed and corresponds to the speed at which slats can be retracted.

VLS means lower selectable speed. It is the minimum selectable speed for the actual slat and flap configuration taking into account the control lever position, the real surface position and the speedbrake configuration. The lowest selectable speed provides a safety margin in order to avoid stalling at low speed and buffeting during cruise.

VMAN or **Green Dot** is a manoeuvring speed and is a function of the weight, the altitude and the number of engines running. It is the optimum speed in the event of one engine failure.

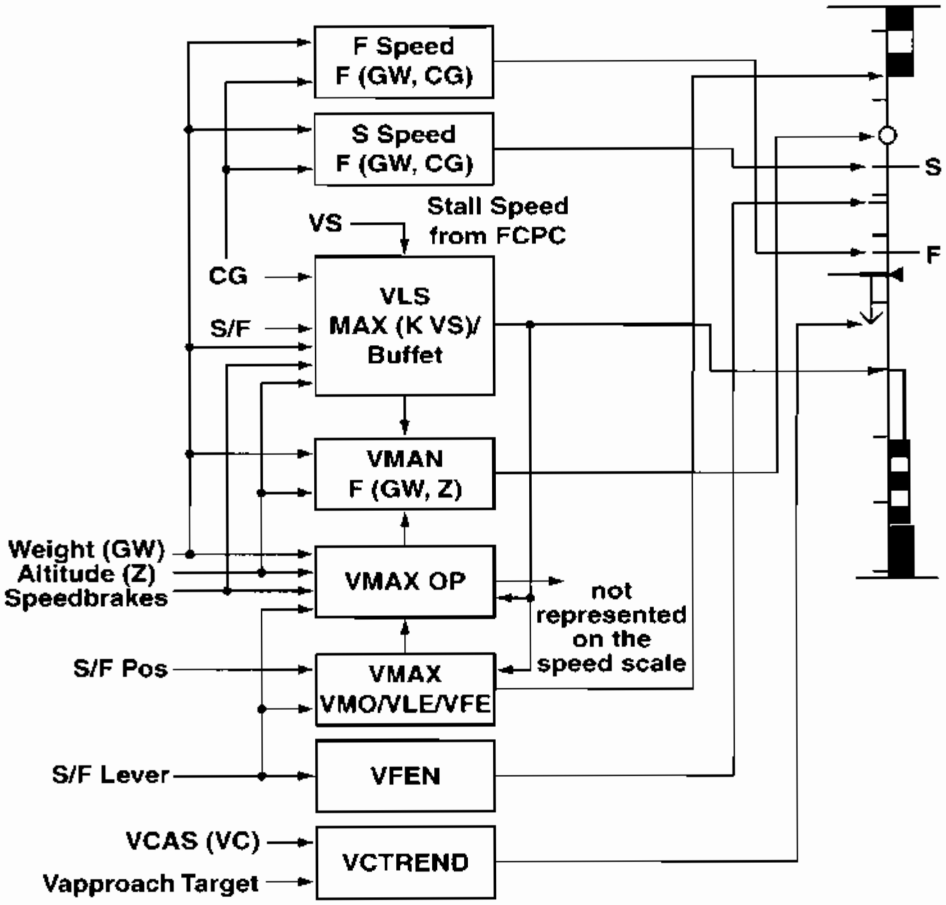
VMAXOP is the maximal operational speed used as a limit in the Flight Guidance part. Note that it is not presented on the Primary Flight Display.

VMAX speed is the maximal speed. It is used by the Auto Flight System in order to prevent excessive speed. The maximal speed corresponds to the Maximum Operating Speed/ Mach (VMO/MMO) in any configuration.

VFEN corresponds to the maximum flap and slat extension speed of the next slat/ flap configuration. The predictive Maximum Flap Extended Speed at next S/ F position.

VCTREND represents the airspeed tendency, that means the aircraft acceleration or deceleration. The airspeed tendency is computed to represent the speed that the aircraft would have 10 seconds later if the acceleration remains constant.

Figure 100: Speed Computation and Display



Auto Flight Failure Warnings

Warning and alerting systems calling the pilots for attention at system failures and alerting the pilots at complete system dropout. Also limit exceeding of flight limits are visually and acoustical presented.

Autoland lights

are triggered below 200ft. in LAND and FLARE mode if an automatic landing related failure occur.

Master warning lights

illuminates red if autopilot disengages due of system failure or manual disengagement. Cavalry charge sound is broadcasted. (Level 3)

Master caution lights

Illuminates amber if a auto flight related failure occurs that causes not a complete disengagement. Single chime sound is broadcasted. (Level 2)

Cockpit speakers

broadcasting a specific sound (Cavalry charge) if the autopilot disengages.
Single chime sounds if Master Caution light is on.
Triple click sounds if the autoland category is downgraded CAT3/CAT2
C-chord sounds for altitude alerting.
Different voice warnings are audible. "STALL", "WINDSHEAR" etc.

Engine and warning display E/WD

presenting warnings and cautions.

System display SD

presenting the actual system status of the flight guidance system.

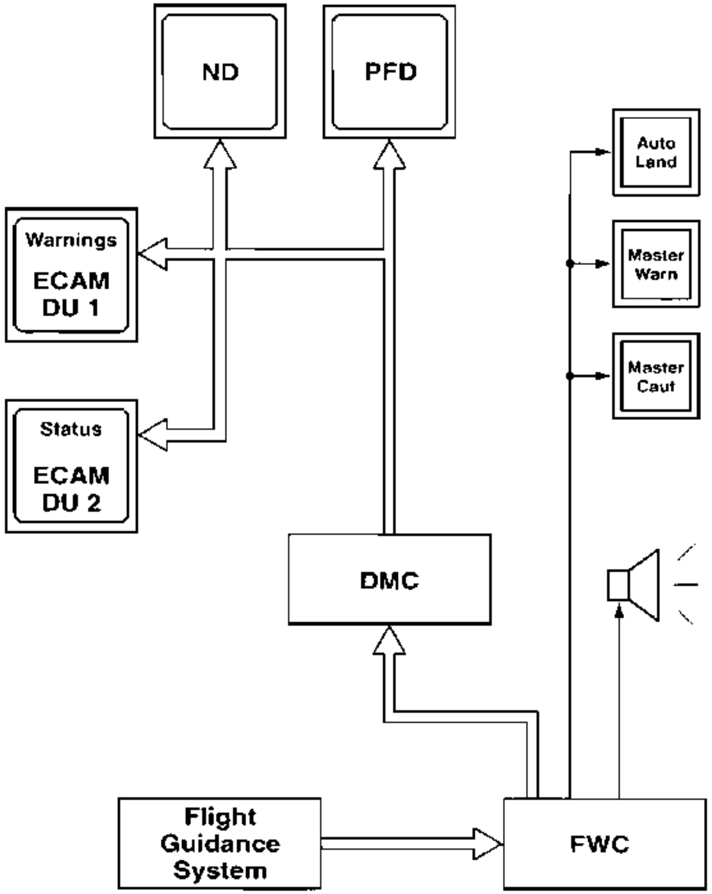
Primary flight display PFD

presenting the actual and armed automatic flight mode and
windshear warning and different flight envelope speeds.

Navigation display ND

presenting the horizontal flight situation.
No specific autoflight messages are shown.

Figure 101: Failure Warning Block Diagram



Fault Isolation and Test

Build In Test

In advanced technology aircrafts with digital flight guidance computers, test and maintenance devices are integrated to assist maintenance engineers for trouble shooting. Some aircraft types are equipped with a dedicated auto flight system status/test or maintenance panel, others use the multipurpose control and display units (MCDU) to access the integrated fault isolation and detection system.

AFS Maintenance Panel

A very useful, the STATUS/TEST panel, is installed in the flight compartment. The panel allows two way communication with the built-in test system (BIT). It provides the operator upon request with a display of memorized failures, test instructions respectively test results and autoland availability.

The Status Test Panel (STP) is the primary Digital Flight Guidance System (DFGS) troubleshooting tool. There are three functions the STP provides:

- Flight Fault Review
- Return To Service Test
- Maintenance Test

The DFGC runs continuous internal self-tests and controls a valid light (CMPVLD) on the Status/Test Panel. Failures detected by these self-tests and other automatic tests are logged in Flight Fault Review. The Maintenance/Return to Service Tests are to be used primarily to test DFGS sensors and inputs for correct operation.

Figure 102: DFGC's and Maintenance Panel

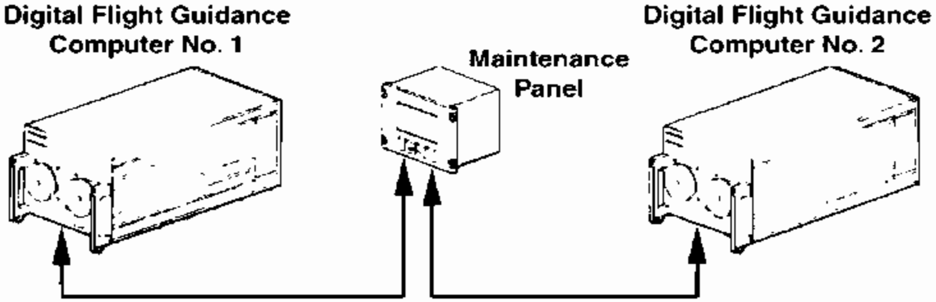
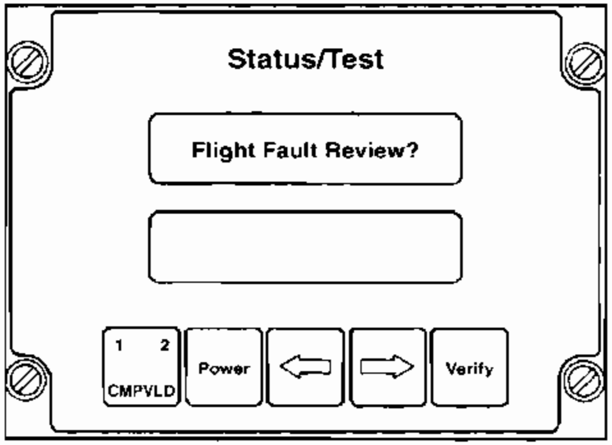


Figure 103: Maintenance Status/Test Panel



Flight Fault Review

This section is used to read failures which occur during flight. The DFGS continuously monitors the performance of itself and all of its sensors for proper operation. If a unit should fail at any time in flight, a corresponding failure will be logged by the DFGC. These failures can then be read out on the STP. Flights and failures are read out in a first-in/last-out method. Therefore, the most recent failure will be the first one in Flight 1. Flight Fault Review has enough memory to log about 350 failures. These failures can be erased by using the Maintenance Memory Erase Feature. Doing this will erase all failures logged in FLIGHT FAULT REVIEW.

Return To Service Test (RTS)

The RTS test is a fast, comprehensive system recheck which is to be run after performing line maintenance. The test requires operator interactions and takes less than 5 minutes to run. At the conclusion of the test, the message "GO" or "NO GO" appears. If a "GO" is received, then the system is capable of performing all of its functions, including fail-passive Category IIIa automatic landings. If "NO-GO" - appears, then one or more failures have been detected and the system affected by the detected failure will be displayed.

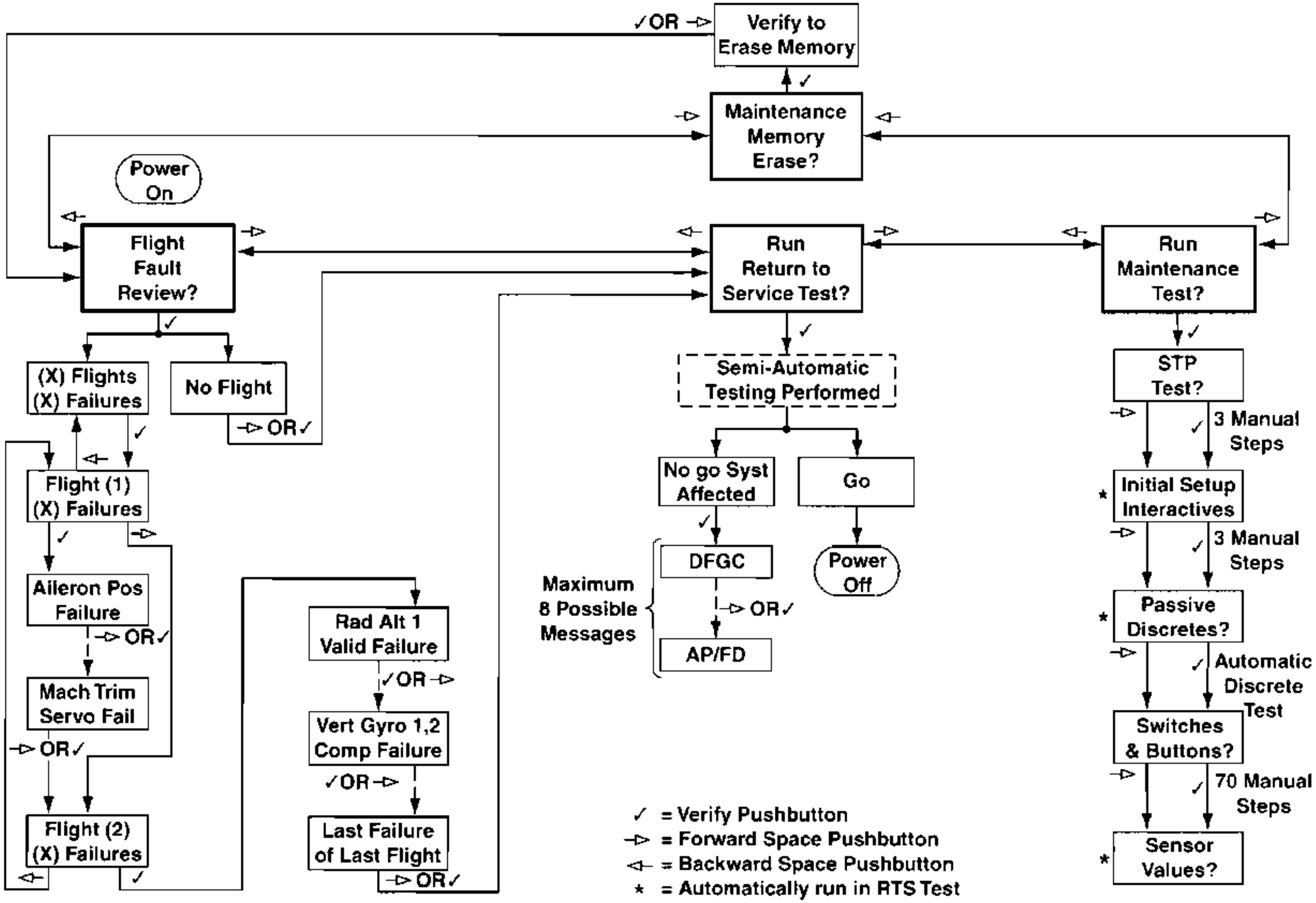
Maintenance Test

The Maintenance Test is an extensive system troubleshooting test. It is structured so that specific tests can be performed to isolate DFGS failures by selective use of the forward space, back space, and verify push buttons.

The flowchart on the left is to be used with the STP to operate the different levels described above. More detailed information on the STP is provided in the Maintenance Manual (C 22-01-05). See the troubleshooting section for a complete list of all failure definitions for those failures that can appear in the Flight Fault Review, the RTS, and the Maintenance Test.

The Flight Management and Guidance Computer performs several tests to isolate any system failure or failed component.

Figure 104: Flow Chart Maintenance Panel (MD-80 Example)



✓ = Verify Pushbutton
▷ = Forward Space Pushbutton
◁ = Backward Space Pushbutton
* = Automatically run in RTS Test

Fault Isolation Detection System

The Auto flight maintenance system comprises a maintenance card and several BITEs. A Fault Isolation Detection System (FIDS) card is physically located inside of each Flight Management Guidance and Envelope Computer (FMGEC). The BITEs are located in the various AFS computers.

The FIDS is connected to the BITEs of the various AFS computers and serves as the SYSTEM BITE. The FIDS is linked in acquisition and reception to the Centralized Maintenance Computers (CMC's).

It receives commands from the CMC, interprets these commands and transfers them to the various BITEs concerned. It can also request the BITE to give complementary information.

It receives malfunction reports from BITEs, manages these reports and, if applicable, consolidates the BITE diagnosis and generates a fault message which is sent to the CMC.

The AFS system BITE has two fault detection and isolation modes.

- In NORMAL MODE, the system stores the failure data relevant to the AFS in nonvolatile memories and transmits this data to the CMC.
- In MENU MODE, the FIDS transmits different menus and submenus according to the operator selection on the MCDU. This is only available on the ground when the CMC itself allows access to System Report Test. The AFS maintenance system always operates in NORMAL MODE as long as it is not interrupted by a CMC request (System Report Test).

The BITE tests performed by the FMGC or FMGEC are:

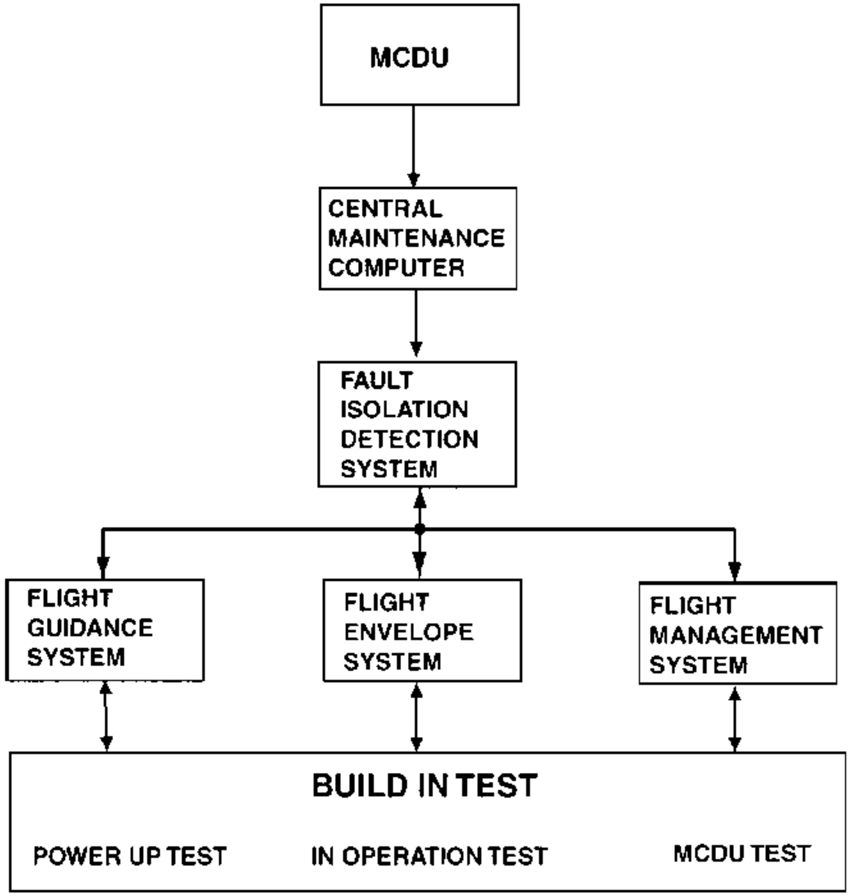
- Power up test
- MCDU test
- In Operation test.

The power up test starts automatically at power up provided that the aircraft is on the ground with engines stopped. It will be Initiated too if the computer power supply has been cut off for more than four seconds under the same conditions.

If the power up test is not ok, you have to dialogue with the FMGC through the CFDS in order to get more information about the failure.

The reading of the BITE contents of the FMGC through the GROUND REPORT function gives the faulty component.

Figure 105: Build In Test access



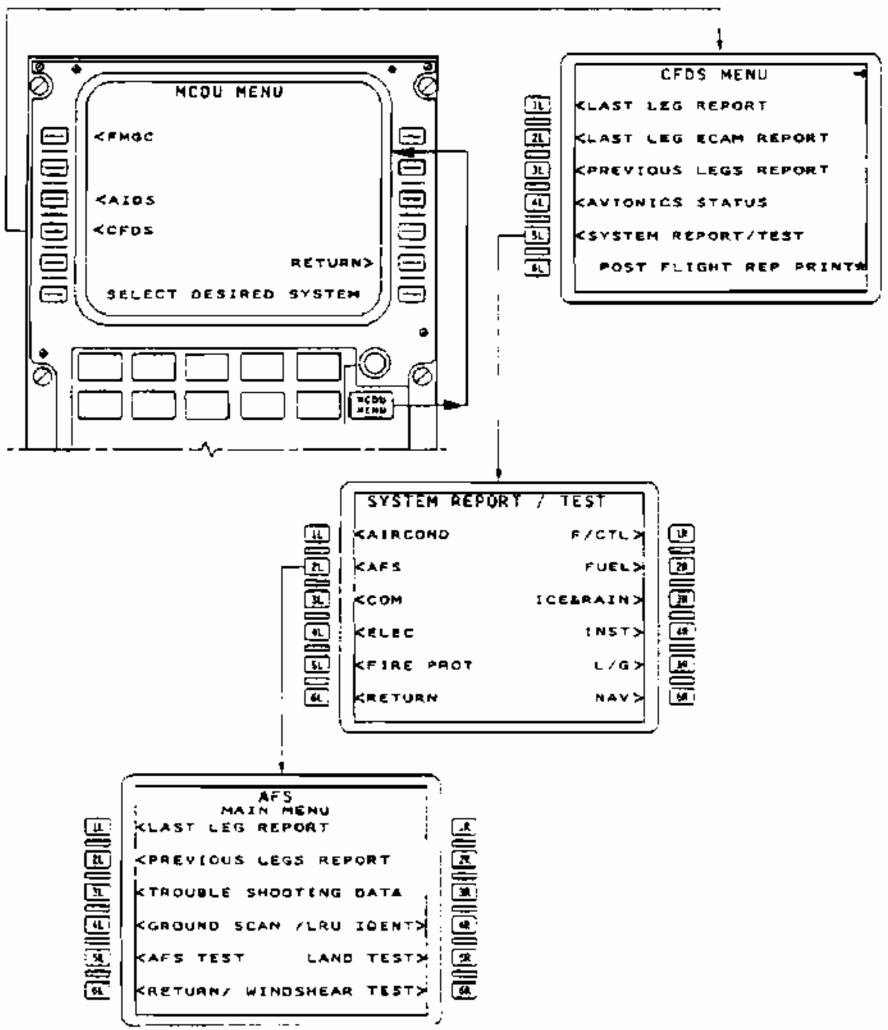
MCDU Test

Each test request made from the MCDU is accepted only if the aircraft is on the ground with engines stopped. The validity of all components can be checked. All the MCDU test requests to the FM are send through the FIDS

These tests are Initiated from the MCDU.

- AFS Test used for:
  Confirmation of an AFS LRU failure before removal.
  Check of a correct Installation and operation of a new AFS LRU.
  Extraction of the status of AFS computer peripheral discretes from ARINC Input messages
- LAND TEST:
  This test enables to check availability of LAND MODE, equipment and wiring required to obtain CAT III.
- GROUND SCAN:
  Simulates that the aircraft is flying. Existing failures are logged in the BITE memory
- IN OPERATION TEST
  The In Operation test is a cyclic test automatically performed when the system operates. During In operation test, the validity of all components are checked.

Figure 106: Auto Flight System Report and Test Initiation



13.4 Communication / Navigation (ATA 23 / 34)

Radio Waves

When a high-frequency AC signal is placed on a special conductor called an antenna, two fields exist: electric fields, called E fields; and magnetic fields, called H fields.

- A shows an electrical generator connected between the two halves of the antenna.
- B shows the development of the magnetic field whose strength is determined by the amount of current flowing. Since this is AC, which periodically reverses, the current is not uniform throughout the antenna, but is minimum at the end of each section, where it reverses, and maximum in the center. The current flows in the direction shown by the arrow I for one alternation and then reverses during the next.
- C shows the development of the electric field. The polarity is shown for one alternation, and the intensity of the E field is determined by the amount of voltage.
- D shows the two fields that exist in the antenna at the same time.

When the AC changes fast enough, the fields do not entirely collapse before the next buildup occurs, and some of the energy is radiated out into space as an electromagnetic, or radio, wave. This wave has two components, the electric wave and the magnetic wave. The waves are at right angles to each other, and both are at right angles to the direction of propagation, or the direction the wave is traveling.

When a radio wave leaves the transmitter antenna, it travels out in space at the speed of light, 300,000,000 meters per second. When this wave strikes the antenna of a radio receiver, it generates a voltage that is a much weaker replication of the voltage in the transmitter antenna.

Figure 1: E and H Field radiated in to Space

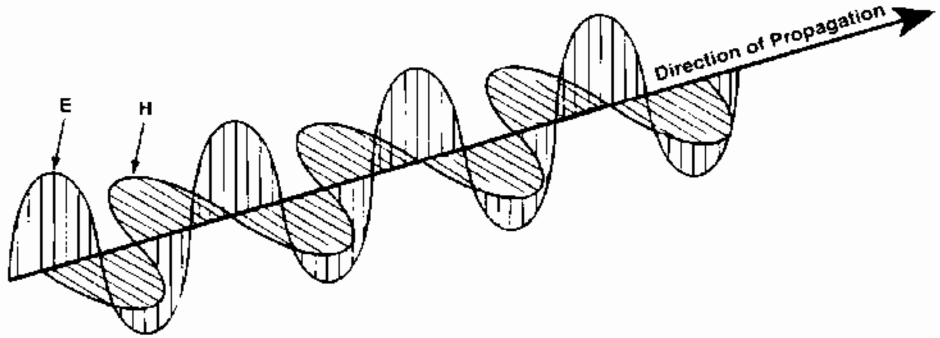
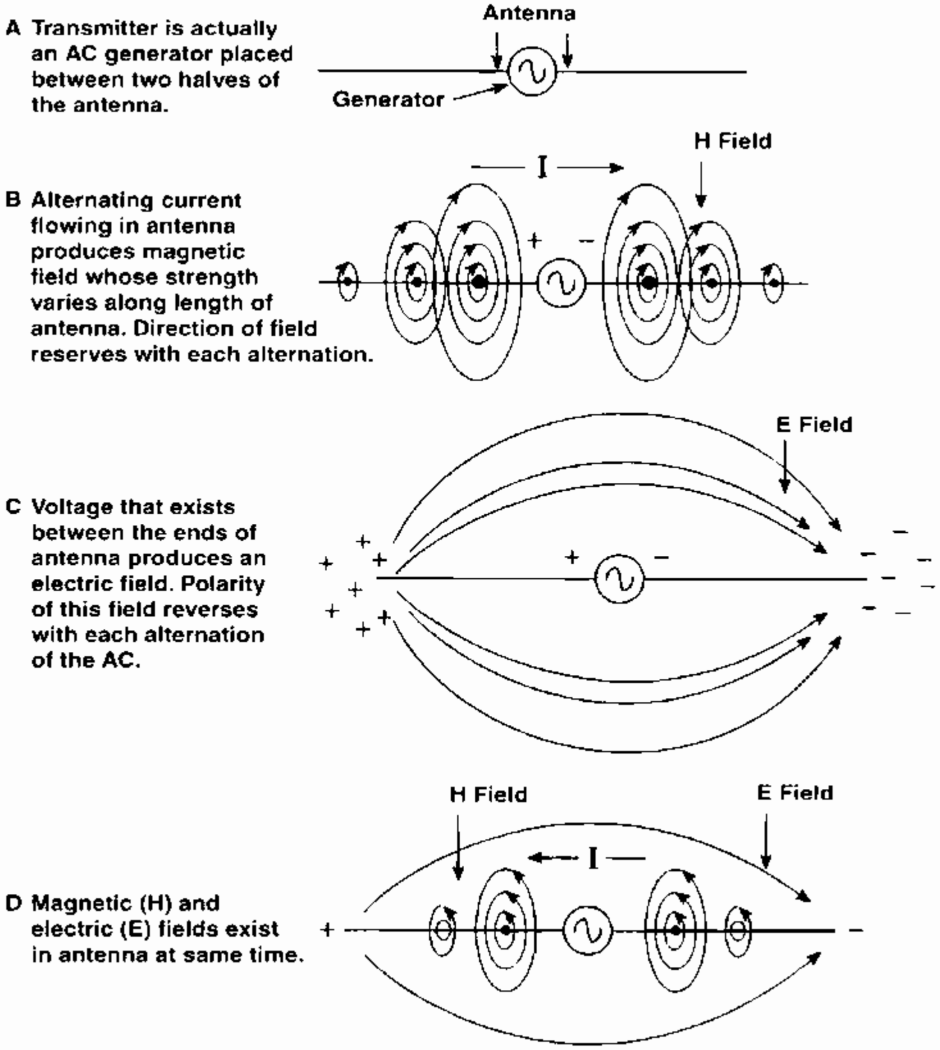


Figure 2: RF - Electromagnetic Fields



A Transmitter is actually an AC generator placed between two halves of the antenna.

B Alternating current flowing in antenna produces magnetic field whose strength varies along length of antenna. Direction of field reserves with each alternation.

C Voltage that exists between the ends of antenna produces an electric field. Polarity of this field reverses with each alternation of the AC.

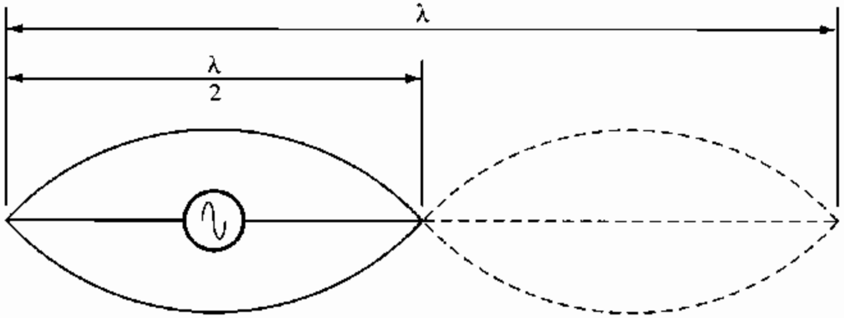
D Magnetic (H) and electric (E) fields exist in antenna at same time.

Antenna

An antenna is a special conductor connected to a radio transmitter to radiate the electromagnetic energy produced by the transmitter into space. An antenna is also connected to the receiver to intercept this electromagnetic energy and carry it into the receiver circuits, where it is changed into signals that can be heard and used. The characteristics that make an antenna good for transmitting also make it good for receiving.

Three characteristics of an antenna are critical: its length, polarization, and directivity. For an antenna to be most efficient, its length must be one-half the wavelength of the signal being transmitted or received, as shown in the figure below. This length allows the antenna current to be maximum.

Figure 3: Antenna Wavelength



When the transmitting antenna is vertical, its electric field is vertical and the magnetic field is horizontal It is picked up best by a vertical antenna. Most LF, MF, and HF communication use horizontally polarized antennas, and higher frequency systems use vertically polarized antennas.

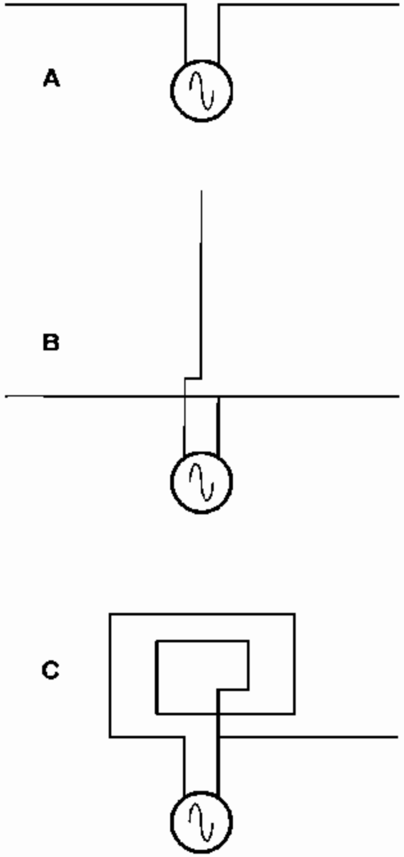
Next figure shows three types of antennas and their directional characteristics.

A The dipole antenna transmits its signal strongest in a direction perpendicular to its length.

B The vertical whip antenna in has a uniform field strength in all directions and is called an omnidirectional antenna.

C The loop antenna is highly directional. Its strength is sharply educed in the direction perpendicular to its plane

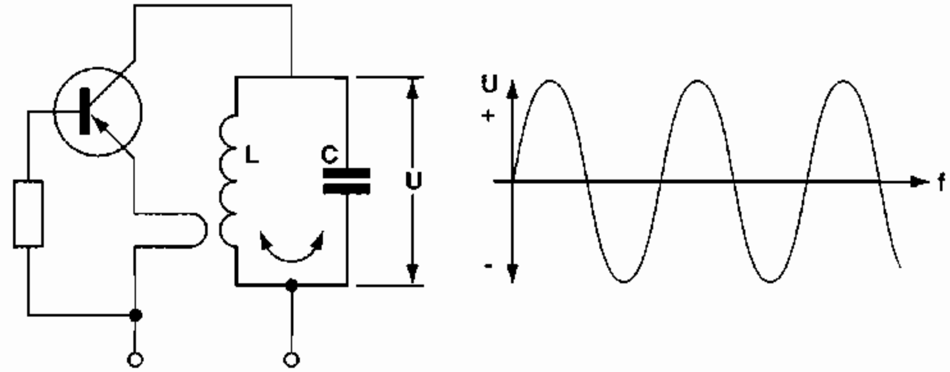
Figure 4: Various Antenna Types



Oscillators

Alternating current is produced with oscillators. There are many different types to produce almost any waveform and frequency. For electronic oscillation to occur, two conditions must be met: Amplification and feedback in the correct phase from the output back into the input. A coil and a capacitor connected in parallel gives a resonant circuit with a specified resonant frequency depending of the capacitance and inductance.

Figure 5: L-C Oscillator with Amplifier



This formula tetermines the resonant frequency of the oscillator circuit.

$$ResonantFrequency = \frac{1}{2\pi\sqrt{LC}}$$

The processes inside a L-C circuit is comparable with a pendule. The potential energy is the electric field in the capacitor, the kinetic energy the magnetic field of the coil. The electric energy changes periodically in the two different forms between capacitor and coil.

a) The resonant circuit has no power

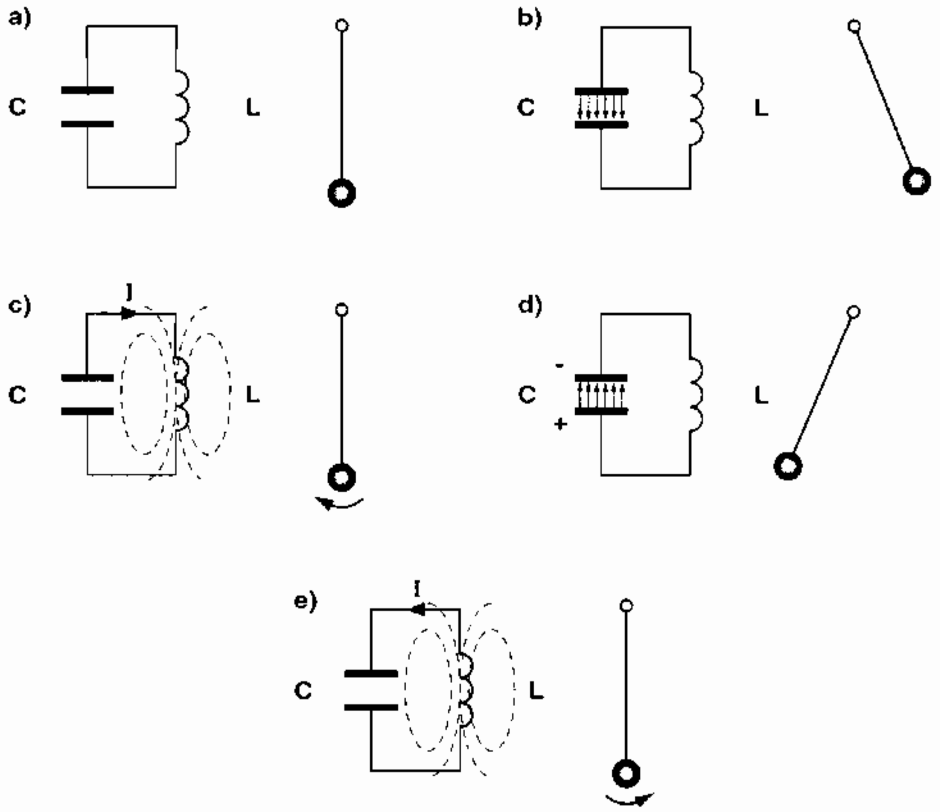
b) The energy is stored in the capacitor like potential energy of the pendule.

c) The energy is in the magnetic field of the coil like kinetic energy of the pendule.

d) The electric energy is back in the electric field of the capacitor

e) The energy is again in the magnetic field of the coil.

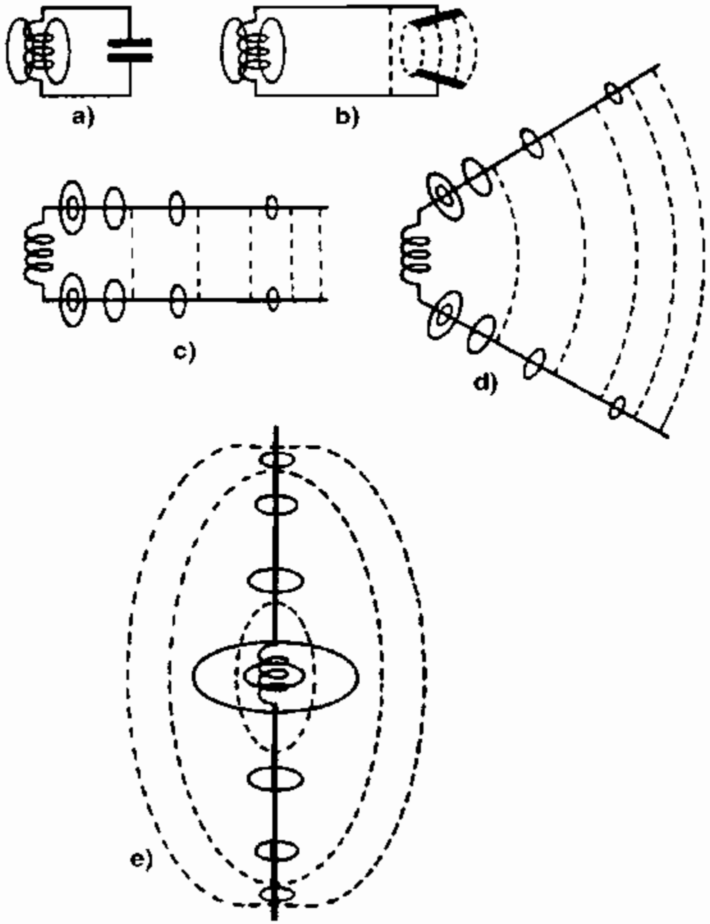
Figure 6: L-C Oscillator Circuit compared with a Pendulum



Antenna, an open Resonant Circuit

The antenna is comparable with a resonant circuit. The energy oscillates between the capacitance and inductance. The circuit is opened and straightened from a parallel circuit a) to the antenna e)

Figure 7: Antenna forming a resonant circuit



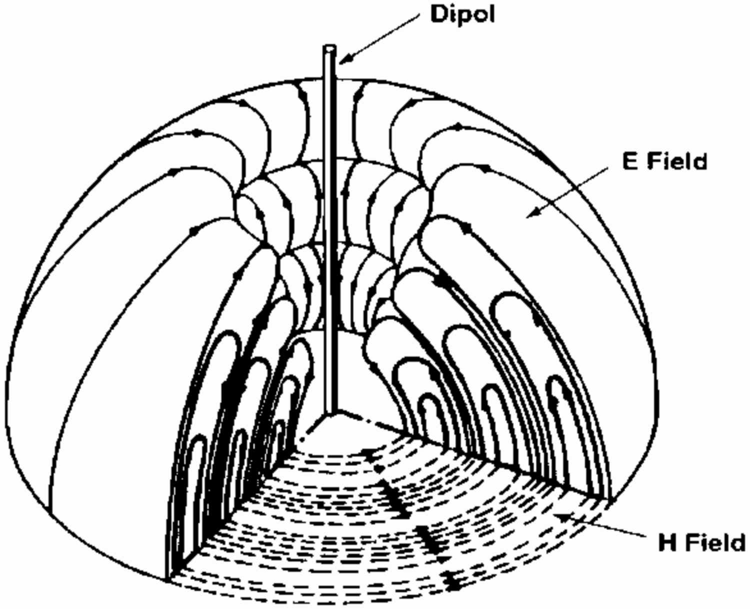
Polarization

To induce the maximum amount of voltage into the receiving antenna, the antenna must be installed in such a way that it is perpendicular to the magnetic H field and parallel to the electric E field in the radio waves.

When the transmitting antenna is vertical, the E field is vertical and the radiation is said to be vertically polarized. The maximum reception is picked up with a vertical antenna.

When the transmitting antenna is horizontal, the radiation is horizontally polarized, and is best received on a horizontal antenna.

Figure 8: Electric- and Magnetic-Fields of a Dipol Antenna



Wavelength

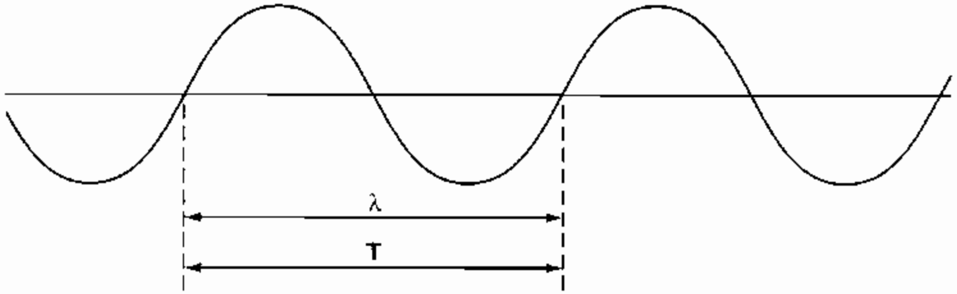
A radio wave is essentially a sine wave, that radiates from the transmitting antenna. There is a definite relationship between the length of the wave and its frequency, and this relationship is extremely important.

The higher the frequency, the shorter the distance between the ends of the wave.

Obtain following definitions:

- **Frequency** f: The number of complete cycles of a recurring event that take place in one unit of time. (Periodes per second)
- **Periode** T: The length of time needed for one complete cycle of oscillation to take place. The periode is inversely related to the frequency of the wave.
- **Wavelength** λ. The distance between a peak or a trough of an electromagnetic wave and the corresponding peak or trough in the next cycle of the wave

Figure 9: Frequency, Period and WaveLength



Wavelength $\lambda = c / f = c \times T$

λ = Wavelength

c = Speed of light = 3×10^8 m/sec = 300'000 km/sec

f = Frequency

T = Time of a Periode = $1 / f$

More simplified:

λ (in Meter) = 300 / Frequency (in MHz/)

Example: Find the wavelength of a signal with a frequency of 127 MHz

Frequency Band

Radio frequencies up to 300GHz are divided into decadic ranges. Each decade is designated as a frequency band. Radar frequencies are divided into special radar bands.

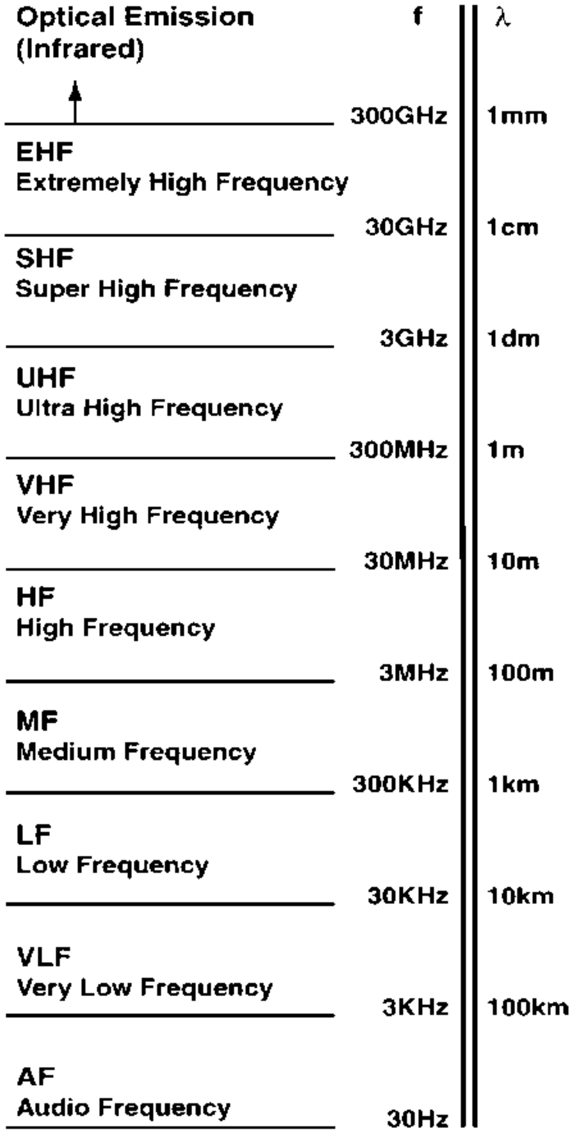
Designation and abbreviations of radio frequencies:

- RF Radio Frequency (Carrier)
- IF Intermediate Frequency
- OF Oscillator Frequency
- AF Audio Frequency

Table 1: Radar Bands

Band	Frequency f	Wavelength λ
P	225 - 390 MHz	133.3 - 76.9 cm
L	390 - 1550 MHz	77.9 - 19.3 cm
S	1.55 - 5.2 GHz	19.3 - 5.7 cm
C	5.3 - 5.8 GHz	5.7 - 5.2 cm
X	5.2 - 10.9 GHz	5.8 - 2.8 cm
Ku	10.9 - 36 GHz	2.6 - 0.8 cm
Q	36 - 46 GHz	8.3 - 6.3 mm

Figure 10: Radio Frequency Bands



Aeronautical Frequency Band

To support the continued growth in the world economy, aviation must continue to introduce new technologies to maintain and improve safety and efficiency and reduce the ATC delays and the environmental impact of its operations. These new technologies can only be implemented if the radio frequency spectrum presently used by aviation is protected from interference from other users and if access is guaranteed.

General concerns

As it is well known, telecommunication is a fast growing industry. To cope with the immense demand of new wide band data transfer technologies, there is an immense need for new frequency bands.

These spectra which intersect for the telecommunication industry are partially identical to the spectra used by aviation. This includes bands used for HF-, VHF-Communications. Primary Surveillance Radar, GNSS, DME and MLS

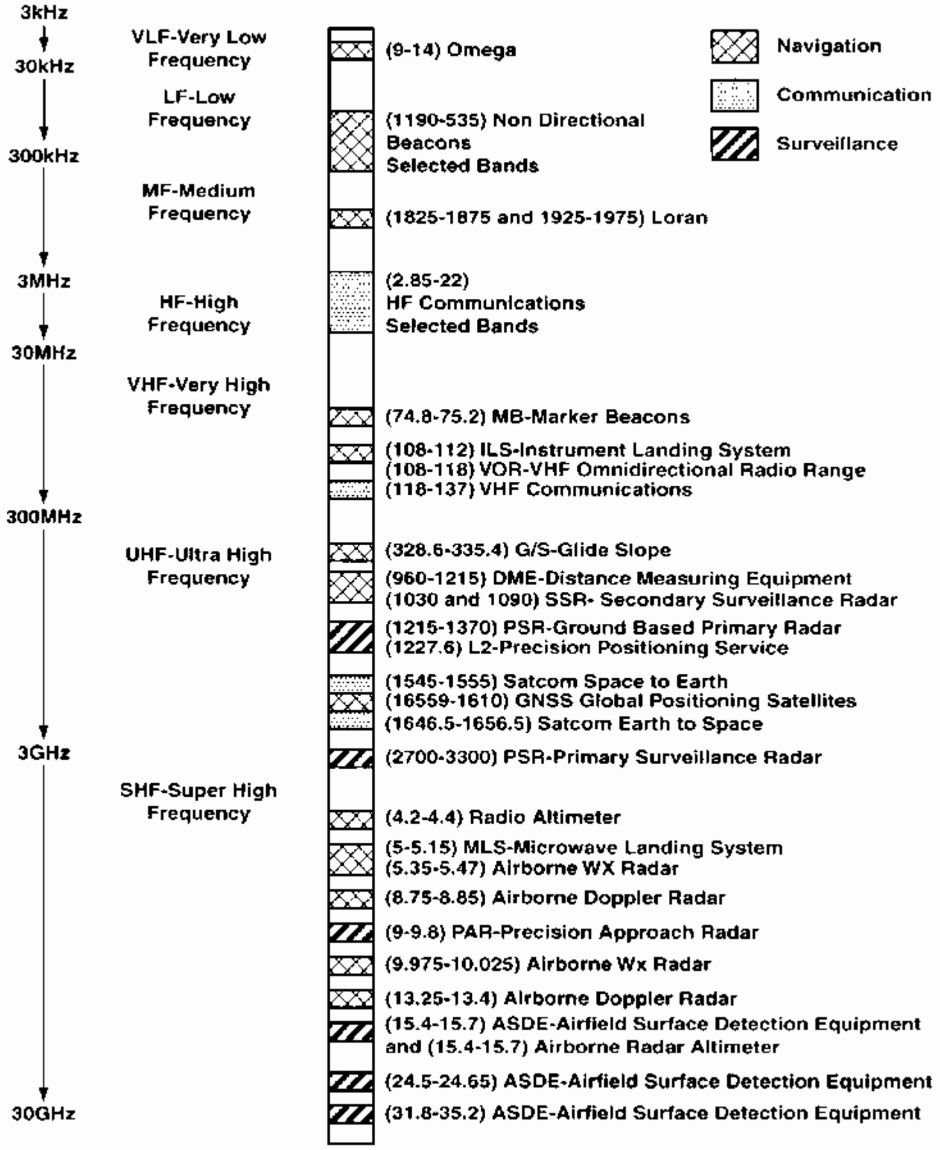
The WRC-2000 (World Radio Conference) has the task of distributing the frequency bands to all users in a balanced manner and in the public (economical) interest.

Importance of protection radio frequencies for aviation

Only the next generation of aviation radio systems introduced predicated in interference free operation, will be certificated for safe use. Until then, aviation systems need an interference free environment, i.e. the frequency spectrum must be protected from other users/systems in the same bands.

The new technologies, such as satellite-based communications systems, have the potential to reduce congestion through improved air traffic control, reduce delays and make air travel safer.

Figure 11: Aeronautical Frequency Bands



Radio Wave Propagation

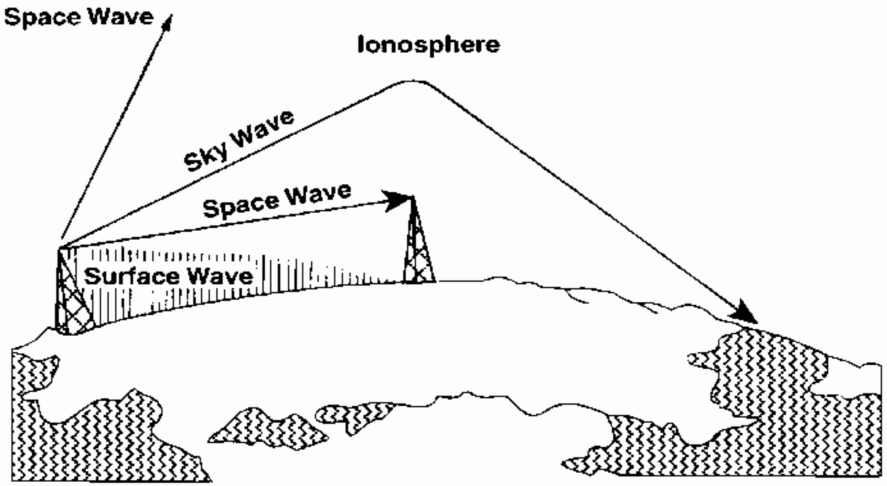
When a radio wave is transmitted from the antenna it moves out along three paths, depending primarily upon its frequency. These paths are surface waves, sky waves, and space waves.

The lower frequencies such as VLF, LF, and MF normally follow the curvature of the earth in surface waves. These waves travel great distances and are used for very long-distance communication and navigation. Commercial broadcast signals follow this path in the daytime.

HF communication and commercial broadcast at night are carried primarily by sky waves. This energy tries to radiate into space, but it bounces off the ionosphere and returns to the earth at a distance from the transmitter. This "skip distance," as it is called, varies and is responsible for the fading of many signals heard from a long distance.

Frequencies in the VHF and higher bands follow a straight line from the transmitting antenna to the receiving antenna and are said to travel by space waves.

Figure 12:



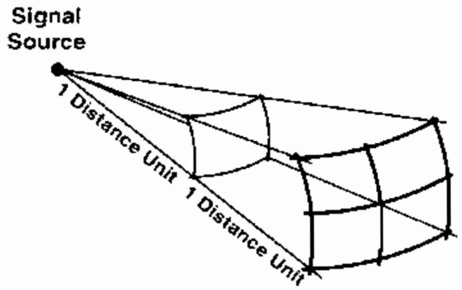
The frequency determines the propagation characteristics.

Radio waves propagate at the speed of light. In fact light waves are electromagnetic waves only of much higher frequency.

Field Strength

The field strength (energy) of radio waves decreases proportionally to the square of the distance from the transmitting antenna. This is due to the fact that the waves are spread over larger and larger areas as the distance increases.

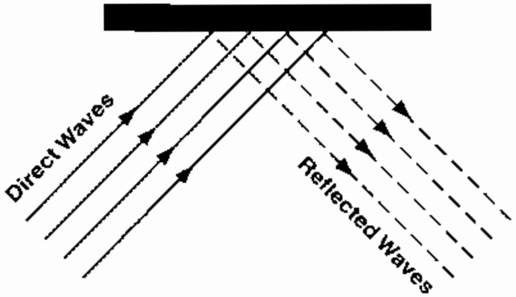
Figure 13: Field Strength



Reflection

Radio waves will be reflected from conducting surfaces in the same manner as light waves are reflected from a sheet of glass.

Figure 14: Reflection

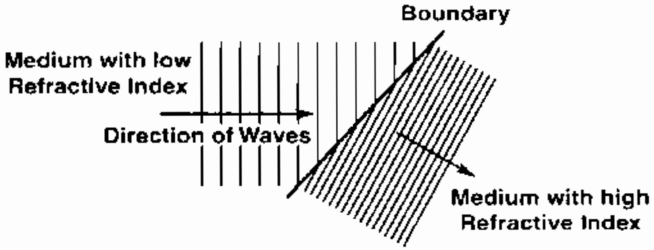


Refraction

When radio waves travel through or over a medium of different conductivity, their path will be refracted (or bent). The classic analogy in optics is the apparent bend in a stick, held at an angle, partly immerged into water.

In radio transmissions the boundary between 2 mediums of different conductivity is not always so abrupt. The radio waves will be bent gradually and their path will be curved at a rate depending on the ratio at which the conductivity of the mediums changes.

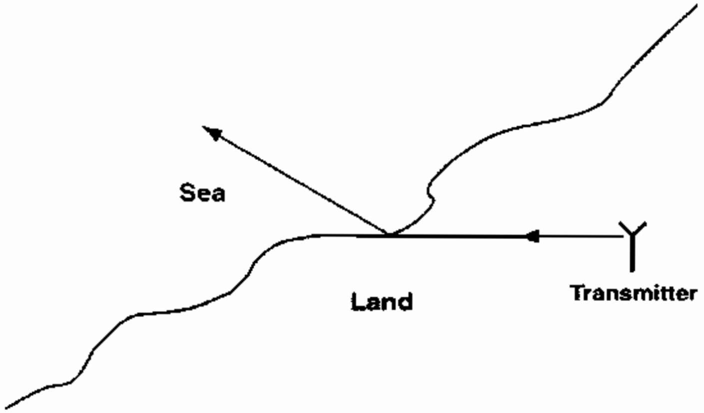
Figure 15: Refraction



Coastal Effect

When radio waves have travelled overland and suddenly cross a coastline, they will be bent abruptly because water has a higher conductivity than land. This phenomenon called coastal effect has its importance in radio navigation.

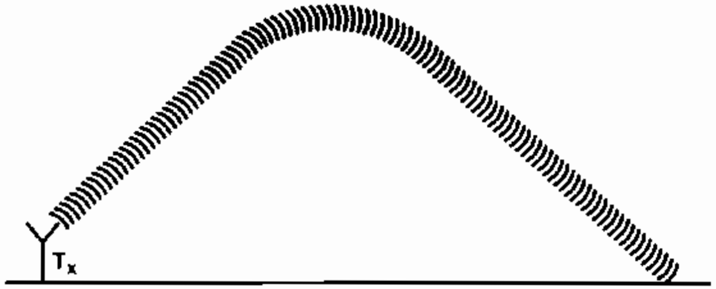
Figure 16: Coastal Effect



Reflected Sky Wave

Radio waves travelling through space with a slower change in conductivity will be bent more gradually until they are eventually reflected to the earth. This phenomenon of space-reflected radio waves is very important in high frequency radio communications.

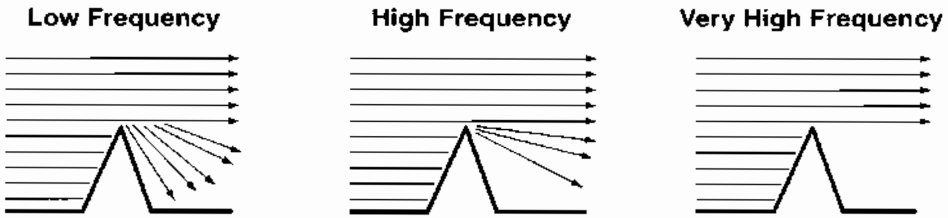
Figure 17: Reflected Sky Wave



Diffraction

Another phenomenon which affects radio waves of lower frequencies is diffraction. Diffraction is the bending of the radio waves when they pass the edge of an obstacle, for instance a mountain top. Diffraction lessens with increasing frequency.

Figure 18: Diffraction



Ground- and Sky Waves

Regardless of their frequencies the propagation of radio waves can be divided into 2 main groups depending on the medium which affects them most.

- The part of the radio wave which travels along the surface of the earth and is mainly influenced by its conductivity is called "ground waves"
- The portion of the radio waves that is radiated into space and is influenced by the conductivity of the various layers it encounters, is called "sky waves".

Ground Waves

Ideal conditions for the propagation of ground waves would be given if the surface of the earth were flat and of constant high conductivity.

Since the surface of the earth is made of various matters and their conductivity influences the propagation of radio waves. Ground waves can only be used to a restricted extent (mainly in the lower frequency bands). The range covered by ground waves depends on the power of the transmitter the frequency used and the conductivity of the surface over which the radio waves travel.

Sky Waves

The portion of the radio waves that is radiated into space would be lost if it were not somehow reflected back to earth.

In fact, the ultraviolet radiation from the sun provides conductive layers of various density at an altitude between 75 and 400 km above the surface of the earth, called the ionosphere, which will reflect the sky waves back to earth.

By constant frequency, the reflection depends on the angle at which the sky waves penetrate the ionosphere. If the angle is too wide (α_0), the radio waves will go through the ionosphere into space, with smaller angle of penetration, the radio waves will be reflected back to earth ($\alpha_{1,2}$).

By constant angle of penetration the frequency of the radio wave governs its reflection capability. Is the frequency too high. e.g. f_1 f_2 the radio waves will go through the ionosphere into space. Only from a certain frequency range will the radio waves be reflected.

Figure 19: Radiation of Ground and Skywaves

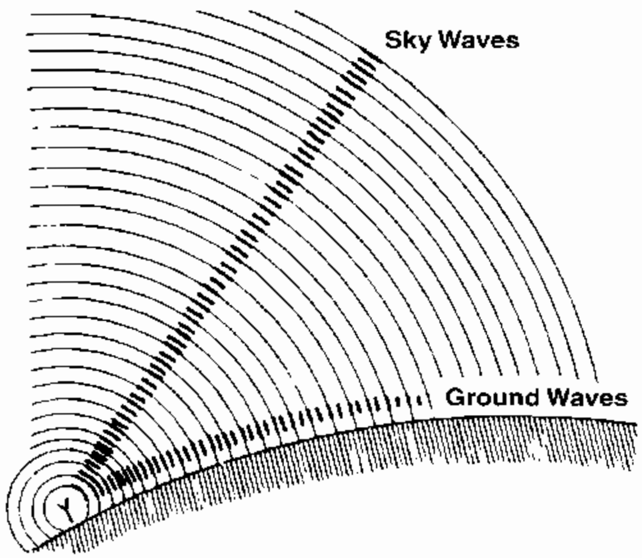
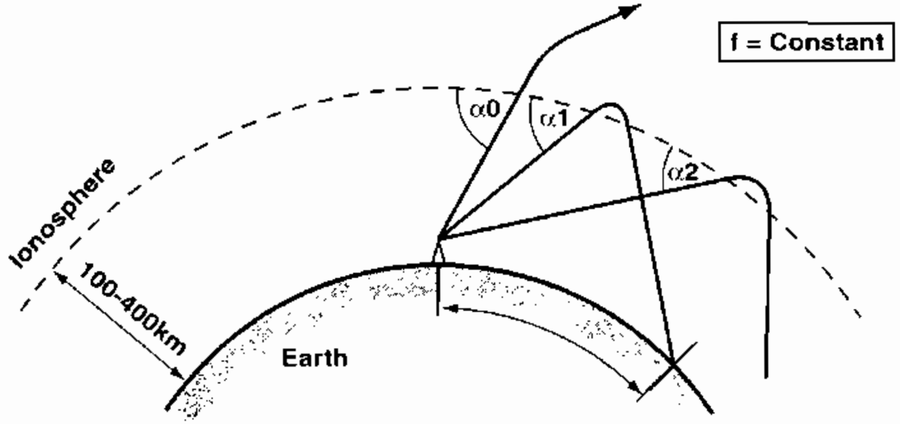


Figure 20:



The Ionosphere

Although very complex in its physical structure, the ionosphere may be described as one or more layers of ionized or conducting air enveloping the globe at a distance between 100 and 400 kilometers from the earth's surface.

Radio transmissions from ground and aircraft stations, unless travelling along the surface of the earth will all enter the ionized layer(s) of the ionosphere. The effect of the ionosphere on radio waves varies directly with their frequency range. Lower frequencies, LF and MF, will be almost completely absorbed by the ionosphere. Thus only the ground waves of these frequencies can be used for communication and navigation purposes.

High frequency radio waves will be less absorbed by the ionosphere and "bend" back to earth at a ratio depending on the frequency range and the "thickness" of the ionosphere layers.

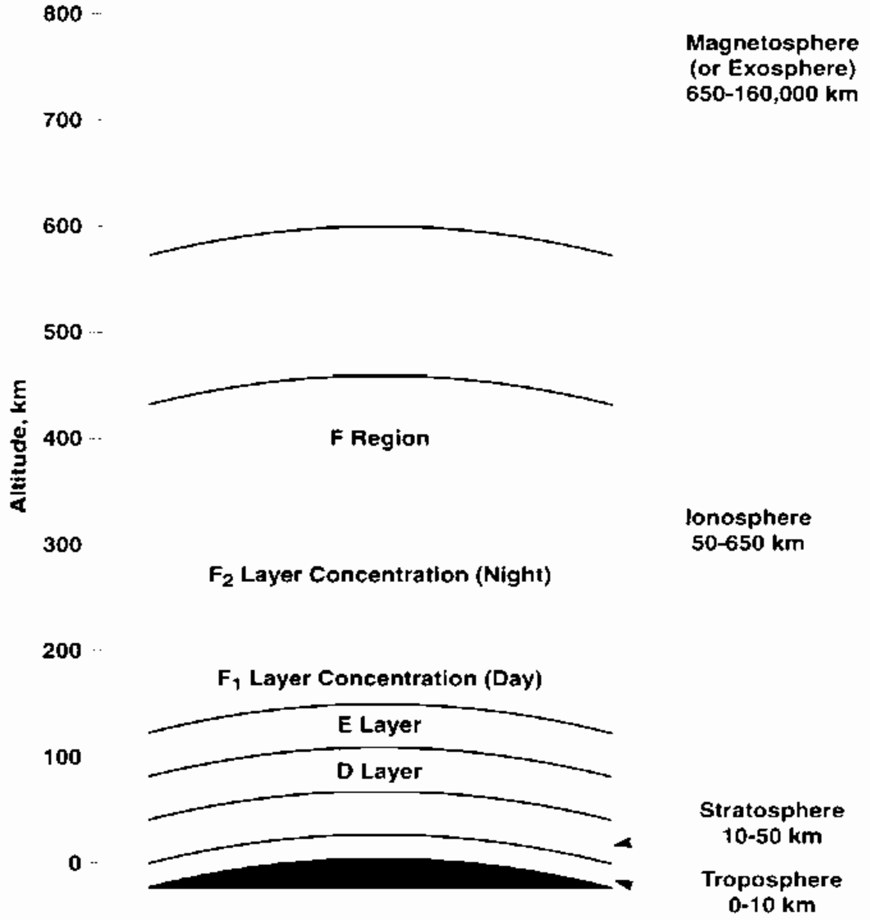
In order to extend the area of possible communication, we could therefore choose higher frequencies. This not only would it increase the communication range, but it would also improve the signal strength within the reception area, because of the reduced absorption of the transmitted signal by the ionosphere.

This has however its limitations; the reduced absorption effect on the higher frequencies is coupled with a reduced ability of the ionosphere to bend the radio wave back to earth. The wave must travel deeper into the ionosphere before reaching the turning point. By increasing the frequency up to VHF range, we come to the point where the wave will not be bent back to earth but keep on travelling into space.

This simplified explanation of radio wave propagation is only intended to give a general idea of its complexity. The "thickness" i. e. the conductivity respectively the absorption capacity of the ionosphere varies greatly between day and night and with the seasons of the year due to greater or lesser sun spot activity. There are several factors involved in selecting the optimum frequency under a specific set of conditions.

Particularly in the case of air-ground communications over widely varying distances, propagation prediction charts have been developed and are issued for quick determination of the optimum frequency to be used.

Figure 21: Ionosphere



Propagation Characteristics of Different Frequency Ranges

VHF - UHF - SHF

Line of sight propagation.

Radio waves in these frequency ranges are not reflected by the ionosphere. Through a slight bending along the surface of the earth, the line of sight is slightly increased beyond the horizon.

All these frequencies are practically not interfered by ionospheric or atmospheric storms and are best suited for aeronautical communication and navigation purposes over short and medium distances.

The ground-to-air communication range on VHF depends directly on the altitude of the aircraft. It can be calculated approximately as follows:

Range in NM = 1.23 x square-root of aircraft altitude in feet

This gives a theoretical communication range of 220 NM with an aircraft flying at 33'000 feet, in actual practice up ta 350 NM.

VHF is the primary communication frequency band for aeronautical services and is used in radio navigation by the ILS and VORs. UHF and SHF are mainly used in satellite communication and radar systems. (ATC radar, ATC transponder, TCAS, DME, weather radar.)

Figure 22: Propagation VHF, UHF, SHF

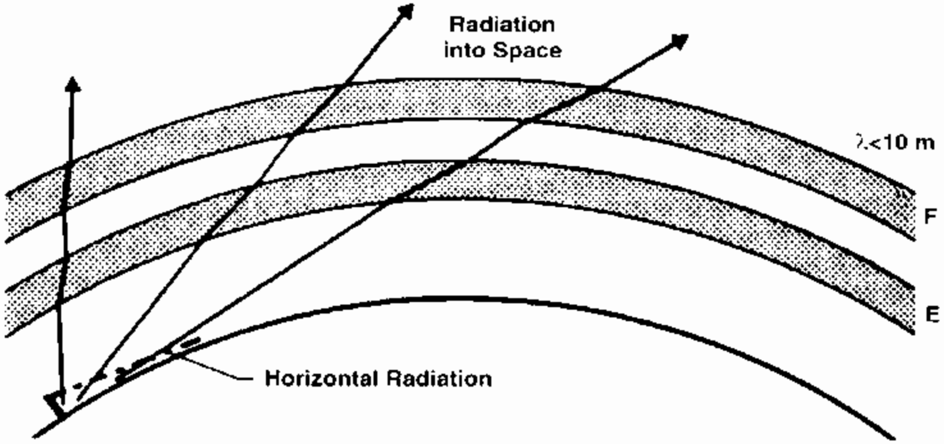
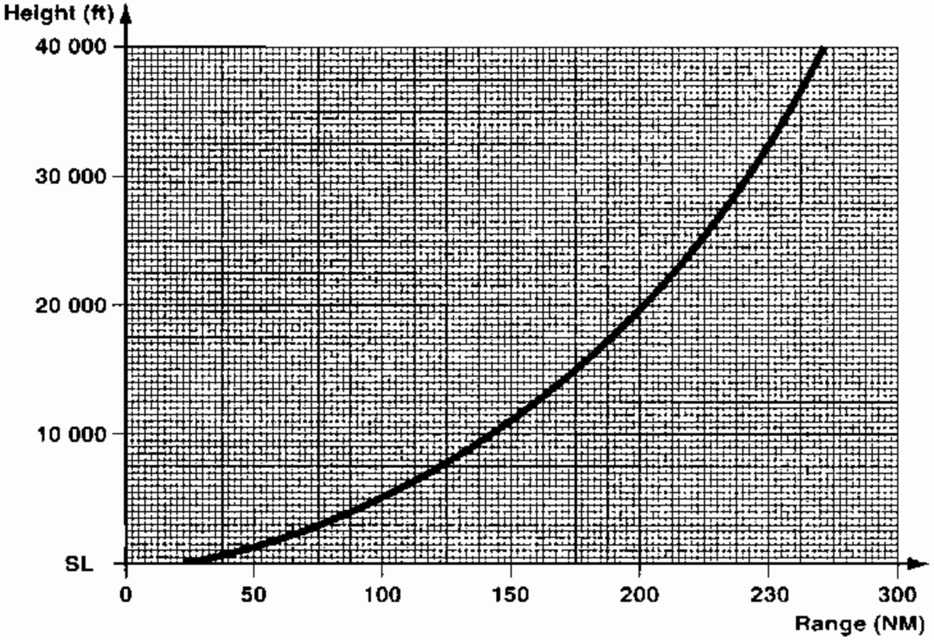


Figure 23: Range of VHF



Short Waves HF

High frequency radio waves propagated into space will be reflected by the ionosphere and render communications possible over very long distances.

The propagation range of the HF ground waves is very small and has no practical value.

Since we have to relay on the ionosphere for HF communications and as we have seen before, the ionosphere is a very unstable "reflector". It is very important to choose the right frequency for a point-to-point communication at a given time.

HF communications are very much affected by ionospheric and atmospheric storms, interferences and fadings.

Figure 24: Propagation Shortwave

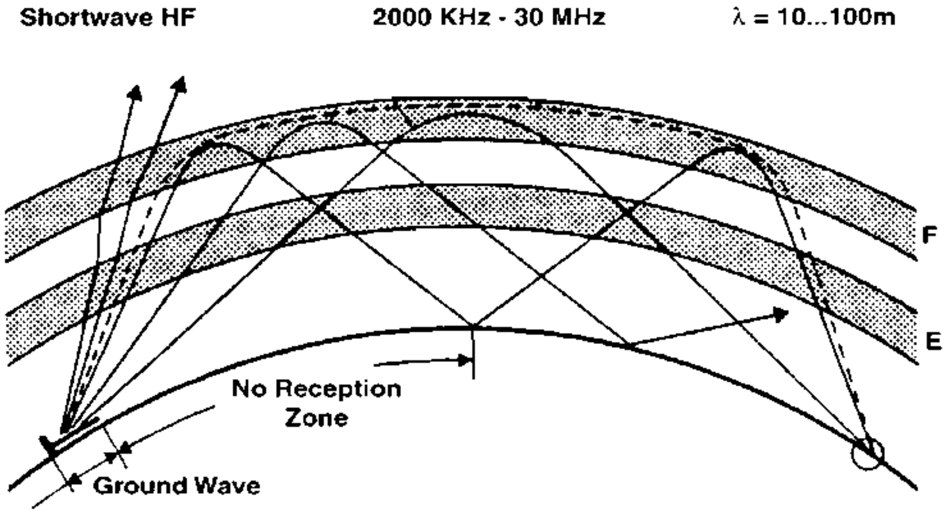
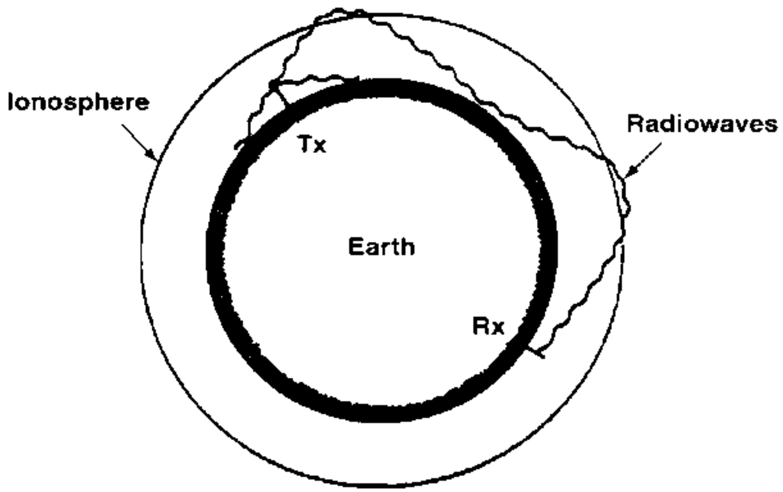


Figure 25: Short Wave Radio propagates worldwide



MF (Medium frequencies) Space and ground wave propagation

The sky waves of MF radio waves are reflected by the lower layer of the ionosphere. The ground waves propagate a few hundred kilometers over the surface of the earth, filling the "no reception gap" of the sky-relected waves.

Continuous reception is possible over considerable distances. MF communication is subject to interferences, fading and is very sensible to atmospheric storms.

LF (Low frequencies) space and ground wave propagation

The main difference between LF and MF is that the ground waves of LF extend to a few thousand kilometers. So that from a given distance from the transmitter interferences between ground and sky waves render reception practically impossible

Figure 26: Propagation Medium Wave

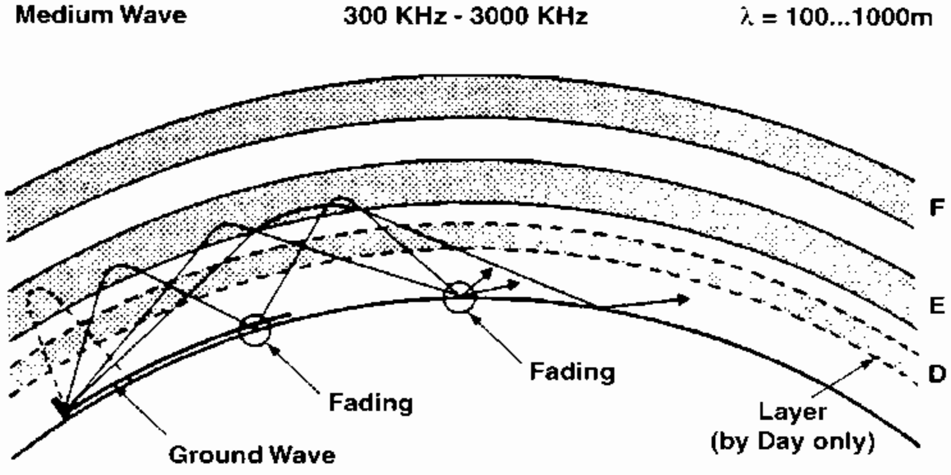
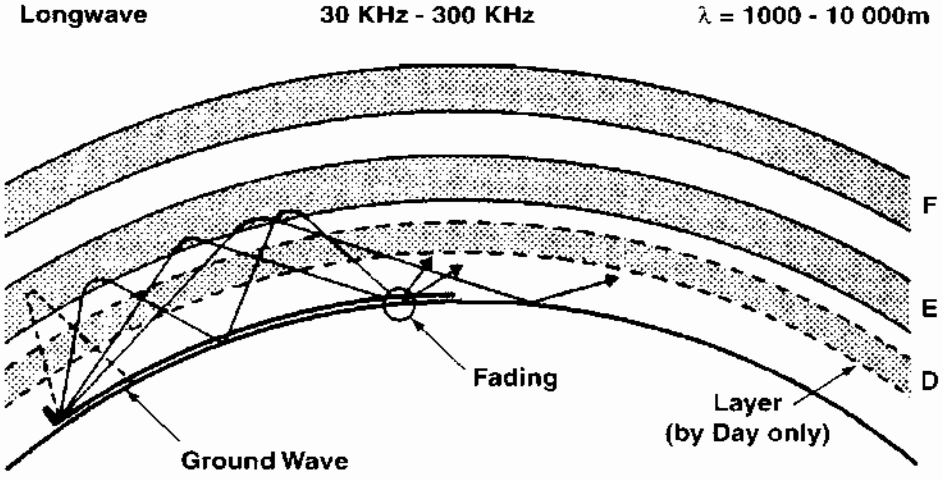


Figure 27: Propagation Long Wave



Undesired Effects

Interferences/Fading

When direct and reflected radio waves reach a receiver antenna simultaneously, the resulting signal is directly dependent on the phase relationship of the 2 waves.

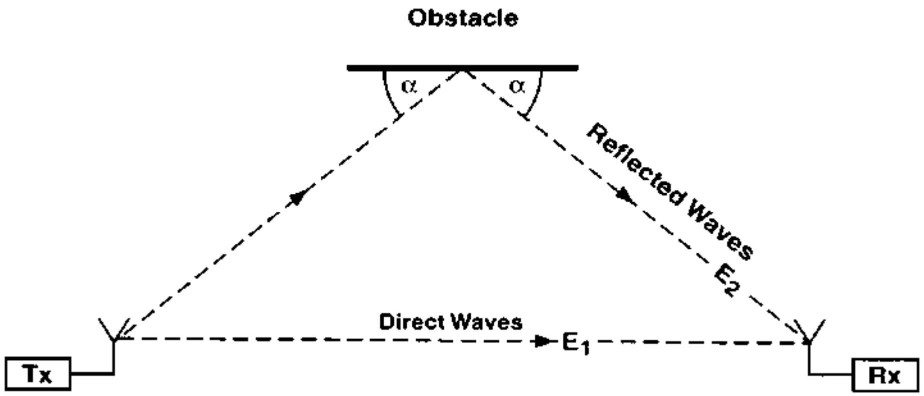
In the case the direct and reflected waves are in phase and the resulting signal strength is the addition of the 2 waves. A clear and strong signal is received.

With reception with a phase difference of 90^0 between direct and reflected waves. Although the resulting signal strength is average, the "readability" of the signal is very poor since the 2 waves are interfering with each other.

When direct and renected waves are in phase opposition (phase difference 180^0), they cancel each other and weak signals will result.

Since we have to relay on the ionosphere to reflect the sky waves for long distance communications, and the ionosphere not being a very constant reflector indeed, all above mentioned situations, with all possible variations, may occur in relatively short periods of time.

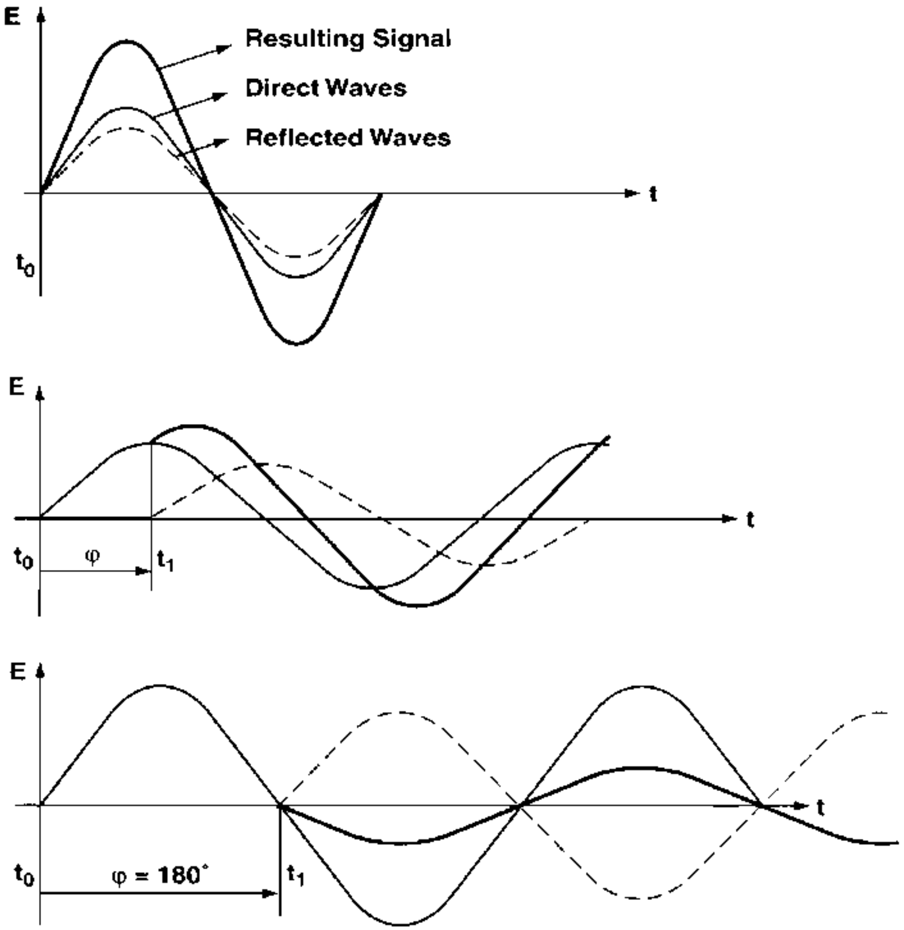
Figure 28: Cause of Interferences



Fading

Sky waves sometimes suddenly disappear as a result of a great increase in the absorption of radio energy in the ionosphere caused by a burst of ionization radiation from a solar eruption, which in turn causes a sudden abnormal increase of the ionization of some portions of the ionosphere. A fade-out is usually complete within less than a minute and it may last from a few minutes to several hours.

Figure 29: Fading



Modulation

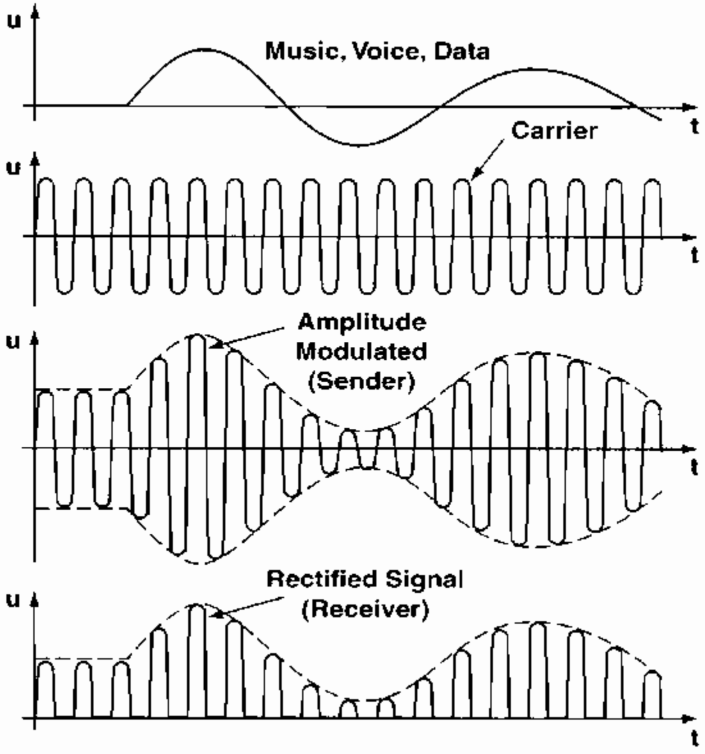
The carrier wave that is generated in the transmitter is just that, a device that carries the information from the transmitter to the receiver. The carrier has a frequency high enough to produce electromagnetic waves that radiate from the antenna, and this frequency is accurately controlled so that a sensitive receiver can select the carrier from a specific transmitter and reject the carriers from all other transmitters.

The carrier itself serves no function other than to carry the signal from the transmitter to the receiver, and the carrier is routed to ground after the intelligence is removed from it. It is the intelligence, or information, produced by the microphone or other type of input like modulated digital data. The process of placing intelligence on a carrier is called modulation, and there are several ways to do it. Three ways most often used in aviation communication equipment are amplitude modulation (AM), frequency modulation (FM), and single-sideband (SSB).

Amplitude Modulation (AM)

Amplitude modulation, or AM, is a method of modulation in which the voltage of the carrier is changed by the audio or data signal. The figure below shows a sinewave audio signal that has been used to modulate a carrier. The voltage of the resulting carrier varies with the voltage of the modulating audio frequency.

Figure 30: AM



Frequency Modulation (FM)

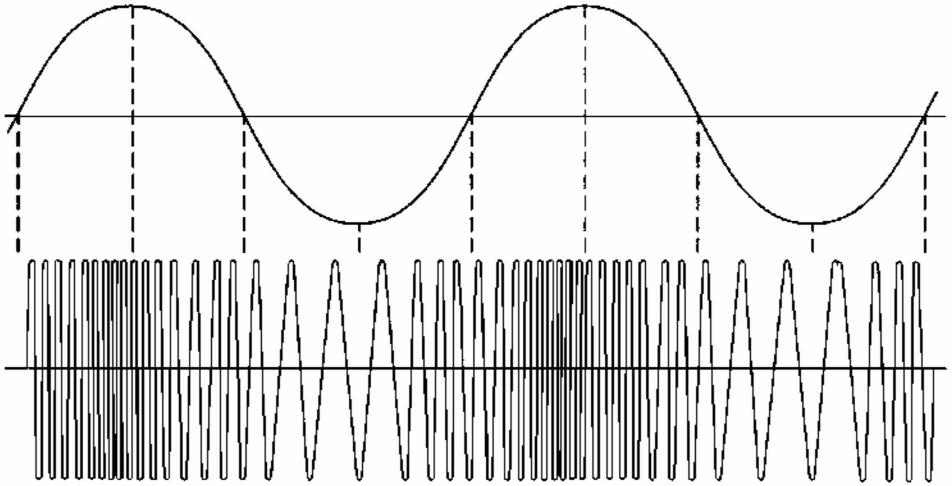
Man-made interference, such as that caused by electric motors and ignition systems, and natural interference, like that caused by lightning in the atmosphere, amplitude-modulate all radio signals in their vicinity. Frequency modulation can be used to obtain interference-free communication or navigation applications.

The voltage variations of the audio frequency signal produced by a microphone are used to change the frequency of the carrier The figure shows that the voltage of the AF rises in a positive direction, the frequency of the carrier increases, and as it goes negative, the frequency of the carrier decreases.

The amplitude of an FM carrier is held constant by limiter circuits, and any interference, which amplitude-modulates the carrier, is clipped off so it does not appear in the output.

When an FM signal is received, the deviations in frequency are changed into amplitude variations in an audio-frequency voltage that is amplified and used to drive the speaker.

Figure 31: FM



Single-Sideband (SSB)

Both AM and FM are limited in that they require a wide band of frequencies for their transmission. For example, if a 25 MHz carrier is AM-modulated with an audio-frequency signal that contains frequencies up to 5 Khz. the transmitted signal occupies a band of frequencies from 24.995 to 25.005 Mhz.

This band includes the carrier, the lower sideband, which is the carrier frequency minus the modulating frequency; and the upper sideband, which is the carrier frequency plus the modulating frequency.

Top left illustration shows the bandwidth required for an AM signal, and right illustration the bandwidth required for an SSB signal. The carrier and the lower sideband have been removed.

All the information needed is carried in either one of the sidebands, and it is inefficient use of energy to transmit the carrier and both the upper and lower sidebands. Removing the carrier and one of the sidebands and using all of the available energy for transmitting the other sideband give the transmitter a much greater range.

Aircraft shortwave (HF) radio communication uses the upper sideband (USB). The lower sideband (LSB) is used for other services and by radio-amateurs.

When an SSB transmission is picked up by an regular AM receiver, it is heard as a muffled noise because it has no carrier to mix with to produce an audible tone. But inside the SSB receiver, a carrier of the proper frequency is inserted and the original sound is reproduced.

Advantage

- Higher range with less transmitter power.
- More radiostations may share a frequency band (see figure below).
- Less reception noise due of smaller bandwidth of the receiver.
- Less fading. No carrier will be cancelled at the ionosphere.

Disadvantage

SSB Receivers circuits are more complex. The missing carrier signal must be added from a very accurate local-oscillator inside the receiver, this makes the receiver expensiv. Broadcasting radios operates on AM, to reduce the cost of the receivers.

Figure 32: AM forming upper and lower sidebands

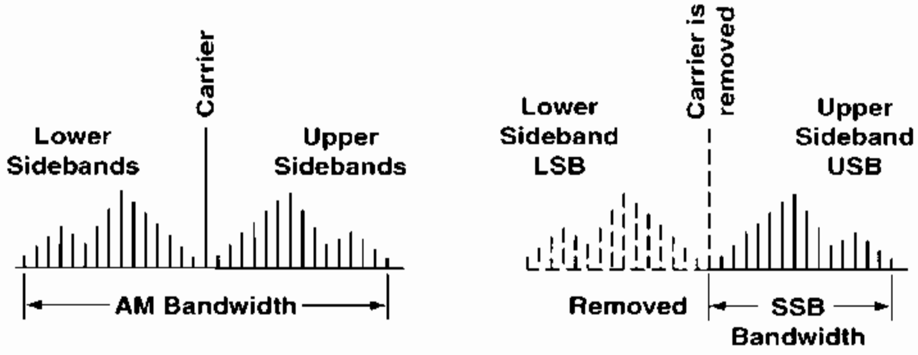
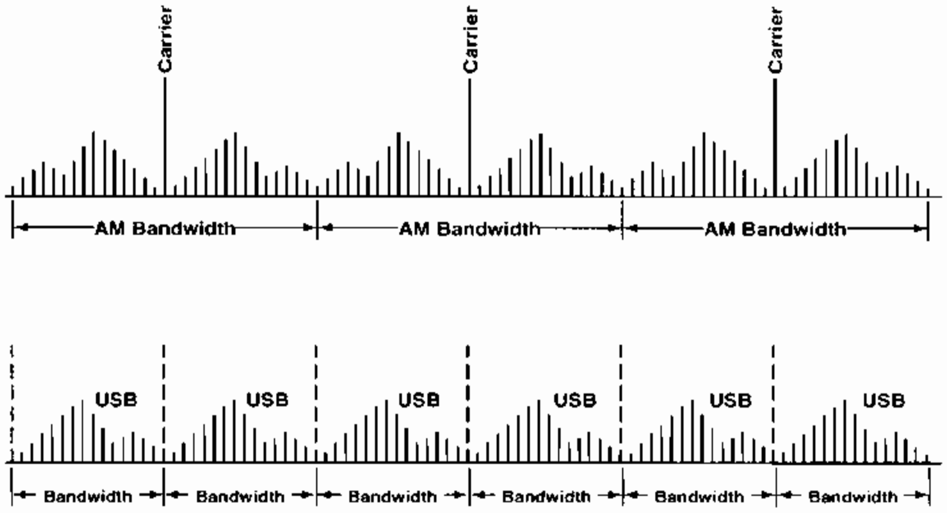


Figure 33: Side Band transmission is reducing the bandwith



Pulse Modulation

Instead of transmitting the information continously, the data signal is periodically sampled and converted in different codes. A periodic short sequence of pulses are used to carry the information. There are different forms of pulse transmitting.

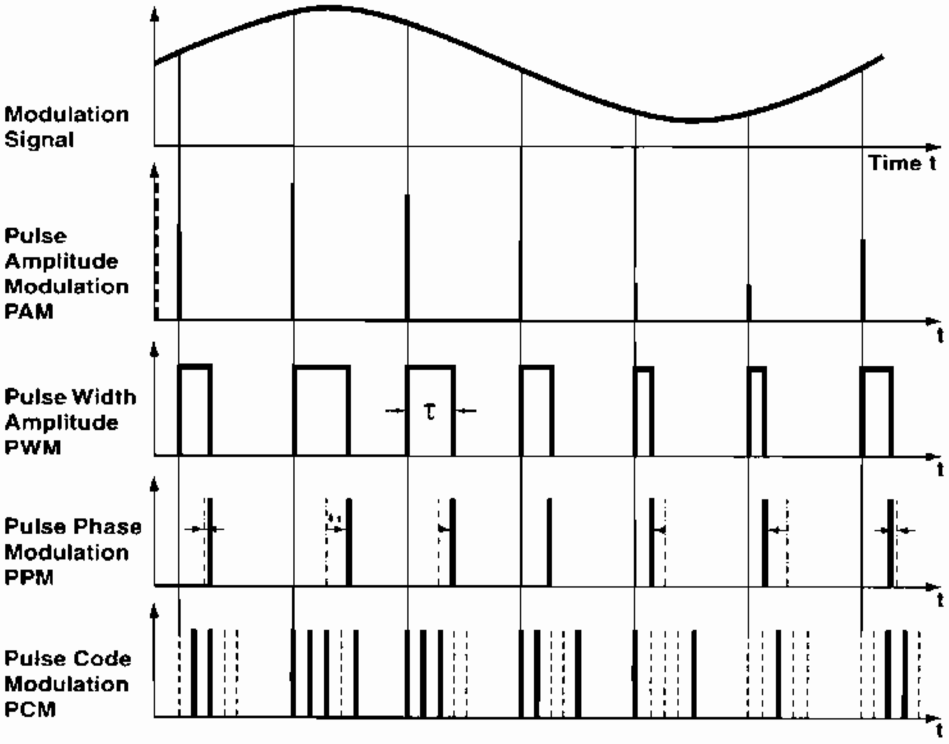
Pulse amplitude modulation PAM

Pulse width modulation PWM

Pulse phase modulation PPM

Pulse code modulation PCM

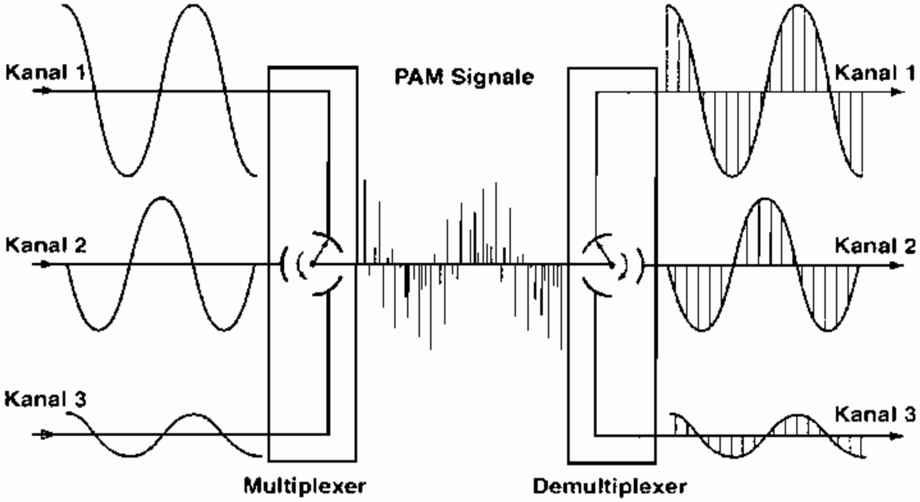
Figure 34: Various Pulse-Modulations



Multiplexing

To send different information on the same line (cable or wireless) time division multiplex TDM samples each channel for a short periode of time. In this way a mixed sequence of pulses (PAM) are transmitted over the line. The receiver has to reconstruct a continously signal from the incomming pulses.

Figure 35: Multiplexer and Demultiplexer



Overview Modulations

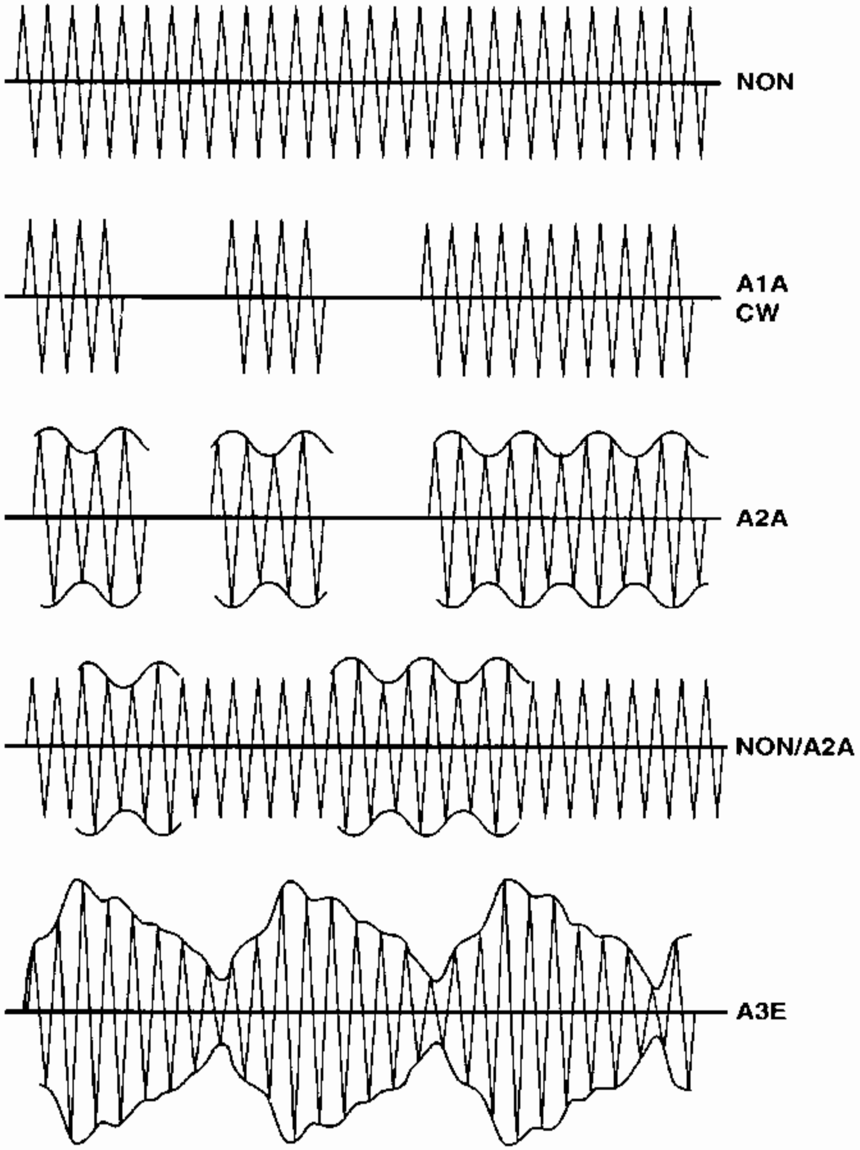
AM Amplitude Modulation

NON	No modulated carrier only
A1A	Telegraphy (morsecode) also known as:
CW	Continious Wave
A2A	Modulated telegraphy without carrier when no tone
NON/A2A	Modulated telegraphy with carrier when no tone
A3E	Voice dual sideband, AM - Broadcasting
J3E	Single side band without carrier

FM Frequency Modulation

F1A	Telegraphy unmodulated CW
F2A	Telegraphy modulated
F3E	FM - Broadcasting
F3C	Faksimile
F3F	Television

Figure 36: RF Carrier and Modulation



Transmission Lines

Transmission cable are used to carry the signal from the radio to the antenna. The correct installation of antenna cable or coaxial cable as it is commonly called, is critical to the proper operation of the radio equipment.

In order for a transmitter to get the maximum amount of energy into its antenna, and for the receiving antenna to get the maximum amount of energy into its receiver, the antennas must be connected to the equipment with a special type of conductor called a coaxial cable. This cable has a central conductor surrounded by a special insulating material. This is, in turn, surrounded by a braided metal shield. All of this is encased in a protective plastic coating. A coaxial cable, commonly called coax, has a specified characteristic impedance that must be matched to the antenna and the transmitter or receiver. Normally this impedance is 50 ohms.

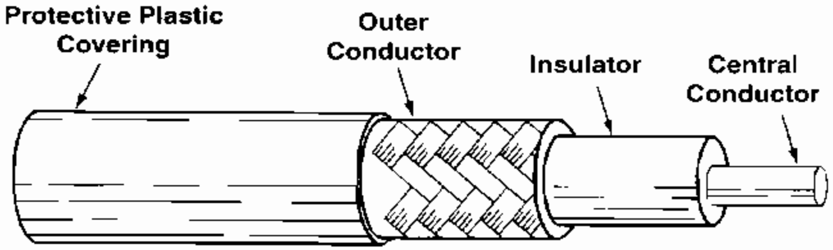
Coax is relatively rugged, but care must be exercised to not bend it around too tight a radius or to allow it to become overheated. Anything that distorts the spacing between the central conductor and the outer conductor can change the characteristics of the coax and decrease the efficiency of the installation.

Always follow the manufacturers recommendations concerning the installation of coaxial cable. In general, the transmission lines should be kept as short as possible. They should not be bent in any radius smaller than three inches (for certain cable the radius should be a minimum of eight inches) always use coaxial connectors for splicing or terminating cables and follow good wiring practices when routing cables through the aircraft.

The length of certain antenna cables is critical to proper operation of the radio. The proper length cable is often matched to a specific antenna. If the cable length must be changed, be sure to use the appropriate test equipment to determine transmission line measurements.

In some cases two radios may use the same antenna if the proper coaxial tee-connector and proper length cable is used. Another method of connecting two radios to the same antenna is by utilizing a coupler or diplexer. The diplexer is used to provide proper impedance matching and isolate the two radios connected to the antenna.

Figure 37: Coax Cable



Conductors for Radio Waves

There are three main types of transmission lines used: coaxial lines, open-wire lines and waveguides. The most common type is the coaxial line, usually called coax.

Parallel Conductors

The second type of transmission line utilizes parallel conductors side by side, rather than the concentric ones used in coax. Typical examples of such open-wire lines are 300 Ohm TV ribbon line. Their advantage is the lower losses in simple multiband antenna systems, coaxial cables are far more prevalent, because they are much more convenient to use. In aircraft this type of cable is not existent.

Waveguides

The third major type of transmission line is the *waveguide*. A waveguide is a hollow, conducting tube, through which microwave energy is transmitted in the form of electromagnetic waves. The tube does not carry a current in the same sense that the wires of a two-conductor line do. Instead, it is a boundary that confines the waves to the enclosed space. Skin effect on the inside walls of the waveguide confines electromagnetic energy inside the guide, in much the same manner that the shield of a coaxial cable confines energy within the coax. Microwave energy is injected at one end (either through capacitive or inductive coupling or by radiation) and is received at the other end. The waveguide merely confines the energy of the fields, which are propagated through it to the receiving end by means of reflections off its inner walls.

Waveguides are used for weather radar system (9.375 GHz.)

Figure 38: Coaxial Cable

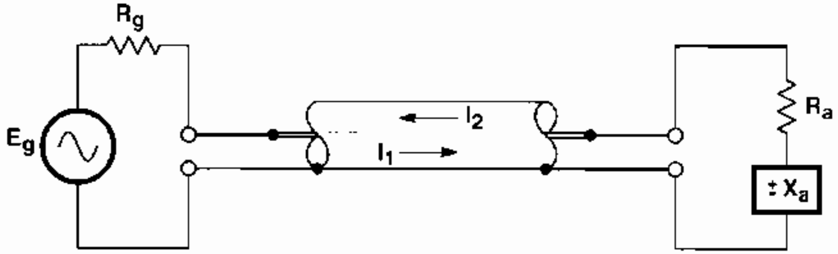


Figure 39: Parallel Cable

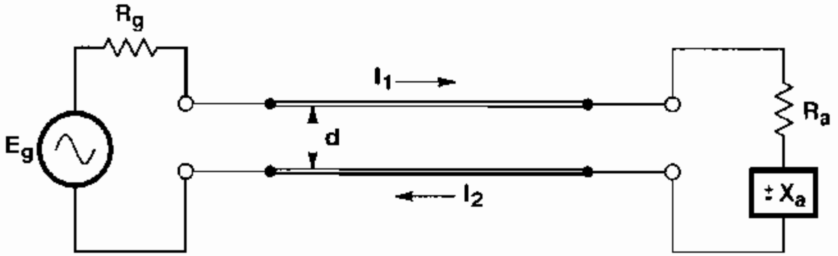
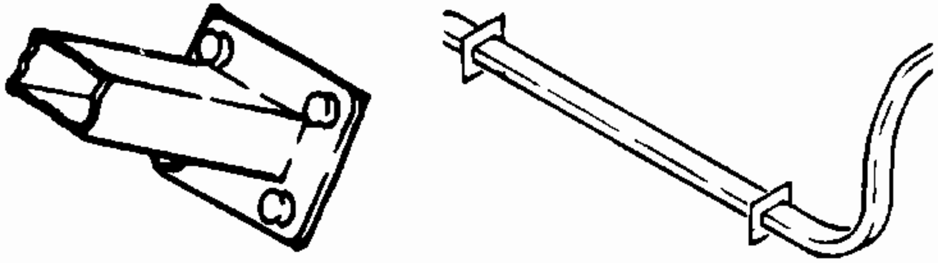


Figure 40: Wave Guide



Perfect line

A perfectly lossless transmission line may be represented by a whole series of small inductors and capacitors connected in an infinitely long line. Each inductor represents the inductance of a very short section of one wire and each capacitor represents the capacitance between two such short sections.

The inductance and capacitance values per unit of line depend on the size of the conductors and the spacing between them. The smaller the spacing between the two conductors and the greater their diameter, the higher the capacitance and the lower the inductance. Each series inductor acts to limit the rate at which current can charge the following shunt capacitor, and in so doing establishes a very important property of a transmission line: its surge impedance, more commonly known as its characteristic impedance. This is usually abbreviated as Z_0, and is equal to square root of L /C, where L and C are the inductance and capacitance per unit length of line.

Matched and mismatched line

At A the coaxial transmission line is terminated with resistance equal to its impedance. All power is absorbed in the load.

At B, coaxial line is shown terminated in an impedance consisting of a resistance and a capacitive reactance. This is a mismatched line, and a reflected wave will be returned back down the line toward the generator. The reflected wave reacts with the forward wave to produce a standing wave on the line. The amount of reflection depends on the difference between the load impedance and the characteristic impedance of the transmission line.

Reflection Coefficient and SWR

In a mismatched transmission line, the ratio of the voltage in the reflected wave at any one point on the line to the voltage in the forward wave at that same point is defined as the *voltage reflection coefficient*. This has the same value as the current reflection coefficient.

Figure 41: Substitute of an electrical Line

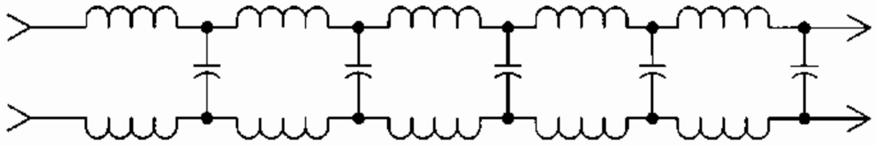
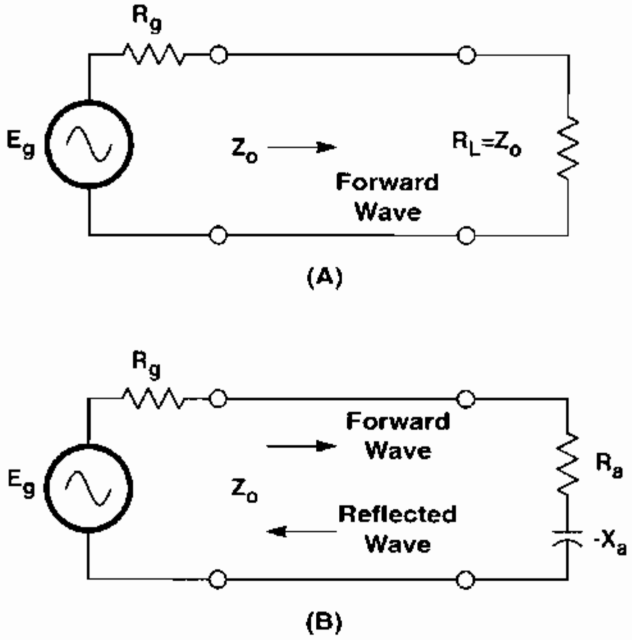


Figure 42: Matched and mismatched electrical Line



Antenna Installation

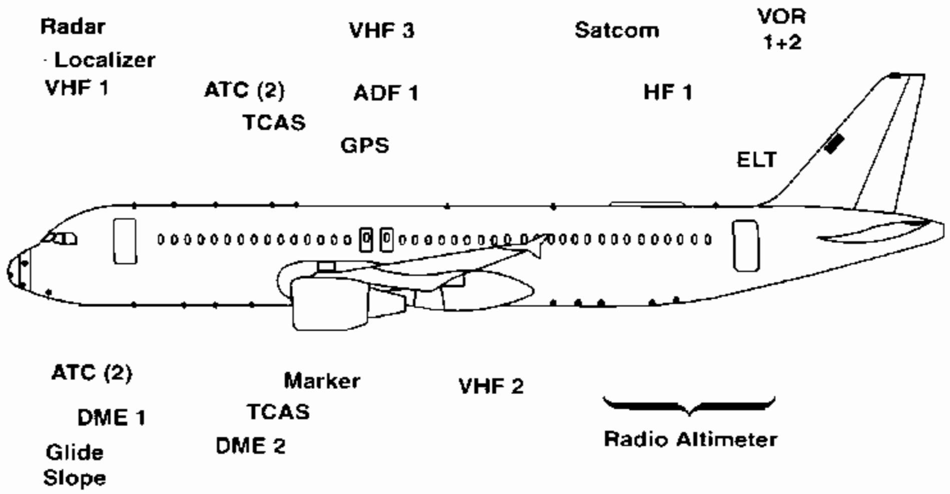
Regardless of the excellence of the equipment, no radio installation is better than its antenna. Each piece of equipment must have a specific antenna, and this antenna must be mounted in a specific location for the most efficient operation. Most antennas are used for both reception and transmitting.

The length, polarization, and location of an antenna is of extreme importance in getting the most efficient transmission and reception from the installed equipment. The types of antennas used with several pieces of avionic equipment are examined here.

The shown antennas are used for:

- **Radar** Radio detection and ranging. Shows the weather in ahead of the flight route.
- **Localizer** Receives lateral guidance for landing.
- **Glideslope** Receives vertical guidance for landing.
- **VHF** Very high frequency communication within a range up to about 300 NM.
- **ATC** Air traffic control transponder. Receives and sends signals for air traffic surveillance.
- **DME** Distance measuring equipment. Detecting the distance to ground stations.
- **TCAS** Traffic collision avoidance system. Alerts pilot if other aircrafts are around.
- **Marker** Receives signal from a beacon at ground, for position determination during approach or enroute.
- **GPS** Global positioning system. Satellite navigation
- **ADF** Automatic direction finder Navigation for short and medium range.
- **Radio Altimeter** Detects the aircraft height above ground.
- **SATCOM** Satellite communication for voice and data.
- **ELT** Emergency location transmitter. Sending signals for searching and rescuing the victims of an accident.
- **HF** High frequency (short wave) communication over whole world.
- **VOR** VHF omnidirectional range. Accurate navigation within 300 NM.

Figure 43: Aircraft with Antennas



Installation of aircraft antenna systems

There are a variety of radio antennas, each designed for a specific radio and installation. Typically the radio antenna must be located on the exterior of the aircraft or located near the exterior protected by a plastic or nonconductive cover. Antennas which are mounted on the exterior of the aircraft are either the blade (rigid) or whip (flexible) type. Flush mounted antennas are located within the aircraft outer cover and produce less drag than an externally mounted antenna.

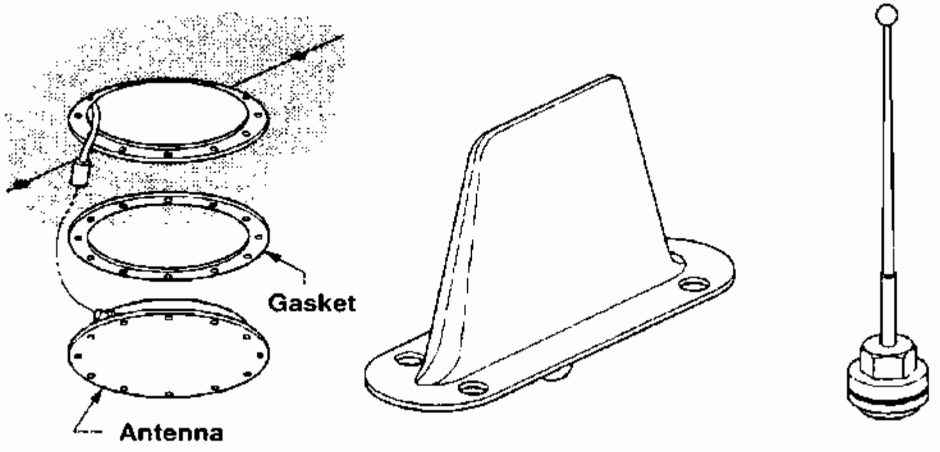
Maintenance procedures

Antennas and their associated cables should be visually inspected for security and integrity. The leading edge of blade-type antennas often deteriorate rapidly on high-speed aircraft. This area should be given particular attention. If the antenna leading edge is deteriorated beyond limits, the antenna should be removed and replaced. In some cases, the antenna may be repaired; however this typically requires a special repair facility.

All antennas or antenna covers should be inspected for a proper seal OR GASKET to the aircraft. If the seal has deteriorated, moisture may enter the antenna or aircraft and create corrosion problems. Remove and reseal any antenna or antenna cover which may admit moisture. Pressurized aircraft also require that special attention be given to the antenna-to-aircraft seal in order that vapors do not leak form the pressurized structure.

Radar antennas are typically housed in the nose-section of the aircraft and are protected form the environment by a non-conductive cover called a radome. The radome should be inspected for cracks and to ensure a proper seal to the airframe. Proper radome repair is critical to the operation of the radar equipment. Always follow the manufacturers recommendations for the repair and/or painting of the radome.

Figure 44: Antenna Types



Flush Mount Type **Blade Type** **Whip Type**

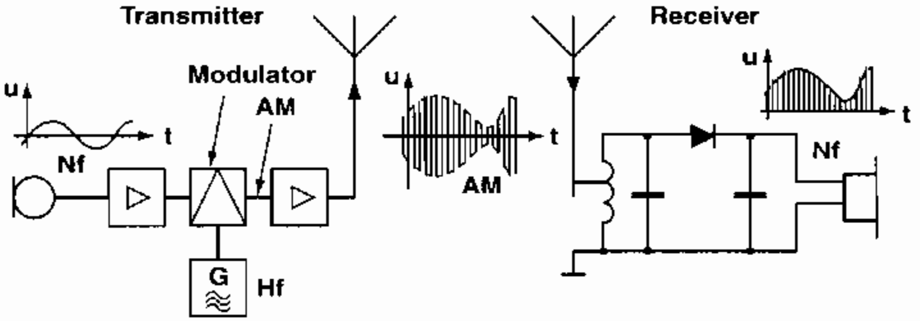
Radio Fundamentals

For many years the only electronics involved in aviation were used for communication and navigation, and all electronic equipment was classified simply as "radio."

Today's aircraft employ vast quantities of electronic equipment, much of it unrelated to either communication or navigation. This equipment is now classified as avionics, build from the words. **avia**tion and electr**onics**.This section considers the portion of avionics that deals with communication and navigation.

Radio is a method of transmitting intelligence from one location to another by means of electromagnetic radiation.

Figure 45: Radio communication using transmitter and receiver



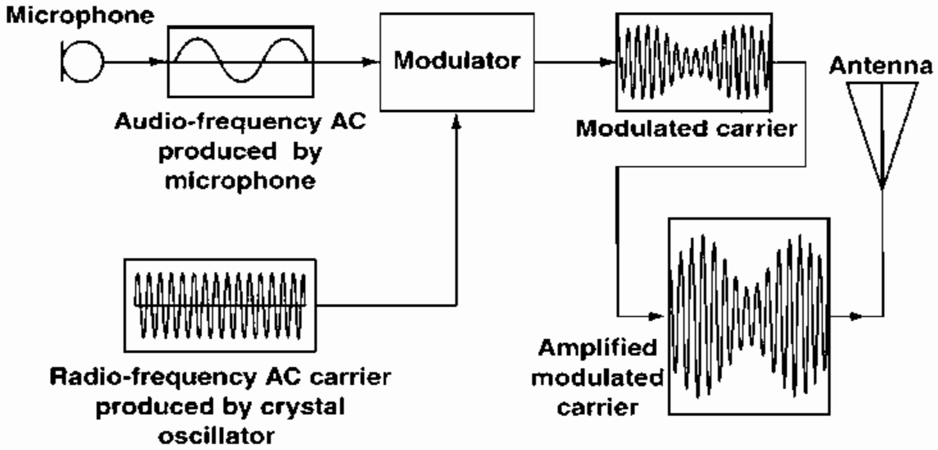
Transmitter

This extremely basic radio shown transmitter contains a crystal-controlled oscillator that produces alternating current with a very accurate frequency in the radio frequency (RF) range. This is above approximately 100 kilohertz.

The intelligence to be transmitted is changed into an audio frequency (AF) electrical signal by the microphone. This AF modulates, or changes, the carrier so that its voltage varies in exactly the same way as the voltage from the microphone. Notice that both sides of the modulated carrier are the same as the AF signal.

The voltage of the modulated carrier is amplified so that it has enough power to radiate into space when it goes to the antenna. The signal radiates out into space from the transmitter antenna.

Figure 46: Transmitter



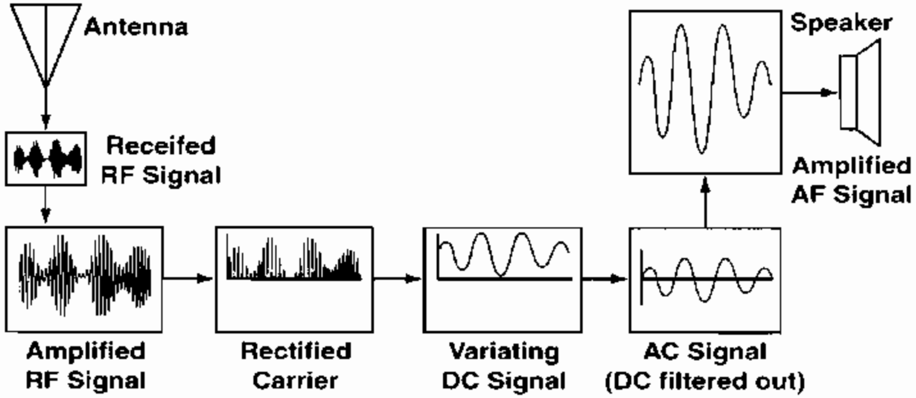
Receiver

The signal radiated out into space from the transmitter is picked up by the receiver antenna. The signal picked up by the antenna is a very weak imitation of the amplified modulated RF signal that was sent to the transmitter antenna.

The weak modulated RF signal is amplified, and then in the demodulator rectified. One half of the RF signal must be removed. This is done in the detector, or rectifier. A variating DC voltage is the result of the rectifier. The DC component of this signal is filtered out. The resulting AC voltage has the same waveform as that produced by the microphone attached to the transmitter. The voltage of this signal is too low, so it is amplified and then used to drive a speaker.

The transmitter uses a crystal oscillator to produce an accurately controlled carrier frequency, and only this one frequency radiates from the transmitter antenna. The receiver antenna picks up not only the signal from the desired transmitter, but signals from every other transmitter in the area as well as electromagnetic radiation from all sorts of electrical devices. In order for a receiver to be useful, it must filter out every frequency except the one that is wanted. To do this, it employs a special superheterodyne circuit.

Figure 47: Radio receiver



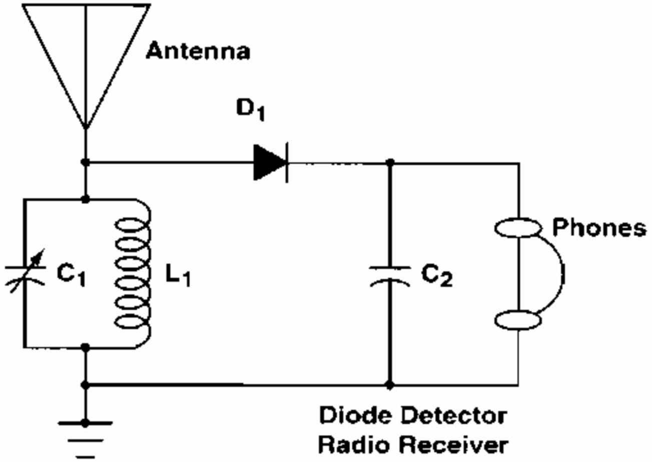
Detector

A very basic receiver is the diode detector. The radiowaves are received by the antenna. A tuneable resonant circuit by C_1 and L_1 will conduct all unwanted frequencies to ground.

The desired tuned carrier frequency will be rectified by the diode D_1. The output of D_1 is pulsating DC. The capacitor C_2 smoothens and averages the DC.

This represents the demodulated AF signal audible through the headphones.

Figure 48: A simple diode detector forming a receiver



Quarz Oscillators

Crystal resonators are small chips or sticks cut in a special way from a crystal. Pressure or pull on the crystal surface cause electrical charge displacement and thus electrical voltages (Piezo-effect).

Conversely, if a alternating voltage is applied to the crystal, it begins to oscillate mechanically. The resonant frequency of the oscillations is highly stable and depends upon the mechanical dimensions of the crystal.

To obtain a very accurate and stable frequency for many different purposes such as clock's, transmitters, receivers and computers quarz- or cristal oscillators are used. According the dimensions of a small quarz piece, a defined resonant frequency is the result.

Figure 49: Circuit symbol and electrical equivalent circuit

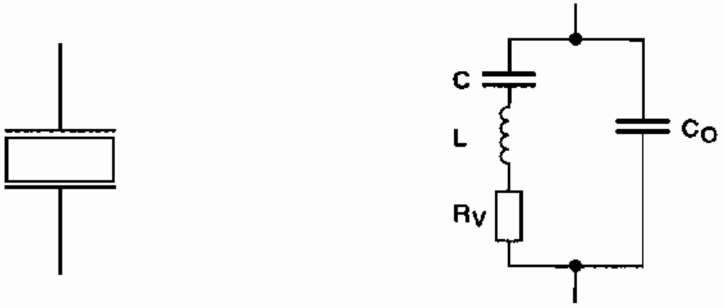
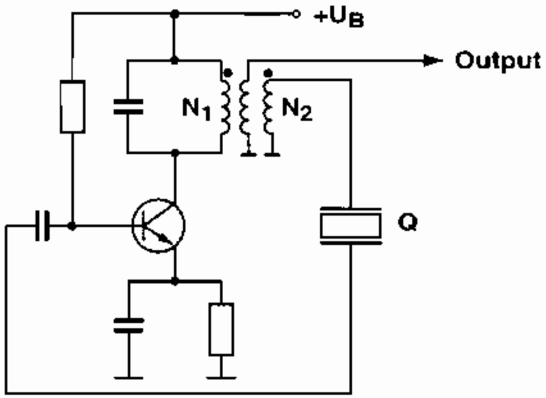


Figure 50: Quarz Oscillator



Phase Locked Loop (PLL) or Synthesizer

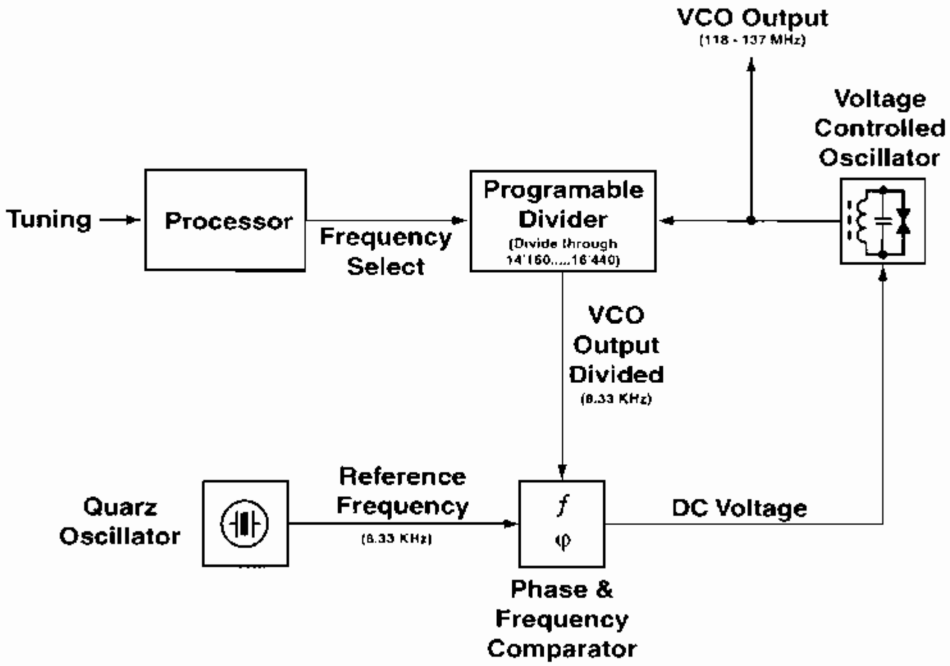
A quarz oscillator produces only one frequency according its dimensions. To produce different selectable frequencies, a phase locked loop is used.

Lets assume the desired output frequency is 121.95 MHz.
The voltage controlled oscillator produces a frequency that is only 120.00 MHz.

The tuning of the desired frequency through processor applies a determined division ratio as frequency select to the programmable divider. The output of the VCO (120.00 MHz) is divided by 14'634.

This results a lower frequency to the phase & frequency comparator (8.2 KHz). The comparator increases the DC voltage to the VCO, the VCO increases the frequency until the comparator gets the divided output of exactly $8^1/_3$ KHz which is equal with the reference frequency.

Figure 51: PLL



Superheterodyne Receiver

The antenna picks up all the radio signals in the area, and they are taken into a tunable preamplifier. This preamplifier uses an electronic filter circuit that passes only the frequency to which the receiver is tuned and sends all of the other frequencies to ground.

We will consider the receiver to be a broadcast receiver tuned to 1'200 kilohertz. The preamplifier amplifies any signal with a frequency of 1'200 kHz and passes all other frequencies to ground.

A tunable local oscillator is included in this circuit. The frequency of this oscillator is varied so it is always a specific frequency higher than the frequency to which the preamplifier is tuned. For most broadcast band receivers, the frequency of the local oscillator is always 455 kilohertz higher than the frequency tuned on the preamplifier.

- For Intermediate Frequency obtain following relationship: **IF = RF +/- f_o**

  (Intermediate Frequency = Radio Frequency +/- Oscillator Frequency)

In this case, the local oscillator produces a signal with a frequency of 1'655 kilohertz (1'200 + 455).

The signals from the preamplifier and the local oscillator are sent to the mixer. When signals with two frequencies are mixed, they produce two other signals:

- one with a frequency that is the sum of the original two frequencies
- the other with a frequency that is the difference between the two.

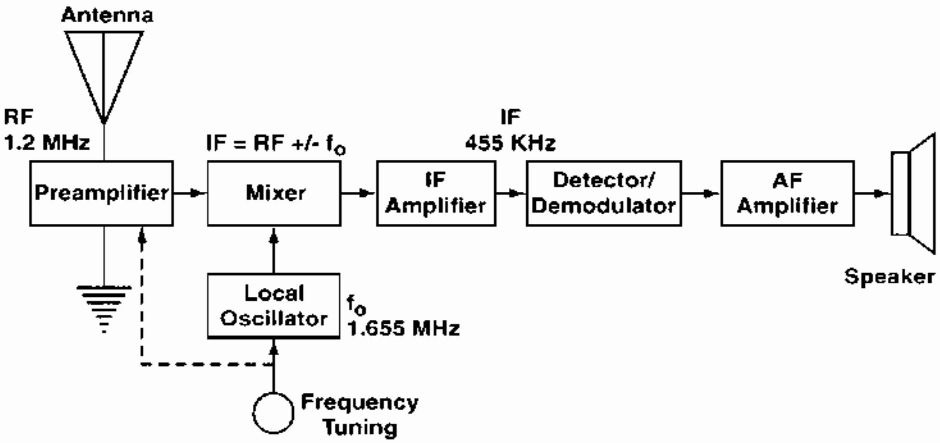
The four signals will have frequencies of:
1'200 kHz, 1'655 kHz, 2'855 kHz (1'200 + 1,655), and 455 kHz (1'655 – 1'200).

The four signals from the mixer are sent into the intermediate frequency (IF) amplifier. This is a very narrow-band amplifier that is tuned to 455 kHz. It amplifies the 455 kHz signal and attenuates, or diminishes, all other frequencies.

The amplified 455 kHz signal is sent to the detector/demodulator, which removes the 455 kHz IF carrier. The detector rectifies the IF signal and removes one half of the envelope.

The resulting signal is an exact copy of the AF that modulated the carrier that is being received. The AF signal is amplified by a audio amplifier stage and drives the speaker. The output of the speaker is the same as the input to the microphone at the transmitter.

Figure 52: Superheterodyne Receiver



VHF Communication Receiver

Communication receivers such as those used in aircraft are more sensitive than the normal household broadcast receiver, and they have more stages.

The signal is picked up on the antenna and amplified by the tuned preamplifier. The local oscillator produces a frequency that is 10.8-megahertz different from the frequency to which the preamplifier is tuned.

These two frequencies are fed into the mixer where they produce a 10.8 MHz intermediate frequency. This IF is amplified several stages of IF amplification and sent into the detector/demodulator, where it emerges as an audio frequency signal that duplicates the AF produced by the microphone at the transmitter.

AGC

To hold the output constant as the input signal voltage changes, some of the output from the detector goes to an automatic gain control (AGC). This is fed back into the IF amplifier in such a way that it increases the amplification when the signal is weak and attenuates it when the signal is too strong.

Squelch

Some of the detector output is sent into a squelch circuit that controls the audio frequency amplifier. When no signal is being received, the AF amplifier output is attenuated, or decreased, so the background noise that makes a hissing sound in the speaker is not loud enough to be annoying.

But as soon as a signal is received, the attenuation is removed, allowing the audio output to be loud enough to be comfortably heard. The output of the AF amplifier goes to a power amplifier where it is further amplified so it can drive the speaker.

If there is a weak communication signal, the squelch also suppresses the communication signal. Therefore adjustable squelch thresholds are provided.

Figure 53: Receiver with AGC and Squelch

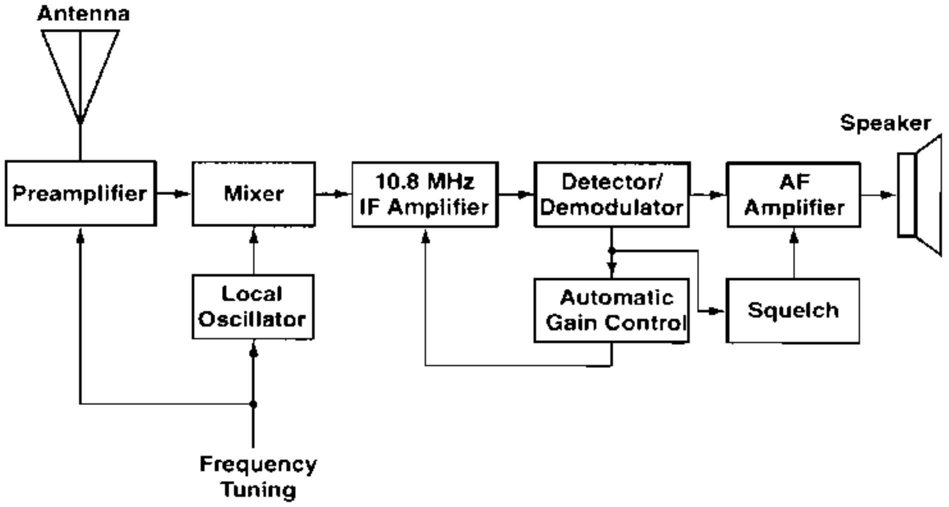
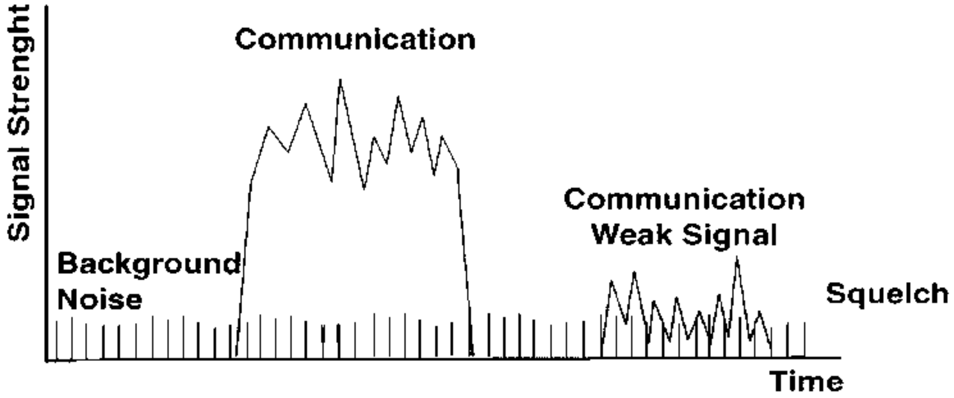


Figure 54: Squelch Function



Dynamics of the Static Electricity

One of the problems we must deal with in radio communication, is precipitation static or abbreviated to p-static. This hissing and buzzing noise is caused by an uncontrolled discharge to the surrounding air of the high potential difference accumulating on the aircraft under certain conditions. Such electrical discharges (also: corona discharge) are accompanied by Ionisation of the air and therefore look like St. Elmo's fire. The installation of static dischargers ensures controlled removal of the electrical charge, solving the problem. One condition is that a sufficient number of dischargers must be present. Since this depends on the type of aircraft it is therefore a problem that must be solved during the design phase.

However, the static dischargers cannot do the job alone. An uninterrupted transport of charge over the fuselage is just as important. Synthetic parts also bring their own specific problems. In this article we spotlight these problems, while at the same time explaining the principles of the static discharger.

Electrical charge

When flying through ice panicies for example cirrus clouds a large number of particles will strike the aircraft and bounce away. Electric charge is transferred at each impact. (We know this phenomenon as triboelectricity). Typically, the aircraft is left with a negative charge while the rebouncing particle acquires a positive charge. Each impact adds to the electrical charge or potential on the aircraft. The developed potential difference can reach high values. Under normal charging conditions this potential can reach values of 100'000 to 200'000 volts In a fraction of a second.

Table 2: Causes of electrical charge

Dust and Sand	Solid particles produces the most violent forms of p-static, especially when there are dry.
Ice Crystals Dry Snow	The colder and drier they are, the more p-static. Found in high cirrus clouds and in cold arctic masses
Rain	Large rain drops also producing p-static

Corona discharge

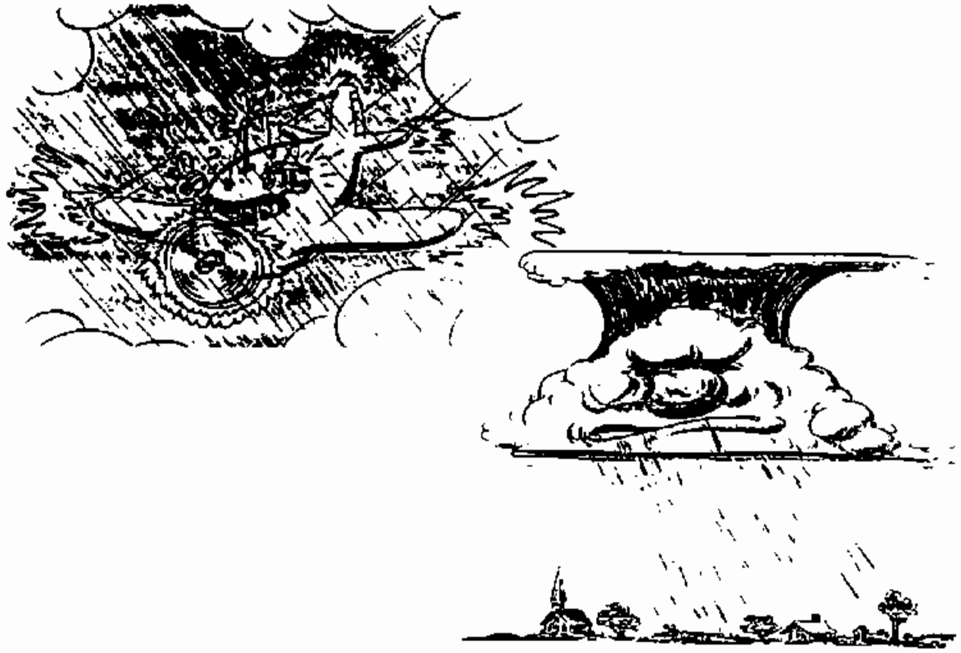
When the potential of the aircraft reaches these high values, some interesting things take place. The electric fields around the aircraft become high, particularly at its extremities (wing tips, tall, etc.). At the sharper edges in these locations, such as at airfoil tralling edges, these fields become high enough to cause Ionization of the air and short bursts of charge, or current, will leave the aircraft (corona pulses).

It is the energy released by the corona pulses, coupled into the radio antennas, that causes the precipitation static (or shortly p-static). In the radio receivers this will become evident, in the form of irregular popping sounds. As the degree of charging increases so does the frequency of the popping, until it becomes a continuous buzzing which increases in intensity. Eventually, it becomes a steady roar which masks all but the very strongest radio signals.

Thunder Clouds

Particles striking the aircraft are not the only cause for high electric fields. They can also develop when flying near or between electrically charged clouds or during electrical storms. In this instance we refer to Induced charging rather than triboelectric charging. The resulting corona pulses, however, will generate the same kind of p-static.

Figure 55: Corona discharge at aircraft extremities and thundercloud



Ionospheric storms

Ionospheric storms (caused by solar activities disturbing the earth's magnetic field) may destroy the normal layer pattern of the ionosphere and cause the ionization to form clouds that move in an irregular manner The disturbing effect of ionospheric storm on sky wave communication is greater in and near the polar regions and becomes negligible at the equator Ionospheric storms may occur at night as well as in day time.

Atmospheric noise

Even when the propagation conditions are very good and result in a signal of usable strength in the receiver antenna, it may not always be possible to carry out communication or get reliable navigation information due to the fact that also noise signals are also delivered by the antenna. These noise signals are caused by radio waves created for instance by thunderstorms, lightning and corona discharges.

Precipitation static

The precipitation static type of noise is caused by corona discharges from different parts of the aircraft structure which in turn are caused by the bombardment of the aircraft with electricity charged raindrops, snowflakes, hailstones, small ice crystals or dust particles.

The atmospheric and precipitation staic noise may be so strong that it will completely mask communication and navigation signals of relatively great strength when the aircraft is in an area of thunderstorms or flying through clouds.

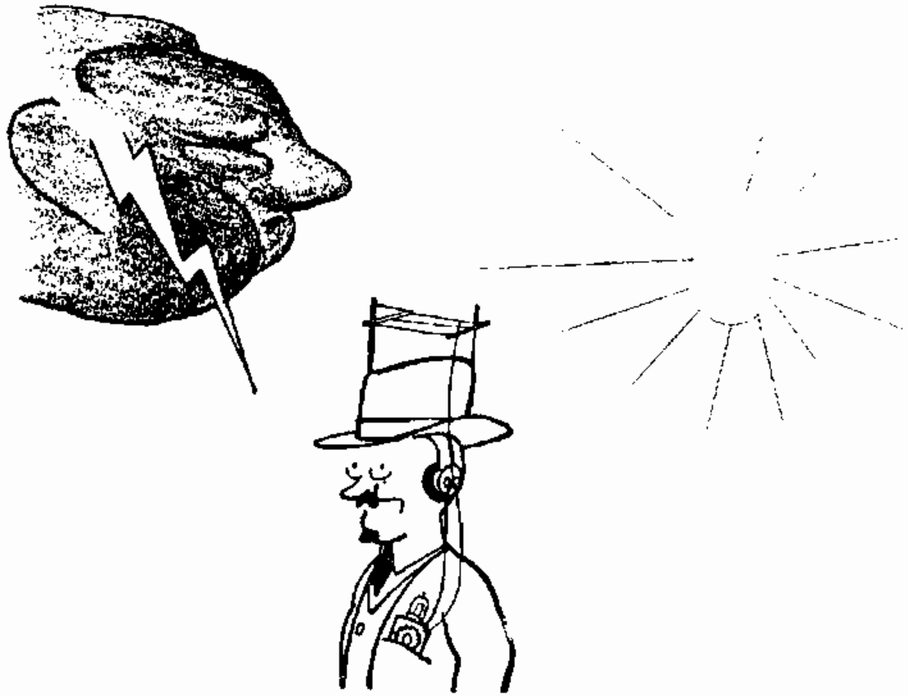
Man made noise

In an aircraft the man-made noise from electrical motors, arching between relay contacts or in electrical motors etc may also reach a disturbing level.

If there is a failure in one of the aircraft's electrical motors or relays or in the filter elements which are used to suppress the noise generated in electrical apparatus, the noise is disturbing the reception. In this case the source of noise has to be found and repaired.

High level man-made noise may also be noted when reception takes place in an aircraft over (or on the ground in) a large city with an extensive traffic of electrical vehicles such as street cars, trolley-buses etc. Electrical welding equipment and equipment for high frequency diathermic are also producing noise of high level.

Figure 56: Different noise affecting the reception



Static Dischargers

One major source of radio interference comes from the discharge of static electricity which is produced on the aircraft due to friction. When ever an aircraft travels through rain, dust or even airborne pollutants, a static charge is produced on the skin of the aircraft.

This static charge is more prevalent on aircraft capable of speeds of 200 kts or greater. The static charge formed on the aircraft skin will not produce radio interference if the charge remains stationary. However, if the charge builds up and becomes great enough, it will discharge from the aircraft back into the atmosphere. This discharge produces a magnetic field which is received by the radio as static interference.

Static dischargers help to eliminate radio interference by lowering the amount of static electrical current which discharges from the aircraft back into the air. Without static dischargers, static electricity would build up on the aircraft to a certain level and then rapidly discharge back into the air. This periodic discharge would continue as long as the static charge continued to build on the aircraft surface.

If the aircraft is equipped with static dischargers, the static discharge occurs at a lower current level and much more frequently. The lower level of discharge current produces an extremely weak magnetic field which is not picked up by radio receivers.

Static dischargers are mounted to the trailing edges and tips of wings, vertical and horizontal stabilizers, and control surfaces. The layout of static dischargers can be different, but work according to the same principle.

Figure 57: Static Dischargers

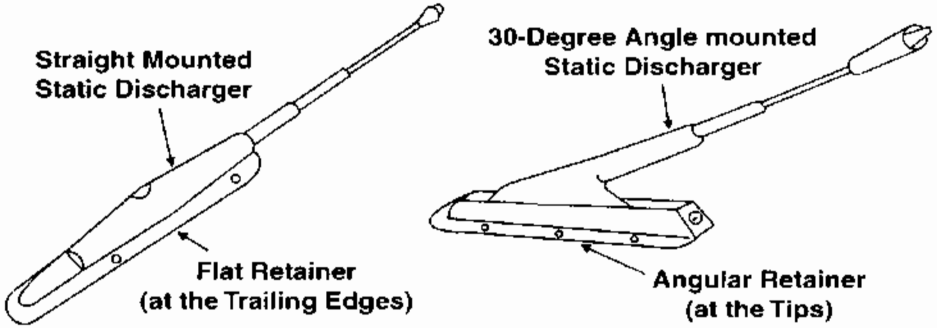
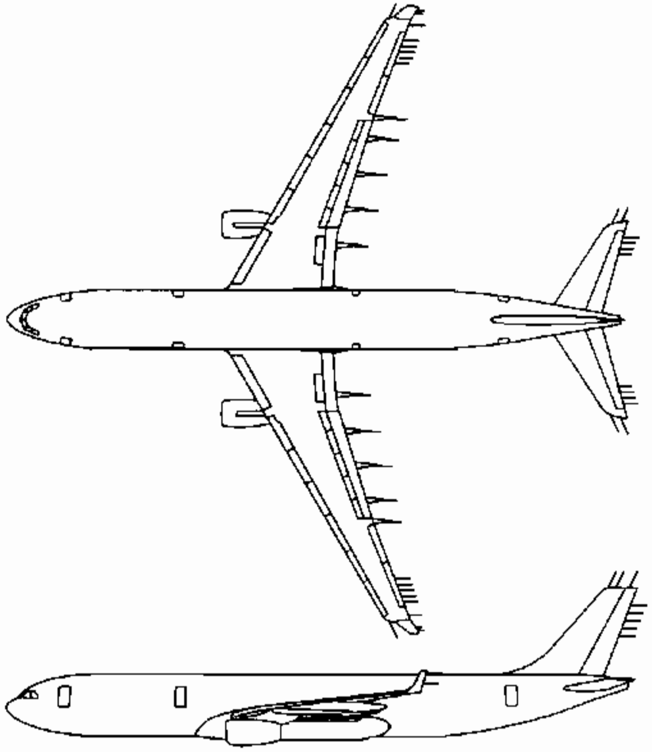


Figure 58: Locations



The Principle of the Static Discharger

P-static interference occurs when the radio noise created by the static discharge current pulses is coupled to the receiving antennas. In accordance with the principles of reciprocity, a receiving antenna has a coupling field identical to the electric field it would create if excited as a transmitting antenna.

This antenna coupling field is mainly concentrated near the extremities of the airframe and especially in regions with sharp curvature, such as the trailing edge of the wing tip. The shape of the field near these extremities does not vary greatly with the type or location of the antenna but is determined principally by the shape of the conducting airfoil.

Unfortunately, the electrostatic field created by a charge on the airframe is concentrated at just those extremities of the airframe where the antenna field is concentrated. Since the corona discharge current flows where the static field is strongest and in the direction of the static field lines, the corona noise currents will flow parallel to the antenna coupling field.

This means that the noise currents will be tightly coupled to the antenna. The static discharger moves the electrostatic field slightly aft, reducing the coupling with the antenna field.

Very important in this respect is the high-resistance rod. This is contained between the metal shank and the tip and acts almost as a non-conductor at rf frequencies.

Consequently the antenna field is not further concentrated. The high resistance rod is a satisfactory conductor at DC, consequently the static field is concentrated near the end of the discharger and the discharge will take place at some distance from the trailing edges.

Since the antenna field is nearly zero in this region only little coupling can occur Away from the tip, the discharge current flowing along the static field lines encounters the antenna field, but since the two are nearly perpendicular to each other, the coupling is very small.

Figure 59: Noise current coupled to the antenna

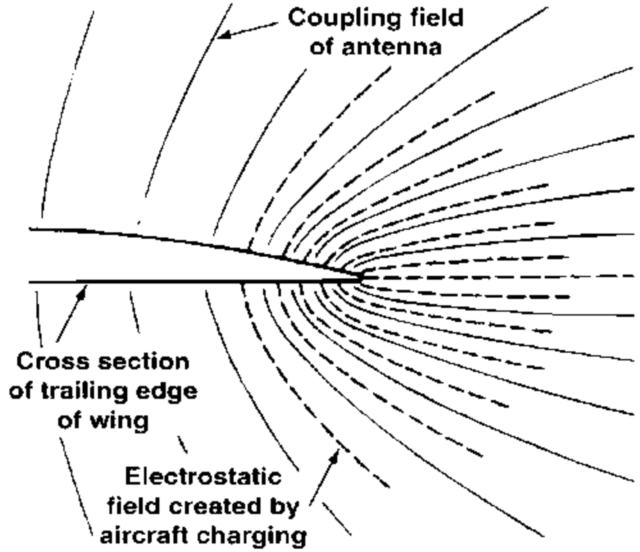
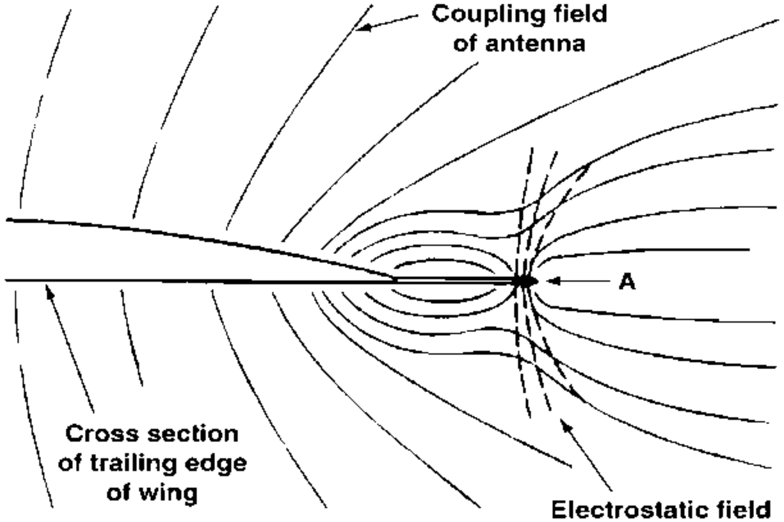


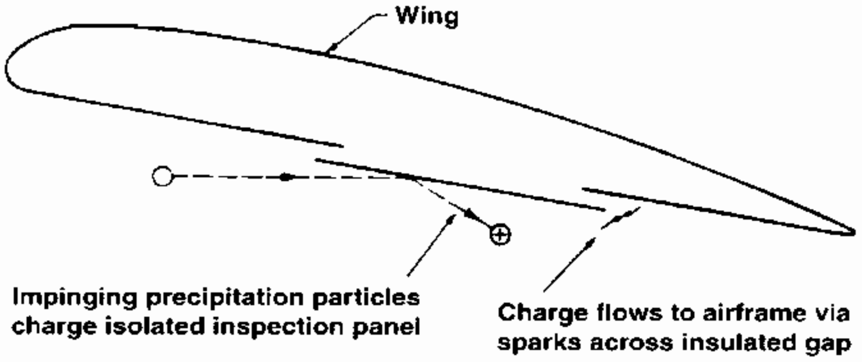
Figure 60: Noise current not affecting the coupling field of antenna



Bonding

As already stated in the introduction, the p-static problem can easily be solved by installing static dischargers. There are, however, some additional issues that require attention. First of all it must be assured that all moving airframe surfaces, detachable panels, etc. are bonded to the main mass of the airframe. This Is done to prevent arcing which might create a fuel storage ignition problem. It is also true that, when moving parts of the aircraft like flaps and ailerons, are not bonded together, then a difference in voltage level can exist between the two surfaces. (Distribution of the static charges through the bearings only is absolutely insufficient). As a result of this differential potential, sparking can be induced across the unbonded portions of the aircraft. We now in effect have a spark transmitter, that couples the energy of the spark into the aircraft antennas and can create crackling noises into the head phones. Similarly, inspection panels can become isolated from the main structure of the aircraft and have the same result

Figure 61: Charging due of incorrect bonding

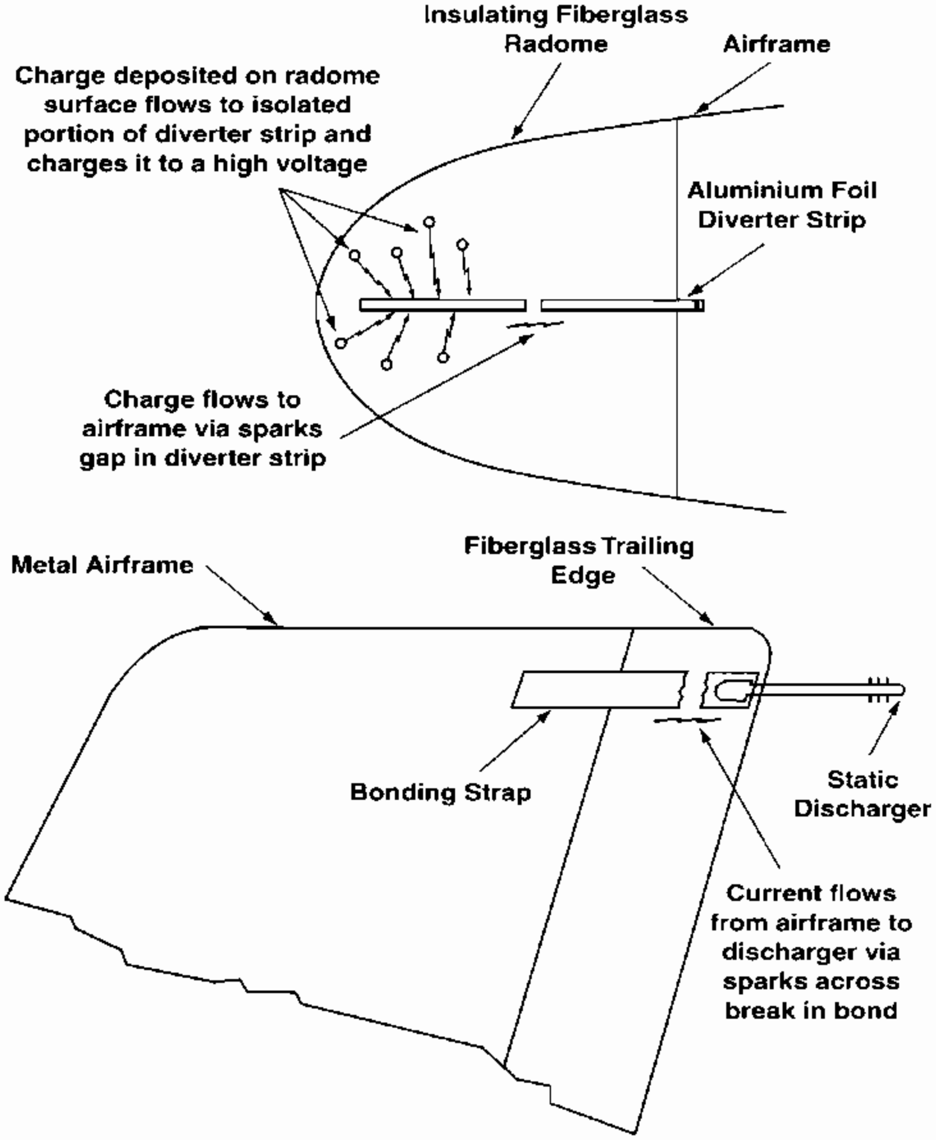


Streamering

Synthetic materials form a different problem. As an aircraft flies through precipitation static conditions these parts will accumulate a static charge (static electricity). Because they are not conductive, they cannot easily lose this charge without further steps. Upon reaching a certain potential difference, the accumulated charge will then discharge all at once. This discharge can couple into the antenna system and create static noise. This phenomenon has been named 'streamering'

The solution is the application of special paint that allows the charge to leak away. Furthermore the radome is equipped with metal strips to drain the static charge without disturbing the radar operation. The strips may not be damaged.

Figure 62: Radome diverter strip and static discharger bonding failure



VHF Communication

Introduction

The VHF is used for short range voice and data communications. The VHF system allows short distance voice communications between different aircrafts (in flight or on ground) or between the aircraft and a ground station.

Frequency:	Very High Frequency 118.000 - 136.975 MHz AM in 25 kHz channel spacing / 760 Channel in 8.33 kHz channel spacing / 2280 Channel
Power:	5 - 25 Watt

Figure 63: Propagation VHF

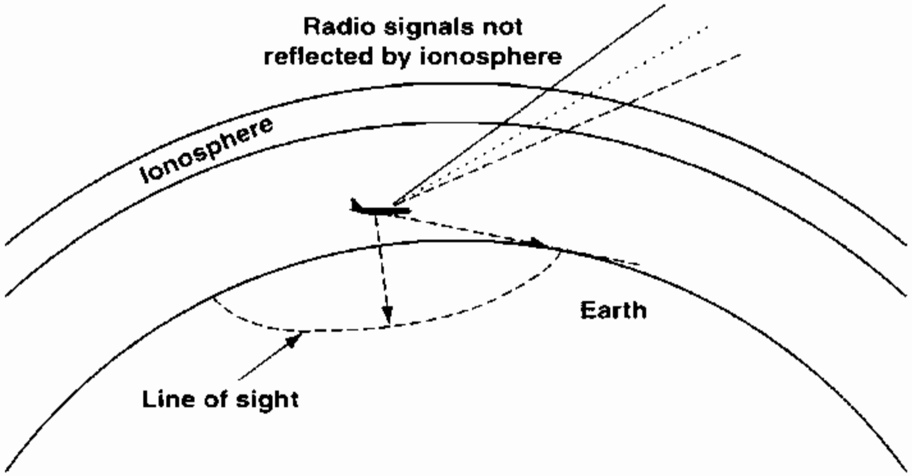
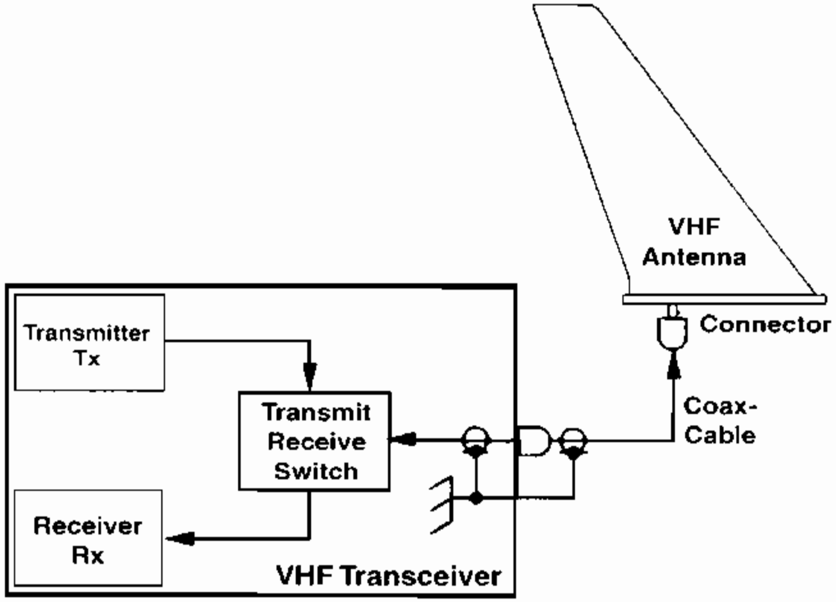
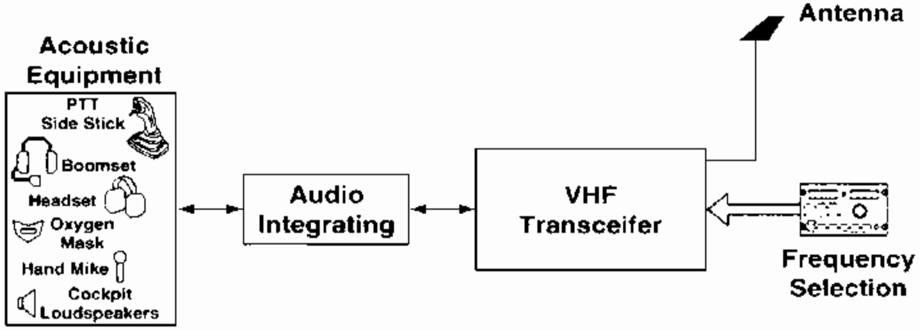


Figure 64: Transceiver



Pressing the Push To Talk switch (PTT) located at handmicrophone, audio control panel, control wheel or side-stick changes from reception (Rx) mode to transmission (Tx) mode.

Figure 65: System simplified



Controls

Tune the desired frequency

Figure 66: VHF COMM Control Panel

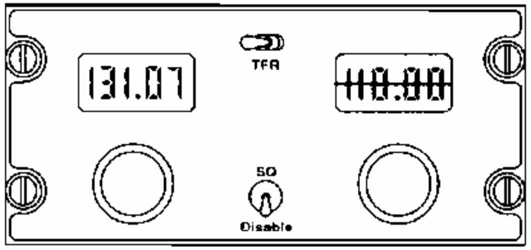
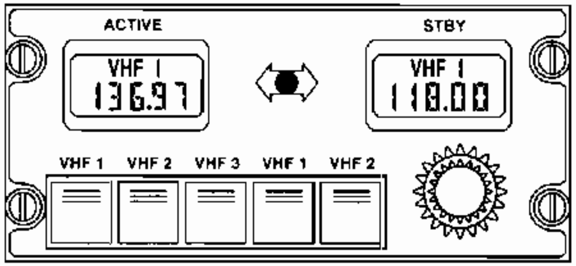


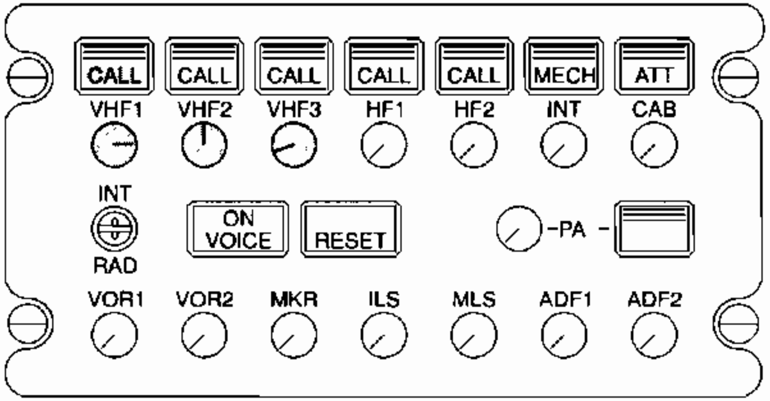
Figure 67: Radio Management Panel tunes 3 VHF and 2 HF Systems



Some useful Frequencies

121.70	MHz	Dispatch Ground	(SELCAL)
131.70	MHz	Dispatch Flight	(SELCAL)
127.20	MHz	VOLMET	Meteo Region
128.525	MHz	ATIS	Meteo Zurich Airport
121.95	MHz	Maintenance Control Center SRTechnics	
122.90	MHz	Maintenance test or working channel (IERA)	
121.75	MHz	Geneva Ground Control	

Figure 68: Audio Control Panel



Reception:
open the respective VHF potentiometer.

Transmit:
press the desired Microfone (CALL) button and
hold the RAD/INT switch in RADio position at ACP or Control Column/Stick, or
press the PTT button at handmicrofone

Never transmit at these frequencies:

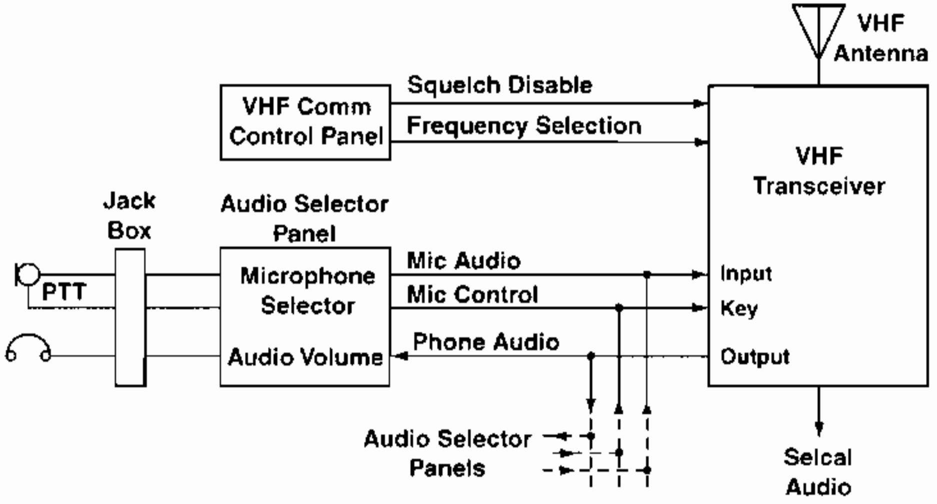
118.00	MHz	Arrival
118.10	MHz	Tower
121.90	MHz	Ground
121.75	MHz	Apron
125.95	MHz	Departure
121.80	MHz	Delivery

121.50MHz EMERGENCY

VHF Communication System

The aircraft is equipped with 1 to 3 independent systems. They either operates in reception- or transmitmode. The operation frequency is selectable at the contolpanel.

Figure 69: System



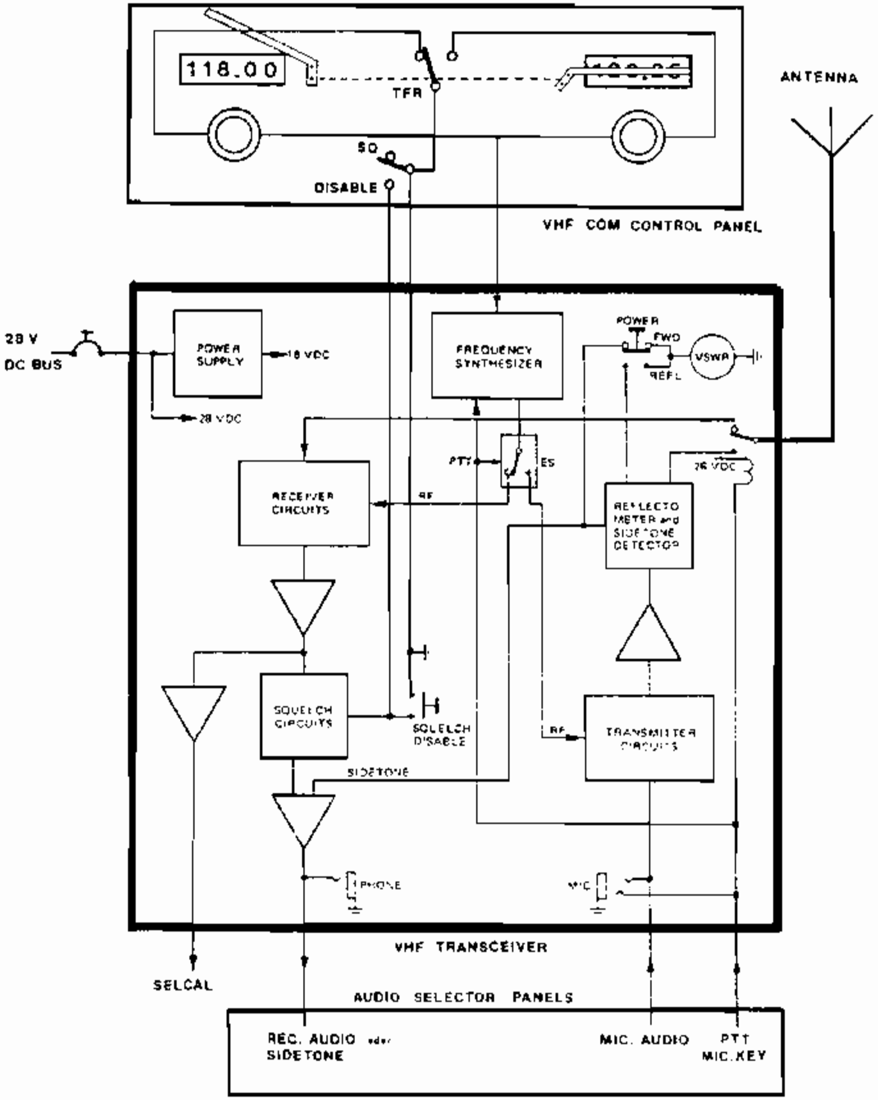
The received signal comes from the antenna to the receiver. The squelch cancels the reception noise with no input signal. The unsquelched output goes direct to the SELCAL decoder

To transmit, the microphone key/Push To Talk has to be pressed. The antenna is now connected to the transmitter. To confirm the transmitter output goes to air, a small amount of RF energy is demodulated and fed back to the receiver output to be listened as a sidetone.

The frequency synthesizer produces according the selected operation-frequency at the controlpanel during Rx mode the local oscillator frequency and during Tx mode the carrier frequency.

A VSWR meter shows the forward FWD or reflected REF voltage to/from the antenna during transmit mode. The ratio U_{REFL}/U_{FWd} = VSWR (Voltage Standing Wave Ratio) is in optimal cases 1. If the ratio is more than 2, a problem in the antenna circuit is present.

Figure 70: VHF Transceiver - Functional diagram



VHF COMM Transceiver

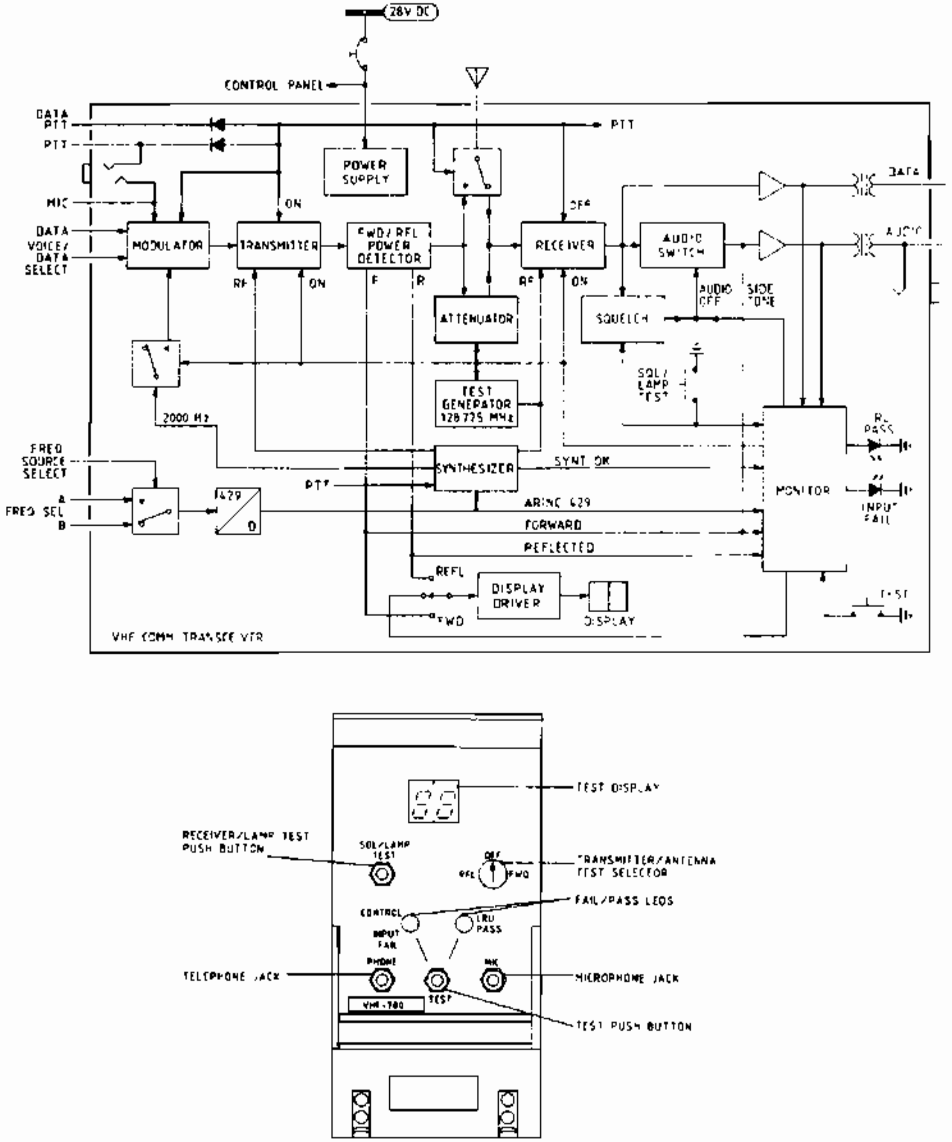
The transceiver operates in the frequency band from 118.00 to 136.975 MHz in 25 kHz or 8.33 kHz steps. The frequency selection comes in ARINC 429 format from the control panel or from an ACARS. A frequency source select input controls the source from which we use the frequency selections.

The VHF COMM receiver detects the audio modulation of the RF signal of the selected frequency. The audio goes through an audio switch to the receiver and sidetone audio output. The squelch takes care that the audio switch switches off the audio when there is no reception of a signal. The second audio output goes directly from the receiver to the data output for equipment such as a SELCAL decoder or an ACARS.

The transmitter starts when there is a ground at the PTT input. This ground starts the transmitter and it stops the receiver. Audio information from a microphone or the optional ACARS goes through the modulator to the transmitter. The transmitter generates an output of the selected frequency with a nominal power of 30 Watt (min. 25 Watt). This output passes through a circuit that measures the forward and reflected power. At the forward power output of this circuit there also is detected audio which goes to the audio amplifier as sidetone.

When you test the VHF COMM transceiver both the transmitter and receiver operate for about 100 milliseconds. The modulation of the transmitter is 2000 Hz and the transmitter output goes through an attenuator to the receiver. The monitor checks the forward and reflected power and shows the VSWR on the display. The monitor also checks the data and headset audio outputs of the receiver for presence and amplitude of the 2000 Hz signal. If there is a failure the LRU PASS light does not come on.

Figure 71: TRx

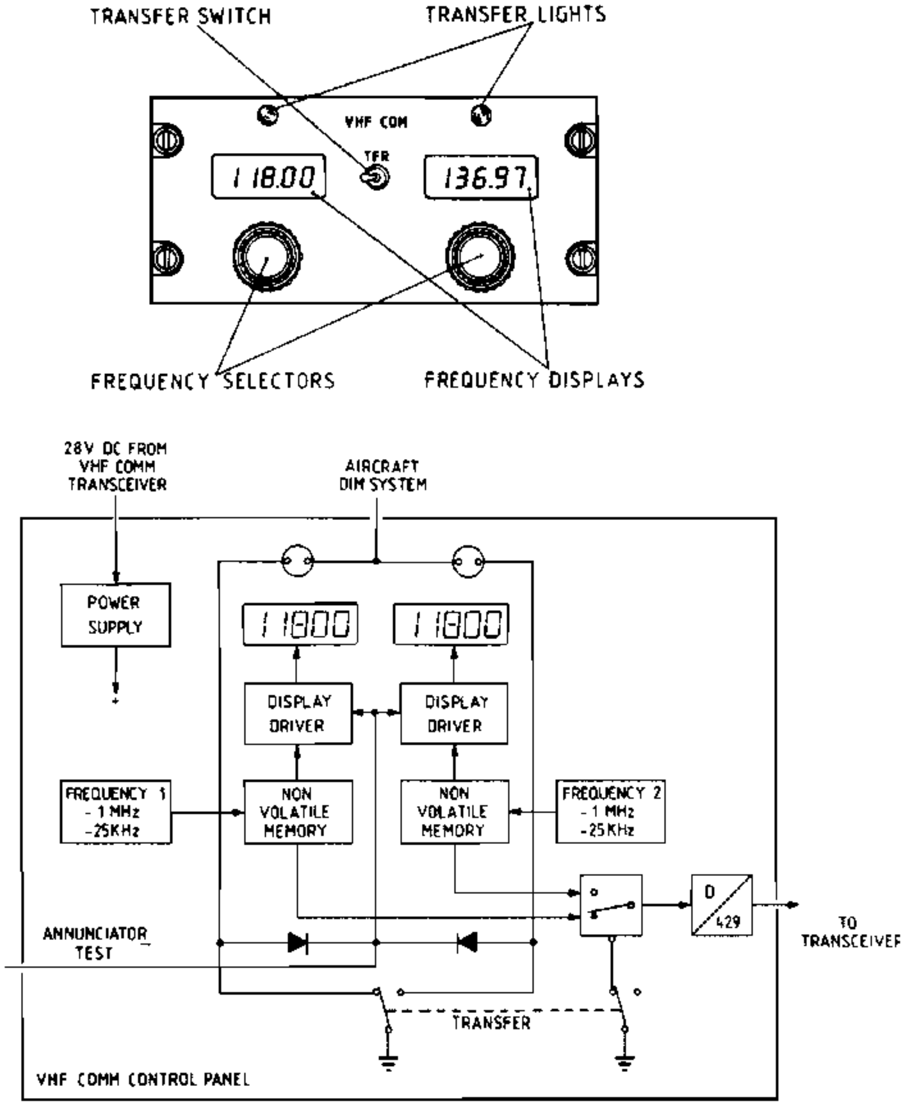


VHF Control Panel

The control panel receives its power supply through the circuit breaker of its VHF COMM transceiver. On the control panel you can select frequencies from 118.00 to 136.975 MHz. On the control panel there is an active and preselected frequency which you can select with a transferswitch. The green transfer light above the frequency display shows which frequency selection is active. When electrical power switches on, the control panel shows the last selected frequencies. The control panel stores these frequencies in non-volatile memory when electrical power switches off. When you select a frequency the control panel updates the frequencies in the non-volatile memory. The non-volatile memory gives the active and preselected frequencies to the display driver and to the ARINC 429 transmitter

When there is a control panel failure when you switch the system on, the transceiver goes to the emergency frequency, 121.5 MHz. When there is a control panel failure during operation of the system the transceiver continues to operate on the last operational frequency.

Figure 72: Control Panel

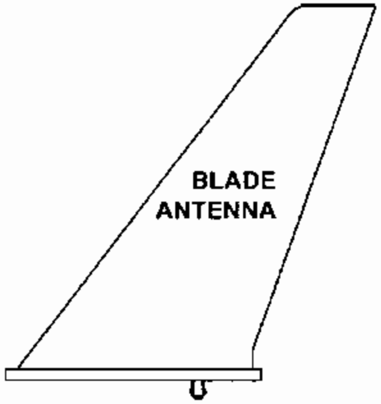


Antenna

VHF transmitters and receivers use a vertically polarized antenna that may be mounted either above or below the aircraft fuselage. Some of the simpler installations use wire whip antennas while the more efficient installations use a broadband blade antenna. Some wire antennas are bent aft at about a 45° angle, which allows them to receive horizontally as well as vertically polarized signals.

A VHF communication antenna is a quarter-wavelength antenna that uses the metal of the aircraft as the other quarter wavelength to give the antenna the required half wavelength. When installing this type of antenna on a fabric-covered aircraft, you must provide a ground plane. This is done by using strips of aluminum foil or a piece of aluminum screen wire that extends out for approximately one-quarter wavelength from the center of the antenna on the inside of the fabric.

Figure 73: VHF Comm Antenna



HF Communication

Introduction

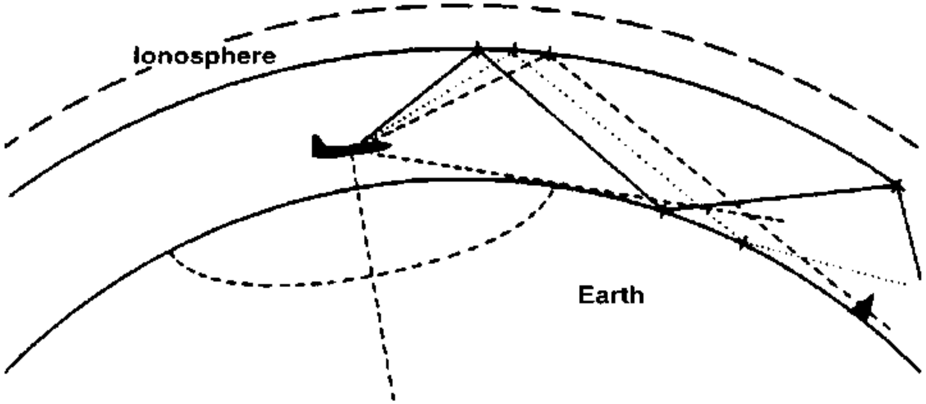
The HF system allows long distance voice communications between different aircrafts (in flight or on ground) or between the aircraft and a ground station.

Table 3:

Frequency:	Shortwave 2 - 29.999 MHz AM
	in 1 kHz channel spacing/28000 Cannel
Power:	100 W - 400 W

The ionosphere reflects the radiowaves back to the earth. This helps to reach depending of the solar activity to reach any point of the world.

Figure 74: Signal Radiation on Short Wave



The antenna must be matched to the transmission frequency. This is done with antenna-coupler near the antenna. Before transmission the antenna is automatically tuned within few seconds.

Pressing the Push To Talk switch (PTT) located at handmicrofone, audio control panel, control wheel or side-stick changes from reception (Rx) mode to transmission (Tx) mode.

Figure 75: HF - COM Block Diagram simplified

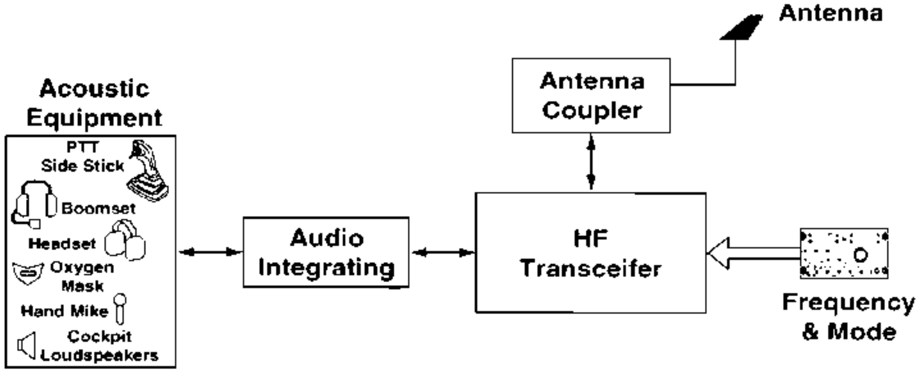


Figure 76: HF Control Panel

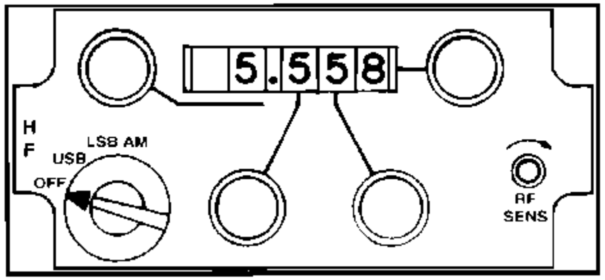
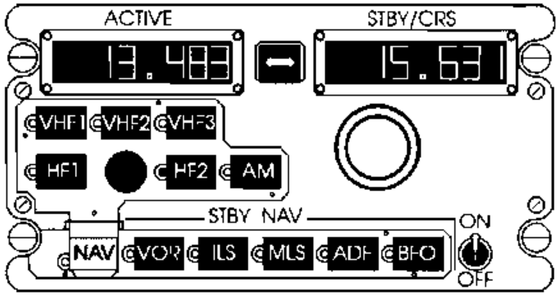


Figure 77: Radio Management Panel



System

This is for communication between the aircraft and ground stations. The ionosphere reflects the frequencies in the HF band, so the line of sight does not limit the reception range of the system. That is why the HF COMM is suitable for long range, world wide communication.

The frequency range of the system is 2 to 29.999 MHz. You can make the frequency selection in 1kHz steps, so there are 28000 channels available. There are two modes of operation, these modes are:

- AM - amplitude modulation
- SSB - upper side band

In the AM mode the system transmits a carrier with amplitude modulation. In the SSB mode you remove the carrier and the lower side band. The system only transmits the USB.

The System has the following components:
a transceiver, an antenna coupler, an antenna and a control panel.

On the control panel you make the mode and frequency selections. The information goes from the control panel to the transceiver through an ARINC 429 data bus.

The control panel also shows the frequency selection. The received audio signals go from the transceiver directly to the audio management system. A data output of the transceiver supplies the SELCAL decoder. The push to transmit (PTT) and microphone signals go directly from the audio management system to the transceiver. The PTT signals also go to the coupler. The antenna coupler adjusts the antenna impedance to get the correct load for the transmitter. To do a tune-cycle after a frequency change the coupler gets a re-channel pulse from the transceiver The transceiver gets a Tune-In-Progress (TIP) signal from the coupler. To monitor the coupler condition interlock signals come and go from the coupler to the transceiver.

Figure 78: HF System

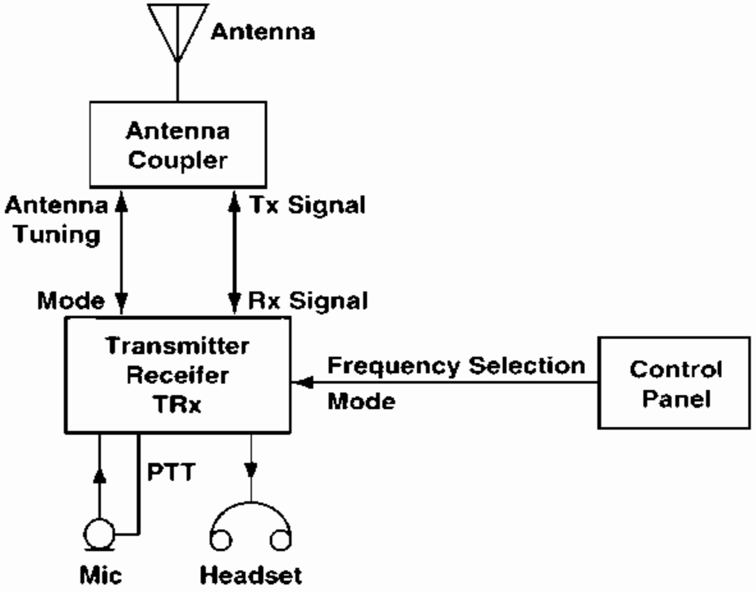
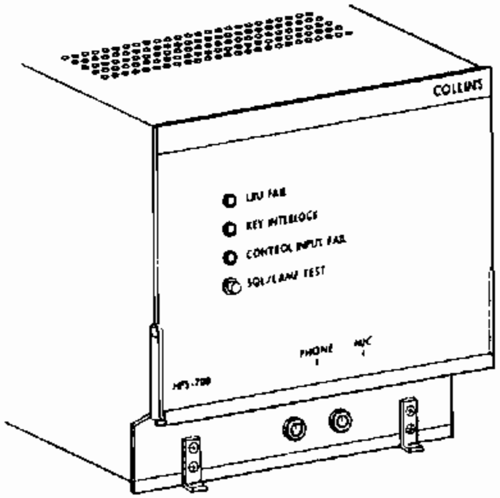


Figure 79: HF Transceiver Unit

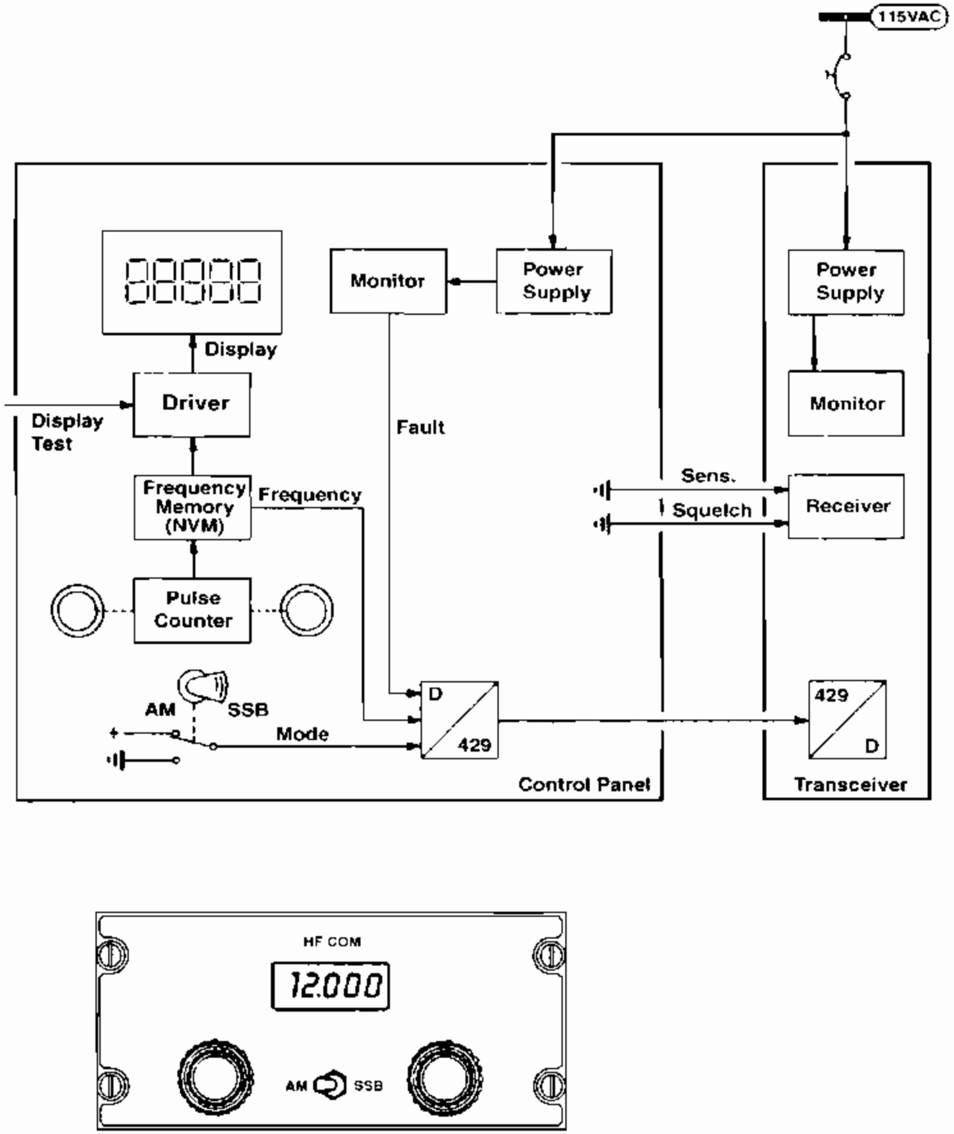


Control Panel

On the control panel are the controls to select the frequency and the mode of operation. This information goes through the ARINC 429 data bus to the transceiver. The display, which is an LCD, shows the selected frequency.With the LCD test switch on the maintenance and test panel you can test the display. A non volatile memory holds the last selected frequency after a power interruption.

The RF sensitivity and squelch lines from the transceiver unit are grounded in the control panel. This gives maximum sensitivity and a disabled squelch setting.

Figure 80: HF Control Panel



Transceiver

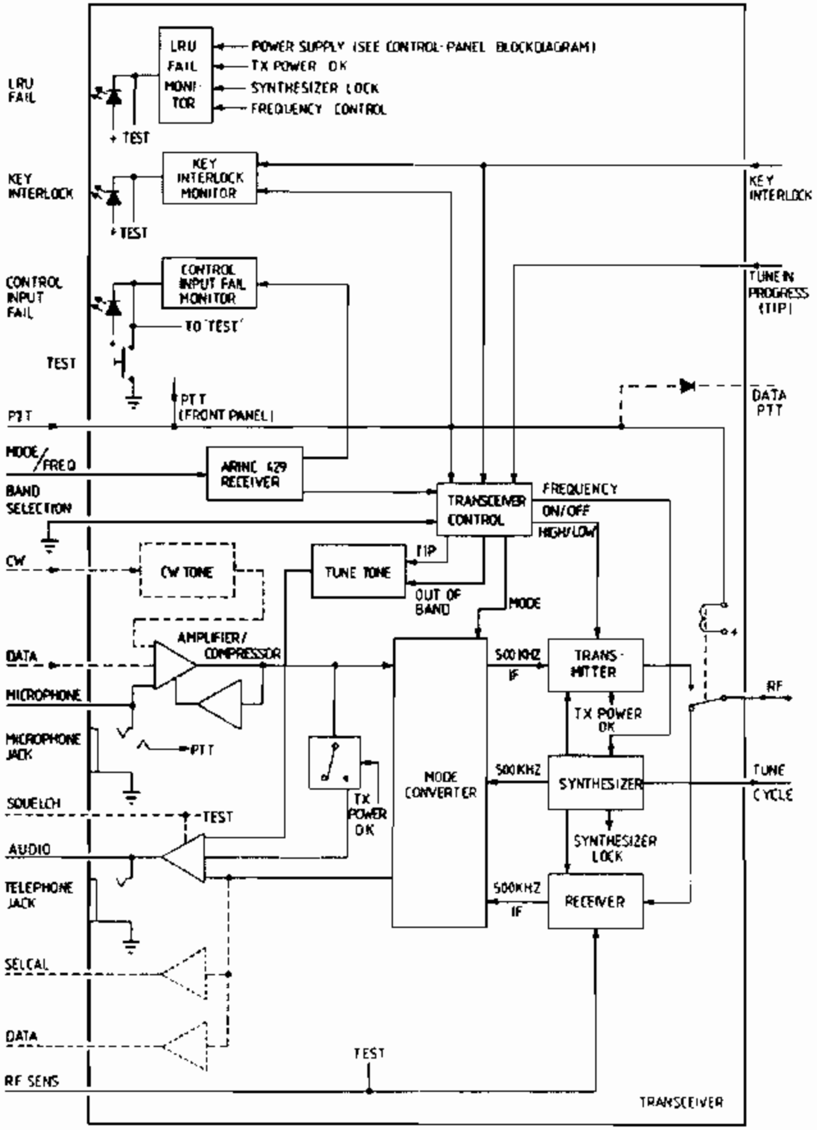
The HFS 700 transmits 125 W in AM mode and 400 W peak envelope power (PEP), in the SSB mode. On the front of the transceiver are a telephone and microphone jack, a test button and 3 fault lights. LRU FAIL, KEY INTERLOCK and CONTROL INPUT FAIL

After switch-on, the transceiver is in the receive mode. It gets the RF signal from the antenna through the antenna coupler. Through the R/T switch the signal goes to the receiver, which makes an IF (intermediate frequency) signal from the RF. It depends on the mode selection how the mode converter detects the audio from the IF signal. When the system is in the USB mode, the mode converter uses a 500 KHz from the synthesizer for detection. From the audio amplifier the audio signal goes to the audio integrating system.

A PTT signal, that comes from audio management, changes the transceiver from the receive mode in the transmit mode. The input microphone signal goes to an amplifier/compressor circuit. This circuit changes the variable input signal to a signal with a constant amplitude, to get a constant modulation level. The mode converter makes from the microphone signal and the 500 kHz signal from the synthesizer an IF AM or USB signal. The transmitter changes the IF to the transmit frequency and amplifies the signal before it goes to the antenna coupler.

Normally the transmitter gives more than 30 W output power and closes a sidetone enable contact and you hear the microphone signal as sidetone. Absence of sidetone, while in the transmit mode, will cause the LRU FAIL light to come on, to show that the transmitter is defective. When the frequency selection on the control panel changes, the antenna coupler must tune to a new position, to adapt the antenna to the new frequency. After a frequency change the receiver gives a tune-cycle signal to the coupler. When you now push the PTT button momentarily the transceiver gets a tune-in-progress signal (TIP) back from the coupler, and the coupler will hold the PTT line low.

Figure 81: HF - TRx



Transceiver (continued)

The TIP signal switches the transmitter to the AM mode and gives a low output power (minimum 70 W). The coupler uses the RF signal to measure the SWR, which it uses to tune the filters in the coupler. The tune-tone oscillator gives a 1000 Hz tone to the audio amplifier during the tune-cycle. When the coupler removes the TIP and PTT signal at the end of the tune-cycle, the tune tone disappears and the transmitter goes off. The system is in the receive mode again.

On the panel of the transceiver are 3 lights (in fact LED's), which show which part of the system is faulty. LRU FAIL shows a faulty transceiver. It monitors the following:

- power supply
- frequency control
- synthesizer out of lock
- transmitter low power « 30W)

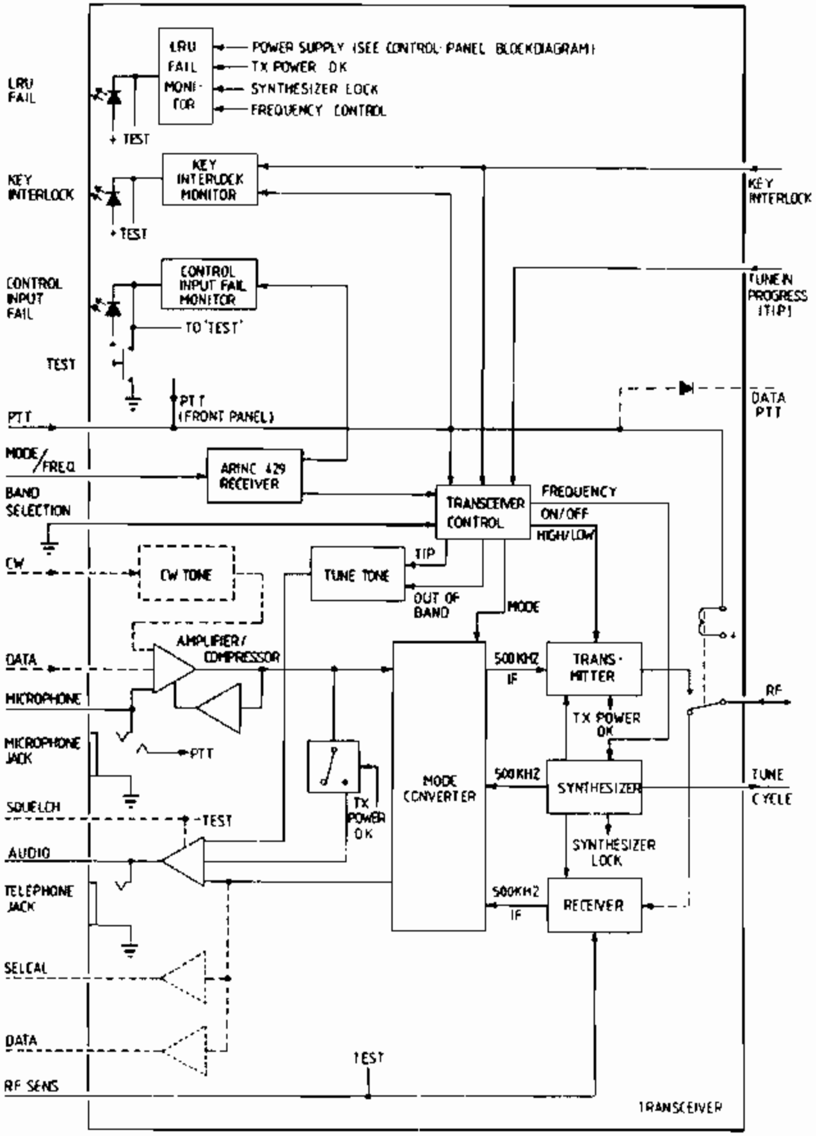
KEY-INTERLOCK shows a faulty coupler. See Antenna Coupler for description.

CONTROL INPUT FAIL shows a faulty control panel. It monitors:

- ARINC 429 bus activity
- Validity of ARINC 429 word.

The transceiver operates in a wide frequency band (2 to 29.999 MHz) or in a narrow frequency band (2.8 to 23.999 MHz). The band selection depends on aircraft wiring. When a transceiver operates in the narrowband with a control panel for the wide band, a frequency selection outside the narrow band gives a 1000 Hz tune-tone warning. This is to warn you for the out-of-band selection.

Figure 82: HF - TRx



Antenna Coupler

Overview

To get optimal power transfer from transmitter to antenna, the antenna impedance must be the same as the transmitter output impedance (50 Ohm) For each frequency the impedance of an antenna is different. Since the antenna on the aircraft has a fixed lenght, it is only suitable for one frequency. The antenna coupler tunes filters to adapt the antenna impedance for each different frequency to the transmitter output impedance. The coupler tunes to minimum standing wave ratio (SWR), which is a relation between forward and reflected power. This is to prevent that too much reflected power damages the transmitter.

The antenna coupler is the interface between the antenna and the transceiver. For each frequency the filters in the coupler have a different position, so after each frequency change the filters must tune to the new position. To do such a tune-cycle the coupler needs RF power from the transmitter for SWR measurement.

The location of the unit is on some aircrafts outside the pressurized cabin. When air pressure is low, arcing occurs easily, especially when you use high voltage as the coupler does. To prevent arcing inside the coupler when the aircraft is at a high altitude, the unit is pressurized. Nitrogen also prevents corrosion inside the unit.

Figure 83: Antenna Coupler

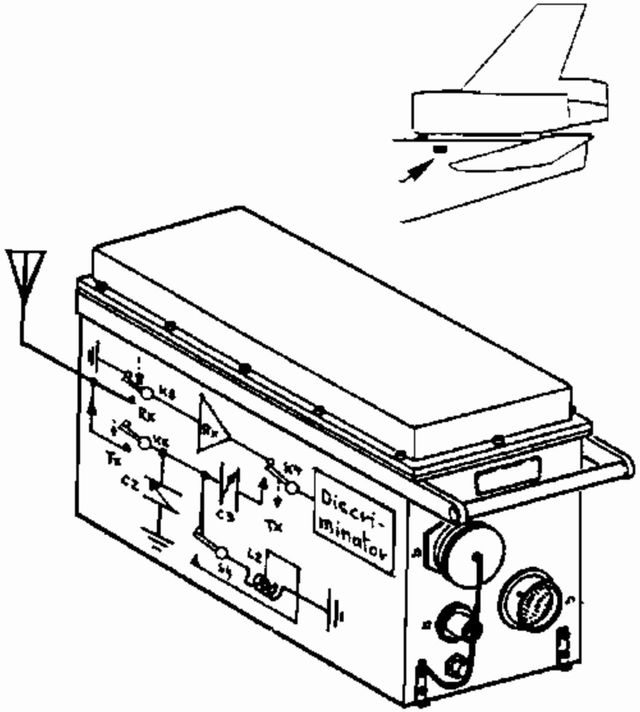
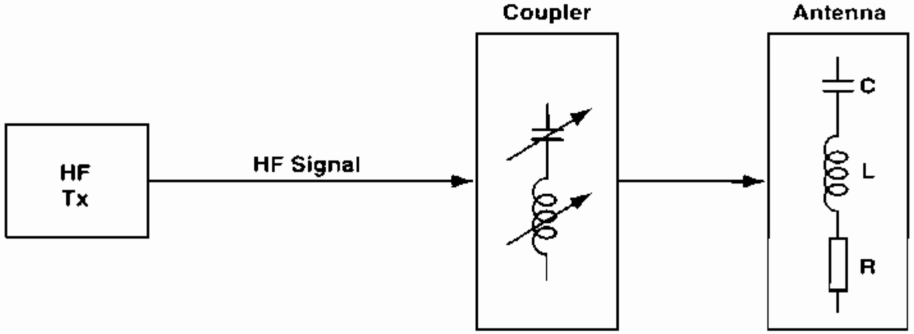


Figure 84: Antenna Matching



Antenna Tuning Sequence

After switch-on or after a frequency change, the coupler must do a tune-cycle before it is ready for transmissions.

After the initial switch-on and a change in frequency selection, the coupler gets a rechannel signal from the transceiver. The filters in the coupler go to a start position, which is a neutral mid-band position.

When you now momentarily push the PTT button, the tune-cycle starts. A tune-in-progress (TIP) and PTT signal go to the transmitter to keep the transmitter on as long as the tune-cycle continues.

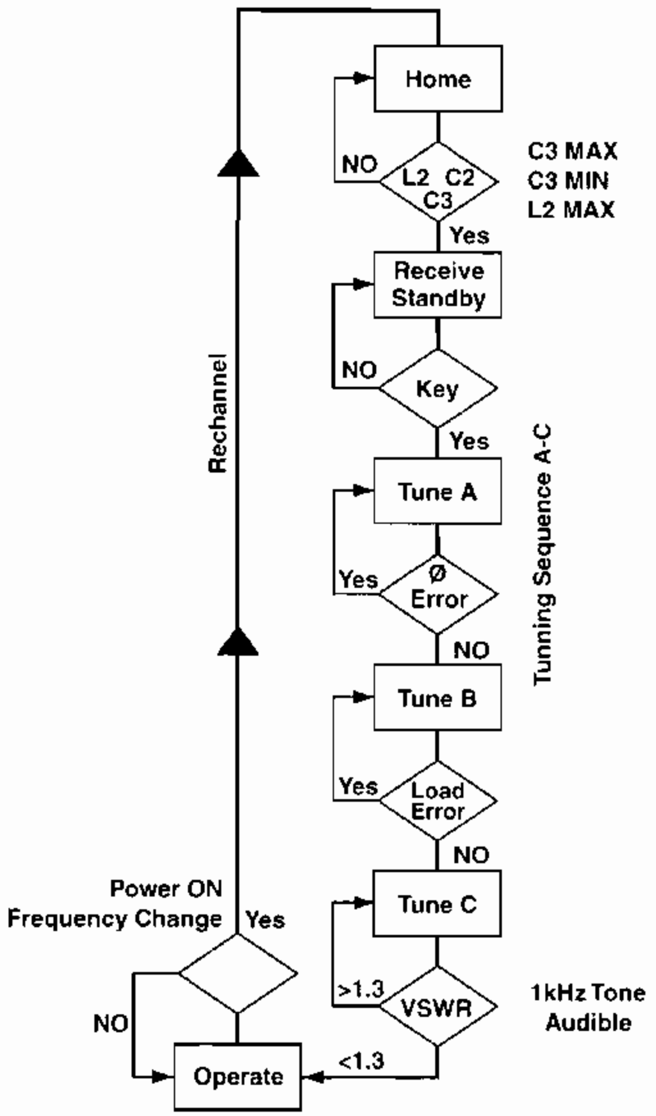
During the tune-cycle, the coupler is in the transmit mode and the transmitter signal goes through the filters to the antenna.

The SWR detector measures the load, and the SWR and the coupler control uses this signal to set the filters in the correct position.

When you have the correct load (50 Ohm) and so a minimum SWR, the coupler filters have the correct position. The coupler control removes the TIP and PTT signal and stops the tune-cycle.

The transmitter goes off, because the TIP and PTT disappear and the coupler goes to the receive mode, but is now ready for transmissions.

Figure 85: Tuning Sequence



Antenna Coupler Function

In the input of the isolation amplifier is a spark-gap. It starts to conduct when it gets a voltage of more than 90V. This is to protect the isolation amplifier and the receiver against lightning strike or high static charges.

After switch-on the coupler comes automatically in the receive mode. The received signal goes to an isolation amplifier This amplifier makes it possible to connect two HF systems to one antenna. After the isolation amplifier the signal goes to the transceiver.

A PTT signal, that comes from the audio integrating system has the following functions: Changes the coupler from the receive in the transmit mode. The TX/RX contacts change from the RX in the TX position. Connects the input of the isolation amplifier to ground to protect the amplifier and the spark-gap against the high transmitter power. Closes a contact to complete the key-interlock signal. The presence of the key interlock signal tells the transmitter that the coupler function is correct so the transmitter can come on.

When there is a dual system the coupler control makes a disable signal which: inhibits the other system so you cannot transmit with two sytems at the same time. Connects the input of the isolation amplifier of the other system to ground, to protect the amplifier and the receiver of the other system. In the transmit mode the transmitter signal goes through the tuned filters to the antenna.

When the coupler control detects a fault it interrupts the key-interlock signal to the transmitter. This inhibits the transmitter and the KEY-INTERLOCK light on the front of the transceiver comes on. When the light is on, it shows one of the following coupler faults: Excessive tuning time (more than 15 seconds): Excessive start positioning time (the coupler fails to go to the start position within 15 seconds, after it got a tune-cycle signal): Occurence of an arc (low pressurization of the unit in combination with high altitude).

Figure 86: Antenna Coupler Functional Diagram

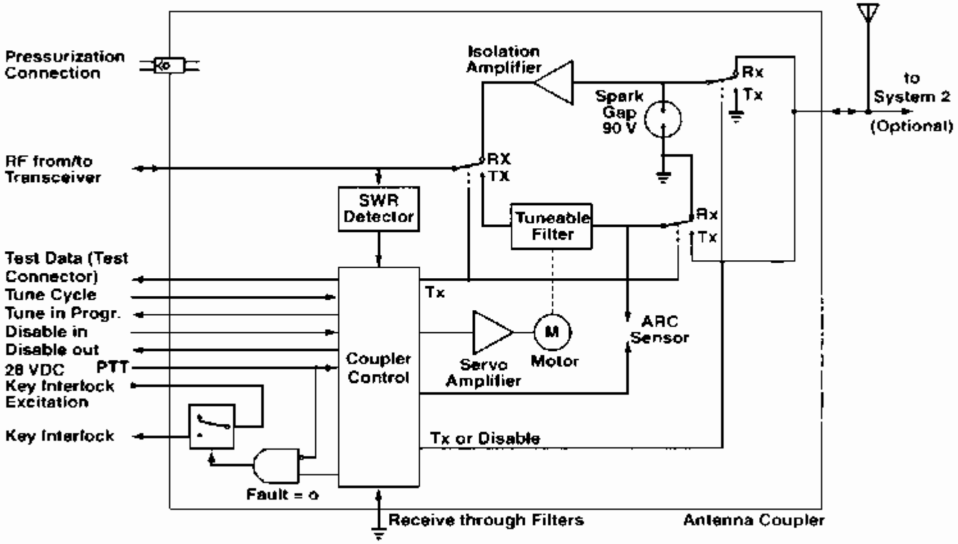
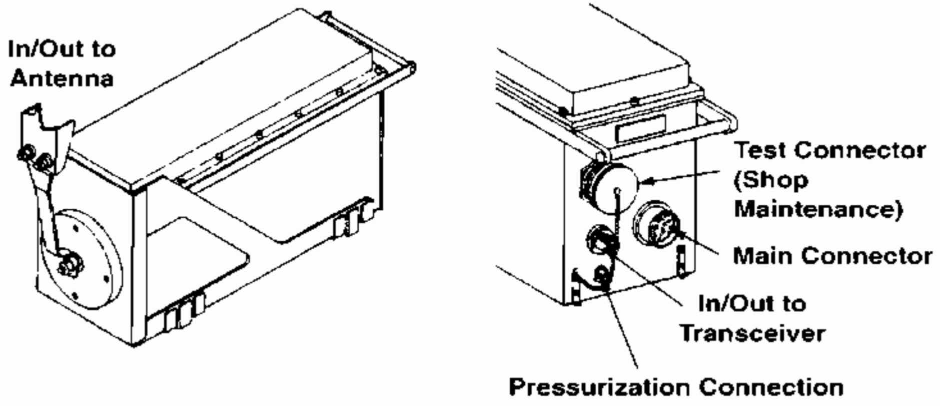


Figure 87: Unit



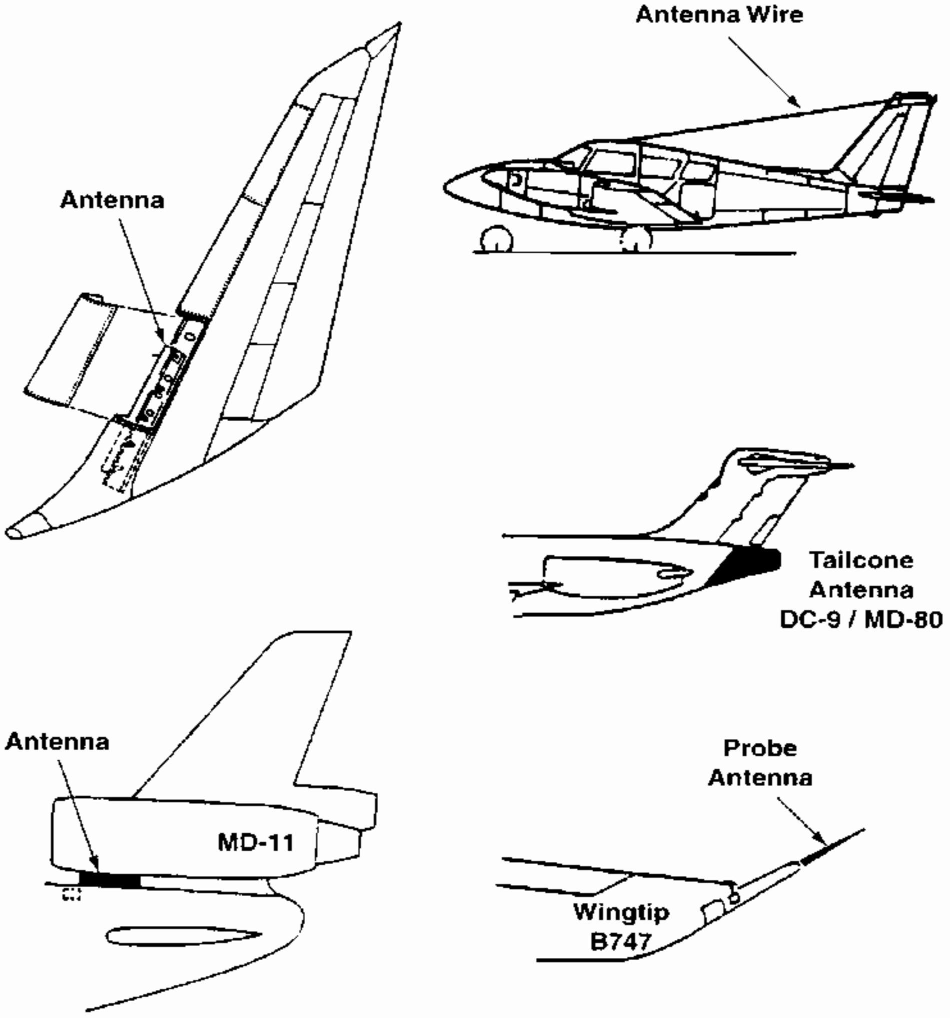
Antenna

Aircraft that fly over the water for long distances rely on high-frequency communications. The lower frequencies used by this equipment require long antenna. The horizontally polarized radiation used by HF communications allows long wires to be used.

In the past, long-wire trailing antennas were used for HFcommunication. These are often installed between a point above the cockpit and the tip of the vertical fin. The wire is often a copper-plated steel wire, but the more efficient systems use an antenna wire encased in a plastic sheath to minimize precipitation static.

Some modern high-speed aircraft have the HF communications antennas built into some part of the structure, such as the leading edge of the vertical fin.

Figure 88: Various HF Antenna Types



Lightning Arrestor

To protect the HF system against high static voltages and lightnings an separate protection device is used. A glassbowl containing a sparkgap. If the voltage is to high the gas inside will ionizise and discharge the energy to the aircraft structure.

If the lightning strike was to strong, the clear glas change its colour to black and the whole device (and in most cases also the coupler and transceiver) must be replaced.

Modern systems uses grounded antennas. One end of the antenna is connected with the aircraft structure. The electric energy of a lightning strike is discharged direct to the structure, so no further protection device is used.

Figure 89: Grounded Antennas (no Lightning Protection needed)

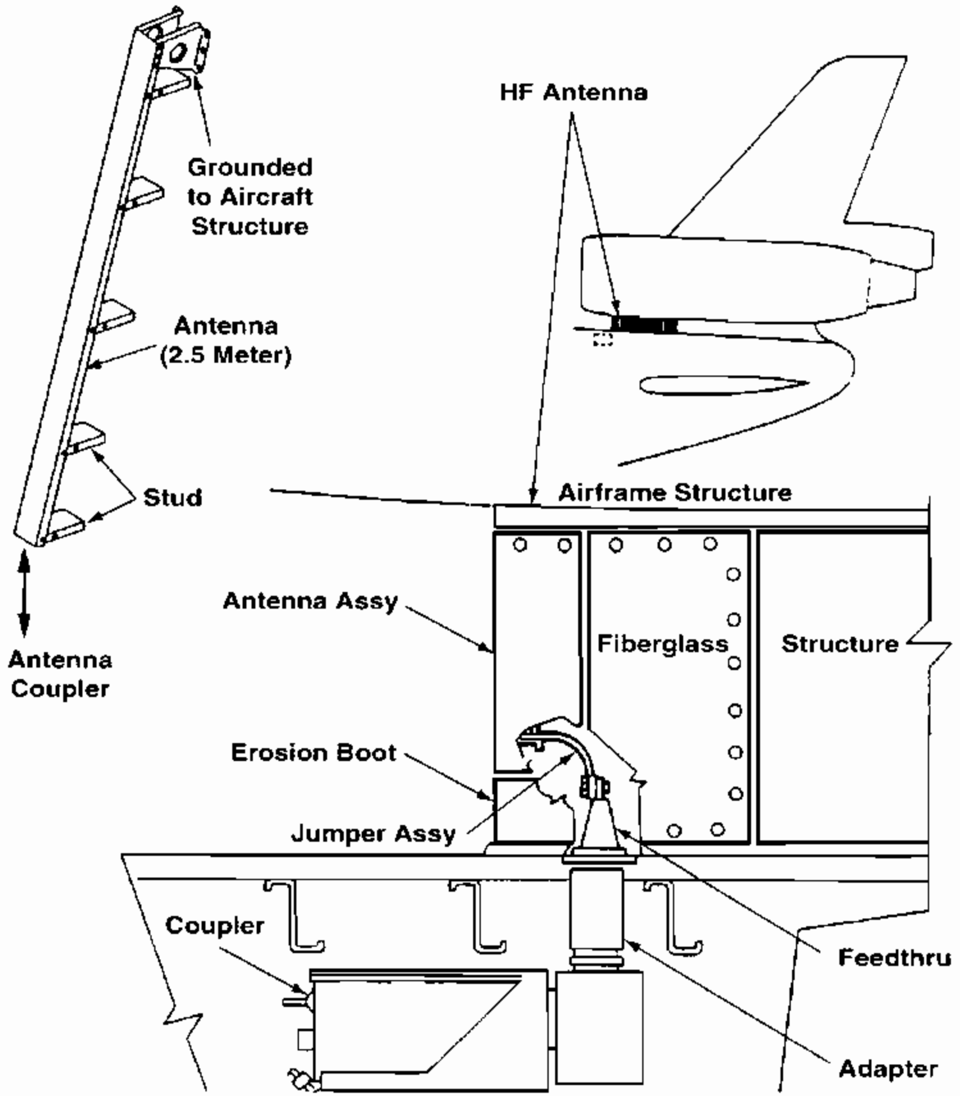
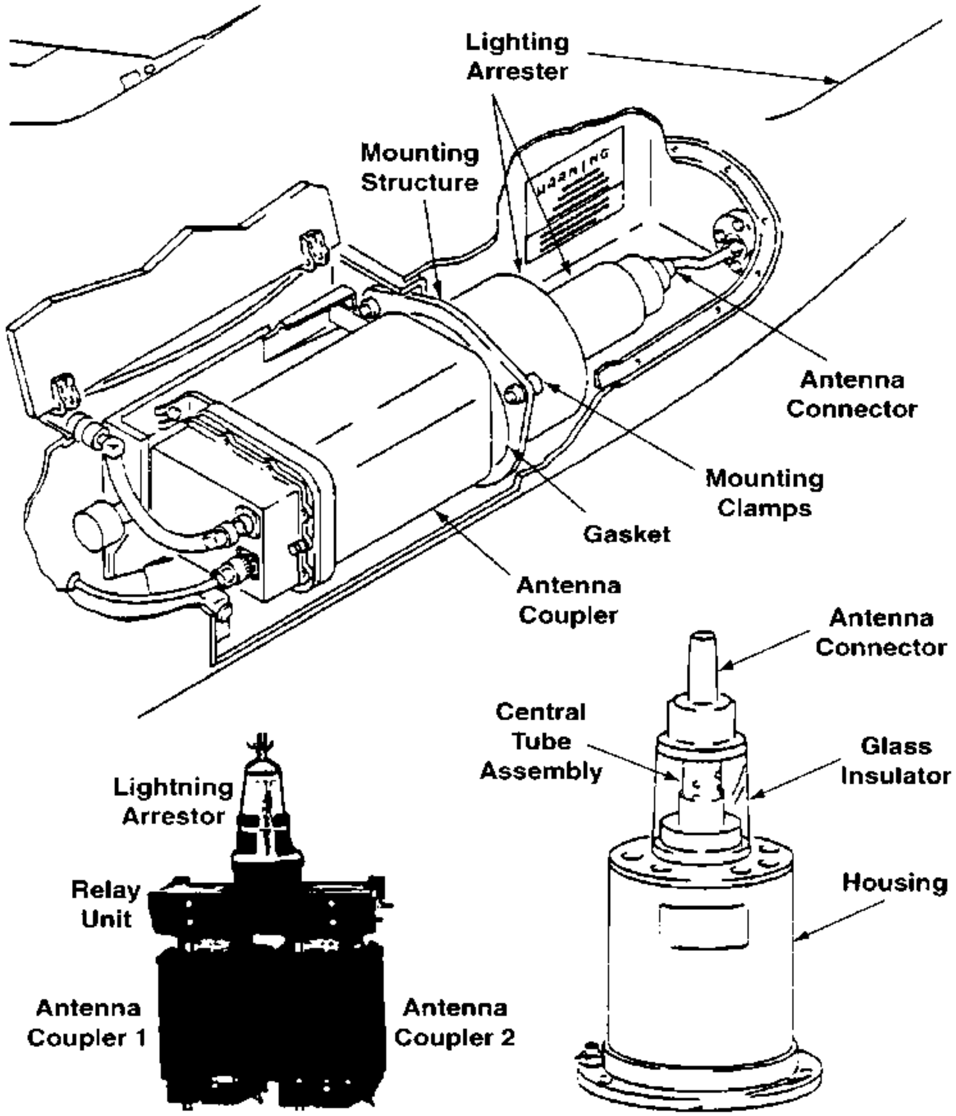


Figure 90: Antenna using Lightning Arrestor



SELCAL

Introduction

The SELCAL (Selective Calling) system provides aural and visual indications of the calls received from ground stations equipped with a coding device. The communication systems used for SELCAL reception, are VHF and HF systems.

The ground station transmits a selective call code, via VHF or HF transmitters. The SELCAL code panel is used to provide the decoder with the SELCAL code dedicated to the aircraft. The transmitter and receiver must be tuned to the same operation frequency.

The SELCAL decoder compares the code selected on the SELCAL code panel with the received code. Once detected, the information is send to the aural warning, which generates a buzzer sound and the "CALL" legend flashes AMBER in the cockpit.

When the RESET key is pressed, the aural and visual indications are cancelled.

Figure 91: Principle

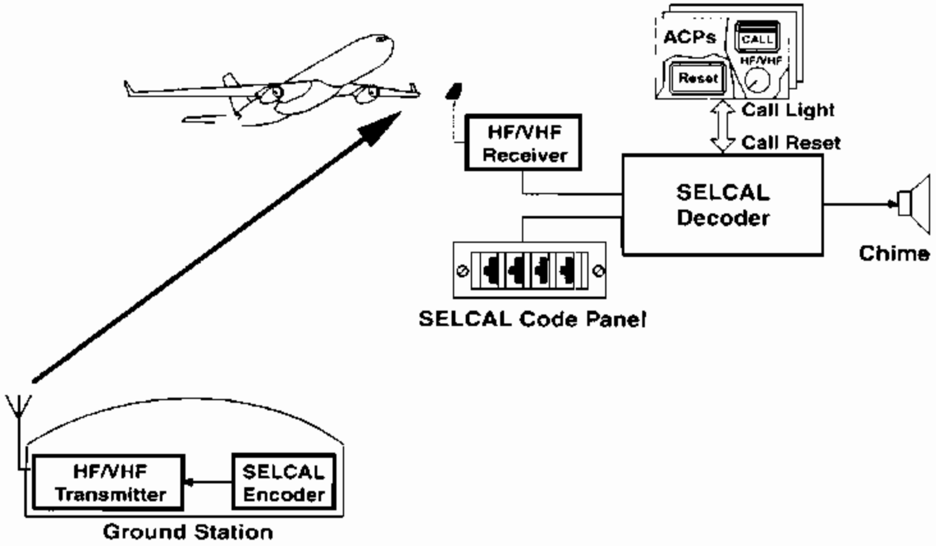


Figure 92: Decoder

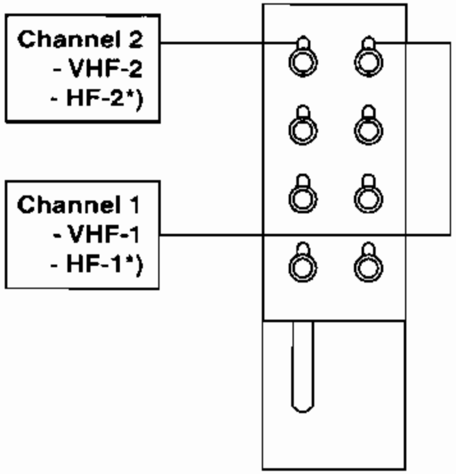
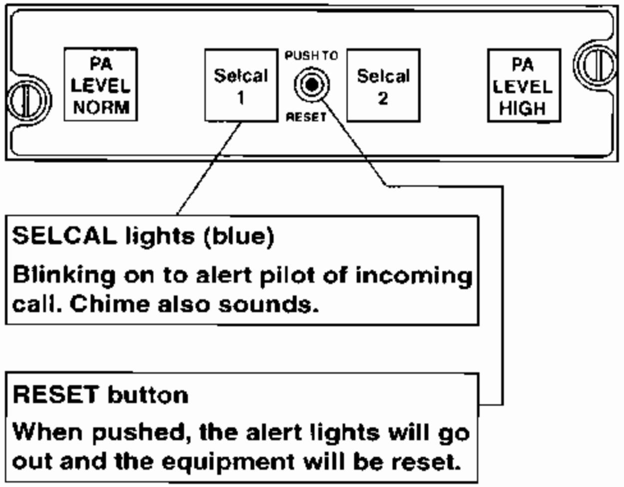


Figure 93: Control Panel



SELCAL lights (blue)
Blinking on to alert pilot of incoming call. Chime also sounds.

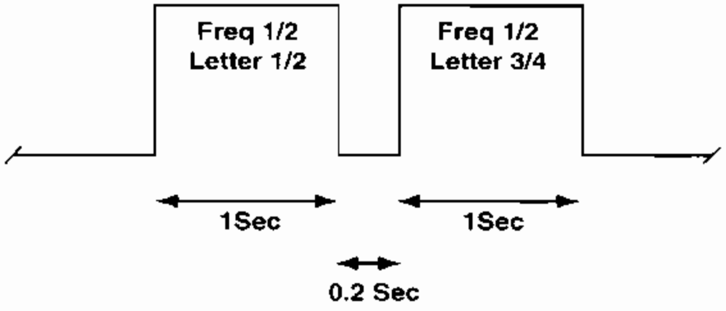
RESET button
When pushed, the alert lights will go out and the equipment will be reset.

System Description

With the Selective Calling (SELCAL) system a ground Operator calls an individal aircraft. SELCAL reduces the pilots workload since they do not have to listen to all the communication receivers all the time. The selective calling system has a SELCAL decoder, which monitors the communication receivers. The ground operator transmits a coded signal with a communication transceiver The aircraft has a specific code and the SELCAL decoder compares the received coded signal with the aircraft code. When the decoder detects a coded signal, which agrees with the aircraft code, a buzzer makes a sound to get the attention of the pilots. Lights on the overhead panel or audio control panels identifies the associated receiver. The pilots must select the proper receiver to listen to the message.

The SELCAL code is a 4 letter word. Audio frequencies, in the range between 300 - 1500 Hz. represent these 4 letters. Each letter has a different frequency. The transmitted code signal has 2 periods and each period contains 2 frequencies. In the 2 periods there are **4** frequencies, which represents the 4 letters of the SELCAL Code.

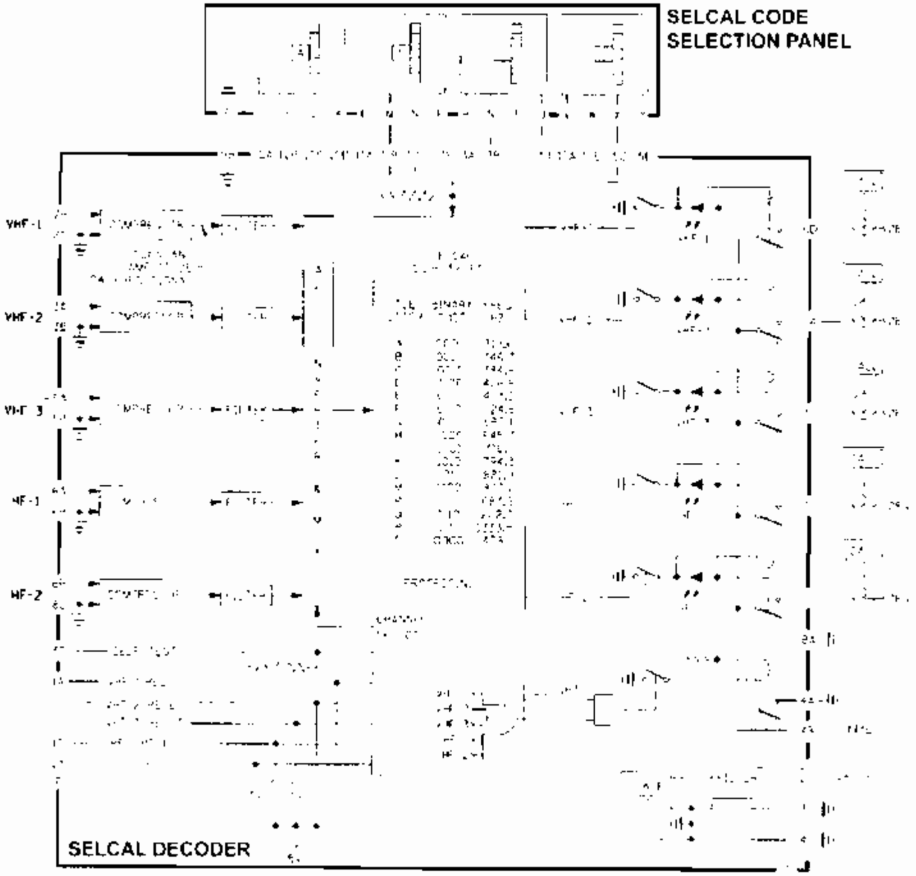
Figure 94: Two Tones carrying 4 different Frequencies



Each communication receiver has a SELCAL data output. This data goes to the SELCAL decoder, which compares the signal with the aircraft code. The code selection unit gives this code to the decoder. When the decoder detects audio, which has the aircraft's Code, the associated channel light comes on. At the same time an audio alert signal goes to the flight warning system, which makes a buzzer tone for audio management. You stop the buzzer and you reset the channel light, when you push the channel light or the resetbutton.

The decoder has 2 or 5 channels. It is a separate unit or it is located inside the audio management unit. The code selection panel contains 4 code select wheels which gives the selected aircraft code to the decoder with 17 wires. For one letter there are 4 wires. A grounded wire represents a binary 0 an open wire binary 1. With 4 wires for each letter there are 16 possibilities.

Figure 95: Decoder Block Diagramm

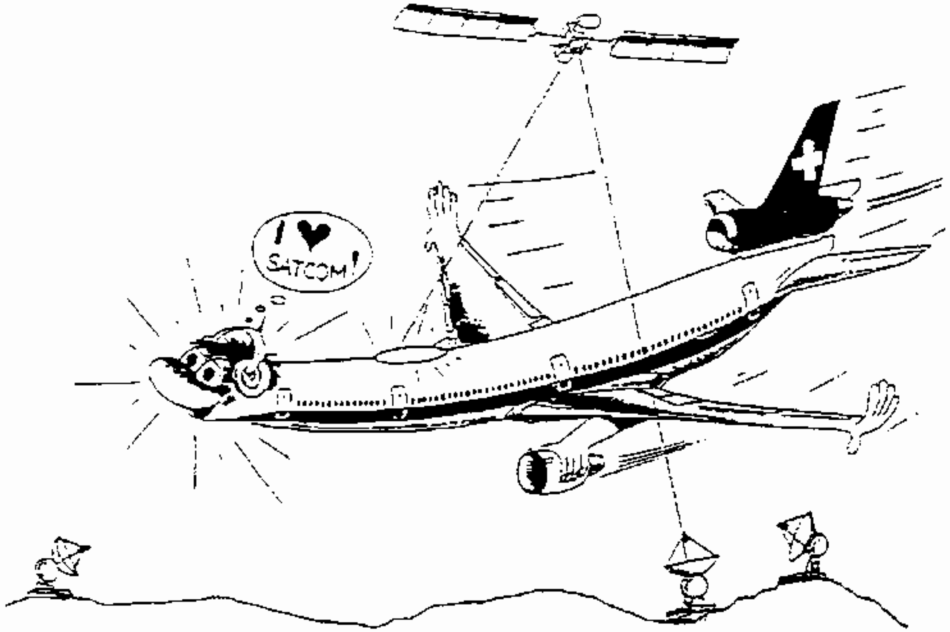


Satellite Communication

Introduction

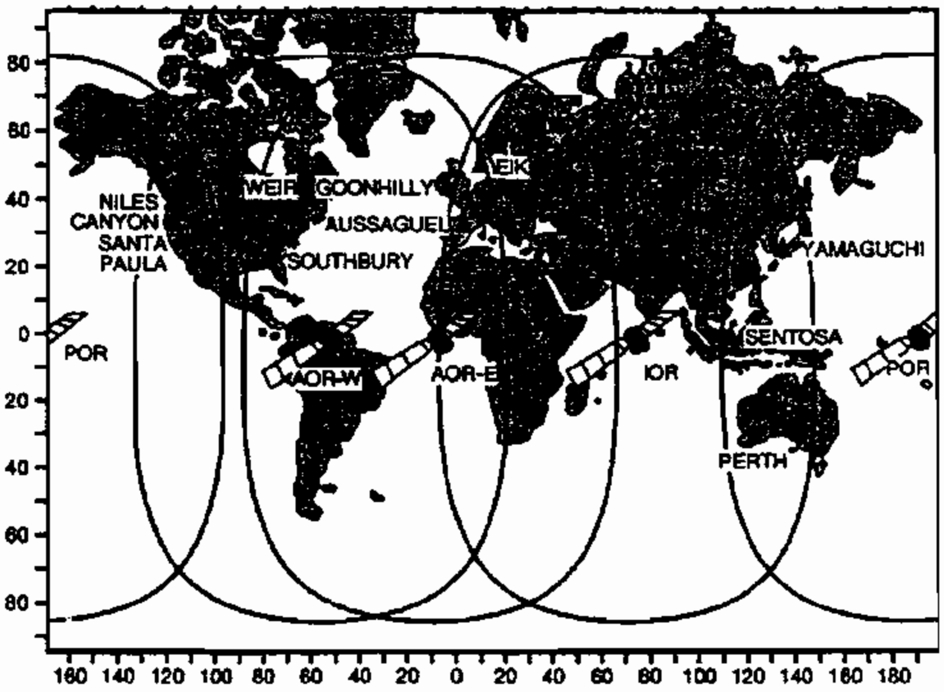
The Multichannel Aviation Satellite Communication System (MCS SATCOM) is a worldwide mobile communications system providing continuous voice and data communications services to and from the aircraft. In addition to the Airborne Avionics (referred to as an Aircraft Earth Station), the total MCS SATCOM system consists of the Space Segment (Satellite), Ground Earth Station (GES) and Public as well as Private Voice and Data terrestrial telecommunications networks.

Figure 96:



The Space Segment comprises Satellite in geosynchronous orbit, providing air-ground packet- switched data services and voice communications using conventions and capabilities which are standardized worldwide. The Satellites function as communication transponders to support L- band links to and from the Aircraft and provide links to and from Ground Earth Stations (GES). There are two space segment providers for Airline Aeronautical Satellite Communications. The first is the International Maritime Satellite Organisation (INMARSAT), whose system is in place today to provide worldwide coverage. The other is American Mobile Satellite Consortium (AMSC) system.

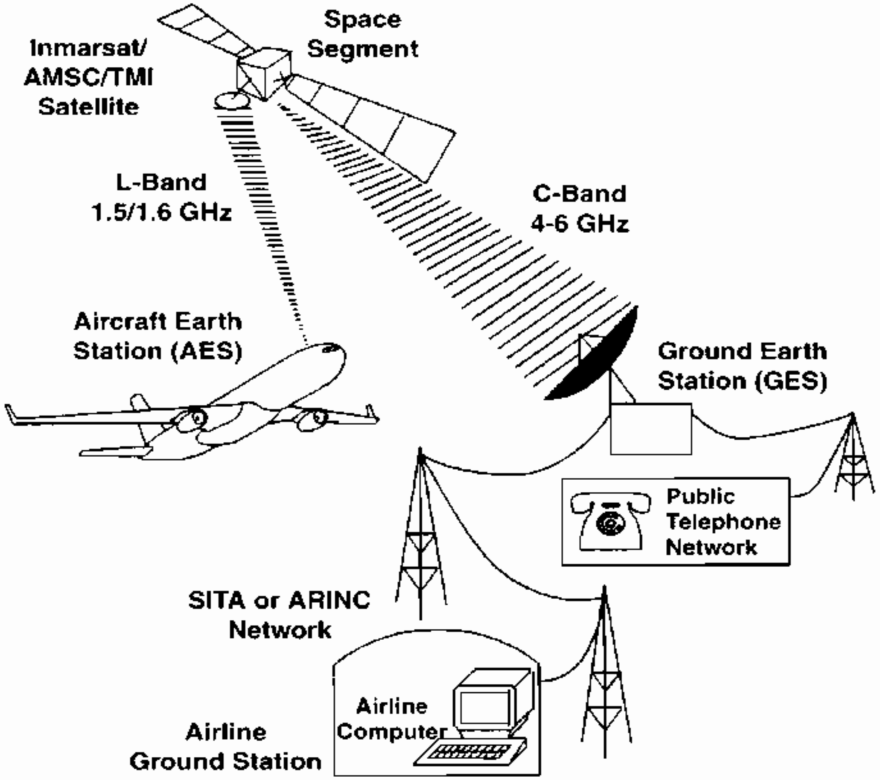
Figure 97: Four Satellites and ten Ground Earth Stations



Ground Earth Station (GES)

Each Ground earth station has the necessary equipment to communicate with terrestrial networks and communicate through satellites with the Aircraft. The GESs are designed to provide the Airline customer with a divers routing of national and international Voice and Data communications via submarine cable, satellite and microwave links to all destinations. Automatic traffic management systems ensure efficient routing of communications using optimum links into Public Switched Telephone Networks (PSTN) and avoiding multiple satellite connections whenever possible. The GESs are strategically placed globally to provide redundancy and diversity in the terrestrial extension of communications. The aircraft will be connected to a GES via a "in- view" satellite depending on the service preference table settings in the AES Satellite Data Unit.

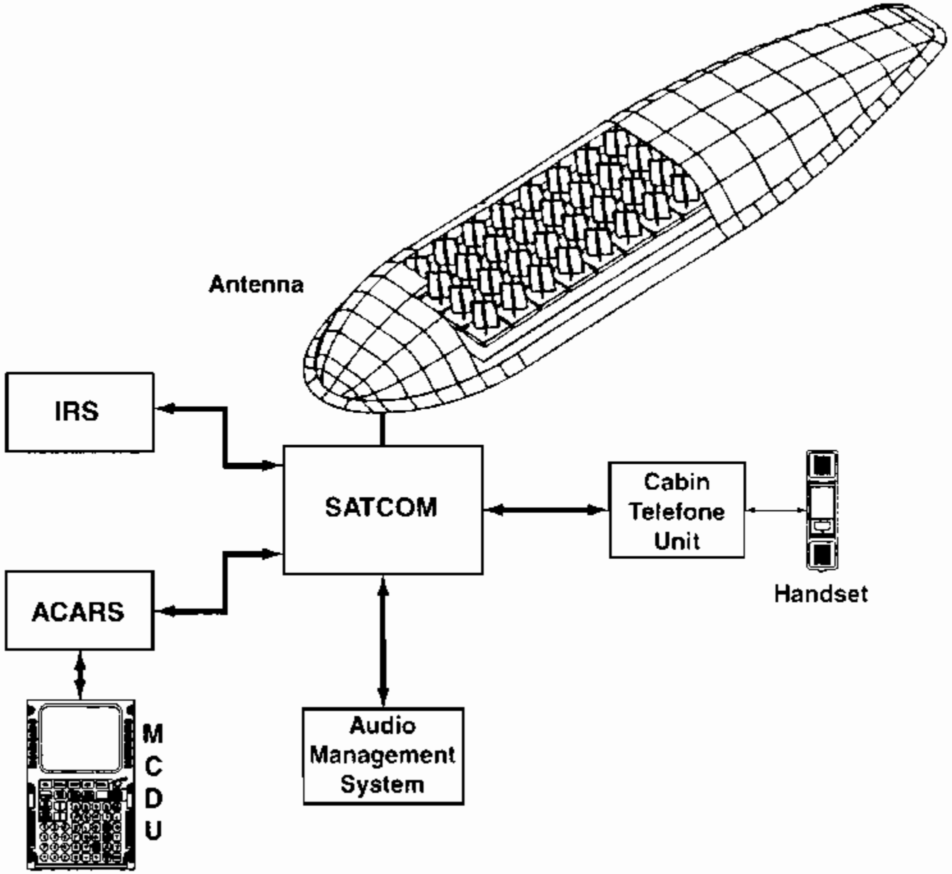
Figure 98: SATCOM



Aircraft Earth Station (AES)

The aircraft earth station comprises the AVIONICS and ANTENNA subsystems, whose primary function is to interface with the SPACE SEGMENT for communications with the GES. The AES accepts DATA and VOICE messages from various sources, encodes and modulate this information onto appropriate Radio Frequency carriers to be relayed by satellite to GES. Standard interface include the ACARS, IRS, MCDUs and Cabin Telecommunications System, for Passenger telephone. Channels are also provided for voice and data communications with Air Traffic Control (ATC).

Figure 99: AES



SATCOM System Description

General

The SATCOM system uses a satellite network, a ground earth station (GES) network, and the aircraft earth station (AES) (that is the aircraft), to supply long-range communications. The satellite communications (SATCOM) system transmits long-range data and voice information through two-way communications with geostationary satellites and a global network of ground stations. The SATCOM system can supply this function to a large number of users and applications. These applications include transmission of data, cockpit voice communication for the flight crew and cabin voice communication for passengers.

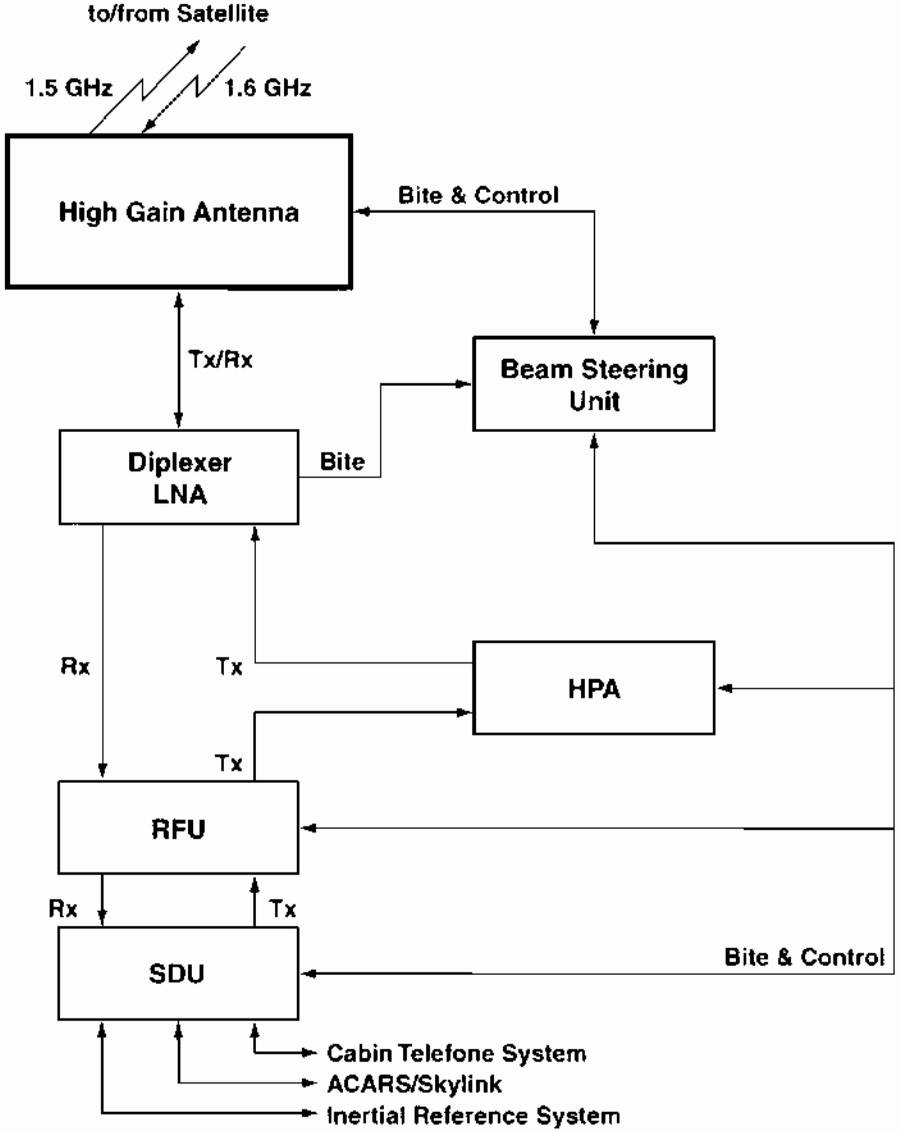
Communications satellites convert the L-band frequencies (1.5- 1.6 GHz) of the aircraft's SATCOM system to the C-band frequencies (4- 6 GHz) of the GES network. This supplies near hemispherical communications.

The satellite communications system uses the subsequent components:

- Satellite Data Unit (SDU)
- Radio Frequency Unit (RFU)
- High Power Amplifier (HPA)
- High Gain Antenna (HGA)
- Diplexer/Low Noise Amplifier (DIP/LNA)
- Beam Steering Unit (BSU)

The SATCOM system has three to six channels. One is for the aircraft communications addressing and reporting system (ACARS) channel, one channel is used for cockpit-communication and the remaining channels are used for cabin-communication (passenger-telefone system).

Figure 100:



Satellite Data Unit (SDU)

The SDU is the main processing element of the SATCOM system avionics and supplies overall AES control and monitoring. The SDU controls timing functions, all system voice and data coding/decoding functions, makes system protocol decisions, and supplies the necessary system interface functions. The voice or data signal is digitized by the SDU, which adds special codes to complete the aircraft-to-ground station connection.

The coded voice/data signal is sent to the high power amplifier (HPA). The SDU also decodes all voice/data signals that are received.

The SDU receives the navigation information and supplies the beam steering unit (BSU) with the azimuth and elevation data necessary to make sure the antenna is pointed directly at the satellite.

High Power Amplifier (HPA)

The HPA amplifies the L-band signals to the power level necessary for transmission to a satellite. The HPA supplies the necessary average output power of at least 40 watts and transmits multiple signals without excessive intermodulation.

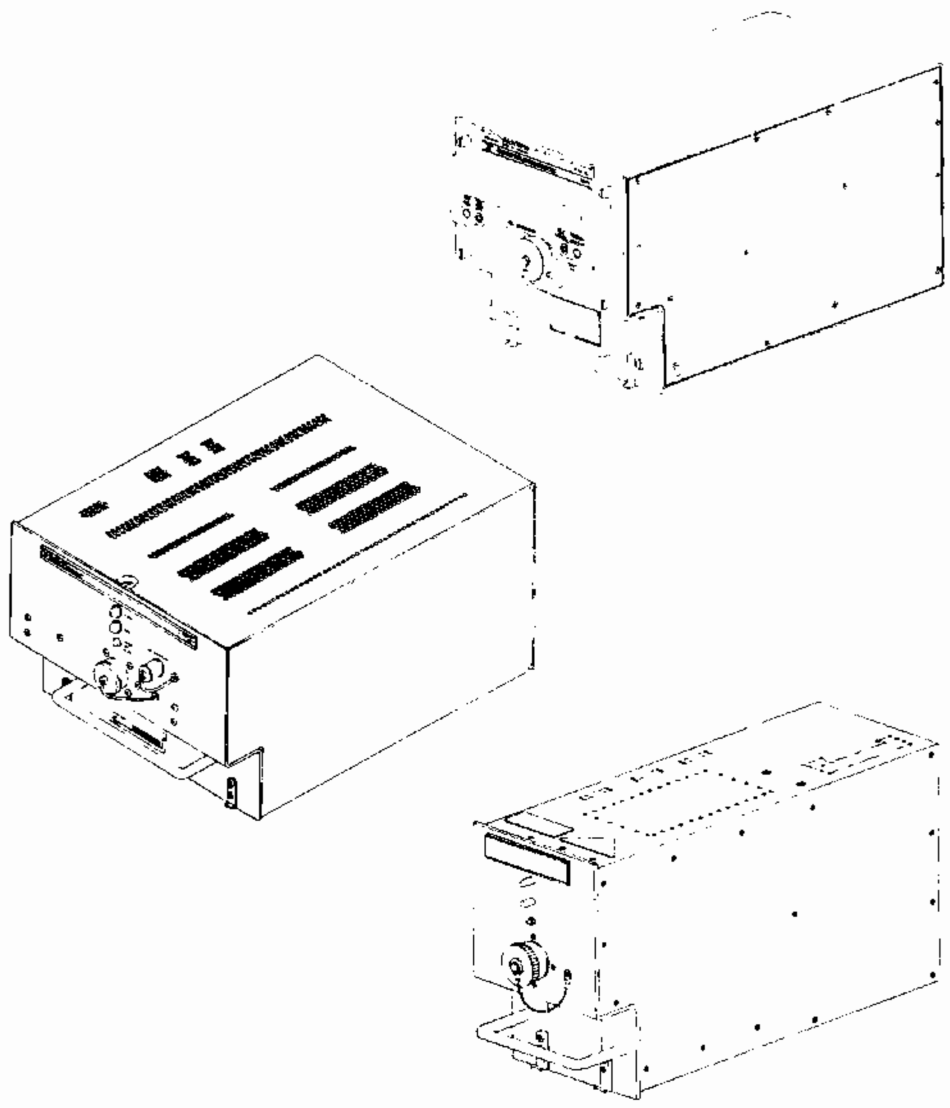
The HPA also controls output power and supplies the necessary radiated power from the AES. The SDU can control the HPA increase in a 15 dB range in 1 dB increments through an ARINC 429 interface. This automatically adjusts the HPA signal strength as necessary for a wide variety of conditions.

Radio Frequency Unit (RFU)

The RFU operates in a full duplex mode (transmission and reception of satellite signals at the same time). The transmit side uses a power amplifier which receives a signal from the SDU, and translates it to correct radio frequency (RF). The receive side uses the output from a low noise amplifier (LNA) and translates those signals for transmission to the SDU.

The RFU is only used on aircrafts operating with six channels. The SDU will provide the nessecary circuits for 3 channel operation.

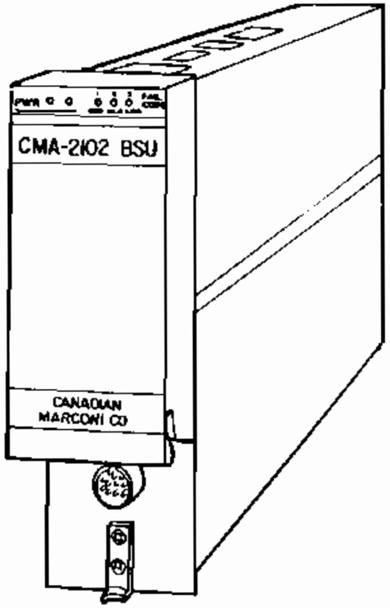
Figure 101:



Beam Steering Unit

The BSU is used with electronically steered antennas and has two main functions. It contains the antenna power supplies and the control interface monitor circuitry. The BSU receives antenna position data and beam change commands from the SDU. This data and beam change commands are received in a standard digital format. The information is then changed into signals that select specific antenna elements in combinations that cause the beam to point at the desired satellite. This keeps the beam automatically pointed in the correct direction.

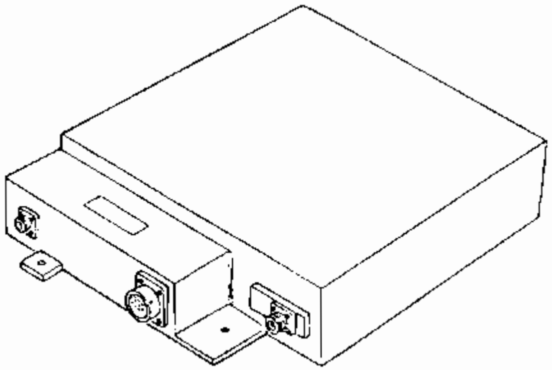
Figure 102:



Diplexer/Low Noise Amplifier

The DIP/LNA makes two-way communications possible, and performs three main functions. It filters the transmit signal (which reduces out-of-band transmissions to the correct levels) and at the same time, prevents de-sensitization of the receive channel during transmission. This receive signal is then filtered, which reduces the amount keep out-of-band signal interference. It also contains an ultra-low noise preamplifier (low noise amplifier) for the receive path to maximize receiver system performance.

Figure 103:



Antenna

This system communicates via satellites which are located in a geostationary orbit of 36'000 km located above the earth equator. The very sharpend antenna beam is directed toward the satellite. The direction of the beam depends from the aircraft position, attitude and heading.

The high gain antenna (HGA) is top-mounted on the outer side of the upper fuselage, on the aircraft centerline. It is a low-profile-plate antenna-array. The 32 radiating elements, phase shifters, corporated feed (power splitter/combiner), and associated driver circuitry are integrated within a low profile, aerodynamically shaped radome structure. The HGA supplies +12dBic minimum gain with near hemispherical coverage. The HGA transmits and receives satellite signals at the same time.

The sum of the radiation of 32 small antenna elements forms a steerable beem toward any direction except downward. A processor insde controls the phase angle of each element.

Figure 104: High Gain Antenna

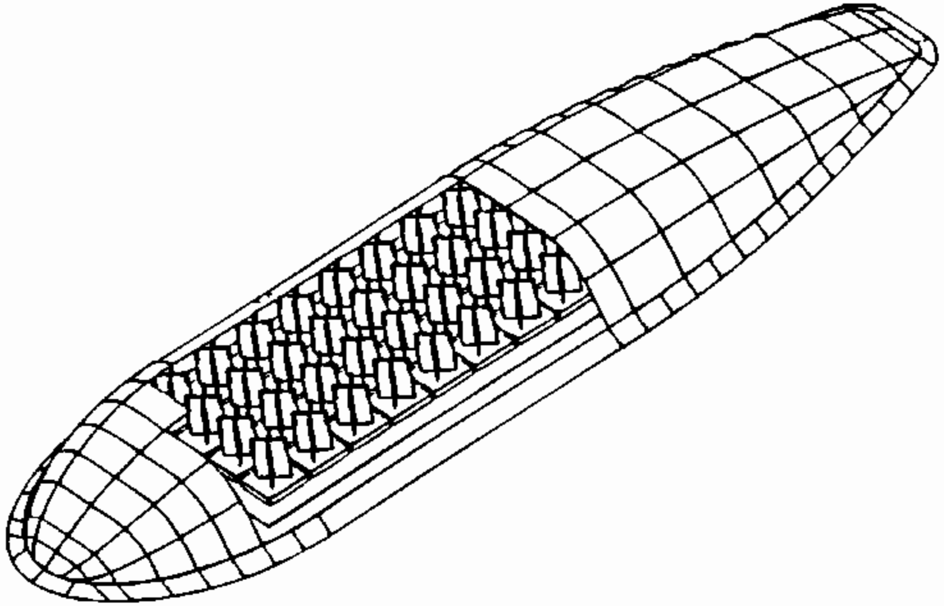
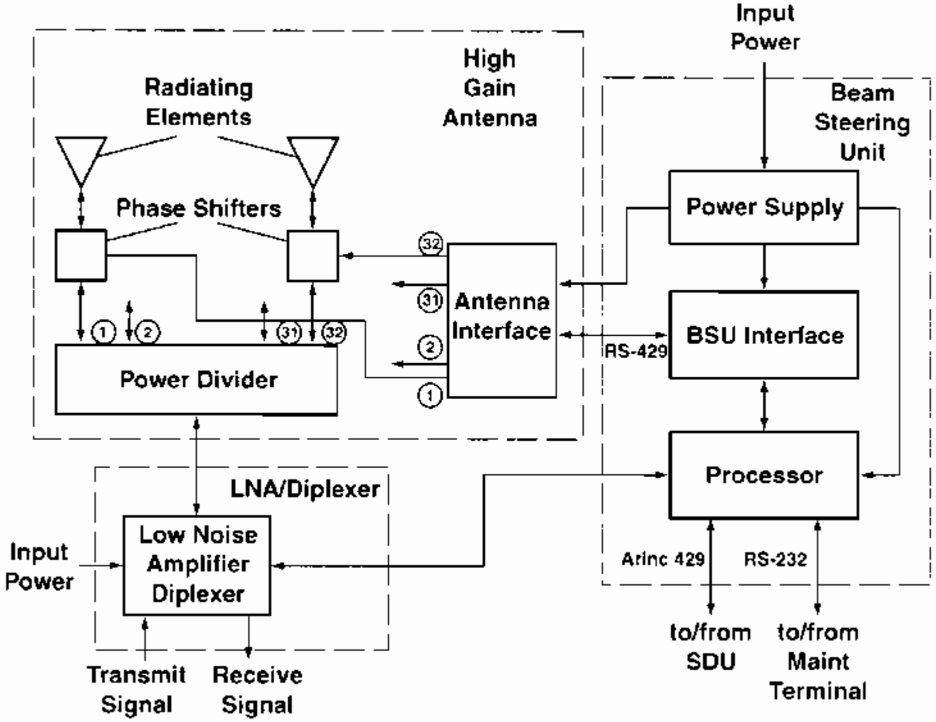


Figure 105: Antenna Cirquit



System Operation

Log-on of the aircraft earth station (AES) to the ground earth station (GES) network begins when electrical power is applied to the AES. Log-on is automatically initiated by the SDU. At this time the SDU receives position and orientation information from the aircraft navigation system. The SDU then commands the antenna to steer towards the appropriate satellite and tune to the appropriate channel for that satellite region (all GESs, channels, and the order of preference in which they are selected, are set up by the user, usually by the telephone handset).

During this process the AES notifies the GES that it is operating in that region and that it is monitoring the GES. The GES identifies the AES by its address, registers the AES as operational in that region, and assigns channels to the AES. All other GESs in that satellite region also note the presence of that AES. This feature assists in the completion of connections for calls (ground-to-air) to aircraft in that satellite region, as well as, allows an AES to place a call (air-to-ground) through a GES other than the one to which it is logged on.

When a call is initiated by an AES (air-to-ground call), the AES signals the GES. When the GES receives the call request, it assigns a pair of C-type channels for voice call, or reserves time on a T-type channel for long-duration data transmissions. The call can then go through. The assigned channels are reserved for as long as the call is in progress.

When the GES receives a call from the ground that is to be sent to an AES (ground-to-air call), the GES verifies whether the applicable AES is operating in that region and if it is monitoring the GES. If it is, the GES notifies the AES that a call is incoming and tells the AES the frequency/time slot assignment. The AES then tunes to the assigned frequencies and sends an acknowledgement to the GES. The GES then passes the call or data to the AES. If the AES is not operating in that region, the caller is notified by the GES that the AES is not available.

Satellite Telephone System

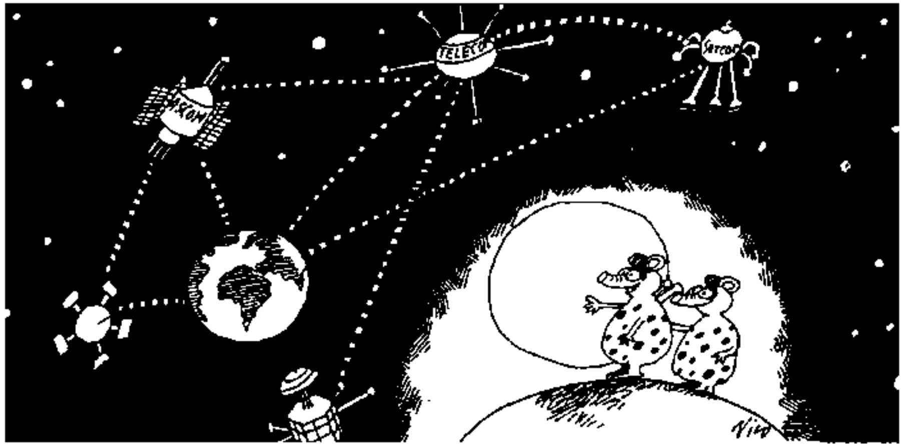
The Cabin Communications System, operates in conjunction with the SATCOM avionics, a space segment (satellites) and a worldwide network of ground stations, provides cabin services such as telephone, data, facsimile, and other communication interfaces.

Cabin communications are accomplished with digitally connected phones. The user interface with digitally connected phones is handled by the Cabin Telecommunications Unit (CTU). The SDU has provisions to support up to four independent channels.

Optional cockpit handsets and/or Audio Management System allows the communication for the pilots.

The distribution to/from all cabin handsets is established via the existing passenger entertainment system and is different in each aircraft type.

Figure 106:



They have a perfect telecommunication system, but they don't speak together.

Figure 107: Airborne Satellite Telephone System

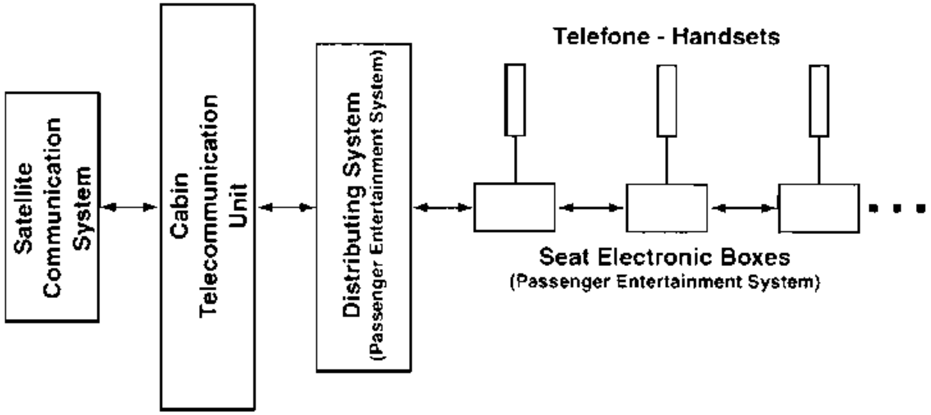
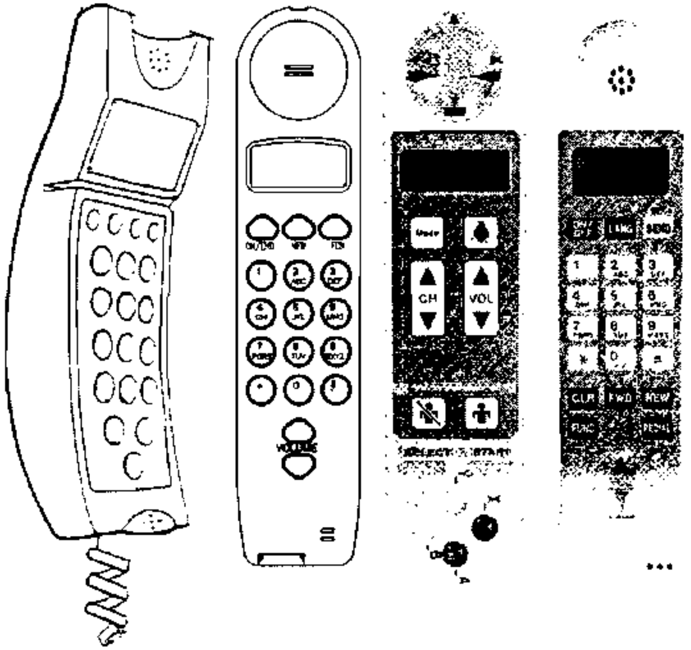


Figure 108: Various Telephone Handsets



ACARS

Introduction

The Aircraft Communication Addressing and Reporting System (ACARS) is an air/ground communication data link network that enables the aircraft to function as a mobile terminal associated with modern airline command, control and management systems.

The ACARS is used to transmit or receive automatically or manually generated reports or messages to or from a ground station. The ACARS is dedicated to Maintenance, Operation and Commercial purposes. The ACARS can manage both transmission or reception of data. Ground- to- air and air- to- ground digital messages are transmitted or received via VHF transceiver or the SATCOM system when the VHF link is not available.

The transmitted information is relayed via the ground stations to a central computer (Singapore for SITA or Chicago for ARINC) where data is converted into airline messages.

A ground network (SITA for EUROPE, ARINC for the USA), transmits the data from the ground receiver to the airline main base.

Figure 109: Aircraft System

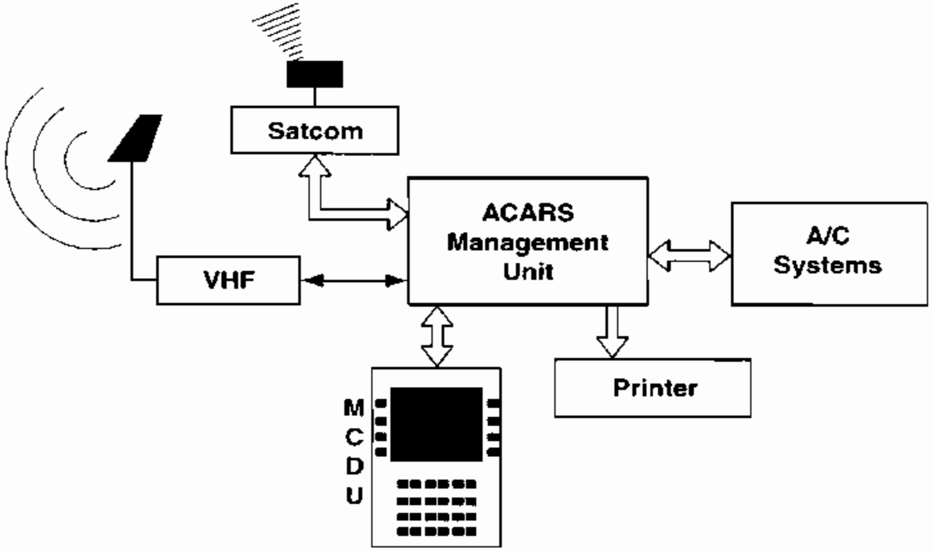
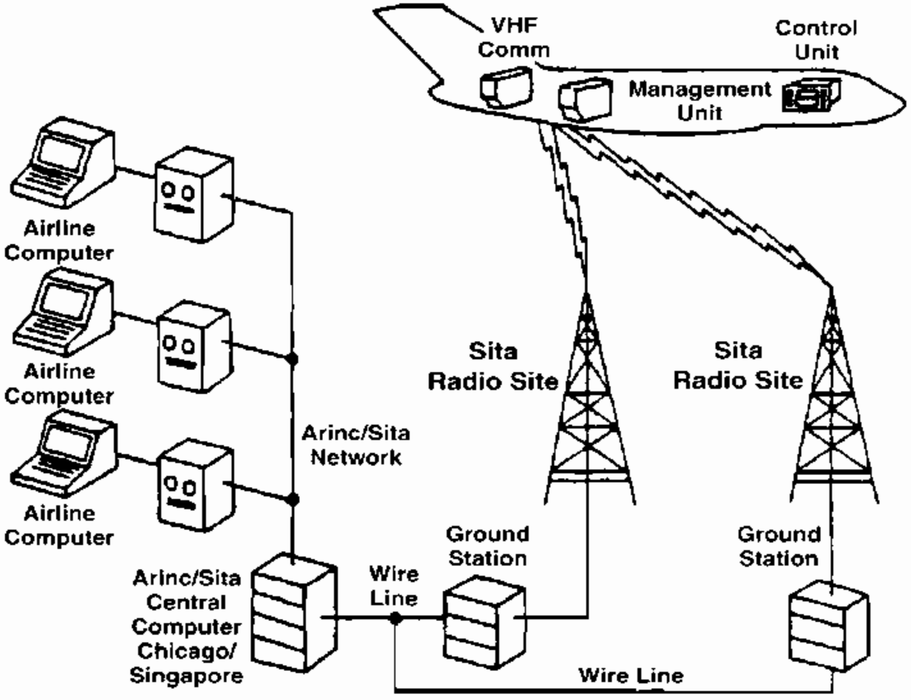


Figure 110: Ground Network with Aircraft



ARINC Aeronautical Radio Incorporated operates ACARS.

SITA Société International de Télécommunication Aérienne operates AIRCOM.

The most part of the world is covered by SITA-AIRCOM operated at 131.725 MHz.

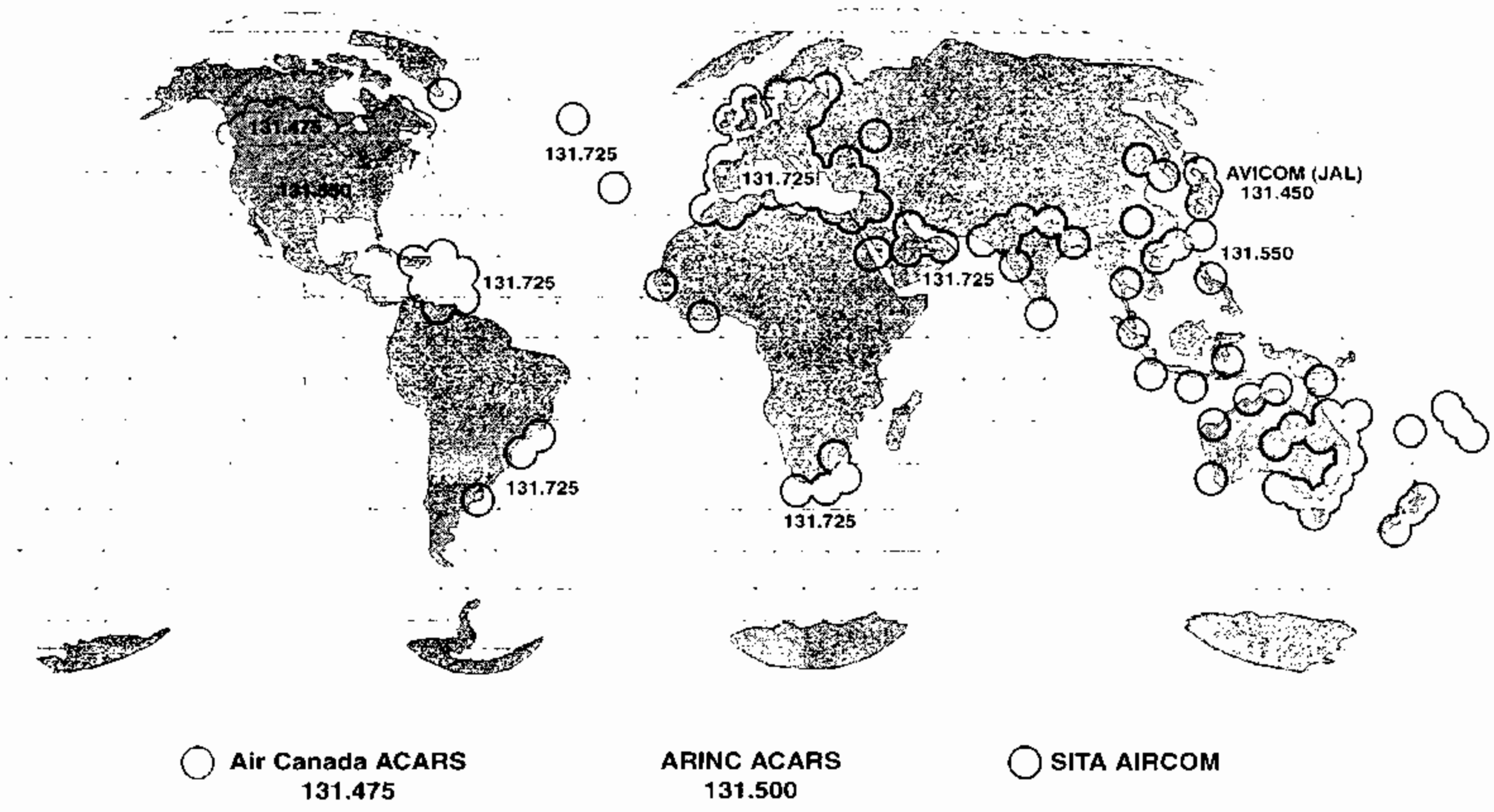
In USA is ARINC-ACARS dominant at 131.550 MHz.

Canada operates the own AirCanada at 131.475 MHz.

Japan uses AVICOM at 131.450 MHz.

If there is to much communication traffic at a certain frequency channel, the ground station initiates an automatic frequency change to an other channel. (Remote Tuning)

Figure 111: Worldwide Coverage of VHF Network



At uncovered areas of the world, if there is no link to a ground station, the ACARS uses the Satellite Communication.

System Architecture

An establishes data communication via VHF to a Regional Ground Station (RGS) or via L-Band (Frequency) to a satellite (SATCOM).

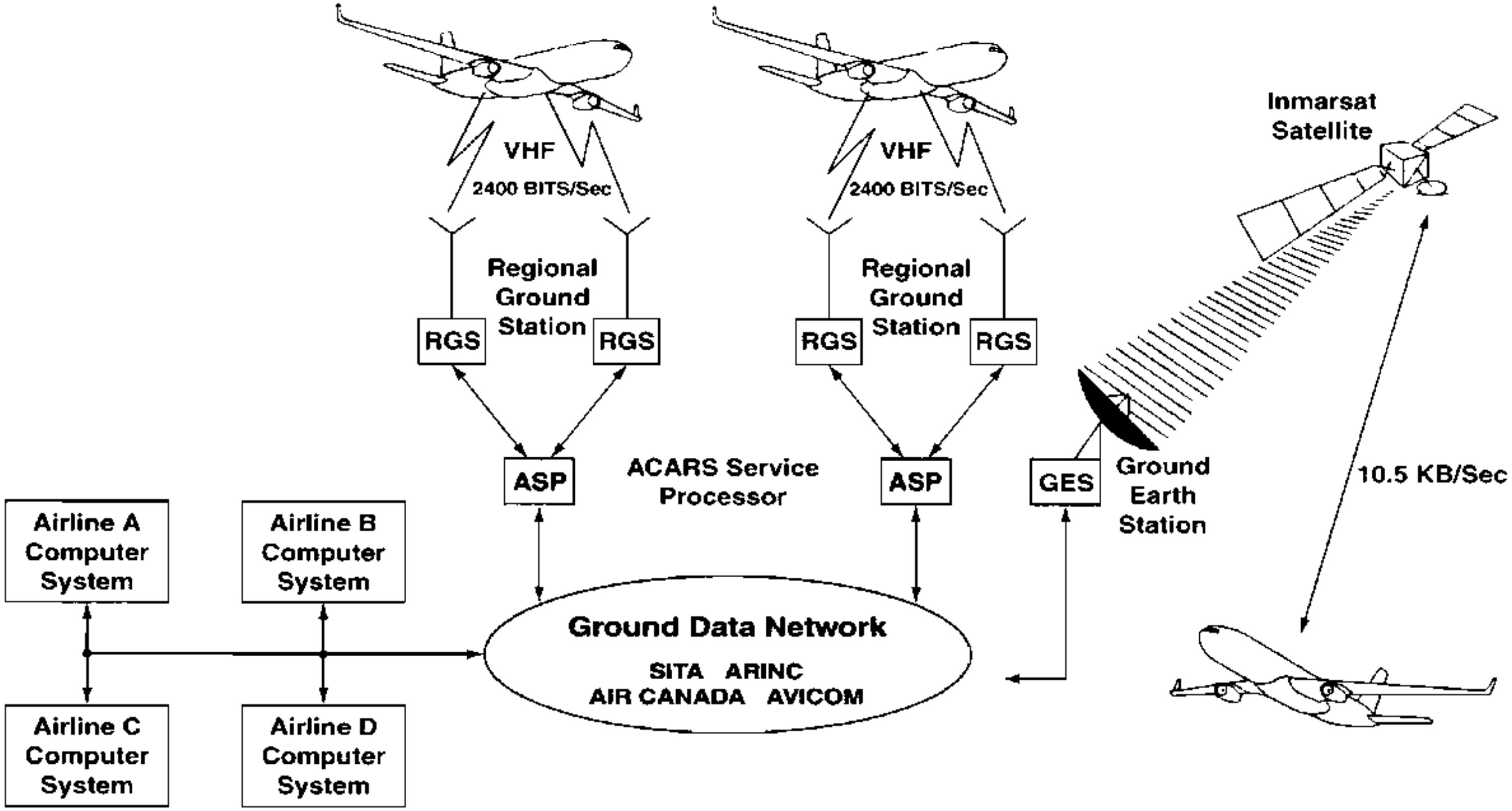
A Remote Ground Station is basically an intelligent VHF transceiver and message converter. Once a RGS has received a Downlink Message from an aircraft, its content is turned into a conventional Telex Message and sent to the ASP.

The ACARS service processor ASP controls all RGS's or earth-stations (SATCOM) connected via ground network. It receives downlink messages from an aircraft via RGS and distributes them to the appropriate designators (Airline Host Computer or Telex printer

Besides the AC-Registration and Flight No., downlink messages coming from a RGS also contain the IATA code of the receivers RGS. Therefore the ASP knows the approximate position of an aircraft upon the last received downlink. Currently there are four major Service Providers offering Air-to Ground Link Message Handling. SITA, ARINC, AIR CANADA and AVICOM.

Messages going to SITA or AVICOM (Japan) are sent to SITA's Service Processor in Singapore always. Traffic designated to ARINC is routed to the appropriate Data Service Processor in Chigago via separate telex connections.

Figure 112: Network



Airborne Components and Subsystems

The ACARS System consists of a CMU (Communication Management Unit), a data printer, a Control-Unit/Terminal (MCDU) for entering and displaying data, VHF Transceiver and SATCOM system.

Communication Management Unit (CMU)

The CMU provides input (receive) and output (transmit) interfaces through VHF-3 or SATCOM for the up- and down-linked messages.

The CMU collects or distributes and formats data from/to various subsystems for transmission to or from the operators ground based computer system.

Out-, Off-, On- and In-event (OOOI) times are automatically generated by a set of parameters permanently broadcasted by sensors and various aircraft system to the CMU. These times are automatically transmitted to the ground system and are used for aircraft movement and messages control.

The CMU controls the VHF-3 communication system in data mode VHF-3 can either be used for digital data link or for voice communication.

Multifunction Control Display Unit (MCDU)

Both MCDU's are hooked up to the CMU and provide the main interface to the crew. It consists of an alphanumeric keyboard and display to control and enter data. CMU status messages are also provided. The CMU shall maintain a dialog with only one MCDU at a time. If selected, the opposite MCDU will duplicate the active ACARS page.

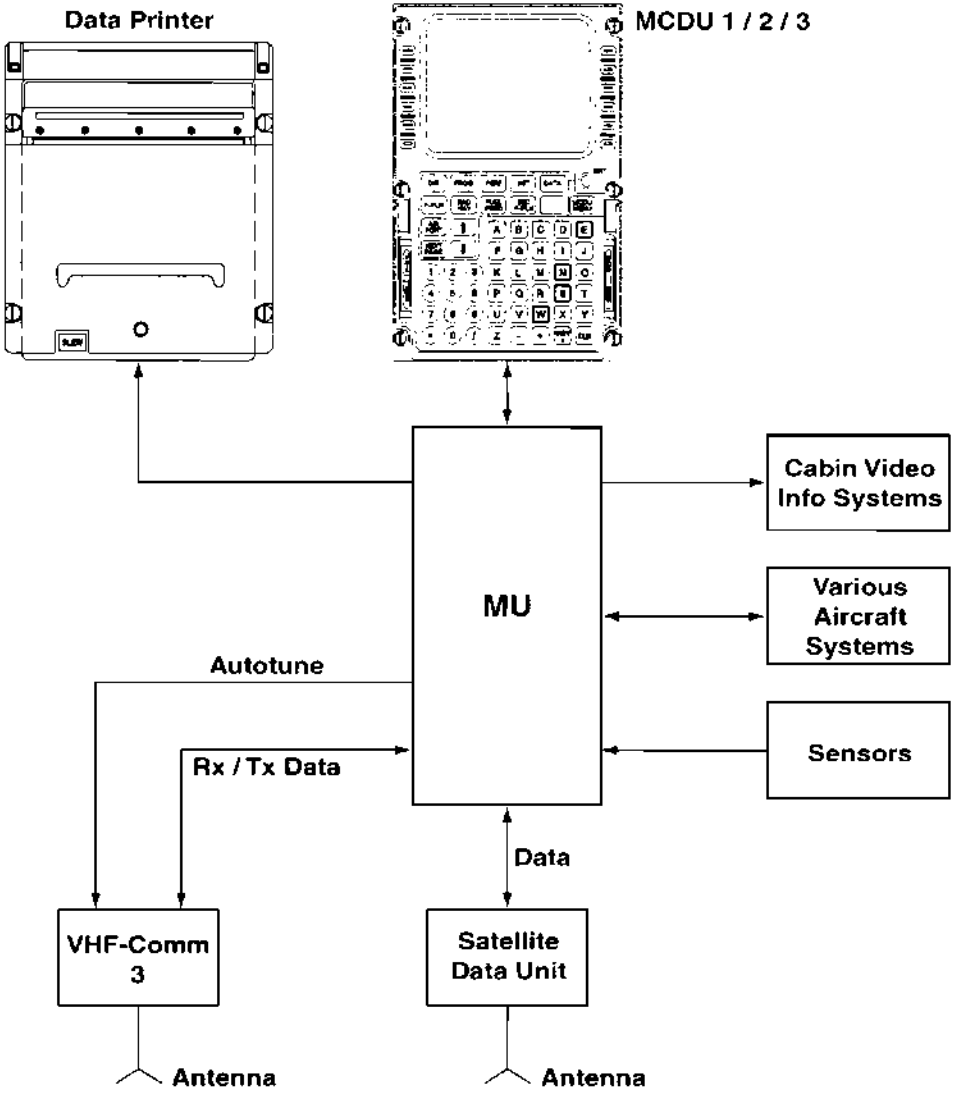
Airborne printer

The multifunction printer is the output device for data.

Furthermore, there is an Cabin Video Information System (Long Haul) providing the display of actual data from ground to all passengers for example:

- Connecting flights
- Information about passenger terminals
- Weather at destination
- Sport results

Figure 113: Interface



Operations, Requests and Communications with ACARS:

The Aircraft Communications Addressing and Reporting System (ACARS) is a two way digital data link between the aircraft and ground stations through the VHF-3 communication system or to Ground Earth Stations (GES) via satellite through the satellite communication system (SATCOM). ACARS provides the means to automatically report vital flight and routine information. In addition the system enables manual routing of pre-canned or free text messages to and from the aircraft.

- System initialisation (must be done before the flight. Flt. Nr. and From-To)
- Mission Status (OOOI, Block Time and Flight Time, UTC)
  Out:Aircraft out gate (Doors closed, Engines Running, Parkbrake released)
  Off: Aircraft lift off
  On: Aircraft touched down
  In: Aircraft in gate
- Sending and Receiving of free messages via telex
- Standard Text (Sending of preprogrammed text)
- Flight Data entering (Fuel, Time and Weight)
- Fueling (Uplift, Fuel on board, supplier, station)
- Automated Terminal Information System (ATIS)
- Destination Weather
- Weather (Actual and Forecast)
- Delay Message (Reason)
- Estimated Arrival Time ETA
- Load Sheet request
- Operation Info
- Operation Flightplan
- Diversion (New Destination, Comment and ETA)
- Parking Position Request
- Passenger Connection Request

Data Format

The data is transmitted via VHF with frequency shift keying in analog format or via SATCOM in digital format. Each alphabetic character is represented with 7 Bit. Each packet is divided in 3 groups:

Preamble 34 Characters: Address and System Protokoll

Message 220 Characters of data

Trailer: 7 Characters Parity and Verification

Figure 114: Data packet ACARS

ARINC Communication and Reporting

ARINC Communication and Reporting is described in Sub Module 5.4 "Data Buses". Title "ARINC" on page 6.

Audio Integrating

Introduction

Modern airliners have a complex interphone system that allows flight crew members to communicate with each other and ground crew-members. The pilots and flight attendants can make announcements to the passengers, and the conversations in the cockpit are recorded for investigative use in the event of an air crash. Each of the subsystems of the Audio Integrating System of a large jet transport aircraft are considered below.

All communications from the flight deck, both internal and external, are directed through audio selection panels at each one of the crew stations. By using switches on these panels, the crew members can receive and transmit on any of the VHF or HF transceivers, can listen to any of the navigation receivers, and can talk over the interphone or the public address system.

Figure 115: Overview

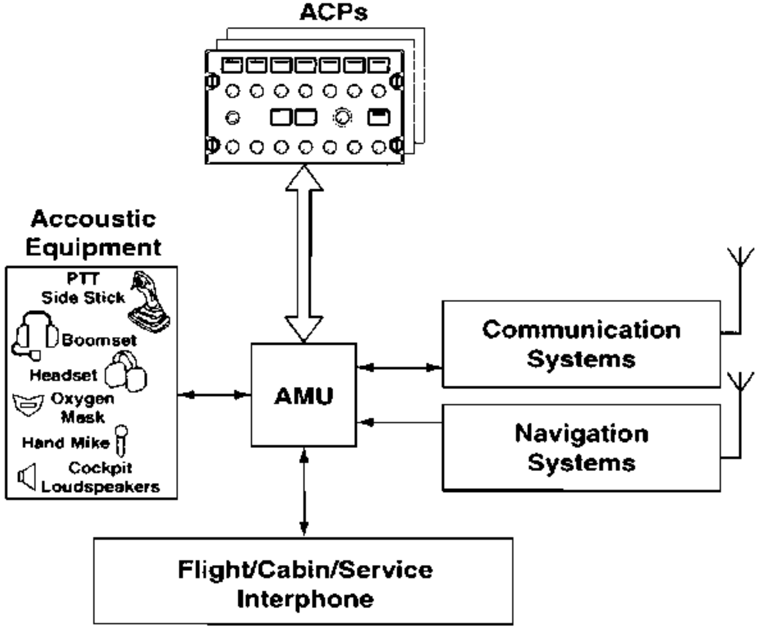


Figure 116: Audio Integrating System

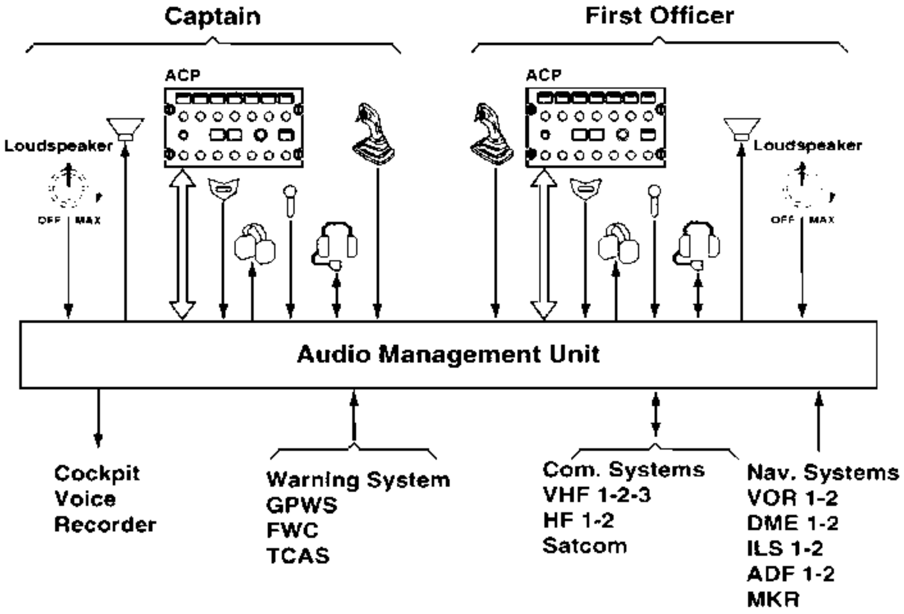
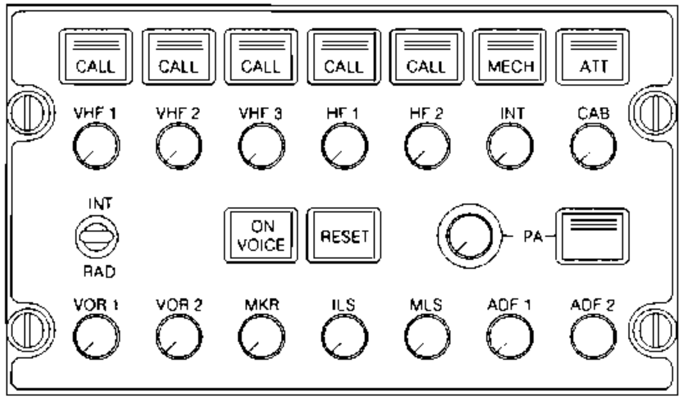


Figure 117: Audio Control Panel ACP



Accoustic Equipment

Headsets, boomsets, cockpit speakers, hand microphones and oxygen masks are used for the communication. Push To Talk switches provides discrete signals to enable the transmission.

Microphone (Mike or Mic)

A microphone is a transducer that converts sound waves into electrical signals. For speech, its frequency response should be as flat as possible from below 200 to above 3500 Hz. Most microphones pick up a lot of background ambient noises because the speech amplification. A "noise cancelling" microphone is recommended to reduce this background pick-up. Microphone output levels vary, depending on the microphone type. Typical mics produce about 10 to 100 mV.

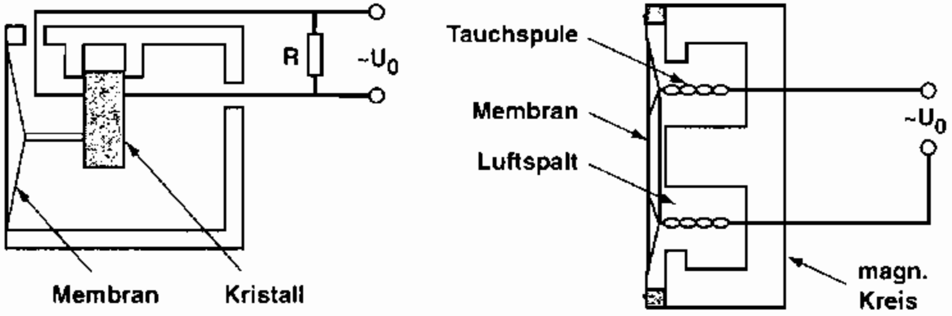
Dynamic

A dynamic microphone resembles a small loudspeaker, with an impedance of about 680 Ω and an output of about 12 mV on voice peaks. In many cases a preamplifier (possibly built-in) transforms the impedance to 100 kΩ or more and delivers about 100 mV on voice peaks. Dynamic mics are widely used.

Electret

"Electret" mics use a piece of special insulator material that contains a "trapped" polarization charge (Q) at its surfaces and a capacitance (C). Sound waves modulate the capacitance of the material and cause a voltage change. A polarizing voltage of about 4 V is required to maintain the charge. The mic output level is fairly low, and a preamplifier is sometimes required.

Figure 118:



Piezo Microphone

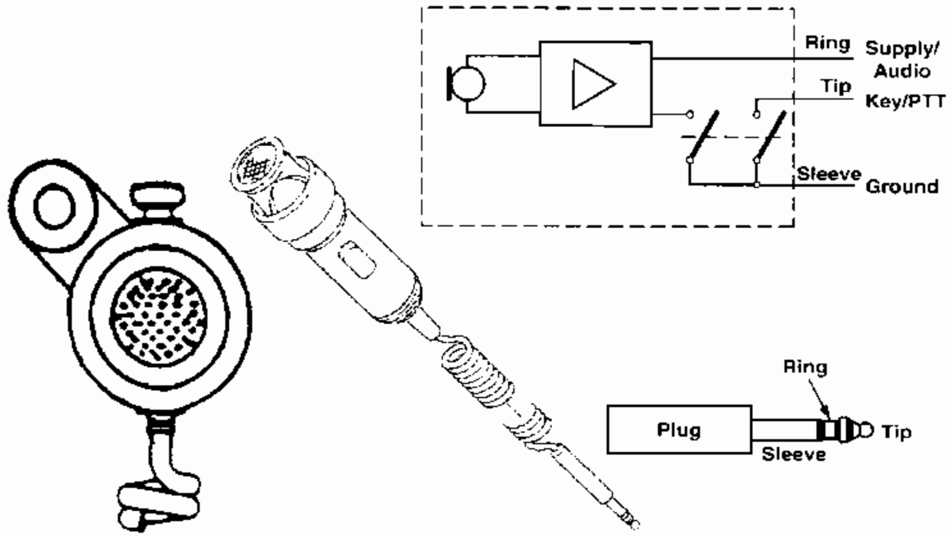
Electrodynamic Microphone

Hand Microphone

The handmic contains the preamplifier and the Push To Talk (PTT) switch.
The DC power for the preamplifier is provided through the same line as the output audio signal AC.

The Push To Talk (PTT) or Key signal is used to change from reception mode to transmit mode.

Figure 119: Microphones



Headset

The headset converts electrical energy into the motion of air molecules we call sound. For reception and understanding of bad, distorted signals, it is better to use a headset instead the loudspeaker

Figure 120:

Boomset

The combination of a headset with a microphone is called boomset. The pilots or maintenance personal does not need to hold the mic, so both hands are free to work.

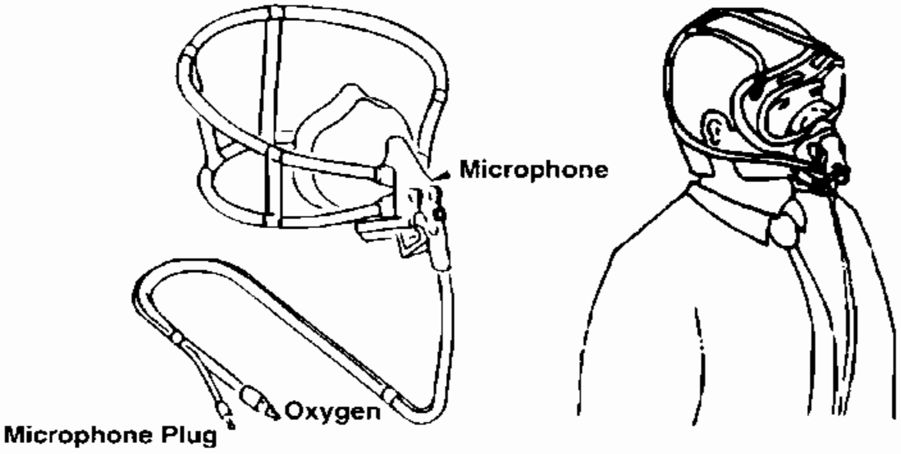
Figure 121:

Oxygen Mask Microphone

If the crew wears oxygen masks, for communication it is important that a microphone changes the voice in a signal to make spoken words in the mask understandable for radio or interphone communication.

This microphone is active as soon the pilot has taken the mask from the stowage container.

Figure 122:



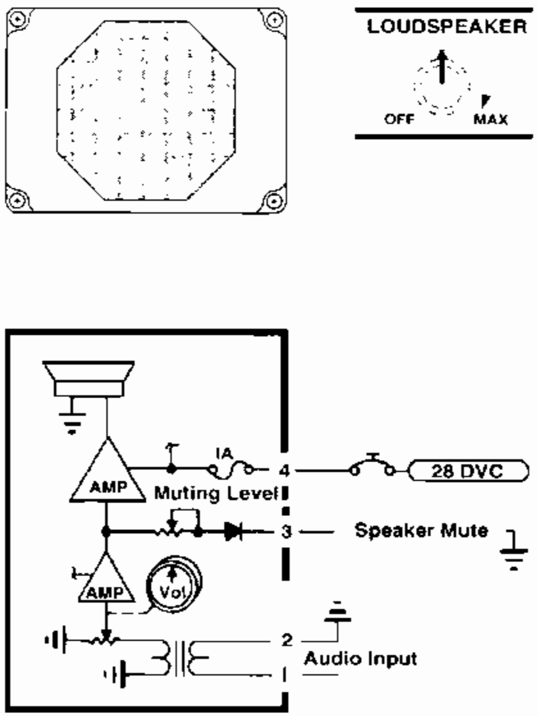
Cockpit Loudspeaker

If the incoming reception signal is clear and understandable the cockpit speaker is more comfortable than to wear the headsets. Amplifier increases the signal level to operate the speaker.

Volume potentiometer is used to select a convenient sound level.

The muting of speaker during radio transmission or interphone operation prevents acoustical feedback (whistling noise).

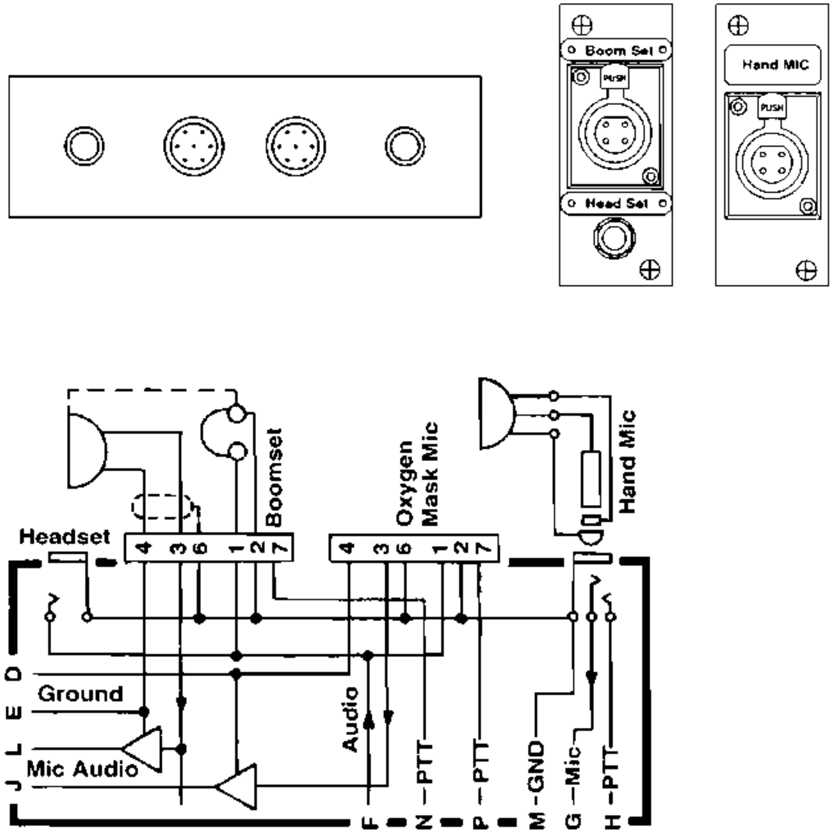
Figure 123:



Connections

The microphones and headsets are connected via jacks located in the cockpit with the audio integrating system. Build in preamplifiers gains the low output level of the dynamic microphones to a appropriate level.

Figure 124: Jack Panel

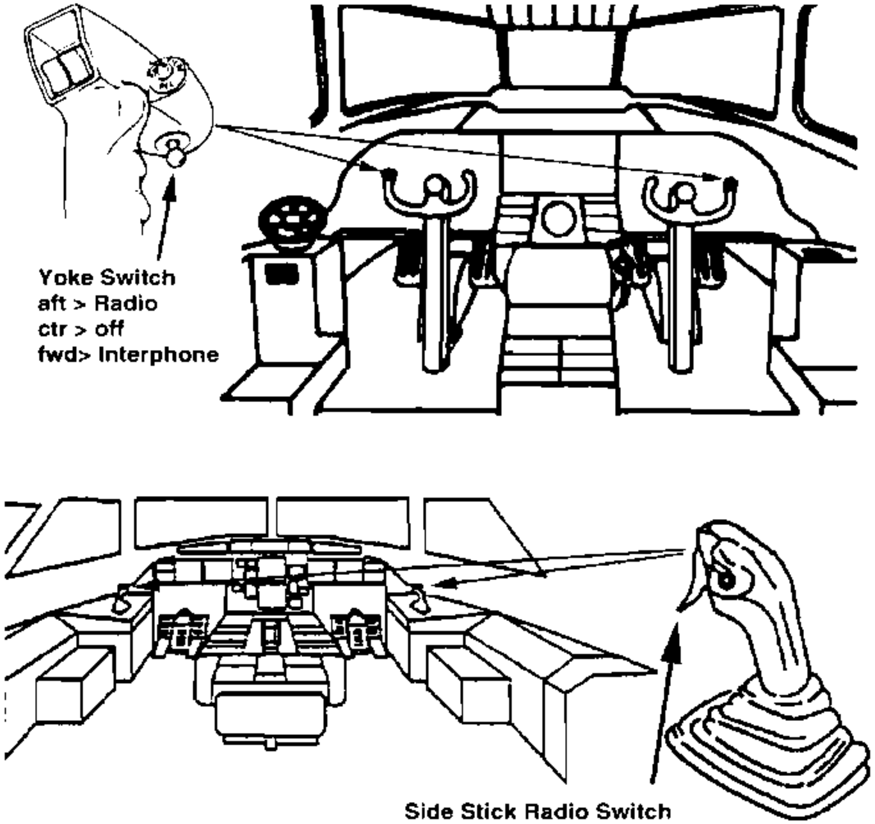


Push To Talk Switches

To change transceivers from the reception mode to transmission mode, PTT or RADIO-INTERPHONE switches are used. Push To Talk switches for using hand microphones are located at the hand microphones.

For the usage of boom- or mask microphones, those switches are located at the steering wheel (Yoke) or at the side sticks in advanced technology aircrafts.

Figure 125: Yocke Switch and Side Stick Switch



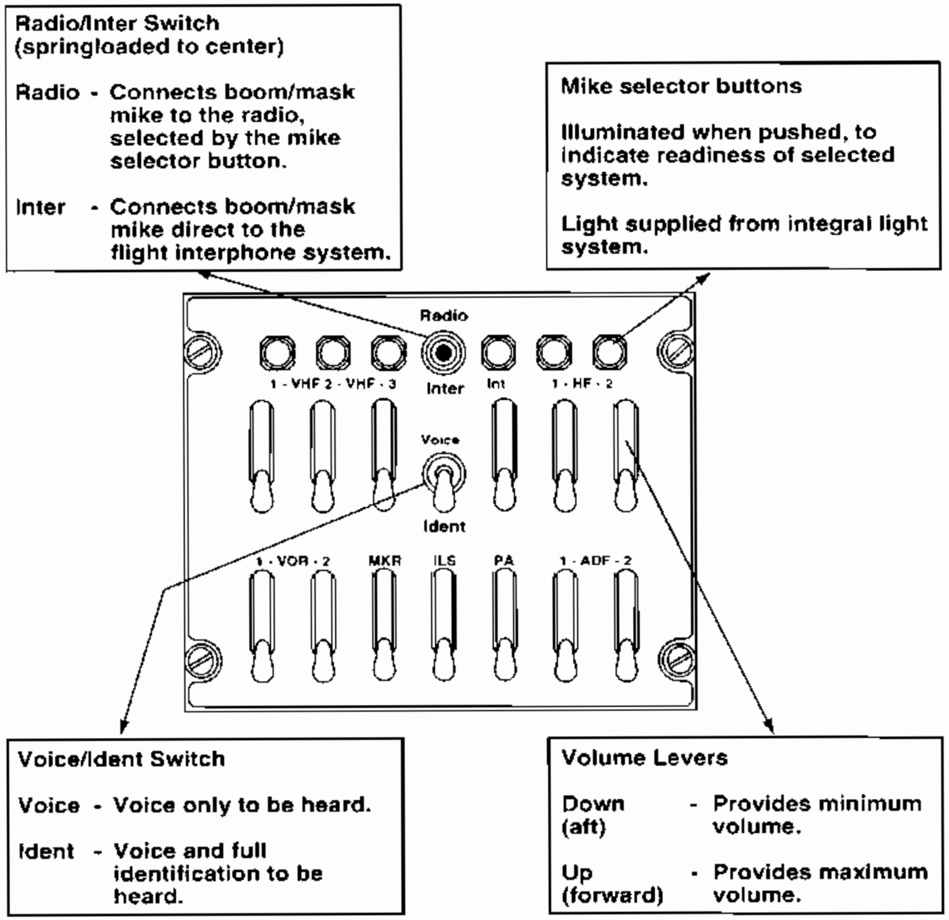
Yoke Switch
aft > Radio
ctr > off
fwd> Interphone

Side Stick Radio Switch
Normal > Boom & Maskmicrophone are disconnected for transmission
Radio > Transmission acc. ACP selection pulled aft

Audio Selector Panel

Each cew member has the possibility to adjust any combination of audio sources and its volume by the volume levers. Also the selection of the microphone signal to **one** of several transmitter or interphone cirquits can be done by pushing the appropriate mike button. A Radio/Interphone switch and the Voice/Ident switch is also located on the panel.

Figure 126: Front View



Radio/Inter Switch
(springloaded to center)

Radio - Connects boom/mask mike to the radio, selected by the mike selector button.

Inter - Connects boom/mask mike direct to the flight interphone system.

Mike selector buttons

Illuminated when pushed, to indicate readiness of selected system.

Light supplied from integral light system.

Voice/Ident Switch

Voice - Voice only to be heard.

Ident - Voice and full identification to be heard.

Volume Levers

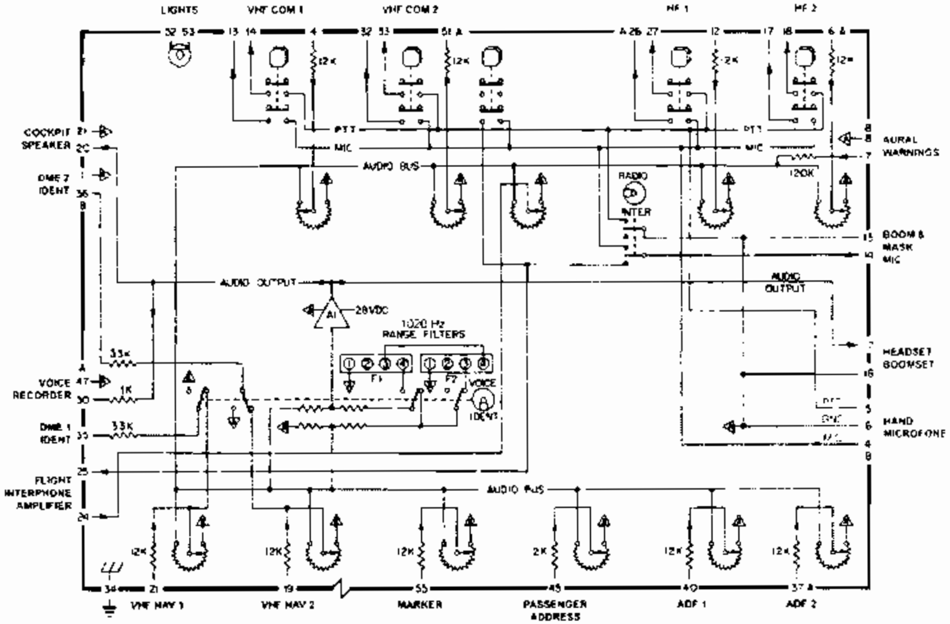
Down (aft)	**- Provides minimum volume.**
Up (forward)	**- Provides maximum volume.**

Two different technologies are applied in the Audio Management System: Digital and analog.

Analog cirquits contains a resistance network with several potentiometers and resistors inside each panel. This network is used to mix all selected audio-outputs in one output signal to head phone, speaker and voice recorder. The loss of signal strength by the resistors is compensated by the build in isolation-amplifier. Reception audio from navigation receivers is routed through 1020 Hz range filters to cancel morsecode signals when listening weather or airport information.

The microphone signal is routed together with the push to talk discrete through the selected mic button to the selected transmitter or interphone system. The mic selectors are mechanically interlocked, so only one transmitter or the interphone system can be used at the time by the crew member. The engaged mic button is illuminated by the integral light.

Figure 127: Schematic



Voice - Ident Filter

The VOICE / IDENT switch is used for cancelling morse code identification signals from ADF, ILS and VOR navigation systems, in order not to hinder voice reception information.

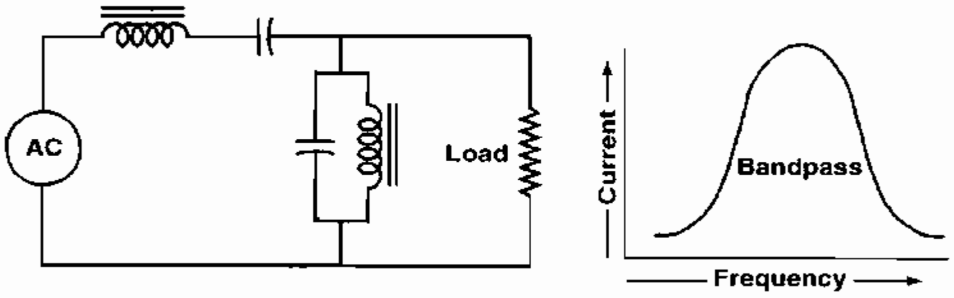
In VOICE position a filter cancels the identification morse code 1020 Hz, so only voice (weather and airport information) will be heard.
The DME identification morsecode 1350 Hz is disconnected by the swich.

In IDENT position both, the station identification and voice can be heard.

In some aircrafts it is possible that in IDENT ONLY position the voice-signal is filtered out, so only 1020 Hz and 1350 Hz morsecode passes the filter.

The filter consists of frequency dependant elements like coils and capacitors.
See example of a band-pass, and band-reject filter

Figure 128: Capacitors and Inductance forming a Filter



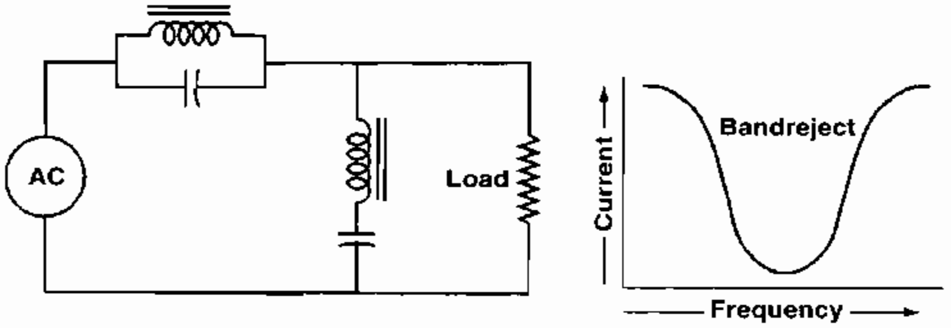
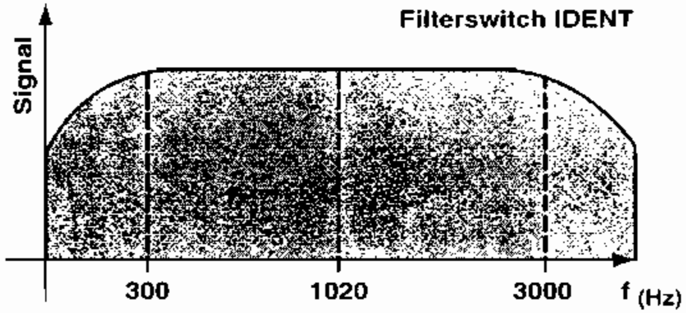
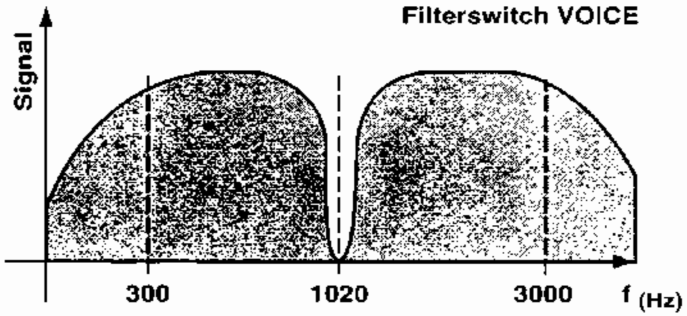
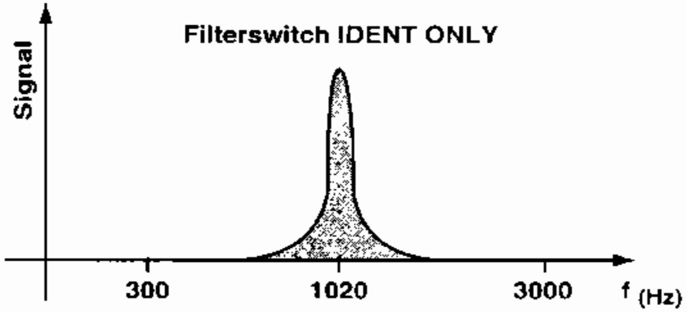


Figure 129: Audio Signal passing the Filter







Digital Audio Control

Audio Control Panel

With the volume controls you set the volume for the various receivers. These controls are potentiometers, and a DC voltage represents the wiper position. This voltage is converted to a digital signal and goes in an ARING 429 word to the audio management unit. An ARING 429 receiver gets the data back after the audio management unit has followed the data commands. When the received data is different from the transmitted data, the comparator gives a channel fault to the flight warning system.

The transceivers have a volume control and a transmitter selector. The volume control operate in the same way as the receiver volume controls. When you select a transmitter this selection goes as discrete in an ARINC 429 word to the AMU.

The positions of the 3 switches R/T-I/C (Radio Transmit - Intercom) Voice-Ident Speaker ON/OFF also go as discretes in ARING 429 words to the audio management unit.

The monitor in the audio control panel does the normal monitoring. When there is a fault in the ACP the monitor gives an ACP fault message signal to the flight warning system.

Figure 130: Front View

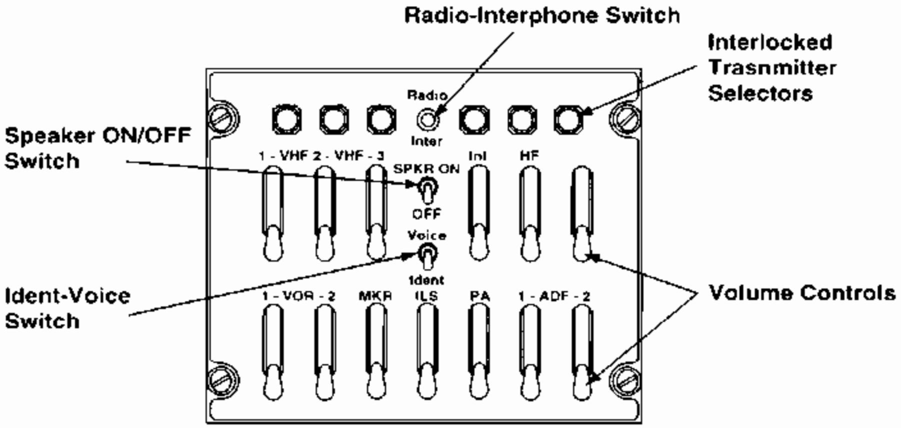
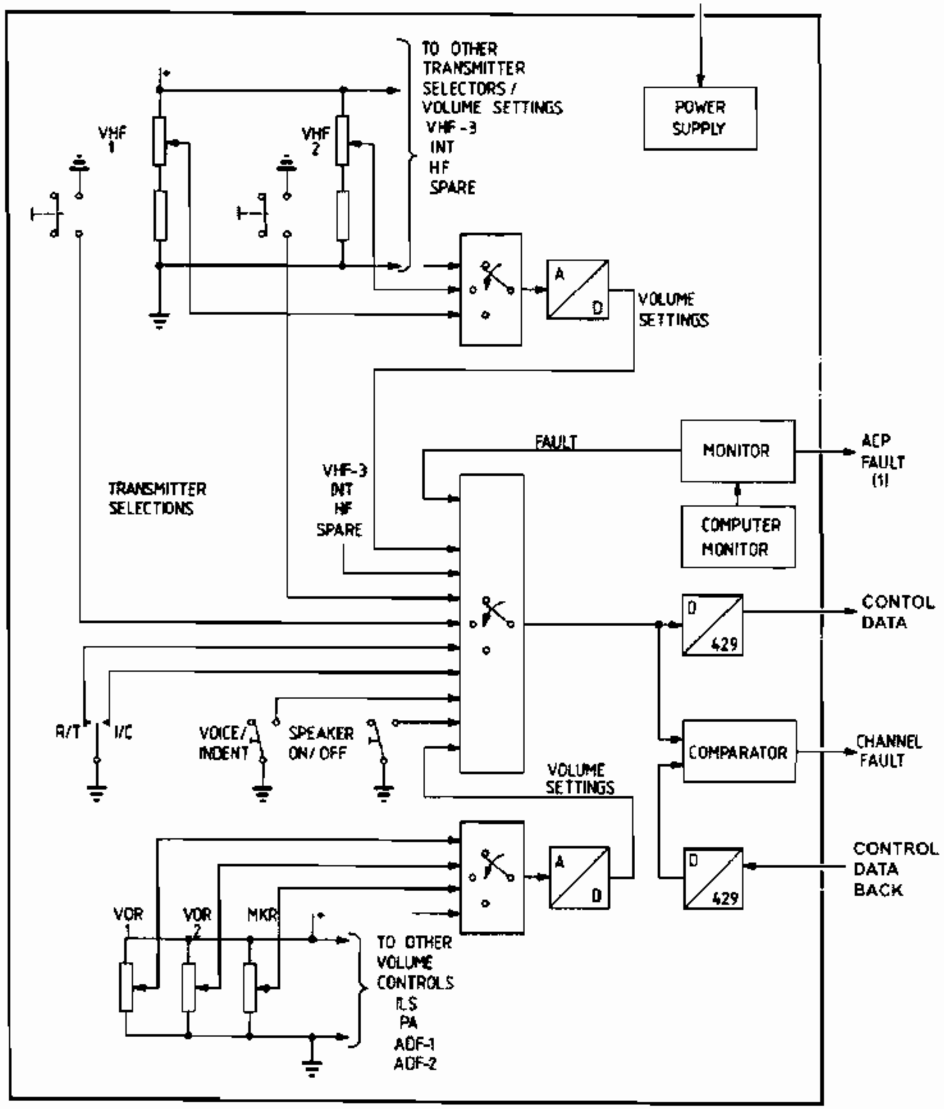


Figure 131: DACP Schematic



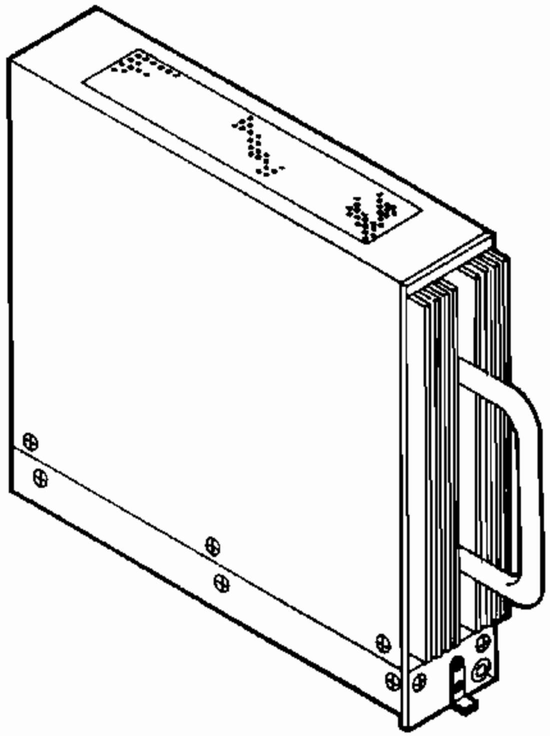
Audio Management Unit

The main part of digital audio management is the Audio Management Unit. It contains for each crew member a station control card. For system redundancy, there are one or more spare channels available.

The audio management unit gets all the audio signals from the communication and alerting systems. These signals go through to the headphones and speakers, depending on the selections of the associated audio control panel. The microphone signals goes according the transmitter selection to the selected transmitter or interphone.

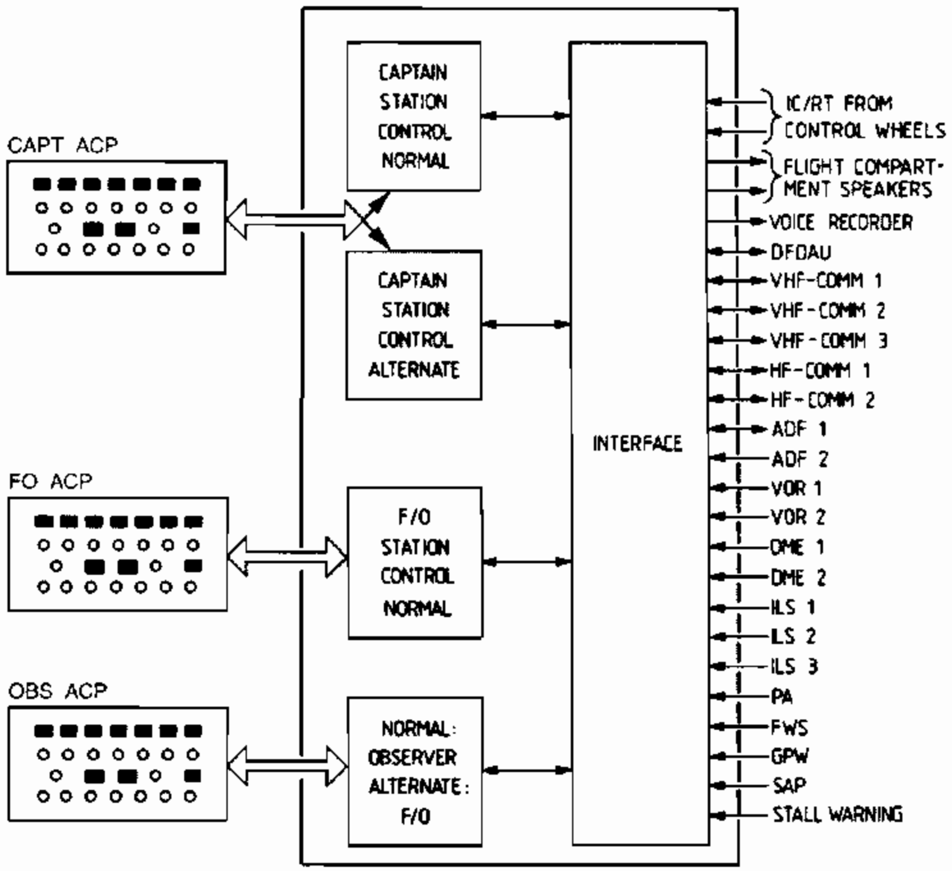
The data transfer between ACP and AMU goes through ARINC 429 buses.

Figure 132: AMU



The interface in the audio management unit is the interconnection to all transmitters, receivers and aural warnings. This means also for the acoustic equipment like speakers, headsets, microphones and PTT switches.

Figure 133: AMU Block Diagram



Station Control

The audio management unit contains for each crew member a station control card.

Each station control has an input to the ARINC 429 receiver. When the received control data is followed, the control circuit gives an "action completed" signal, which activates an electronic switch. Through this switch an ARINC 429 transmitter gets the control data and sends this data back to the ACP for verification of the correct operation of the data bus and the station control.

There is a microphone selection circuits on each station control which have 2 inputs: one for a boom/mask microphone and one for a hand microphone.

With the RT-IC switches on the audio control panel or control wheel you select between flight interphone or a radio transmission. The transmitter PTT and the microphone selection circuits apply the microphone and PTT signals to the transceiver in accordance with the selection on the ACP.

On the audio control panel you select which receiver signals go to the telephone and speaker amplifier. For some receivers like VOR, ILS and ADF there is also a VOICE/IDENT selection. The signals go to a filter which either removes the ident tones or the voice from the audio. The telephone amplifier supplies, through the jackbox, the telephone.

Figure 134: Reception and Transmission Control via ARINC 429

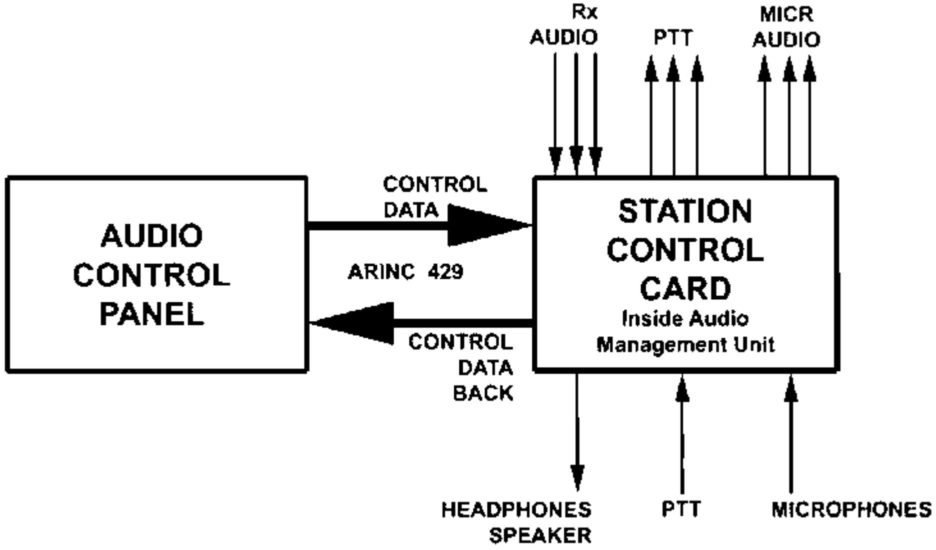
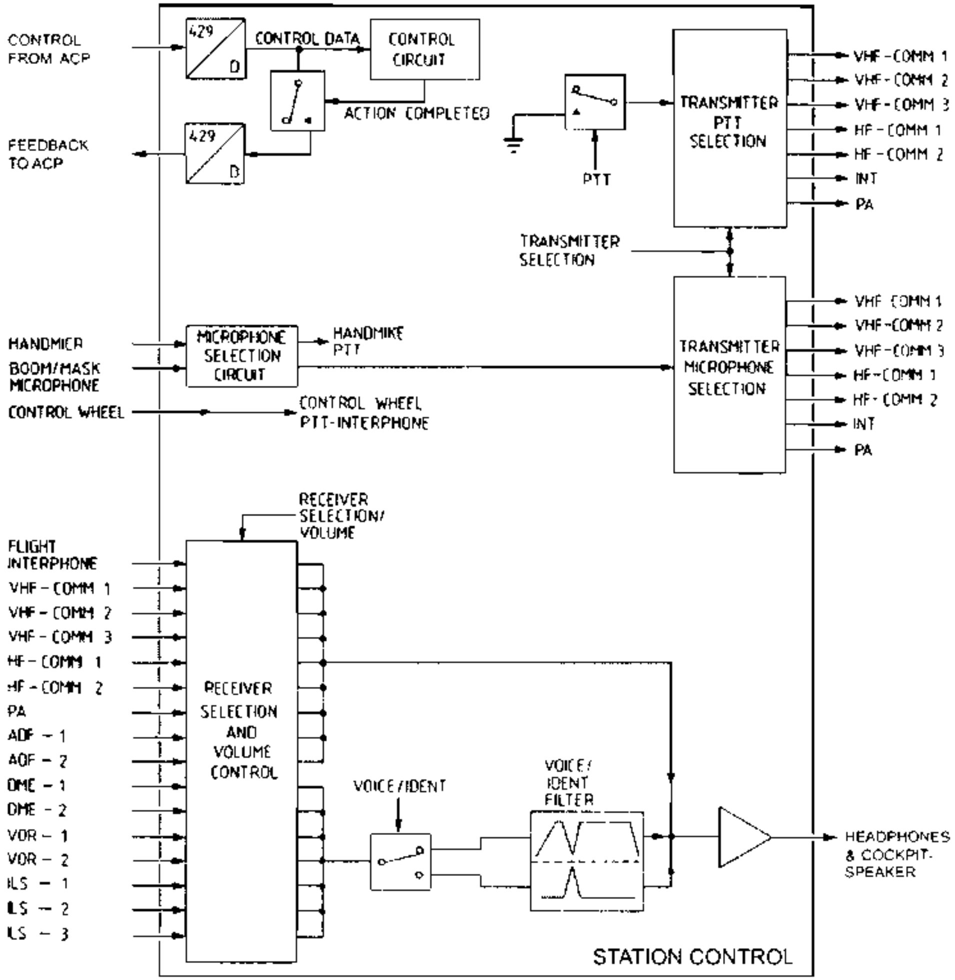


Figure 135: Station Control Function



Interphone

Allows communication between people inside or outside of the airplane. The connections are made via the wiring in the airplane. Three interphone systems can be distinguished: Flight-, Cabin- and Service or Maintenance Interphone system.

Flight Interphone

Takes care of the communication between the flight deck crew among themselves and between the flight deck crew and the ground engineer when the engines are started and during a test run. The audio distribution or integrating system is used for the amplification and distribution of the audio signals. This means that the flight deck crew can use the boomset, hand microphone headset and speaker. The flight interphone system can be selected on the audio control panel. The ground engineer can plug in his headset in the flight interphone jack located in the nose wheel area. Older types of airplanes have a separate flight interphone amplifier.

Figure 136: Communication Inside Cockpit and Ground Crew

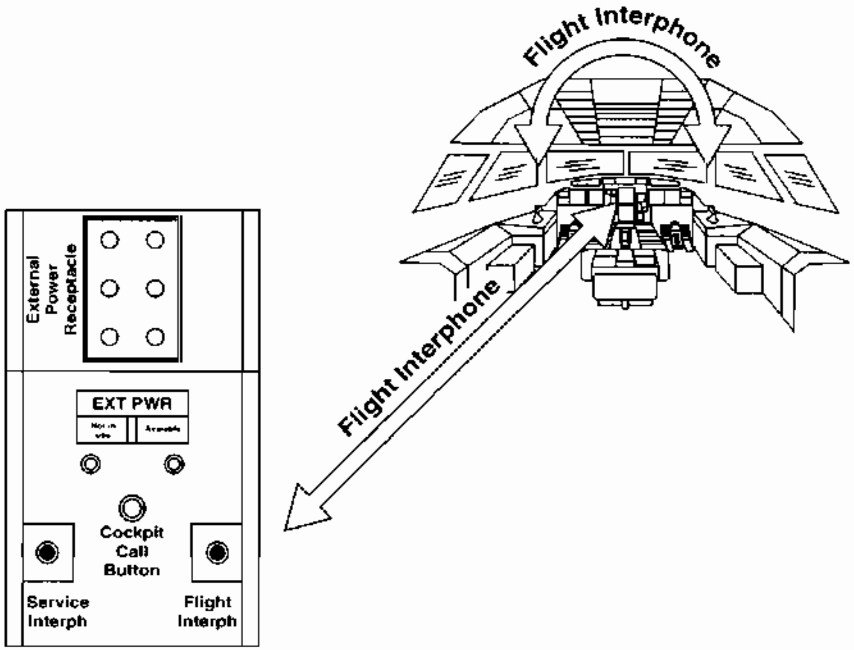
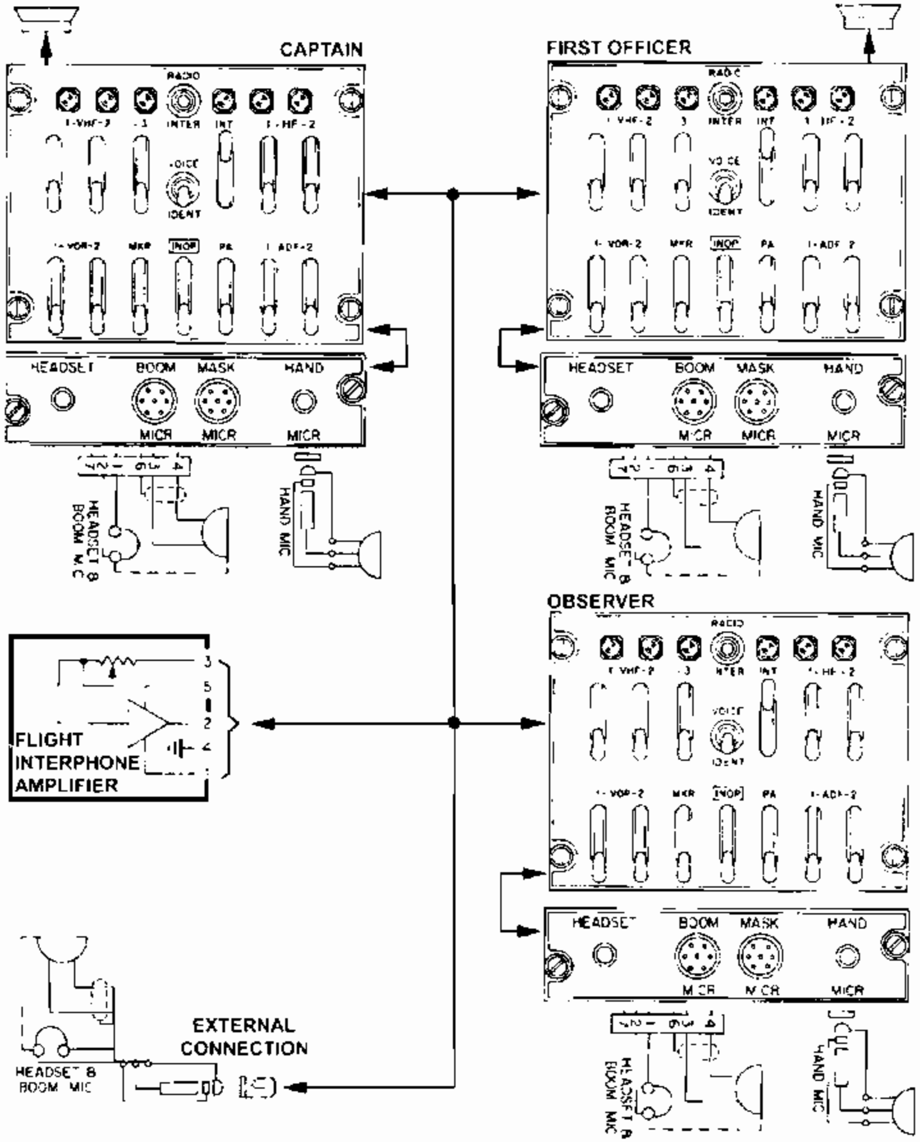


Figure 137: Flight Interphone Schematic



Cabin Interphone

Cabin crew can communicate among themselves and with the flight deck crew via the cabin interphone system. The cabin interphone system consists of three components.

- Cabin interphone handsets
- Control circuits inside Cabin Intercommunication Data System CIDS or a separate amplifier.
- Call panels or call buttons at handsets.

Figure 138: Communication Between Cockpit and Cabin

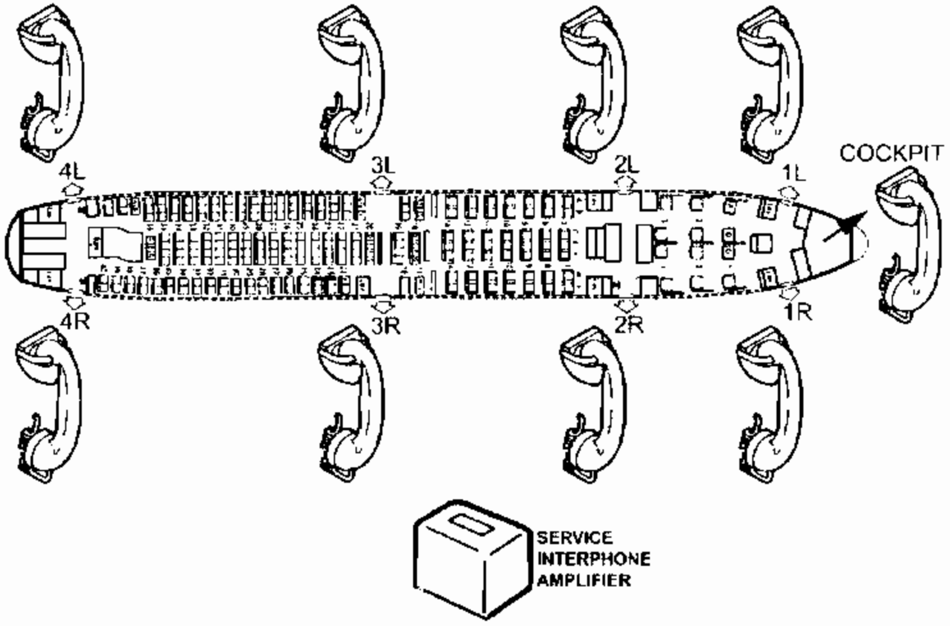
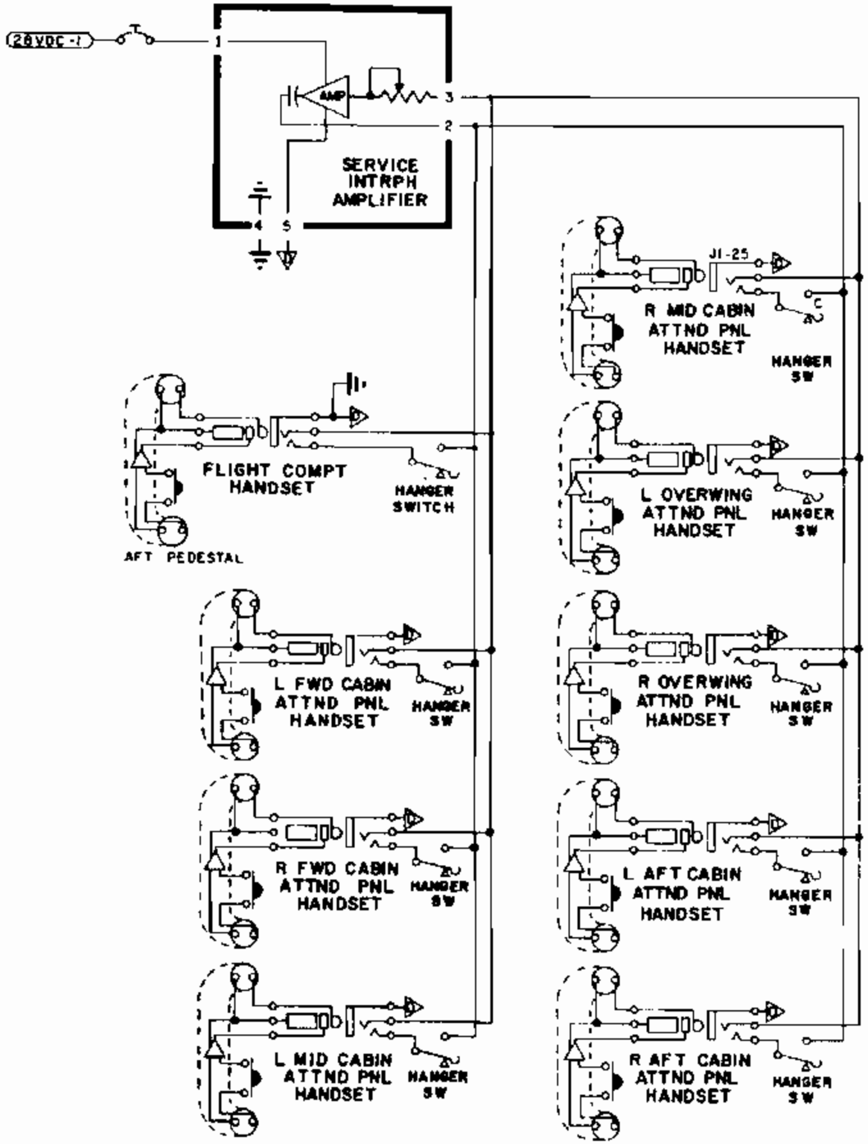


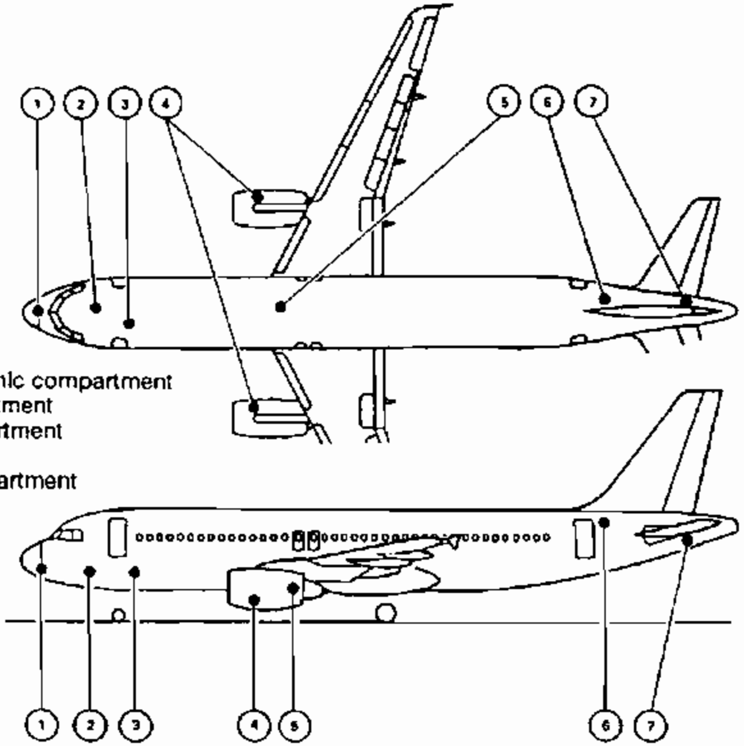
Figure 139: Cabin Interphone Schematic



Service or Maintenance Interphone

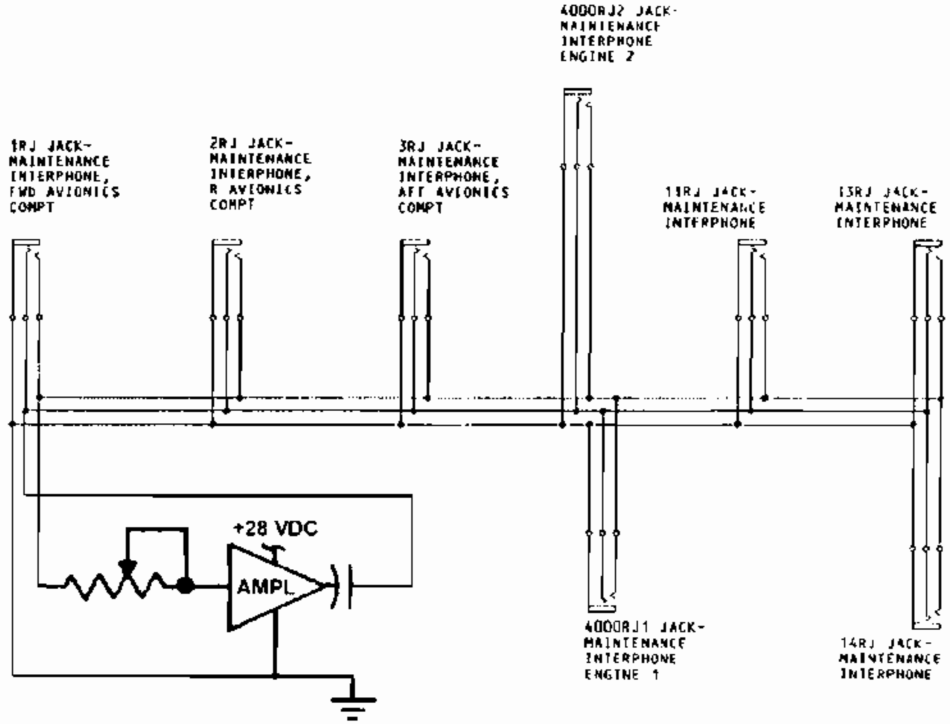
The service interphone system takes care of the communication among maintenance personnel during maintenance activities. The service interphone system consists of a number of plug in jacks can be found at various places in and on the airplane. The service interphone system uses the audio distribution system for amplification and distribution of the audio signals. Older types of airplanes have a separate service interphone amplifier.

Figure 140: Communication between various Locations Cabin and Cockpit



1 Forward electronic compartment
2 Electric compartment
3 Avionics compartment
4 Engine (L & R)
5 Hydraulic compartment
6 Aft section
7 APU bay

Figure 141: Service Interphone Schematic

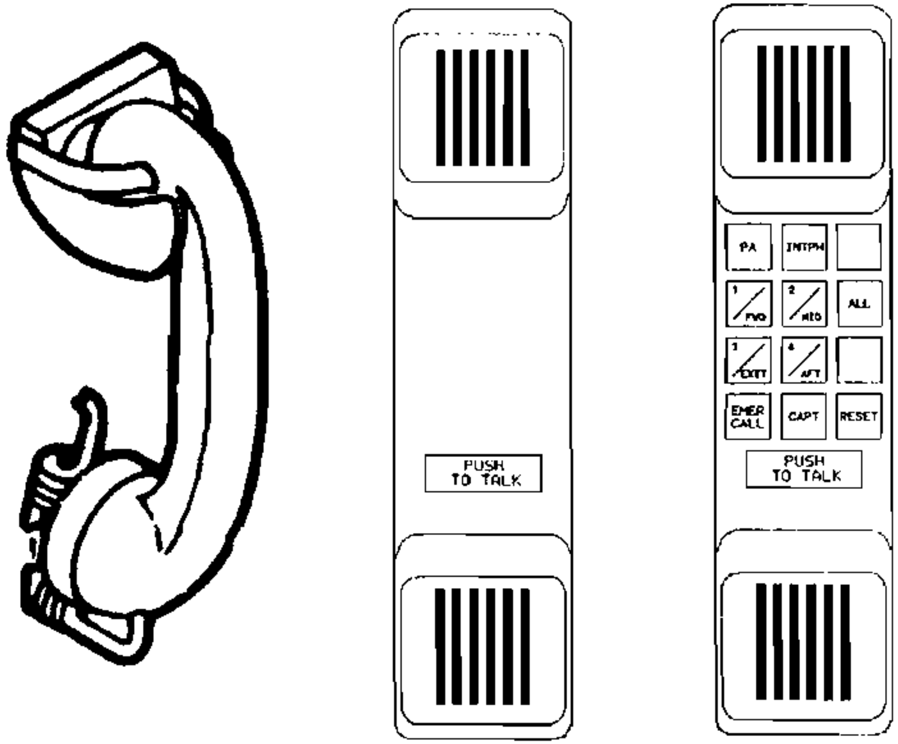


Cabin - Service Interphone Handsets

One handset is located in the cockpit and several handsets are installed in the cabin at the attendant stations. The handsets are also used as a microphone for public announcements via the public address system.

Dial buttons makes possible to communicate with a dedicated partner station or cockpit, so other crew members are not able listening private communications. So a digital central switching system (Cabin Intercommunication Data System CIDS) is used.

Figure 142: Various Handsets



Interconnections between interphone systems

- The flight interphone makes it possible for the flight deck crew to communicate with each other and with the ground engineer.
- The cabin interphone is used by the cabin crew to communicate among themselves and to communicate with the flight deck crew.
- The service- or maintenance interphone is used by the maintenance personnel to communicate with each other.

Depending of aircraft type, it is possible to interconnect this three interphone systems in the following way.

- Cabin interphone with service- or maintenance interphone.
- Flight interphone with cabin interphone
- Flight interphone with maintenance interphone

Therefore dedicated switches are used or it is done automatically after landing.

To interconnect the service interphone of older aircrafts, it is nessecary to install an external jumper cable between the flight interphone jack and service interphone jack.

Ground Crew Call

The ground crew has a flight-deck call button in the nose wheel well that, when depressed, sounds a low chime on the flight deck and illuminates a ground-crew call light. When the ground-crew call button on the flight deck is depressed, a horn in the nose wheel well sounds. When the chime or the horn sounds, the appropriate crew members can use the interphone system to communicate with the one who initiated the call.

Figure 143: Ground Crew Call and Cockpit Call

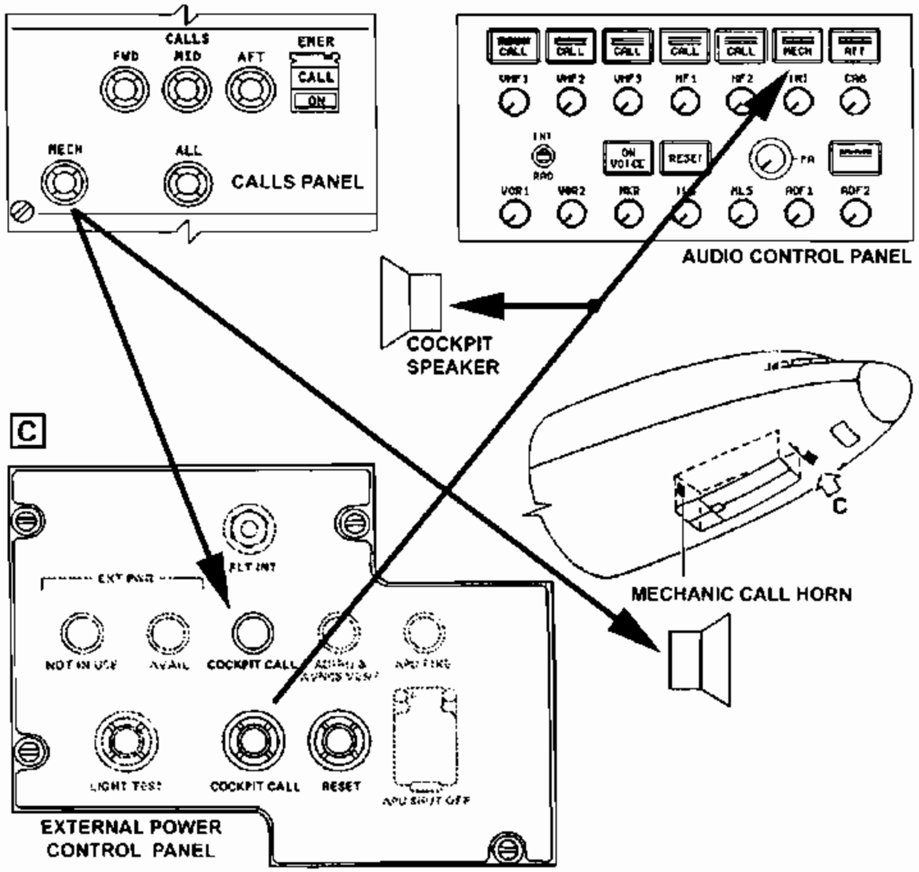


Figure 144: Ground Crew Call Schematic

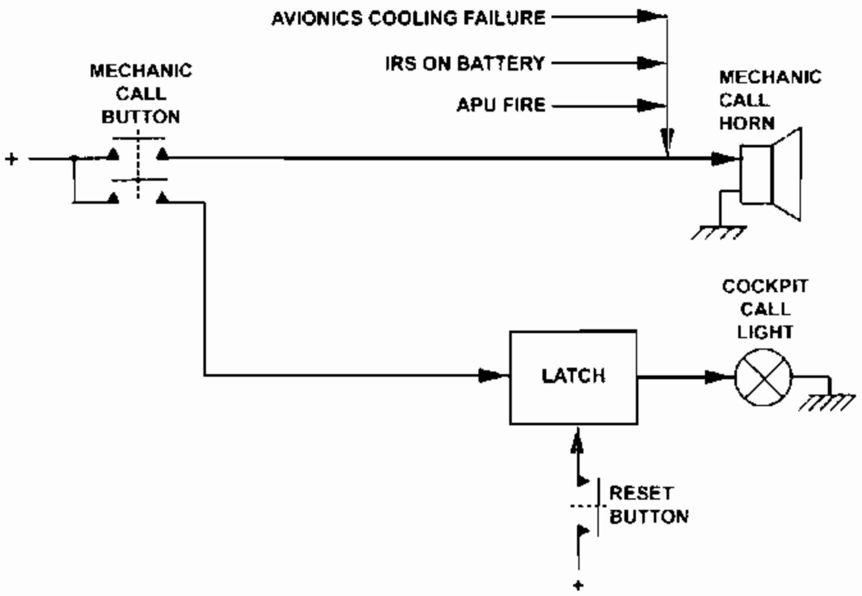
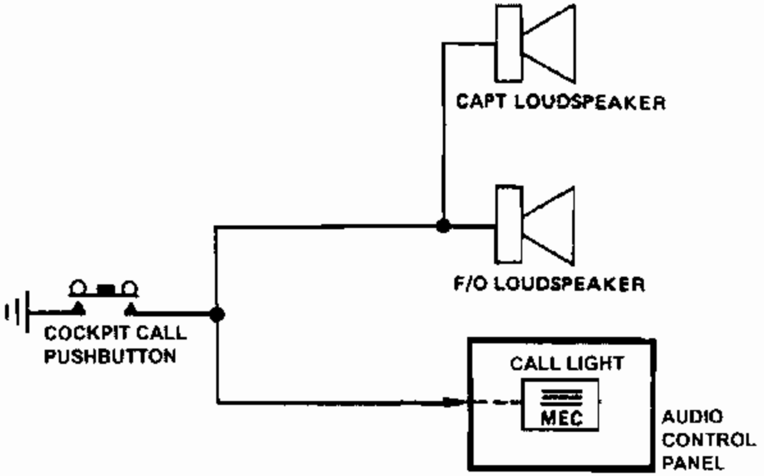


Figure 145: Cockpit Call Schematic



Cockpit Voice Recorder

Introduction

The cockpit voice recorder, or CVR, is an important device for determining the cause of an aircraft accident. An endless tape or a solid state memory allows for minimum 30 minutes of recording, and then it is automatically erased and recorded over. There are four inputs to the recording heads: the microphones of the captain, the first officer, the observer, and a microphone that picks up received audio and cockpit conversations. These microphones are always "hot" and do not require any type of keying. The pick-ups are all in the cockpit, but the actual tape recorder is in a fire resistant box usually located near the tail of the aircraft, and is painted bright orange so that it is easily identified among the wreckage.

Figure 146: CVR System Block Diagram

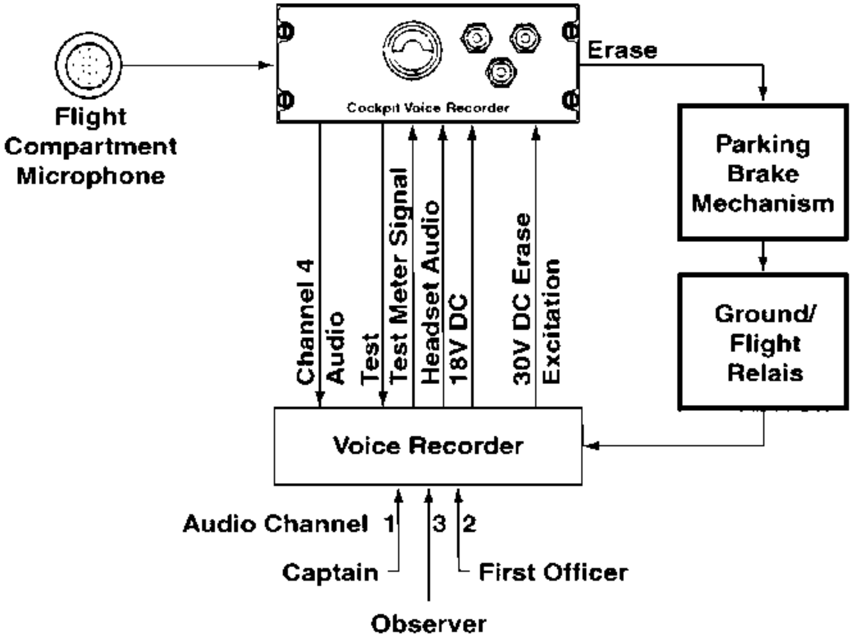


Figure 147: Location in Aircraft

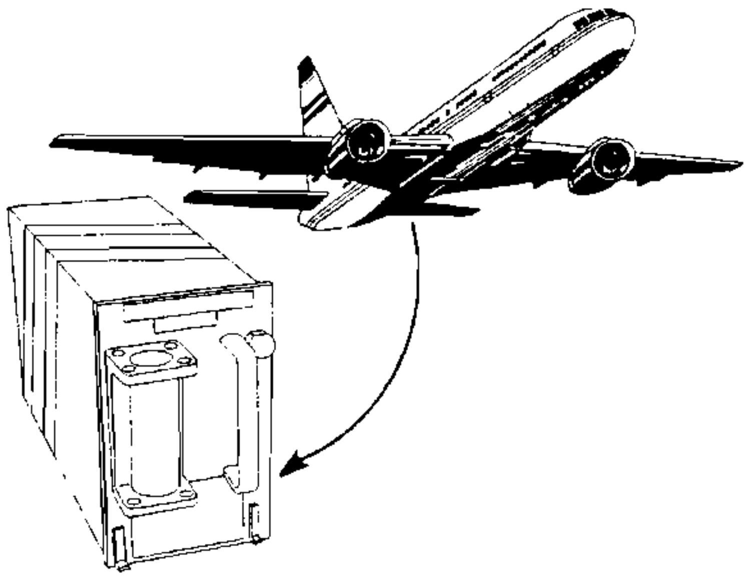
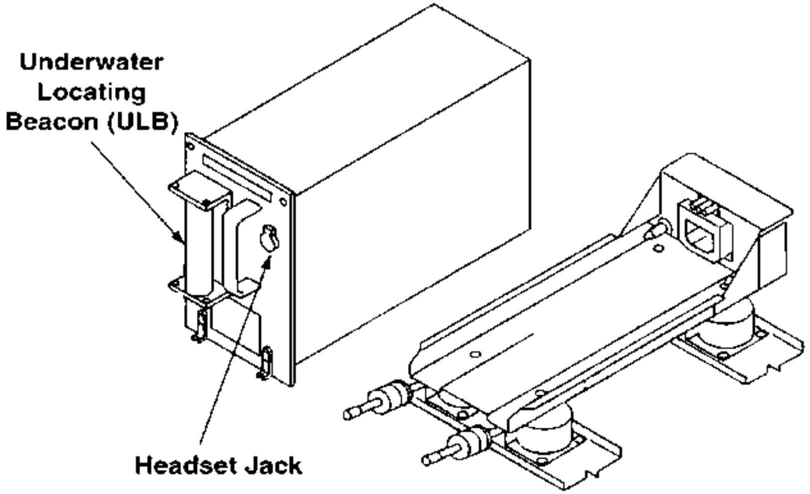


Figure 148: Recorder, Shelf and ULB



Function

A voice recorder records information on an endless magnetic tape or in to a solid state memory. This recording is kept of the last 30 minutes of flight crew communication and conversation. This information is essential for accident investigation, therefore the voice recorder is an airworthiness requirement. For accident investigation the voice recorder is used in combination with the flight data recorder.

The voice recorder has a protective casing which gives the recorder a bigger chance to survive a crash. Also the location of the recorder, in the tail of the aircraft, increases the survival chances. The casing has a bright orange color with white fluorscent tape stripes. This makes the recorder easier to find. On the front panel of the voice recorder is an underwater locator beacon. Under water the underwater locator beacon transmits ultrasonic pulse signals, which makes it easier to find the recorder.

The voice recorder system gets audio signals and records them on 4 separate tracks. On the tracks are the following audio signals:

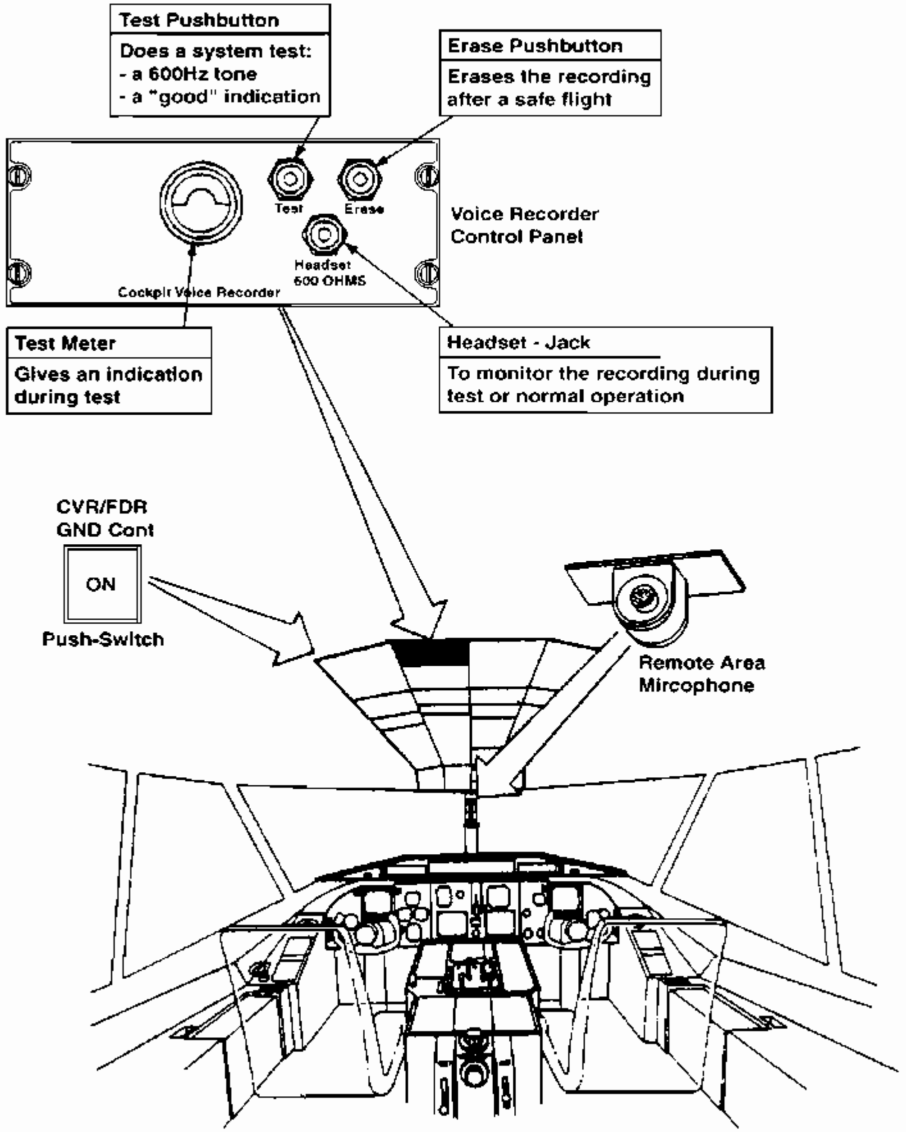
- Channel 1: - all selected audio from the captain's audio station
- Channel 2: - all selected audio from the first officer's audio station
- Channel 3: -all selected audio from the observer's audio station.
  Time reference signals from the flight data recording system.
- Channel 4: - all area-sound-signals from the flight compartment microphone.

The voice recorder control panel has the controls for a TEST and ERASE function of the recorder. The erase function goes through interlock conditions. The control panel has straps for the setting of an internal amplifier.

The voice recorder gets the electrical power automatically when one of the engine is started (fuel levers open) or the aircraft is in flight. A time delay relay removes the power from the voice recorder 5 minutes after the aircraft is on the ground and all fuel levers are closed.

Manually you apply power to the voice recorder with the CVR/FDR GND CONT pushswitch on the avionics switch panel. The automatic power switching overrides the manual switching.

Figure 149:



Recorder

The voice recorder contains a magazine and electronic circuitry. The magazine contains the endless tape, a bulk erase coil, an erase head, recording heads and a monitor head.

The electronic circuitry is a power supply, bulk erase switching, a bias oscillator and for each recorder channel an amplifier and mixer. There is also a test oscillator and multiplexer, and a meter circuit.

Once the voice recorder gets electrical power the recorder starts to record the audio and time signals on the 4 tracks of the tape. Before the tape passes the record heads it passes an erase head to erase the previous recording. The bias oscillator supplies the erase head.

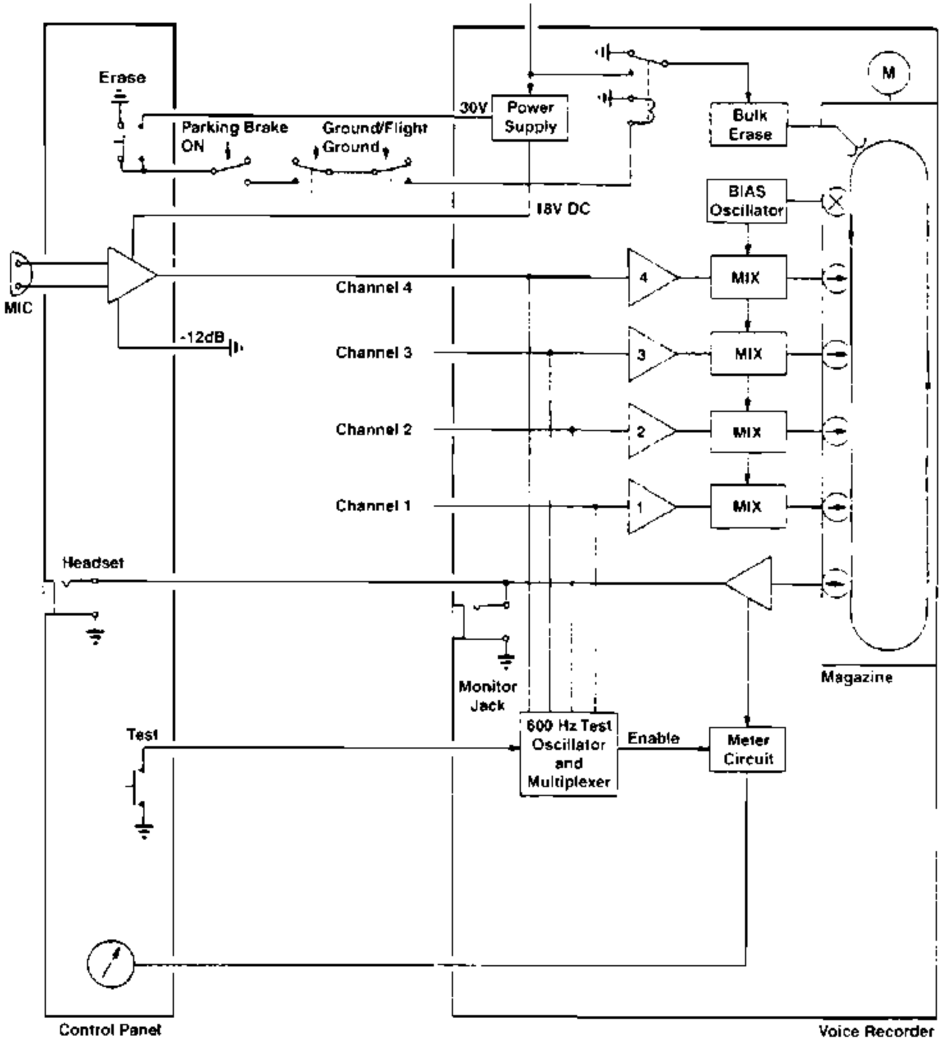
The audio signals from the audio management unit or the remote area microphone go to amplifiers and from there to mixers. From the mixers the signals go to the record heads, which put signals on the tape. In the mixer the audio signals are mixed with the bias oscillator signal.

After the tape passes the record heads, it passes a monitor head, which gives the recorded signals to a monitor amplifier. This amplifier supplies the telephone jacks on the recorder front panel and the control panel. During test a meter circuit measures the signal strength. A test meter on the control panel shows the signal strength (only during test!).

The ERASE pushbutton on the control panel gives the pilots the possibility to erase all the recorded information after a succesfully completed flight. The erase pushbutton is operative when the aircraft is on the ground and the parking brake is set. When you push the erase pushbutton a relay in the voice recorder applies 115 V AC to a bulk erase coil. When you hold the pushbutton for at least 2 seconds the strong 400 Hz magnetic field completely erases the recording on the tape.

Recordings are stored to a magnetic tape. The tape unit can be endless or automatic reversing after 15 minutes to continue recording to other 4 tracks. After other 15 minutes the recorder beginns to overwrite the previous 30 minutes old recording. The tape unit is located in a crash and heat survival case.

Figure 150: Recorder with endless Tape (analog recording)



Solid State Cockpit Voice Recorder CVR

Todays technology is the possibility to store the recording in digital format. There are no moving part, which can be worn. (solid state)

Flash Crash Survivable Store Unit FCSSU

The non volatile flash memory is encased in a crash hardened titan alloy unit.

Storage capacity: 4 Channels for 30 minutes high fidelity
all channels up to 4 hours low fidelity

Acceleration surviving: 3400 g's

Force to withstand: 5000 lbs (2.27 metric tons)

Deep sea pressure: 20'000 ft (6096 m)

Temperature to survive: 1100 °C

Figure 151: Analog Magnetic Tape and FCSSU (Memory Module)

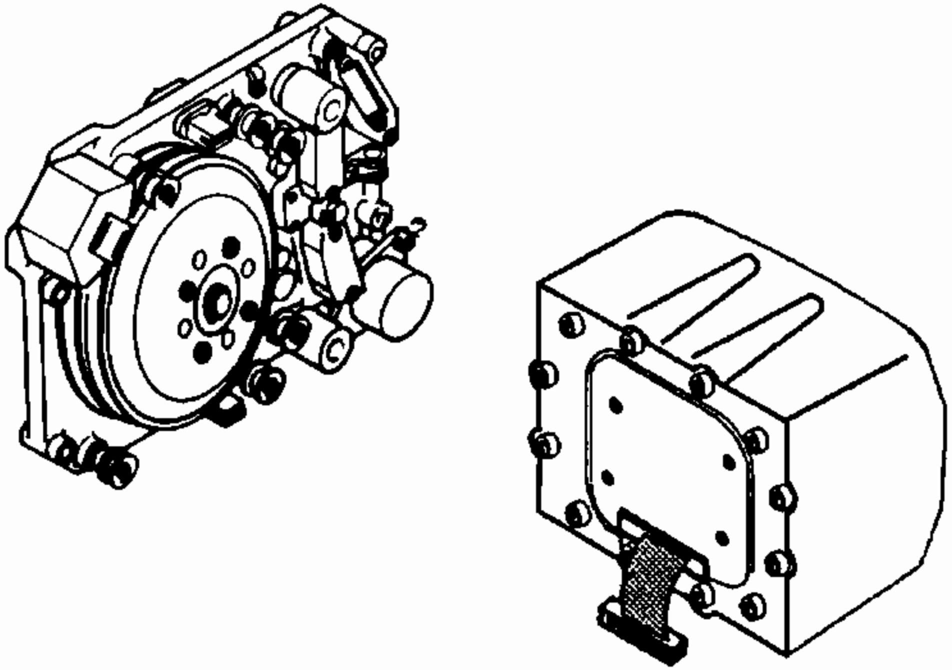
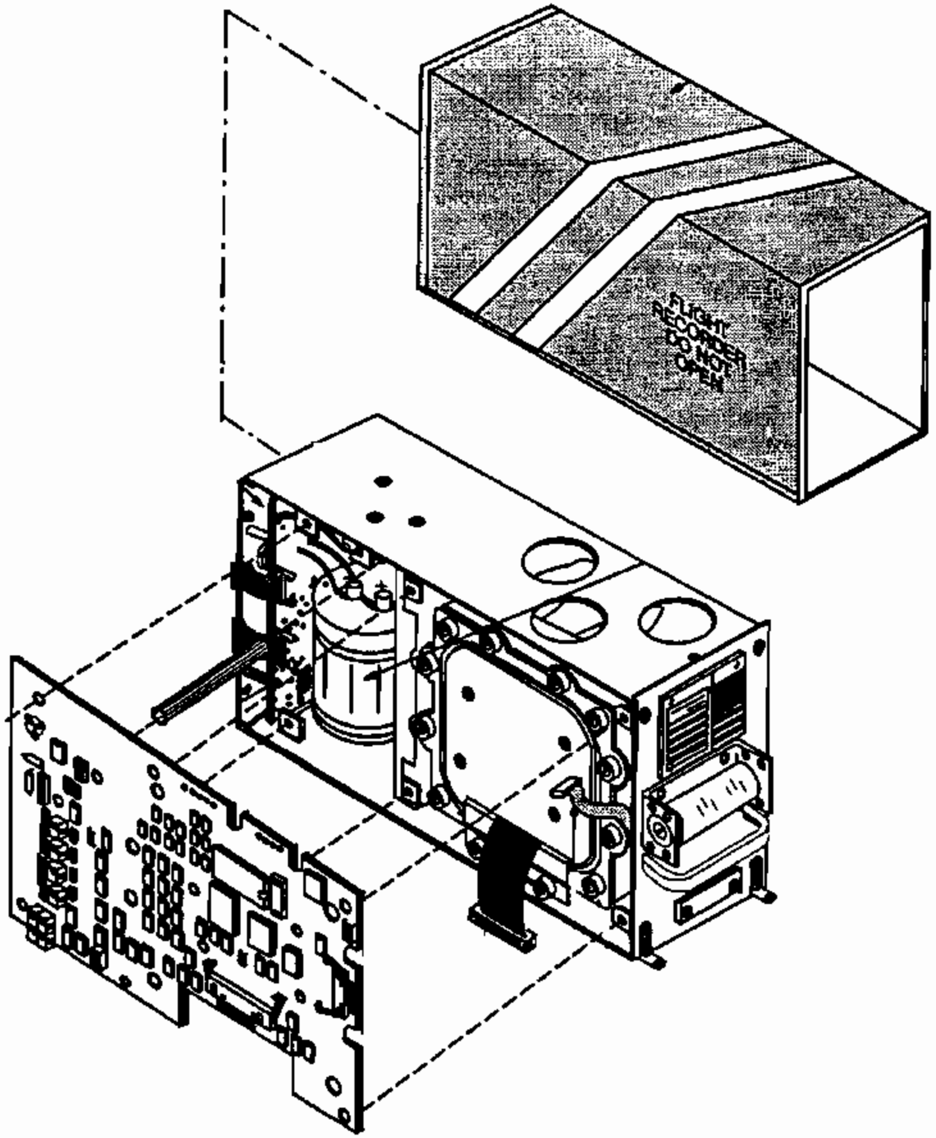


Figure 152: CVR Solid State



Underwater Locator Beacon ULB

The Beacon is a battery operated underwater acoustic pulse generator that is activated when the switch end is immersed in either fresh or salt water.

The water switch is part of a low-current triggering circuit, which when closed by a resistance of less than a few thousand ohms, such as immersion in water, will initiate normal pulsing of the Beacon oscillator circuit. The output voltage of the oscillator is impressed upon the piezoceramic transducer ring. The resultant mechanical motion is coupled to the metal case of the Beacon, which in turn, radiates it into the surrounding water as 37.5 kHz acoustic energy.

The pulses generated are of 10-millisecond nominal duration, and they occur once per second. The Beacons operate continuously for at least 30 days after being immersed. The Beacons will withstand depths to 20,000 feet and they can be detected at a range of 2000 to 4000 yards, depending upon sea state, nearby boats, marine animals, gas or oil lines, and other factors contributing to the ambient noise level in the 35 to 40 kHz frequency range. The internal battery must be replaced every 2 - 6 years.

Figure 153: ULB Schematic

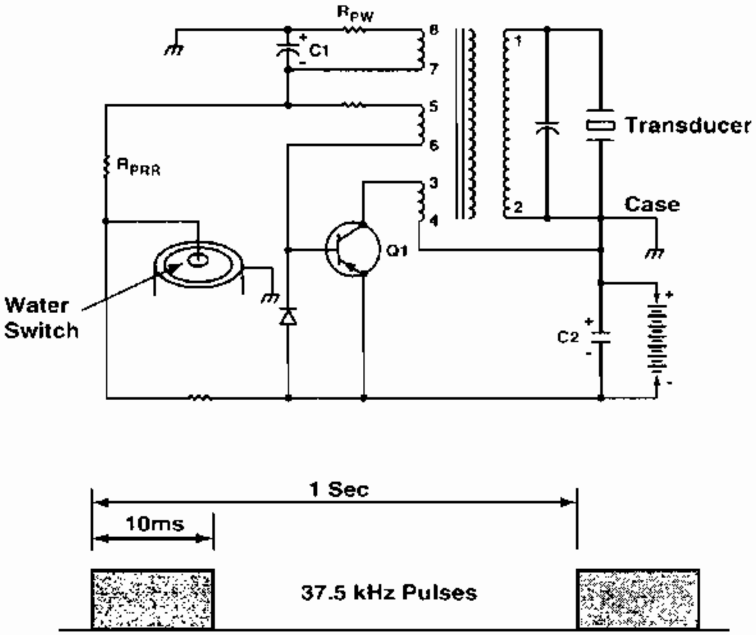


Figure 154: ULB

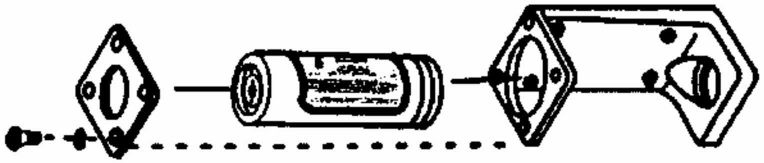
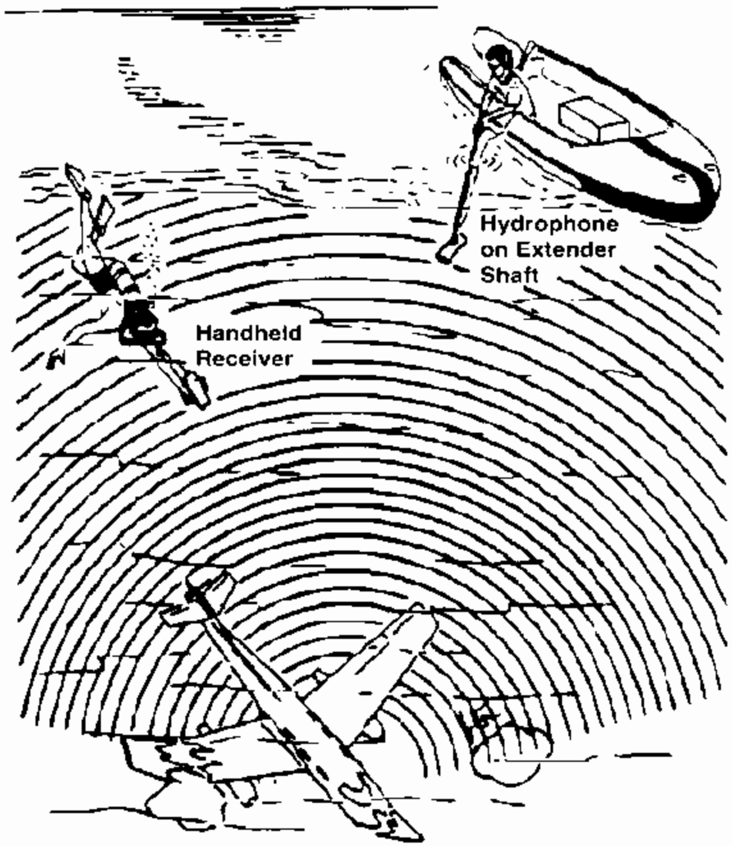


Figure 155: Locating an Aircraft in Water or Swamp



Emergency Locator Transmitter ELT

Introduction

An emergency locator transmitter (ELT) is a small, self-contained radio transmitter mounted in a location where it is least likely to be damaged in a crash. It has an inertia switch that closes in the event of a crash and starts the transmitter emitting a series of down-sweeping tones simultaneously on two emergency frequencies, 121.5 MHz in the VHF band and 243.0 MHz in the UHF band. The battery in an ELT has a design life long enough to operate the transmitter continuously for 48 hours.

ELTs are installed as far aft in the fuselage as it is practical to place them, and they are connected to a flexible whip or external antenna. The installation must be such that orients the inertia switch so that it is sensitive to a force of approximately 5G along the longitudinal axis of the aircraft.

When an ELT is properly installed, it requires little maintenance other than ensuring that it remains securely mounted and connected to its antenna. There must be no evidence of corrosion, and the battery must be replaced according to a specific schedule. Non rechargeable batteries must be replaced when it has reached its usable life. The date required for its replacement must be legibly marked on the outside of the transmitter case and recorded in the aircraft maintenance records.

An ELT can be tested by removing it and taking it into a shielded or screened room to prevent its radiation from causing a false alert. An operational check may be made with the ELT in the aircraft for no more than three audible sweeps.

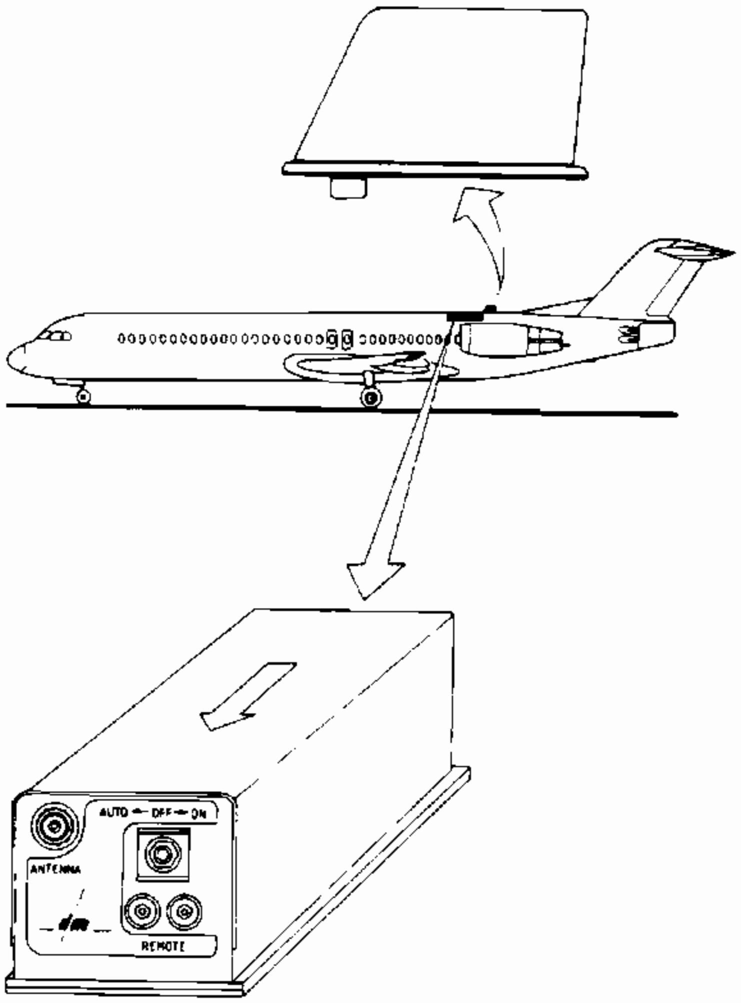
This test must be conducted within the first five minutes after any full hour.

Orbiting satellites of the COSPAS and SARSAT (Search and Rescue Satellite) system can locate the position of the signal by doppler effect to approximately 14 km. The mission control center then initiates the rescue which is done with conventional radio direction finding equipment on 121.5 MHz.

The transmitter is installed in the ceiling of the cabin. To make the unit sensitive for the shock-detection the unit needs to be installed in the correct way. Therefor an arrow on top of the unit shows how to install the unit with respect to the direction of flight.

The ELT antenna installed on the rear-top of the fuselage transmits the ELT signals.

Figure 156: Transmitter and external Antenna Location



ELT Function and Operation

An internal battery pack in the battery compartment is the power supply of the unit. When power is supplied to the audio generator and the oscillator the transmitter starts to transmit the down-sweeping audio signal on the distress frequencies.

If the transmitter is switched on (automatically or manually) an audio signal is modulated on the international distress frequencies of 121.5 MHz. and 243.0 MHz. The audio signal is a down sweeping signal from 1600 Hz to 300 Hz which is repeated 3 times a second.

With the switch on the transmitter front-panel in the ON position the transmission is started. With this switch in the AUTO position the internal impact-switch and the ELT control panel are enabled. The impact switch starts the transmission if a shock of 5 g. for a minimum of 11 msec. is sensed. The automatic transmission is reset when the remote pushbutton in the flightdeck is switched to ON and switched back to AUTO again. With the remote pushbutton in the ON position the transmission is also started.

On the front of the unit are two connection points for remote control and antenna.

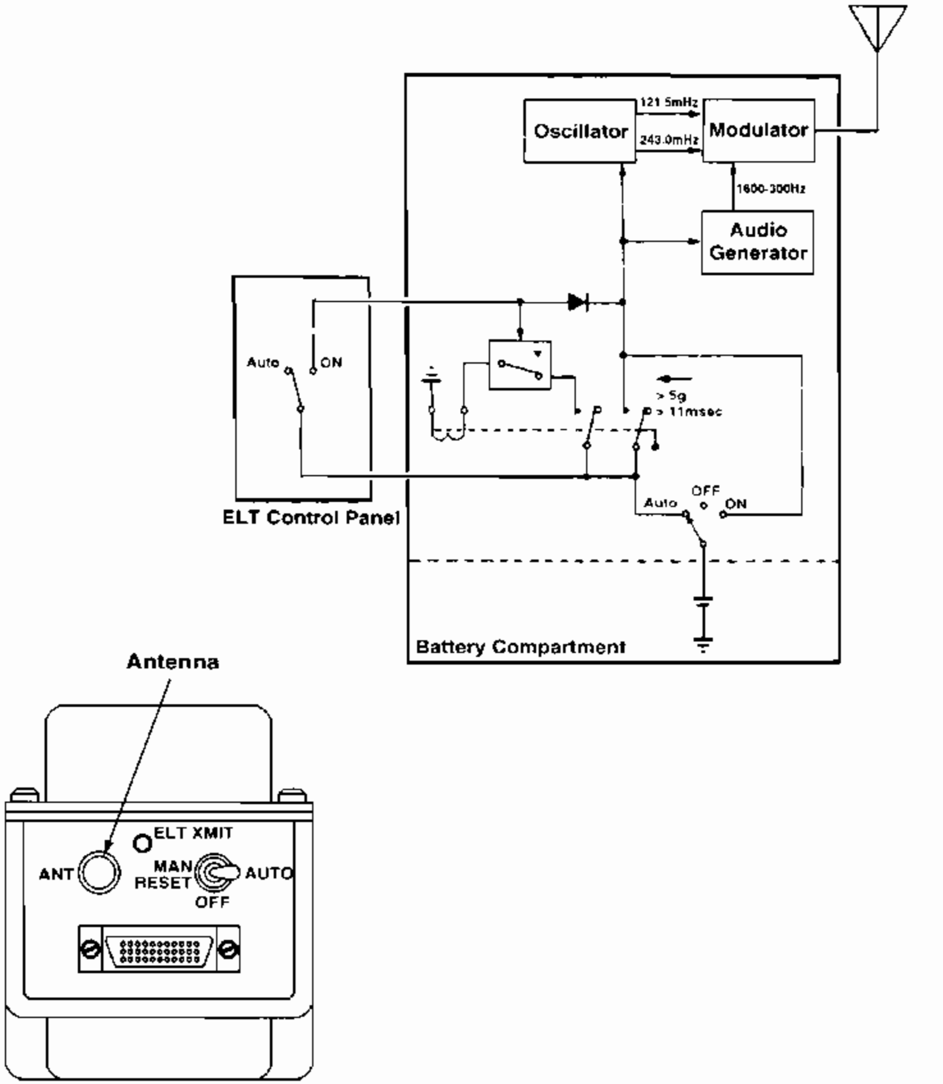
A 3-position toggle switch.

- OFF position the transmitter is disabled.
- AUTO position automatic control of the transmitter. If the automatic control is enabled and the unit senses a shock of at least 5 g. for a timeduration of 11 msec. the transmitter starts to operate automatically.
- ON or MAN/RESET position, the transmitter starts to transmit. The automatic transmission is reset when the toggle switch is switched to ON and switched back to AUTO again.

A red light shows the ELT is operating.

A small whip antenna is provided, if after an accident the ELT is removed from the aeroplane.

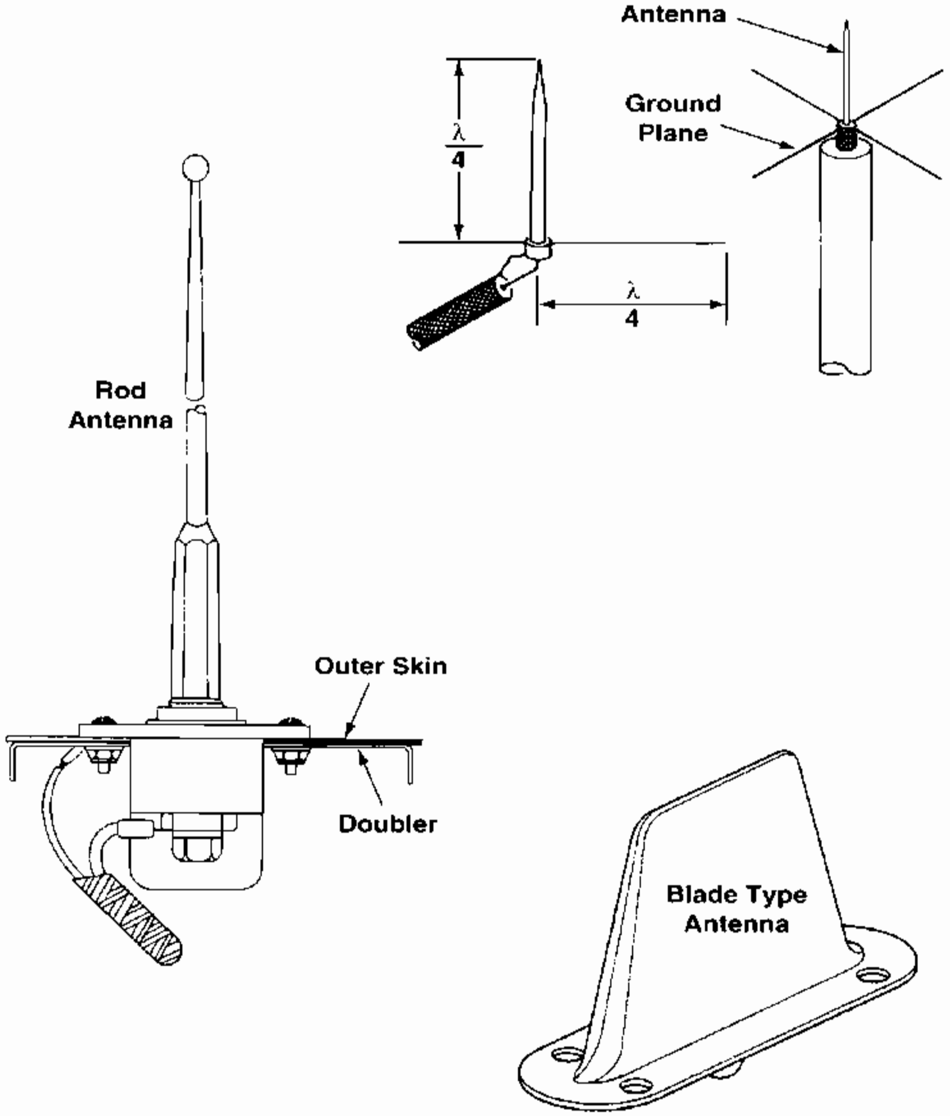
Figure 157: ELT



Antenna

The emergency locator transmitter antenna typically uses a thin wire whip antenna mounted as far aft in the fuselage as possible, but ahead of the empennage. It is usually mounted on top of the fuselage, where it is least likely to be damaged.

Figure 158: Antennas



Automatic Direction Finder ADF

Principle

The ADF is a historic short and medium range radio navigation aid, which receives and interprets the signals provided by a non directional and broadcasting ground station.

The combination of signals, received from two loop antennae and from one omni-directional sense antenna, provides bearing information. The two loop antennae are positioned 90° apart on the aircraft structure. The signal from the omni-directional sense antenna is not affected by the relative bearing.

An additional Morse signal is provided to identify the selected ground station. The ADF system also provides aural identification of the ground station. Newer receiver also decodes the Morse identification which is received. For entertaining, listening of broadcasting radio staions at long- and medium frequency is possible.

Figure 159: Bearing Indication

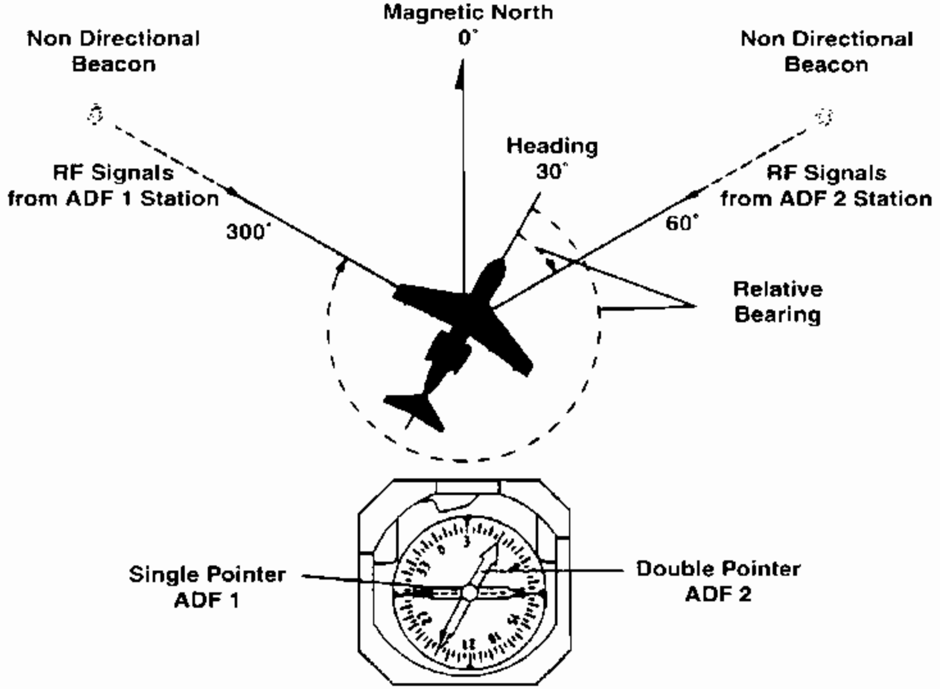


Figure 160: NDB Radiating Electromagnetic Fields

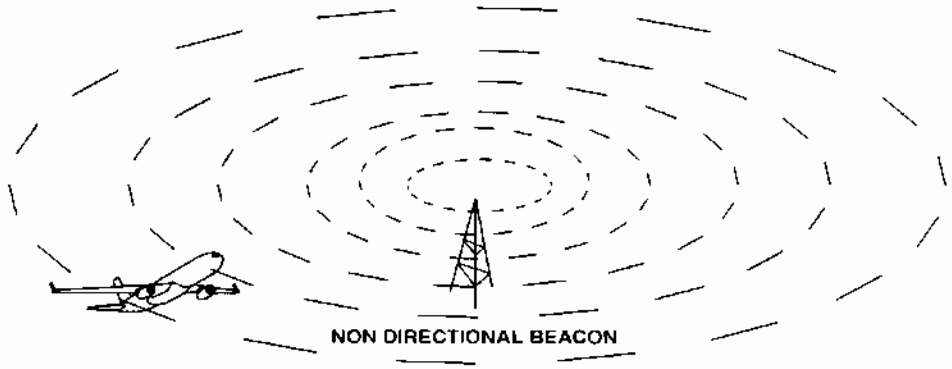
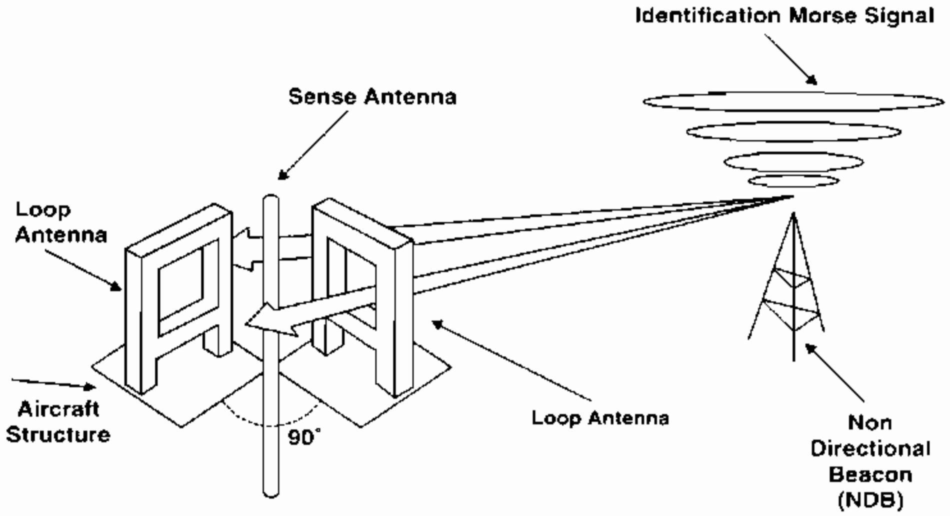


Figure 161: Principle



Control

- Frequency selection:
  Long and medium frequency (LF and MF) 190 -1750 KHz
- A1 - NORM Switch
  A1: Reception of non modulated morse code (continious wave CW)
  Normal: Reception of normally modulated NDB's and broadcasting stations.
- ADF - ANT Switch
  ADF: Reception with Loop- and Sense Antenna. (Direction finding)
  ANT: Reception with Sense Antenna only. (Listening of broadcating)
- TFR Switch
  Transfers the receiver tuning to the standby frequency

Figure 162: ADF Control Panel

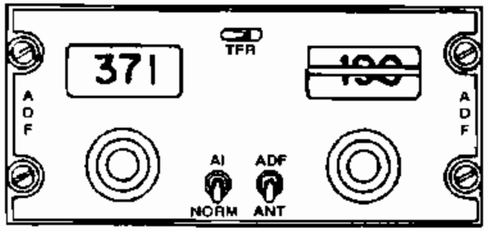
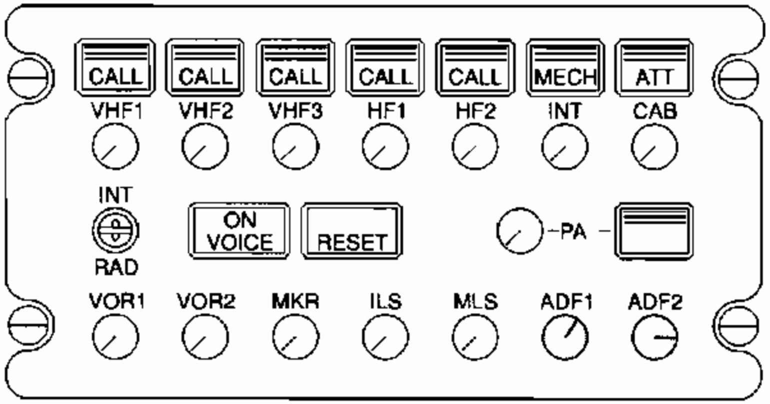
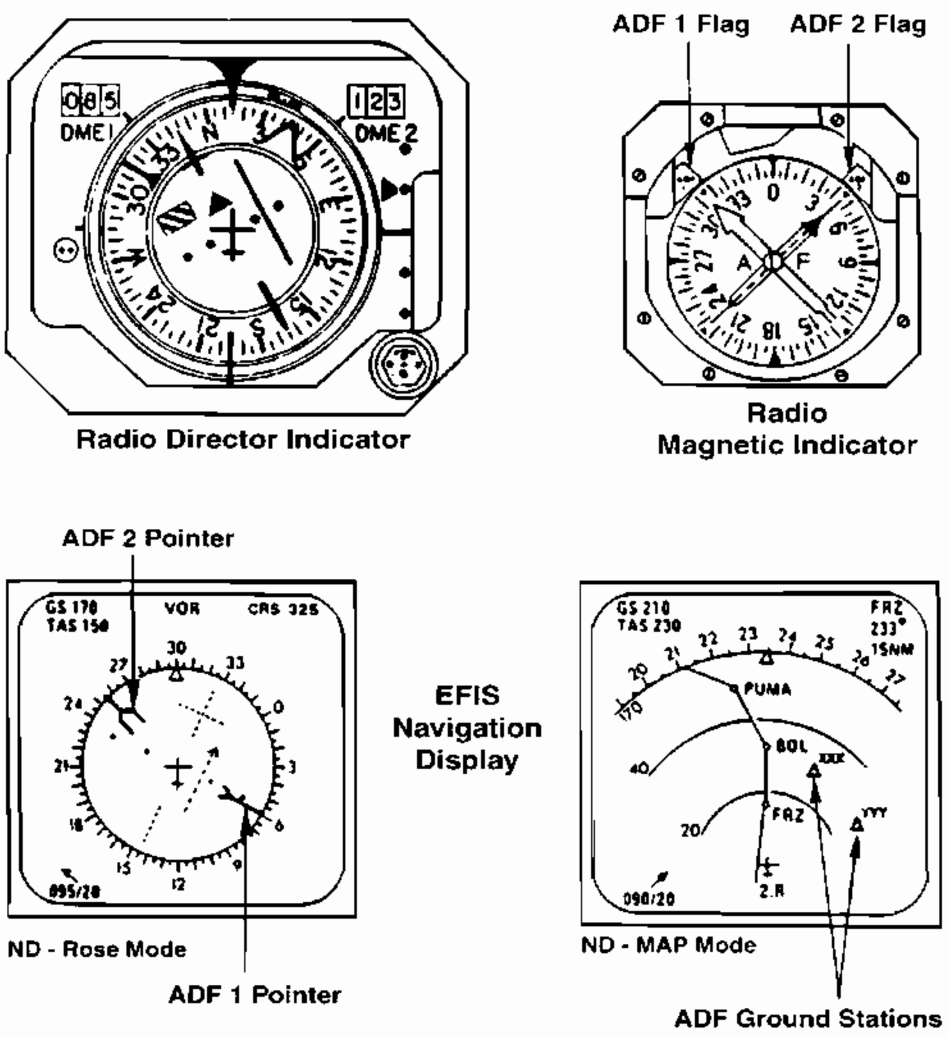


Figure 163: Audio Control Panel for ADF Call Listening



Indication

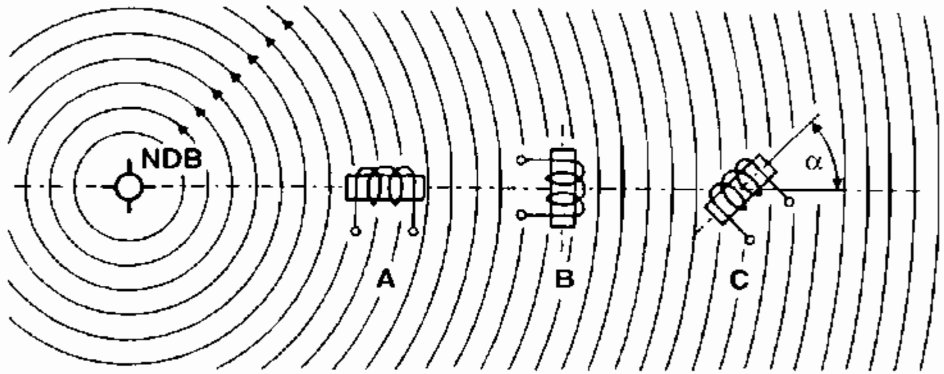
Figure 164: Various ADF Bearing Indications



Direction Finding

The direction sensitive antenna receives depending on its position in the magnetic field of a transmitter, will receive a stronger or weaker signal. By rotating the loop 360° we experience 2 maximum and 2 minimum signals. To find out the only possible direction to the radiostation, the signal of a second, non-directional antenna (called sense antenna) is added to the signal of the loop antenna. Only the combination of the 2 signals will give the correct bearing to the selected NDB, which is displayed on the navigation instrument in the cockpit.

Figure 165: Loop Antenna in H-Field



Loop antenna in position:

A Output voltage is minimal

B Output voltage is maximal

C Output voltage is $U_{maximal} \times \sin \alpha$

According the phaseangle between loop and sense-signal, the automatic direction finding circuit steers the loop-antenna respective the loop-resolver to the correct null position.

Figure 166: Loop and Sense Antenna in RF Field of NDB

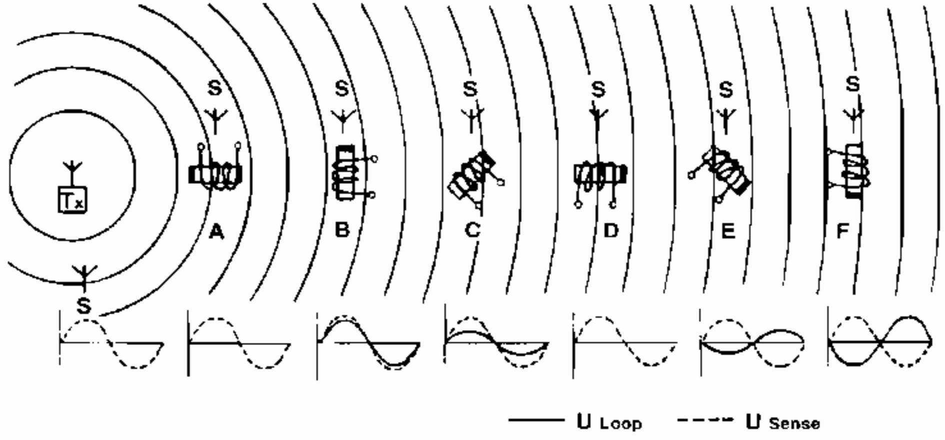
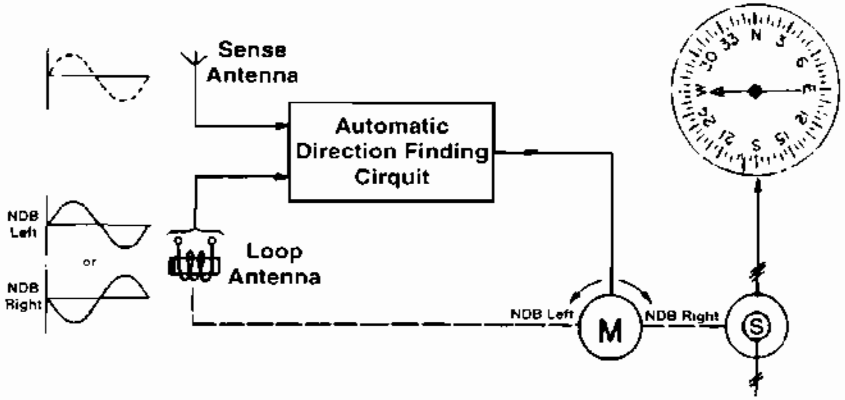


Figure 167: Principle of Direction Finding



Receiver

An ADF receiver operates in the LF and MF frequency bands and has inputs for two different antennas, a loop and a wire-type sense antenna. The output of the loop antenna varies with the direction between the plane of the loop and the station being received. The output of the sense antenna is omnidirectional, meaning that its signal strength is the same in all directions. The field of the two antennas, when mixed in the ADF receiver, is heart-shaped with a very definite and sharp null.

When the frequency of a radio beacon is selected, the signals from the two antennas mix and a voltage is generated in the receiver that causes the loop-drive motor to rotate the loop. The loop will rotate until the combined field is the weakest, the null. The same signal that drives the loop antenna drives the needle of the ADF indicator.

The next figure shows a highly simplified block diagram of a rotating-loop ADF system. The output of the loop antenna is amplified and mixed with the output of the sense antenna. This combined signal is amplified by a tuned amplifier that filters out all but the desired signal. The signal is mixed with the output of a local oscillator to produce an intermediate frequency. The IF is amplified, demodulated, and detected and sent to an audio power amplifier and then to the speaker. A voltage is taken from the output of the detector, filtered and amplified, and used to drive the loop-drive motor. This voltage has the correct polarity to drive the loop in the proper direction to reach its null position. The needle of the ADF indicator is driven by the same signal, and it shows the position of the station relative to the nose of the aircraft.

The beat frequency oscillator (BFO) connected to the IF amplifier is used when the ADFreceiver is tuned to an modulated transmitter. The transmissions from radio beacons in some foreign countries are not modulated, and in order to hear the station, a signal is generated by BFO. Almost all radio beacons are modulated, so the BFO is not switched in.

Antennas

The automatic direction finder requires two antennas:

- The loop antenna has traditionally been a rotating device enclosed in a rather large housing. Now, almost all ADF installations use fixed loops mounted in thin streamlined housings.
- The sense antenna is a omnidirectional antenna to receves the electric component of the radiowaves transmitted from the NDB. In older airplanes this antenna was a separate pole, wire or in fiberglass contained wire grid.

Figure 168: ADF Receiver (Classic)

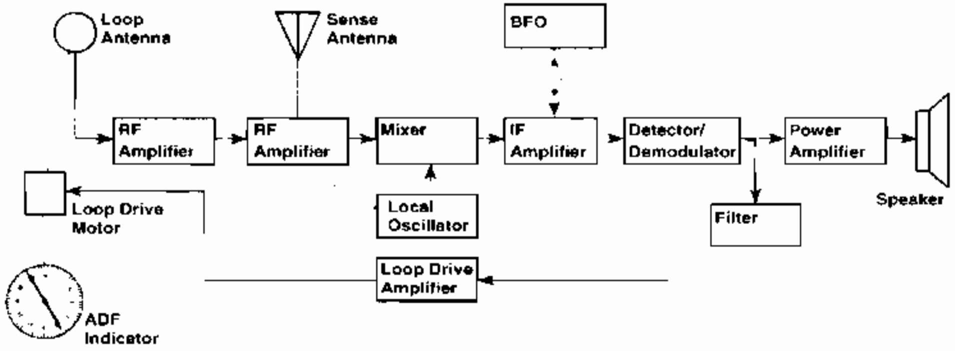
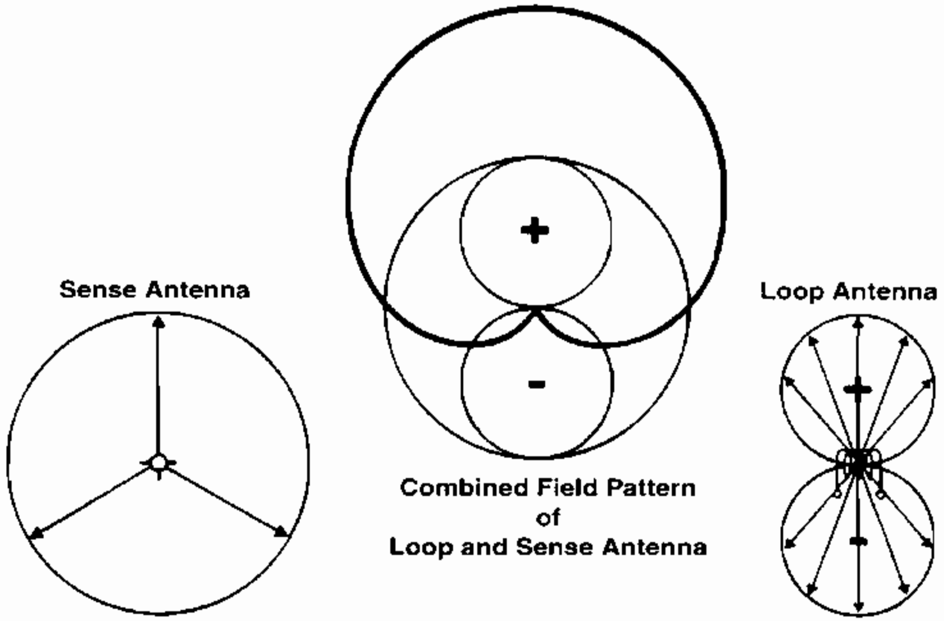


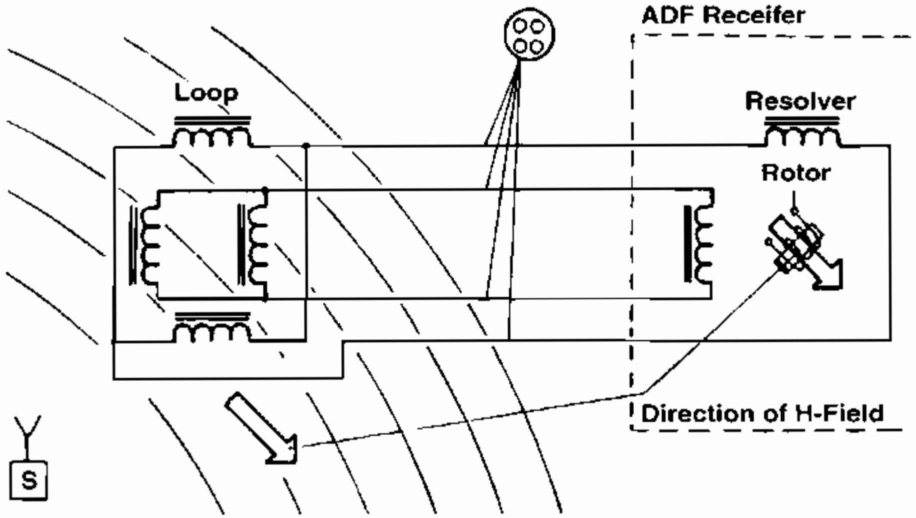
Figure 169: Loop and Sense Antenna Pattern and their Combination



Fixed Loop Antenna

Today the rotating loop antenna has been replaced with a nonrotating fixed loop. The nonrotating loop is actually two fixed-loop antennas connected to two fixed stator windings in a resolver, or goniometer. The fields of the two stator windings induce a voltage in the rotor, and this voltage is sent into the loop input of the ADF receiver. The signal is processed in the receiver. The output of the loop-drive amplifier drives a small motor inside the ADF indicator that drives the rotor of the goniometer until it aligns with the null.

Figure 170: Principle of Fixed Loop Antenna

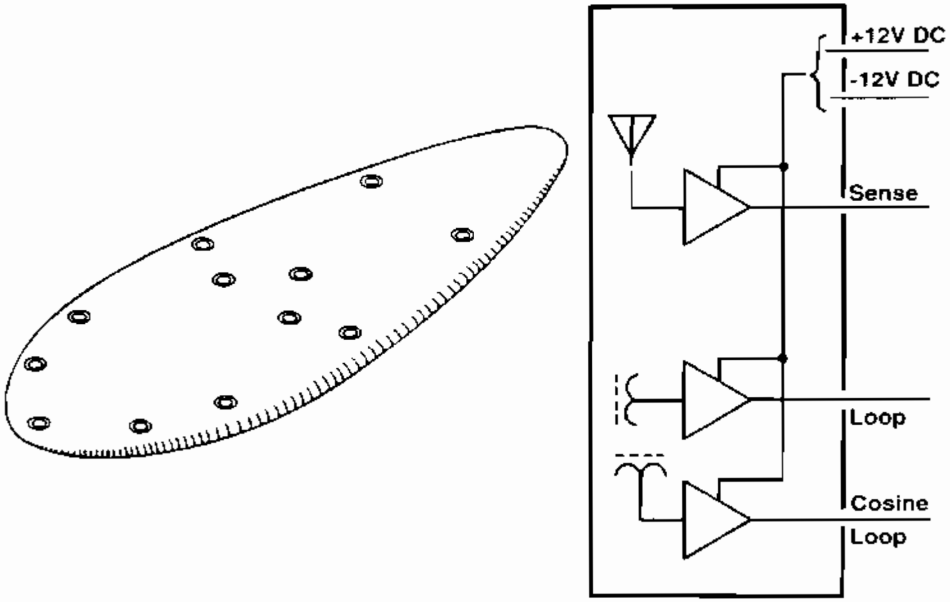


Combined Antenna

The ADF antenna contains a sense antenna and two loop antenna's. The sense antenna is an omni-directional electrical antenna. The loop antennas are directional magnetic antennas which are perpendicular to each other. One loop antenna is the sine antenna, the other the cosine antenna. The amplifiers in the ADF antenna amplify the loop and sense antenna signals to make the signal transport and antenna cable less critical. The power supply for the amplifiers is + 12 V DC and -12 V DC from the ADF receiver power supply.

The ADF basically measures the bearing (direction) to the selected station with its loop antennas. The sine antenna that points for/aft mainly receives signals from stations to the left or right of the aircraft. The "cosine" antenna that points left/right mainly receives signals from stations before or behind the aircraft. Stations at angles in between the for/aft and left/right line of the aircraft induce voltages in both antennas.

Figure 171: Loop and Sense Antenna combined



Digital Receiver

The ADF receiver operates in the frequency band from 190.0 to 1750.5 kHz in 0.5 kHz steps. The frequency selection comes in ARINC 429 format from the ADF control panel. A test discrete input starts the ADF receiver self test.

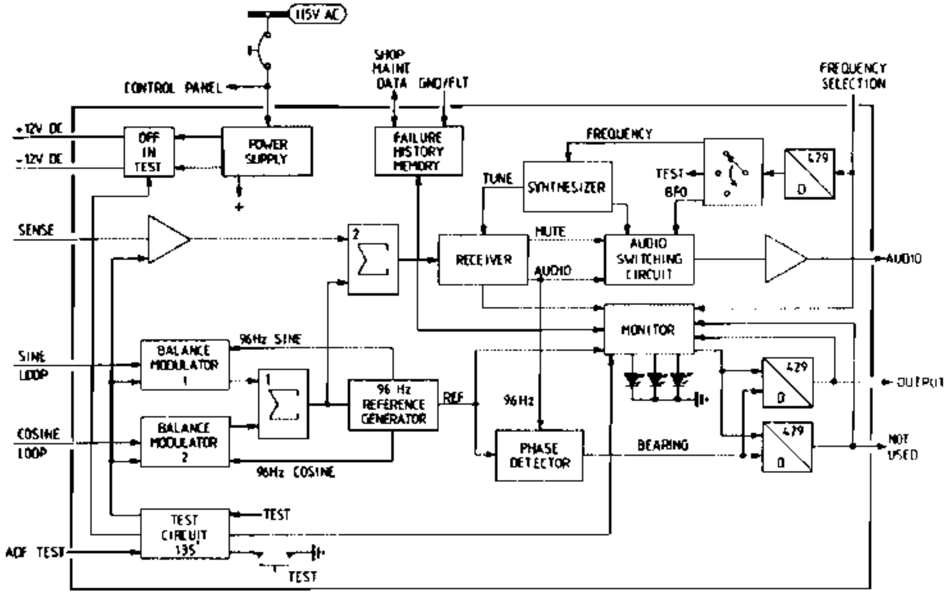
The balance modulators modulate the output of both loop antennas with a 96 Hz audio reference signal. The balance modulator 1 modulates the "sine" loop antenna output with a 96 Hz sine signal. The balance modulator 2 modulates the "cosine" loop antenna with a 96 Hz cosine signal. The two loop antenna signals with their 96 Hz modulation go to a summing circuit 1 which adds the two signals. The output of the summing circuit 1 also has a 96 Hz modulation. This 96 Hz modulation has a phase relation with the 96 Hz reference that depends on the direction of the station. The phase difference depends on the amounts of loop antenna signal with sine and cosine modulation which the summing mixes.

The summing circuit 2 mixes the sense antenna signal with the signal combination of both loop antennas. This eliminates the 180° directional ambiguity of the loop antennas. The output of summing circuit 2 goes to the receiver. The receiver detects the audio of the station of the selected frequency and the 96 Hz. The audio goes to the audio management system. The 96 Hz goes to the phase detector, which changes the phase difference of the two 96 Hz signals into a bearing output. The bearing information goes through two ARINC 429 transmitters to the consumers.

If the monitor detects a failure it makes the sign status matrix (SSM) of the bearing output word invalid. When the aircraft lands the ground/flight discrete commands the ADF receiver to put the detected failure in the non-volatile memory. With special equipment in a workshop you can read the contents of the non-volatile memory.

When the receiver receives no useable signal or when the synthesizer fails, the audio switching circuit switches the audio off. The A1/NORM switch commands the audio switching circuit to give a 1000 Hz tone when the receiver receives a carrier.

Figure 172: Blockdiagram



Bearing

Relative Bearing Indicator RBI

The oldest type of indication. The heading scale is always fix and not rotateable. The arrowhead of the pointer shows in direction toward a NDB. The angle between the aircraft longitudinal axis and a tuned radiostation is called relative bearing.

The absolute bearing from the aircraft position toward a non directional beacon named QDM must be calculated by the pilot.

Radio Magnetic Indicator RMI

The heading dial rotates automatically with the compass system. At the heading reference line, also named lubberline the actual magnetic heading is shown. The pointers are showing the direction from the aircraft position toward tuned non directional beacon called QDM (Direction Magnetic) or also defined as absolute bearing.

The single or red pointer shows the bearing of ADF 1.
The double or green pointer shows the bearing from ADF 2.

Relative Bearing

Pointer 1 shows 90° (3h position)
Pointer 2 shows 0° (12h position)

Absolute Bearing

Pointer 1 shows QDM 45° (3h position)
Pointer 2 shows QDM 315° (12h position)

Figure 173: Relative Bearing

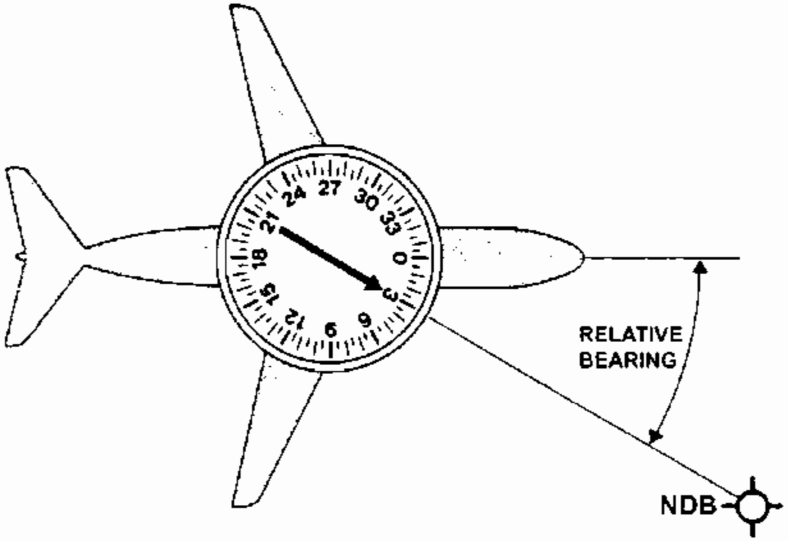
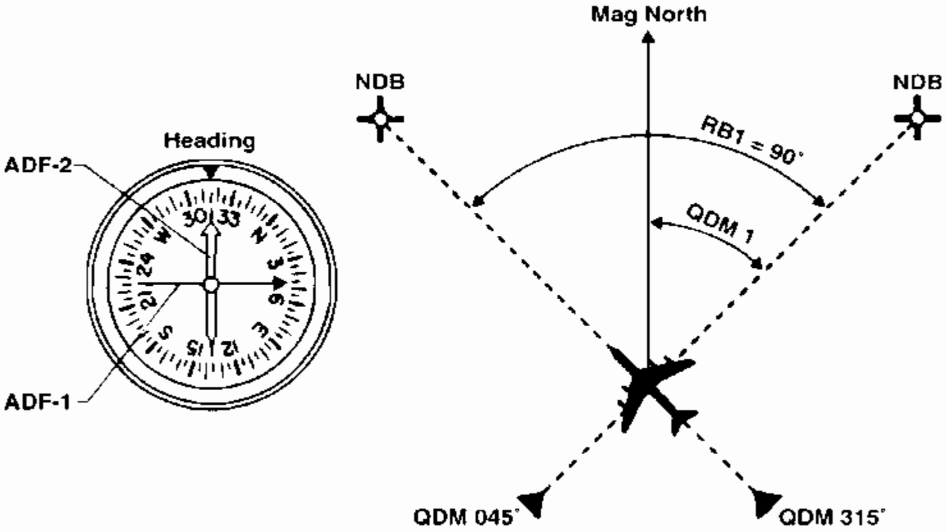


Figure 174: Absolute Bearing

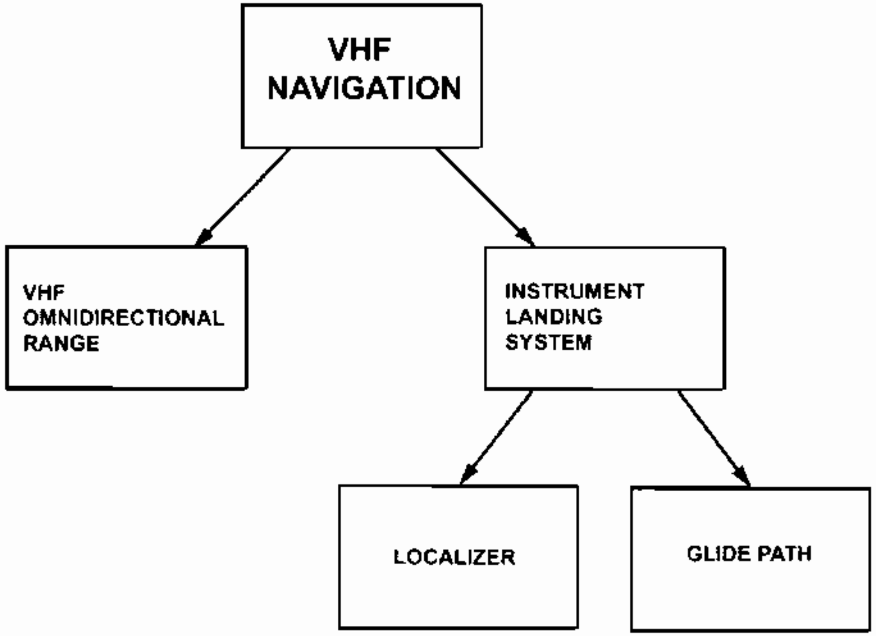


VHF Navigation

Overview

The VHF Navigation contains following subsystems.

Figure 175:



The landing chart demonstrates the usage of ILS.

The chart at next page shows different VOR station around Zurich.

Figure 176: Zurich ILS 16

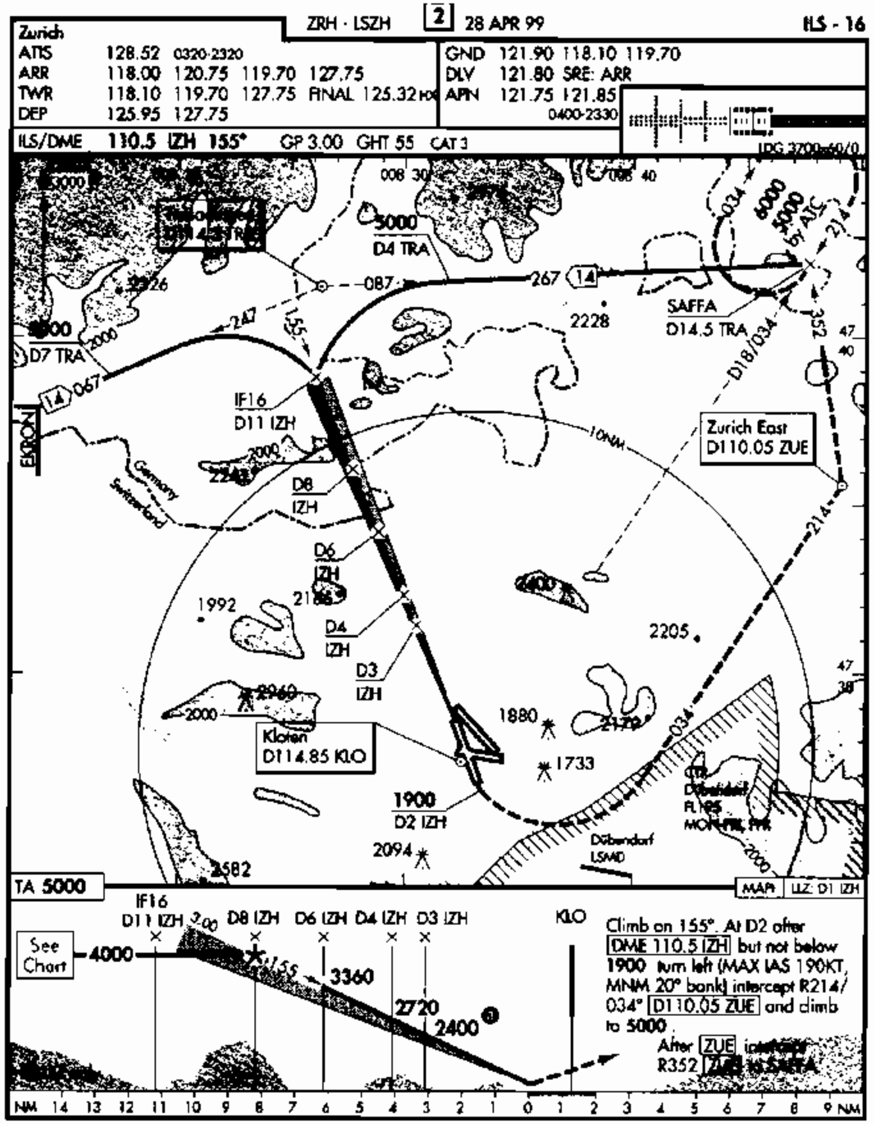
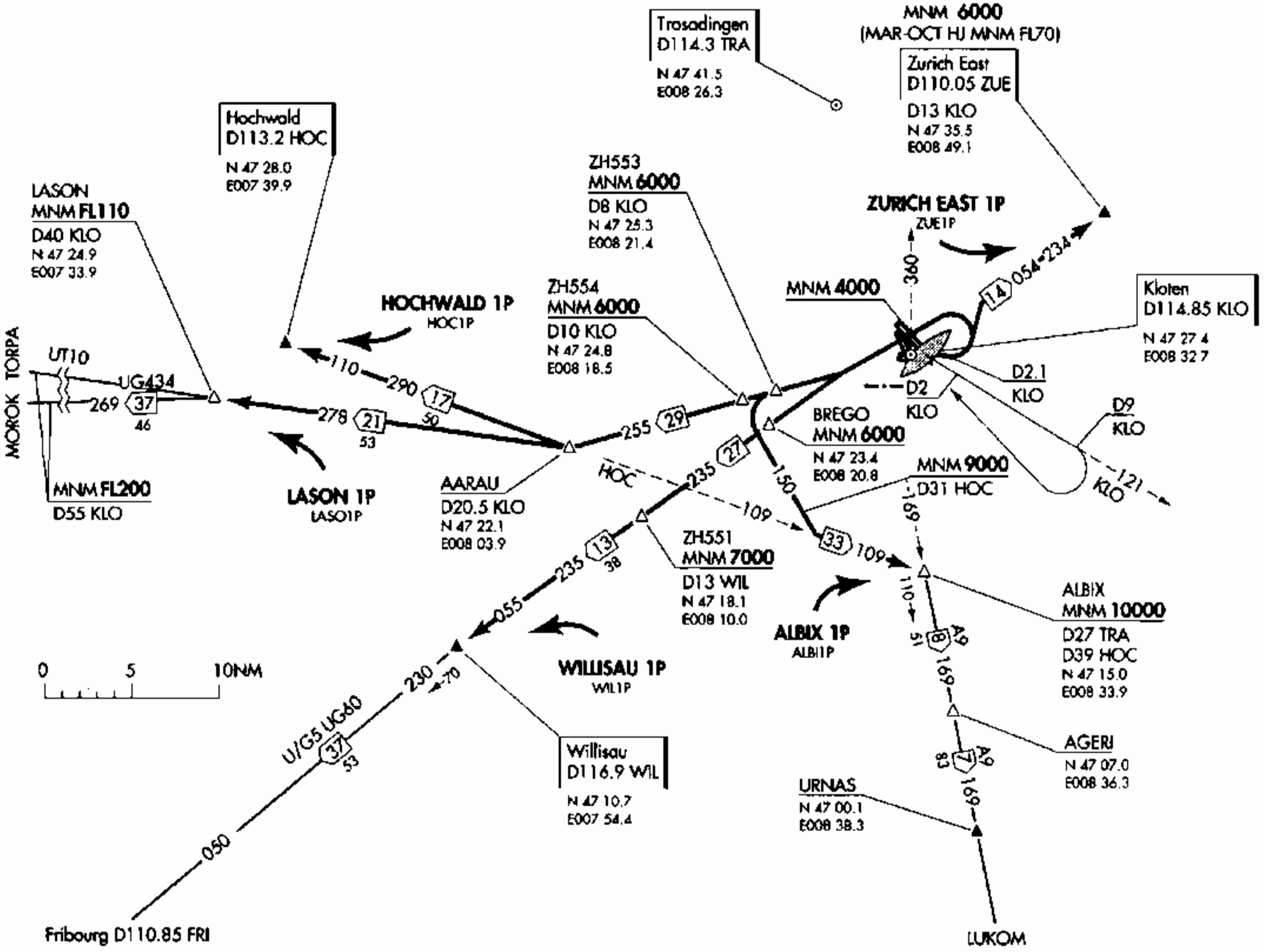


Figure 177: Airways around Zurich with VOR Stations



ILS Instrument Landing System

General

The Instrument Landing System allows the aircraft to follow an optimum descent. The descent axis is determined by the intersection of a localizer beam and a glide slope beam. The beams are created by ground stations. The ILS allows measurement and display of angular deviations.The ILS also detects Morse audio signal which identifies the ILS ground station.

Figure 178: Runway with Localizer and Glideslope

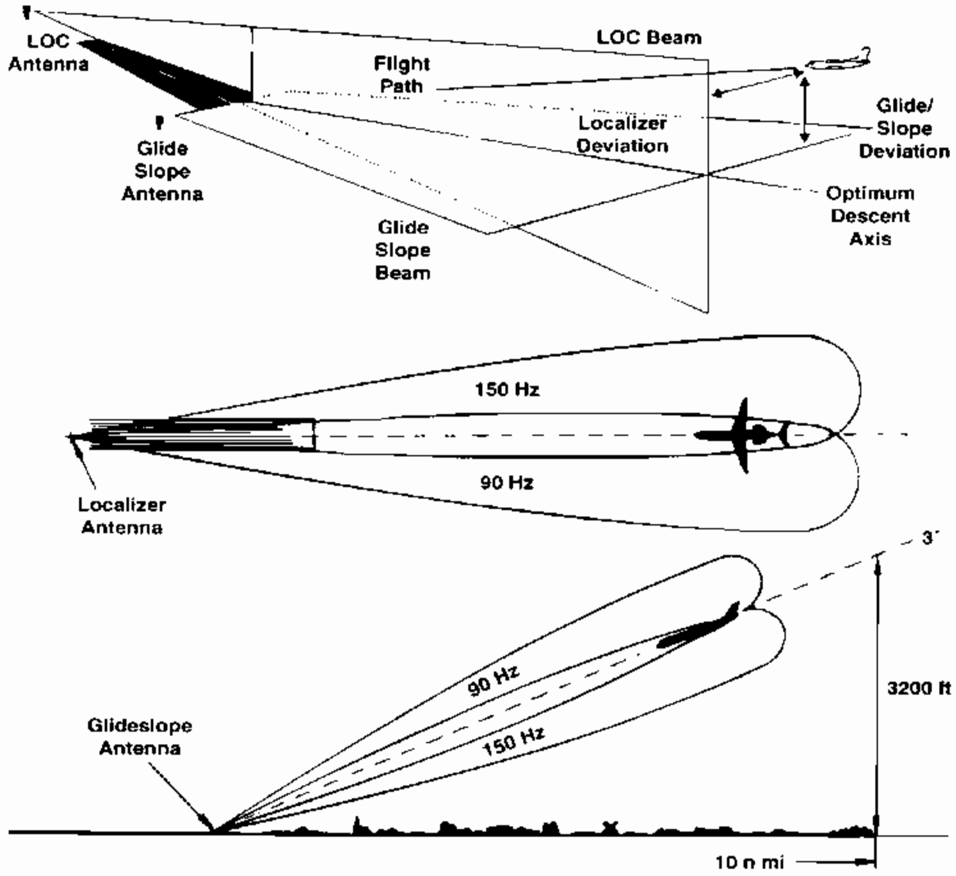


Figure 179: Display

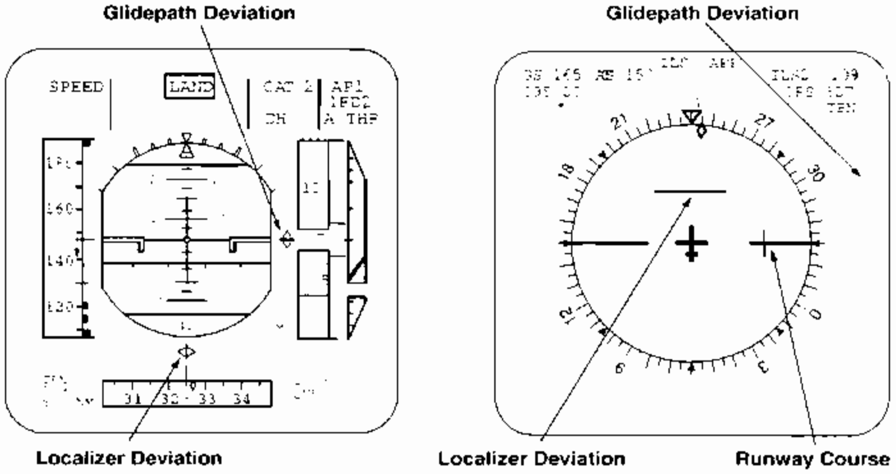
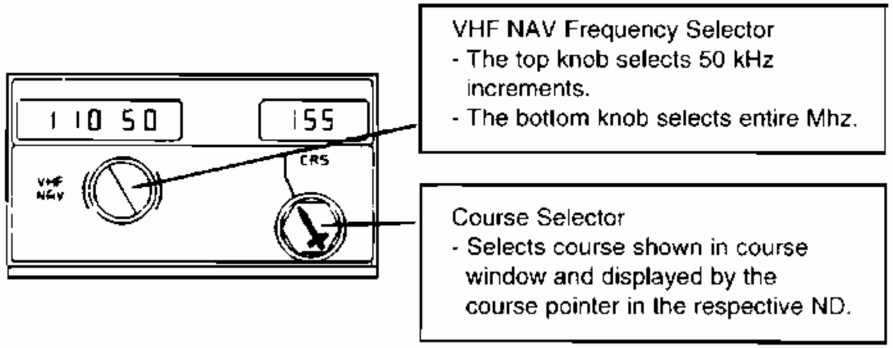


Figure 180: Radio Management Panel



VHF NAV Frequency Selector
- The top knob selects 50 kHz increments.
- The bottom knob selects entire Mhz.

Course Selector
- Selects course shown in course window and displayed by the course pointer in the respective ND.

Frequency:

Localizer 108.10 - 111. 95 MHz all odd 1/10MHz steps 40 Channels (Even 1/10 MHz steps are reserved for VOR)

Glide Path reception is about 330 MHz paired with Localizer channels.

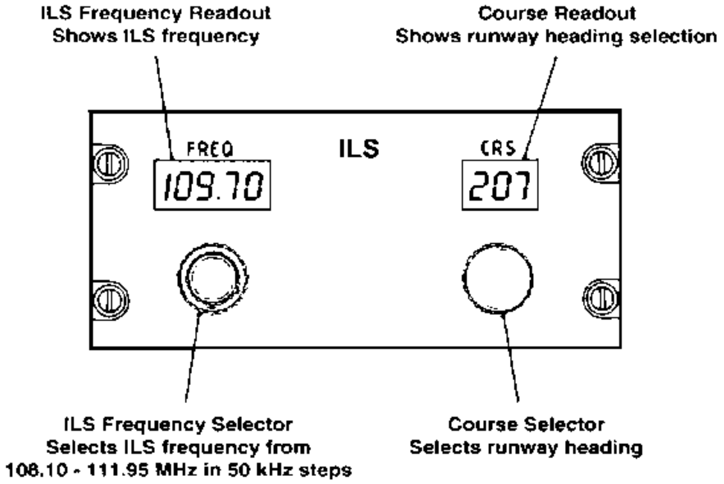
Tuning

The operator has to tune the ILS via control panel or MCDU. In automated flightdecks the Flight Management System executes an automated tuning before the begin of the approach.

Localizer and Glidepath Frequencies

Each glide slope channel is paired with a specific localizer frequency and is automatically selected when the pilot tunes the VHF nav receiver to the localizer frequency.

Figure 181: ILS Frequency Selector



This Radio Management Panel can be used to tune the following systems:

- VHF communication transceiver
- HF communication transceiver with SSB/AM select

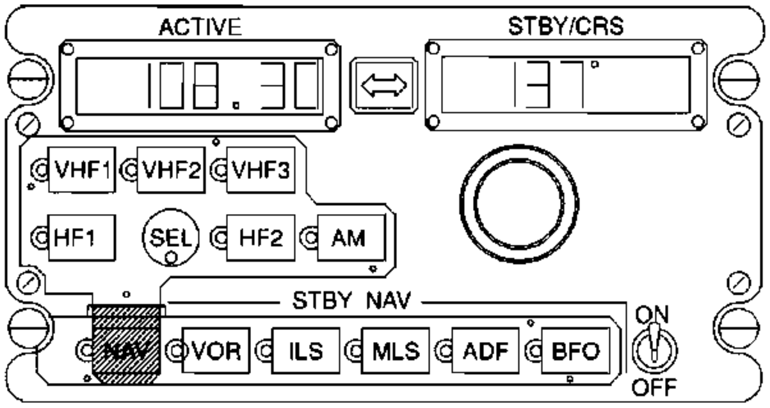
Backup tuning for:

- VOR Receiverfrequency and course
- ILS Receiver frequency and runway heading
- ADF Receiverfrequency and BFO on/off

Table 4: Localizer and Glidepath Frequencies in MHz

LOC	GP	LOC	GP	LOC	GP	LOC	GP
108.10	334.70	109.10	331.40	110.10	334.40	111.10	331.70
108.15	334.55	109.15	331.25	110.15	334.25	111.15	331.55
108.30	334.10	109.30	332.00	110.30	335.00	111.30	332.30
108.35	333.95	109.35	331.85	110.35	334.85	111.35	332.15
108.50	329.90	109.50	332.60	110.50	329.60	111.50	332.90
108.55	329.75	109.55	332.45	110.55	329.45	111.55	332.75
108.70	330.50	109.70	333.20	110.70	330.20	111.70	333.50
108.75	330.35	109.75	333.05	110.75	330.05	111.75	333.35
108.90	329.30	109.90	333.80	110.90	330.80	111.90	331.10
108.95	329.15	109.95	333.65	110.95	330.65	111.95	330.95

Figure 182: Radio Management Panel



Navigation Radio Tuning

Auto Tuning

FMGC provides the frequency selection based on its database.

Manual Tuning

Enter the desired station code or frequency/course on MCDU.

Standby Tuning

Enter the desired station frequency/course on RMP or MCDU

Figure 183: Navigation Radio Tuning

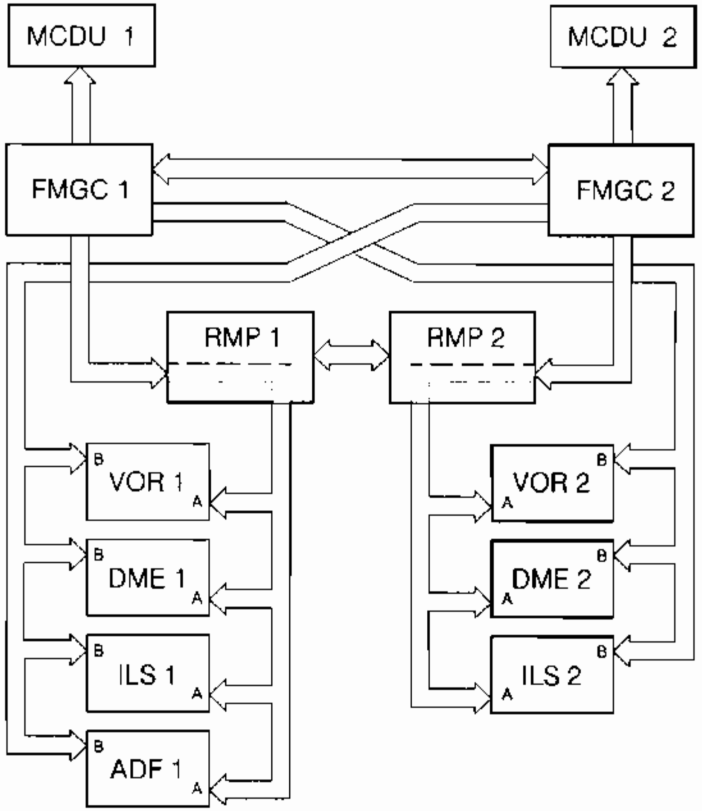
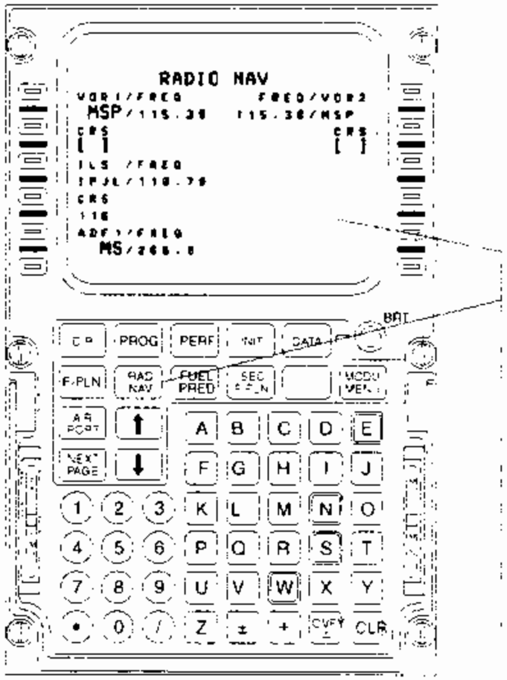


Figure 184: MCDU useable for Navigation Radio Tuning



Radio Nav Frequency and Course Selection

- Select RADIO NAV page for manual tuning of VOR, ILS and ADF stations used for display, and for tuning status of navigation radios.
- Frequency/Course or Ident/Course are manually inserted via the MCDU. Manual entries are displayed in large fonts.
- FMGC autotuned radios are displayed in small fonts.

NOTE: DME's used for display are automatically tuned according to the automatic or manual selection of a VOR and/or ILS radio.

Localizer

Ground Facility

The localizer signal comes from a transmitter located at the end of the runway that operates in the frequency range from 108.10- 111.95 MHz. The localizer transmits two beams one on the right side of the runway center line and one on the left side of the runway center line.

The beam on the right side has a 150 Hz modulation, the beam on the left side has a 90 Hz modulation. When the aircraft flies over the extended center line to the runway it receives both signals with an equal strength. When the aircraft deviates from the center line there is a difference in signal strength. The system measures the deviation from the center line by comparing the strength of these 90 Hz and 150 Hz modulation signals.

Figure 185: ILS Runway

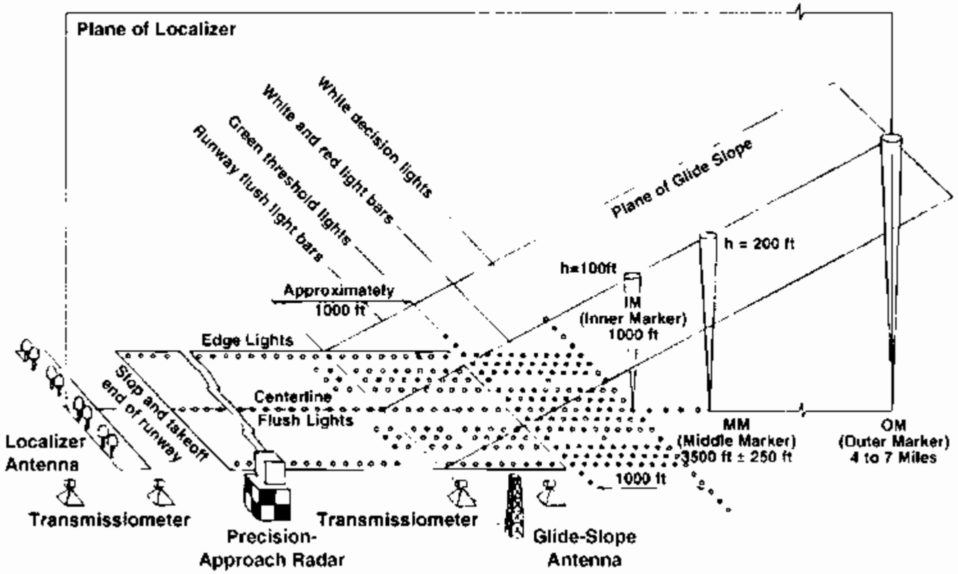


Figure 186: Antenna Pattern

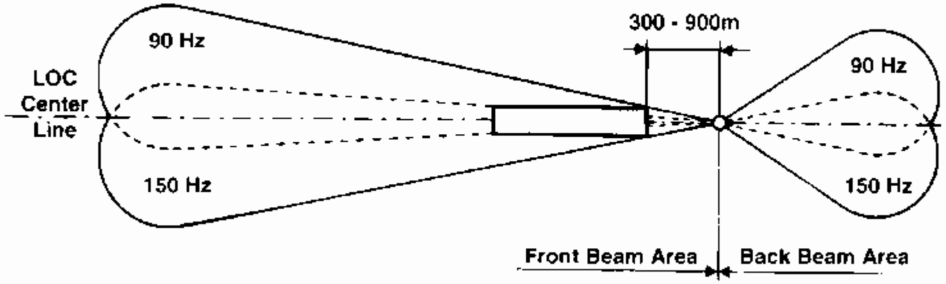
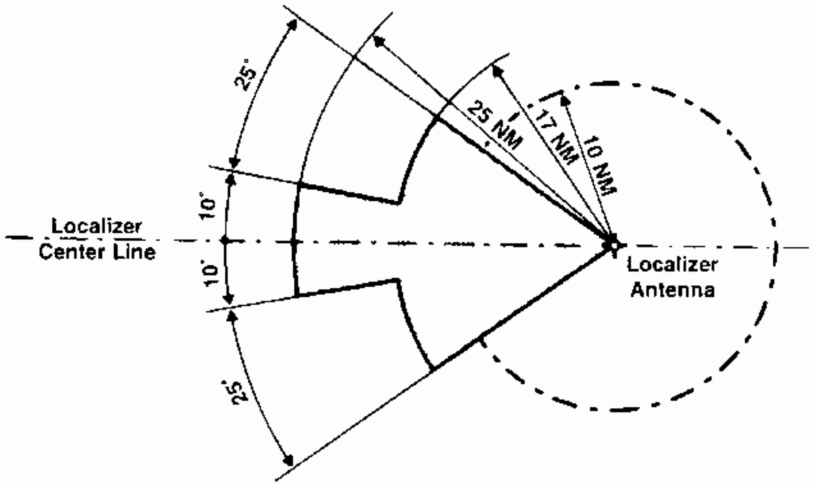


Figure 187: Range



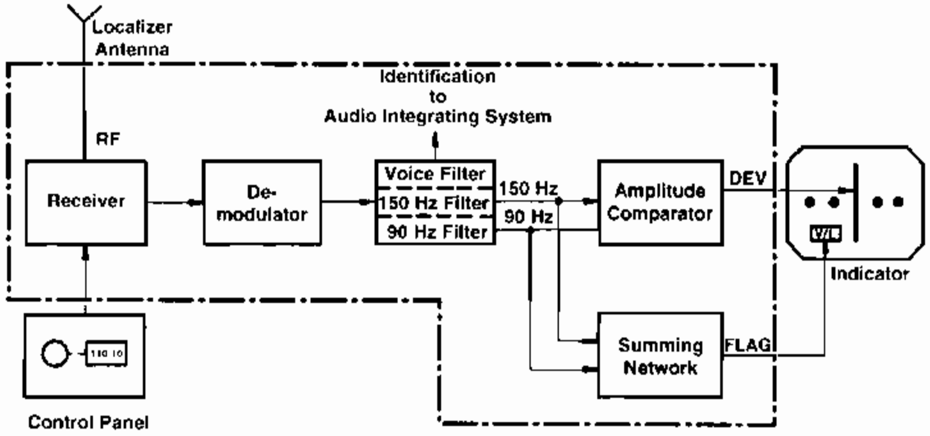
LOC Receiver

When the VHF Nav receiver is tuned to a localizer frequency, the localizer circuitry is activated. The signal from the antenna is taken into the receiver and passed through two filters. One filter passes the 90-Hz tone and the other passes the 150-Hz tone. This audio signal is rectified and changed to a DC voltage applied to the amplitude comparator that drives the pointer of the Left-Right indicator

The summing network verifys the correct reception of both signals.

A spoken weather- and runway- information (Automated Terminal Information System ATIS) or/and 1020 Hz morsecode identification is routed through the voice filter to the cockpit speaker or headphones.

Figure 188: LOC Receiver

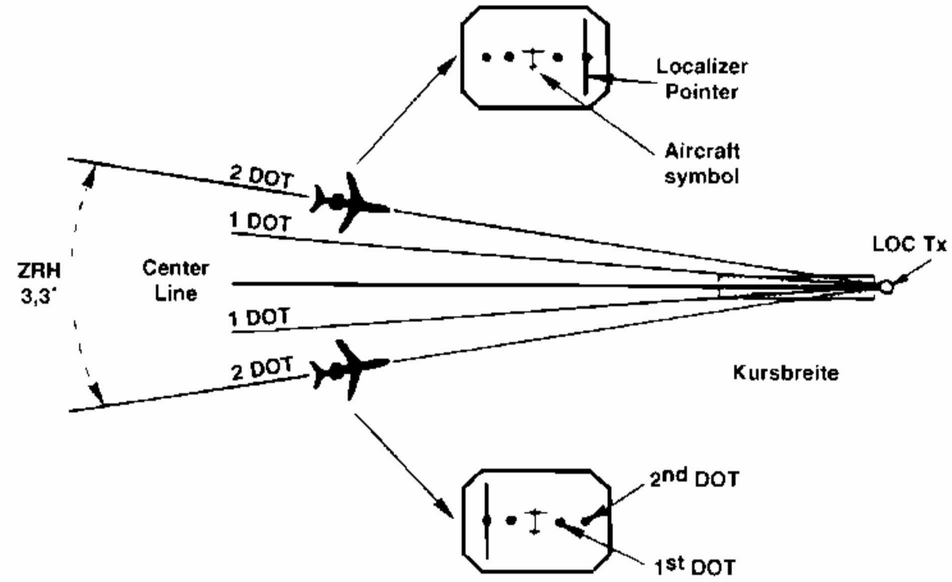


LOC Display

When the aircraft is to the right of the runway center line, it is in the 150-Hz modulation area, and the needle deflects to the left, showing that the runway is to the left. The needle deflects full scale when the aircraft is approximately 2.5 Dot off of the center line. This translates to about 1,500 feet at five miles out, but becomes less as the runway is approached. If the aircraft moves to the left of the runway center line, it is in the 90-Hz area and the needle is driven to the right, indicating that the runway is to the right of the aircraft.

The localizer signals extend from both ends of the instrument runway. When the aircraft is approaching the runway from the end that has the glide slope, it is said to be making a front-course approach and the pilot turns toward the needle when the aircraft is off course. When approaching from the opposite end of the runway, the aircraft is making a back-course approach. When the aircraft drifts off course the pilot must turn it away from the needle to get back on course.

Figure 189: LOC Indication



Glide Slope or Path

Ground Facility

The glideslope signal comes from a transmitter at the beginning of the runway that operates in the frequency range from 329.15 MHz to 335 MHz.

The glideslope transmits two beams to give vertical guidance over the glidepath. The glidepath has an angle of approximately 3°. The glideslope beams are just like the localizer, modulated with 90 Hz and 150 Hz. The 90 Hz modulated beam is above and the 150 Hz modulated beam is below the 3° glidepath. The system measures the deviation from the difference in signal strength between the 90 Hz and 150 Hz modulation signals. The navigation display shows localizer and glideslope deviation.

The glide slope transmitter and antenna are located about 750 to 1,250 feet from the approach end of the runway and offset about 250 to 600 feet from the runway center line. It transmits a highly directional signal that is approximately 1.4° wide and is angled upward from the transmitter at an angle of approximately 3°.

The signal from the glide slope is transmitted on one of 40 UHF channels between 329.315 MHz and 335.00 MHz, and the antenna is a small UHF dipole that is sometimes built into the front of the VOR/localizer antenna.

Figure 190: Glide Path Antenna Pattern

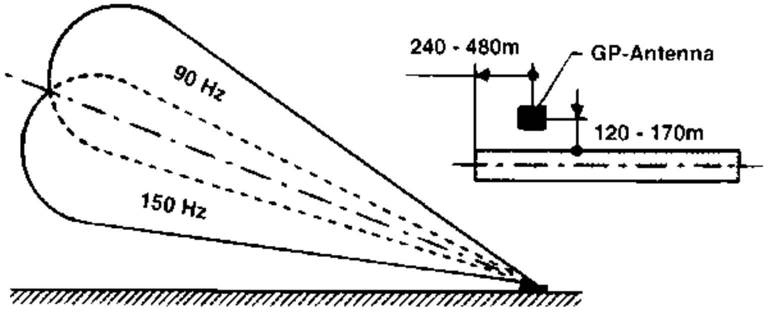
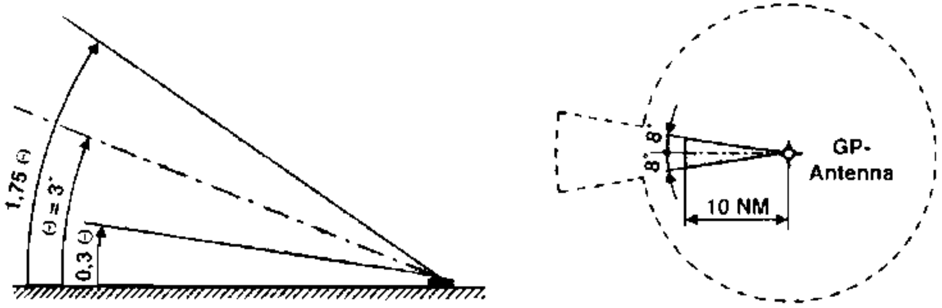


Figure 191: Range of Glide Path

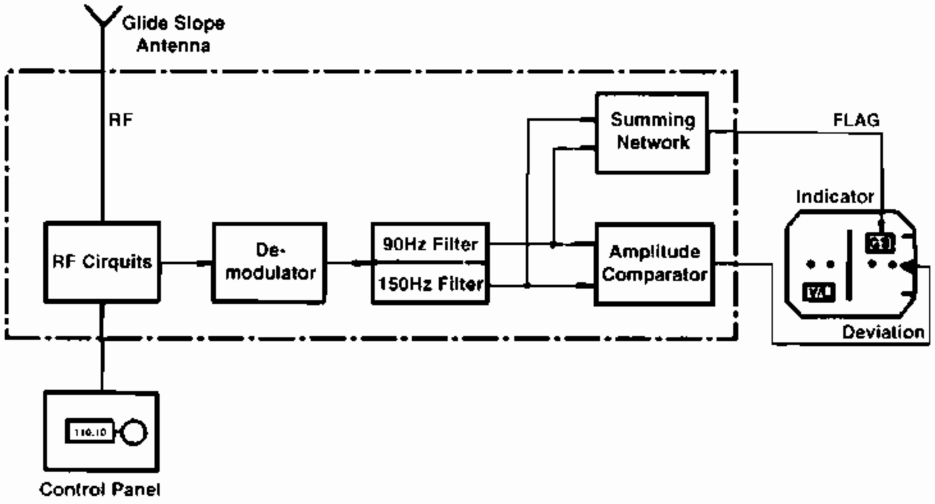


GS Receiver

Two signals using the same carrier are transmitted from the antenna system in such a way that they overlap to form the glide slope. The upper signal is modulated with a 90- Hz tone and the lower signal is modulated with a 150-Hz tone.

When the signal is received, the audio modulations are filtered and converted into DC voltages that drive the deviation pointer

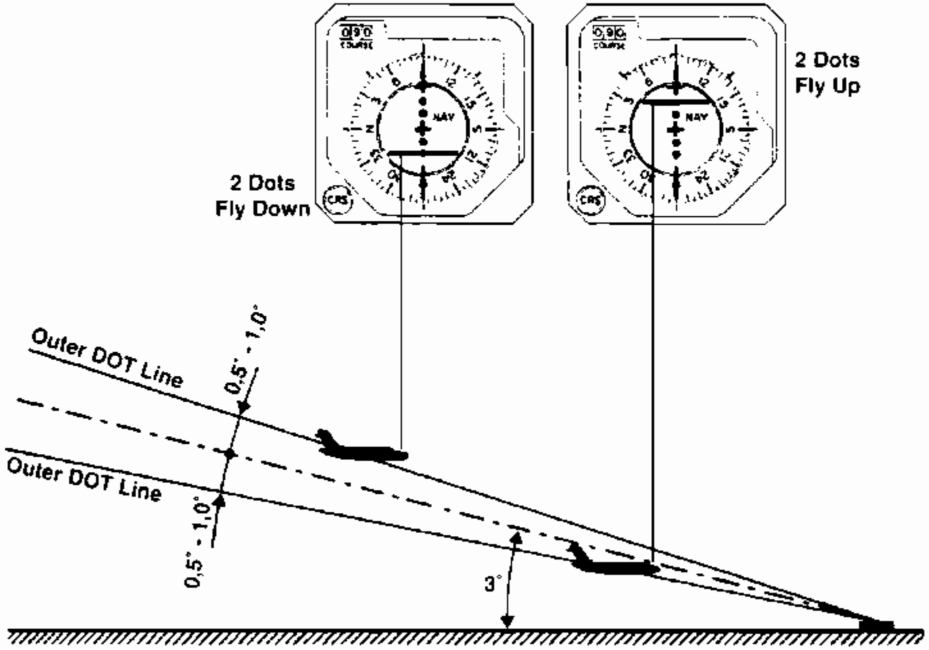
Figure 192: GS Receiver



GS Display

If the aircraft is above the glide slope, it is in the 90-Hz modulation and the pointer is driven downward to show the pilot to fly down. If the aircraft is below the glide slope, it is in the 150-Hz modulation and the pointer is driven up to instruct the pilot to fly up.

Figure 193: GS Indication



System Layout

One, two or three receivers are installed. The receivers gets their VHF signals from a VHF NAV or localizer antenna. The UHF signal is received by the GS antenna. Tuning and course selection occurs via controlpanel or automatically from FMS. Tune- and test inhibit disables ILS tuning and testing during approach and autoland operation.

The receiver gives the output to automatic flight guidance system (autopilot), FMS, flight data recorder, ground proximity warning system and EFIS. The localizer audio output is routed to audio management system.

If two or more ILS receivers are provided, all of them must be tuned to the same frequency, especially on airports with parallel runways.

Figure 194: Discrepancy of Localizer Displays

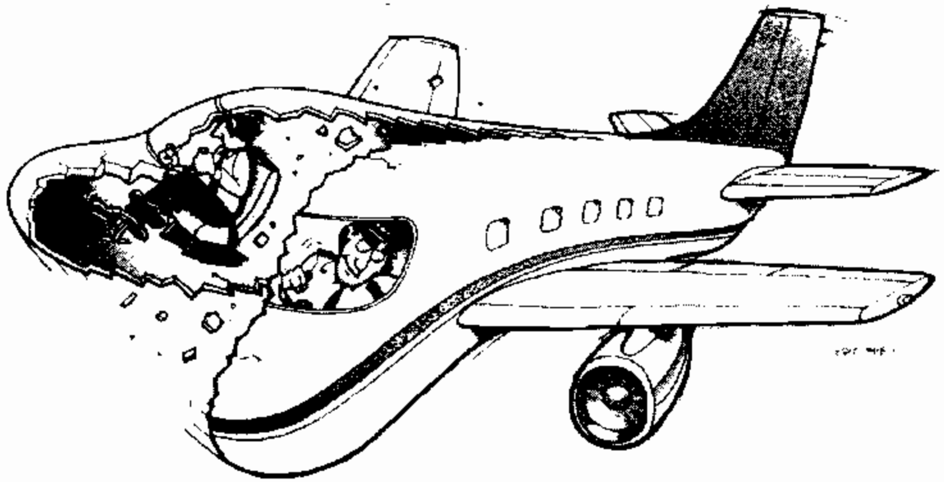
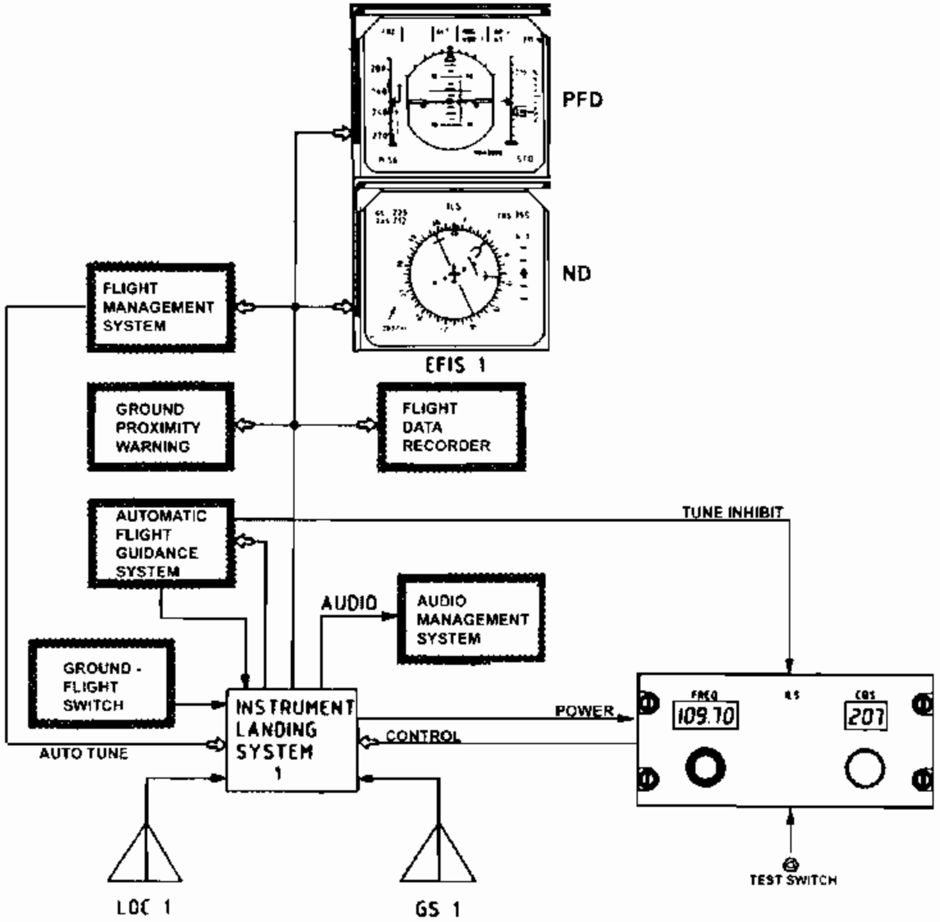


Figure 195: ILS



ILS Approach

An automated or manual approach to the runway occurs in a predetermined sequence:

1. The aircraft flies according a preselected heading.
2. ILS frequency and runway course is selected. Autopilot is prepared to fly according localizer.
3. The localizer deviation corresponds a predetermined value (2 dots). The localizer deviation and course error is used to steer the aircraft.
   The descent altitude is reached and beeing hold. The system is ready to fly in the glideslope.
4. The centerline of the localizer is nearly reached. The aircraft maintains the centerline.
5. The aircraft flies from below into the glide slope beam. The deviation is less than 2 dots. The aircraft beginns with a slight descent.

6 The aircraft has centered to the glidepath and maintains the centerline.

7 Some automated confidence test of the autopilot system occured.

8. At about 135 feet the aircraft heading is aligned with the runway course.
9. The vertical speed of the aircraft is reduced for touch down.
   At touch down the aircraft lowers its nose.
10. For rollout guidance the localizer deviation is used to maintain the aircraft on the centerline.

Figure 196: Approach

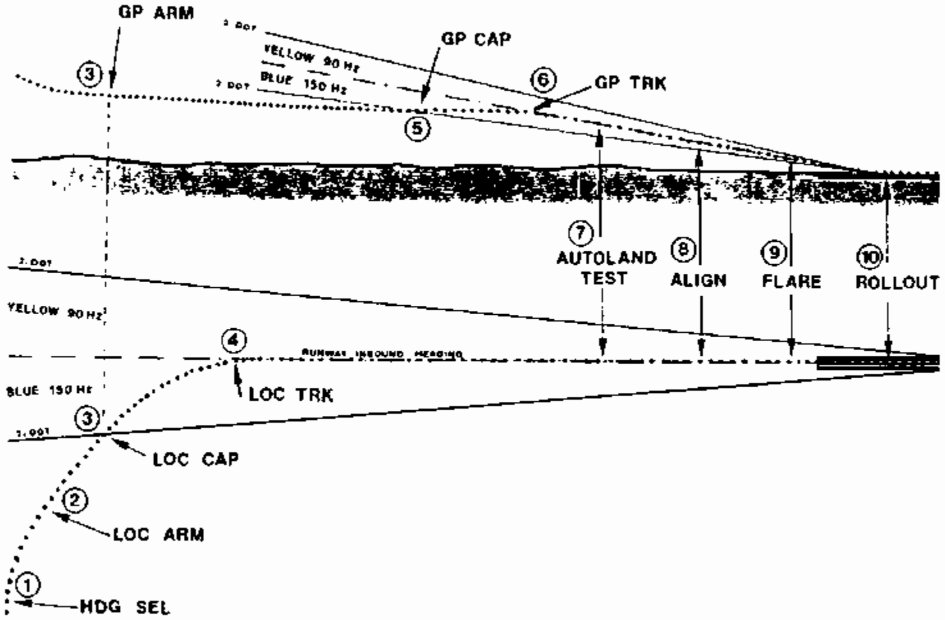


Figure 197: ILS Categories

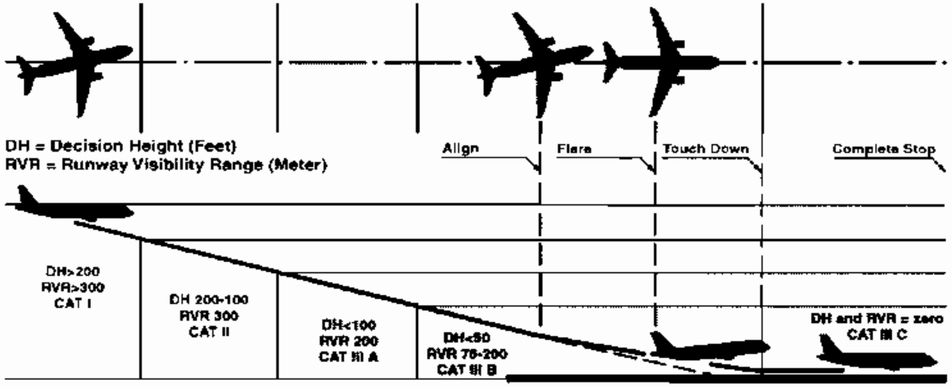


Figure 198: Geneva ILS Runway 05/23

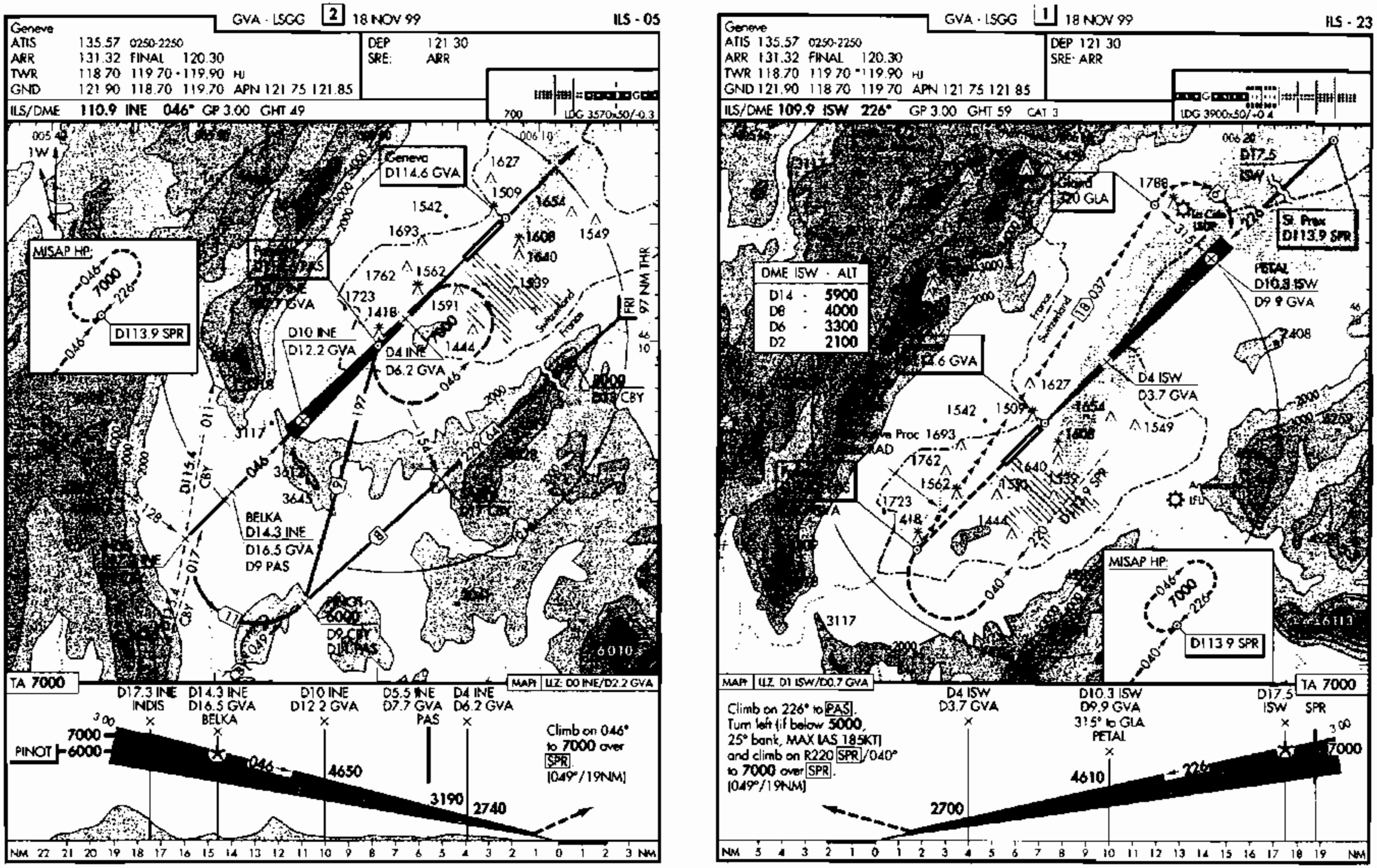
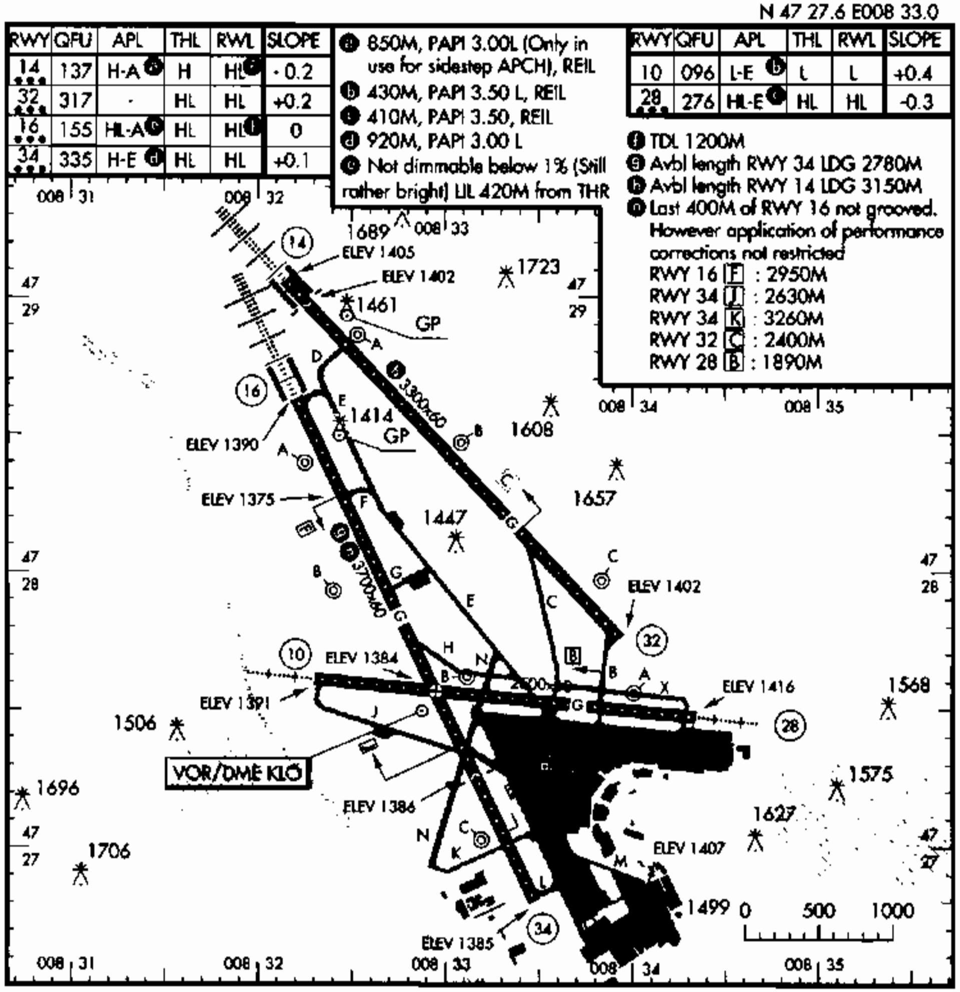


Figure 199: Zurich Airport



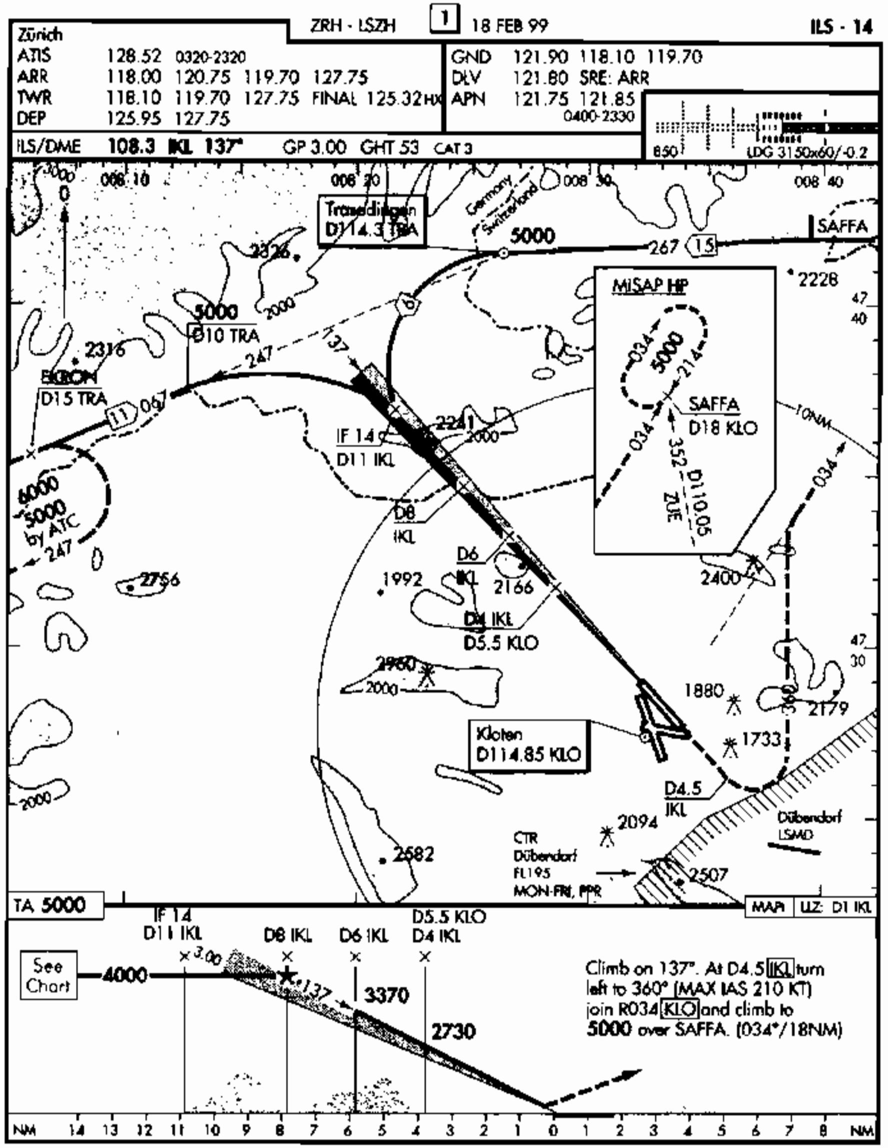
N 47 27.6 E008 33.0

RWY	QFU	APL	THL	RWL	SLOPE
14	137	H-A ⓐ	H	HL ⓔ	- 0.2
32	317	-	HL	HL	+0.2
16	155	HL-A ⓒ	HL	HL ⓘ	0
34	335	H-E ⓓ	HL	HL	+0.1

RWY	QFU	APL	THL	RWL	SLOPE
10	096	L-E ⓑ	L	L	+0.4
28	276	HL-E ⓒ	HL	HL	-0.3

ⓐ 850M, PAPI 3.00L (Only in use for sidestep APCH), REIL
ⓑ 430M, PAPI 3.50 L, REIL
ⓒ 410M, PAPI 3.50, REIL
ⓓ 920M, PAPI 3.00 L
ⓔ Not dimmable below 1% (Still rather bright) LIL 420M from THR
ⓕ TDL 1200M
ⓖ Avbl length RWY 34 LDG 2780M
ⓗ Avbl length RWY 14 LDG 3150M
ⓘ Last 400M of RWY 16 not grooved. However application of performance corrections not restricted
RWY 16 F : 2950M
RWY 34 J : 2630M
RWY 34 K : 3260M
RWY 32 C : 2400M
RWY 28 B : 1890M

Figure 200: Zurich ILS Runway 14



ZRH - LSZH 1 18 FEB 99 ILS - 14

Zürich
ATIS 128.52 0320-2320
ARR 118.00 120.75 119.70 127.75
TWR 118.10 119.70 127.75 FINAL 125.32HX
DEP 125.95 127.75
GND 121.90 118.10 119.70
DLV 121.80 SRE: ARR
APN 121.75 121.85 0400-2330
ILS/DME **108.3 IKL 137°** GP 3.00 GHT 53 CAT 3

Climb on 137°. At D4.5 IKL turn left to 360° (MAX IAS 210 KT) join R034 KLO and climb to **5000** over SAFFA. (034°/18NM)

ILS Receiver

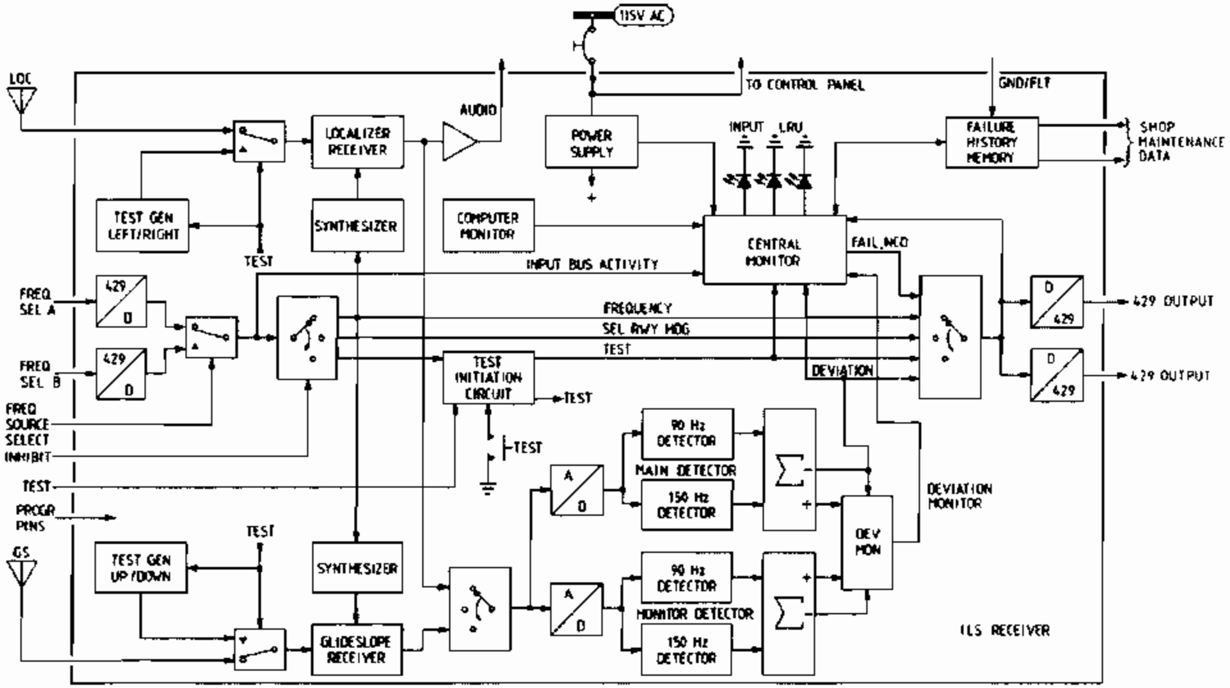
The ILS receiver contains two independent receivers, the localizer and the glideslope receiver. The localizer receiver operates in the frequency band from 108.00 MHz 111.95 MHz. The glideslope receiver operates in the frequency band from 329.15 MHz- 335.00 MHz. Frequency selections come from the control panel in ARINC 429 format. The 429 to digital converter decodes the 429 signal, the multiplexer seperates the various types of information of the decoded signal. The frequency selection information goes to the localizer and glideslope synthesizers.

The localizer and glideslope receivers detect the audio modulation of the RF signals of the selected frequency. The audio output of the localizer receiver contains the station morse-identification and the 90 and 150 Hz. The identification audio goes to the audio management system. The 90 Hz and 150 Hz audio of the localizer and glideslope receivers goes alternately through the multiplexer to the 90 Hz and 150 Hz detectors.

After the analog to digital conversion the detectors measure the ratio of the 90 Hz and 150 Hz signals. This ratio is a measure for the deviation. The localizer and glideslope deviations go from the detector through the multiplexer to the ARINC 429 transmitter

To monitor the operation of the 90 Hz and 150 Hz detection there are two detectors. Each detector measures the 90 Hz and 150 Hz signal levels and ratios and gives this information to the deviation monitor. The central monitor receives the results of the power supply monitoring, the computer monitor, and the deviation monitor. If there is a failure the monitor makes the SSM of the faulty ARINC 429 label invalid. Upon touch-down the receiver puts the current failures together with a flight segment number in the non-volatile failure history memory. This non-volatile failure-history memory is mainly for workshop maintenance. Besides the localizer and glideslope deviation the ILS receiver also gives the frequency selection and runway heading as ARINC 429 output. The ILS receiver does not use the selected runway heading for its calculations.

Figure 201: Blockdiagram



Antennas

The VOR and the localizer function of the ILS share the same antenna. The left figure shows a "ram's-horn" VHF V-dipole antenna. The favored location for this type of antenna is on top of the aircraft above the cabin with the apex pointing forward.

Other high-efficiency VOR antennas are of the type shown in the right figure. The two antennas are designed to mount on the upper section of the vertical stabilizer of a single-finned airplane or on either side of a helicopter tail boom. The two antennas are connected together through a phasing coupler to provide a single 50-ohm input in the VOR, localizer, and glide slope bands.

The glide slope portion of the ILS operates in the UHF range. Its antenna is a UHF dipole mounted near the front of the aircraft, sometimes on the same mast as the VOR/LOC antenna. Some general aviation aircraft mount the glide slope antenna inside the cabin in roughly the same location as the rear view mirror in an automobile.

Figure 202: VOR/LOC Antenna (Boomerang Type)

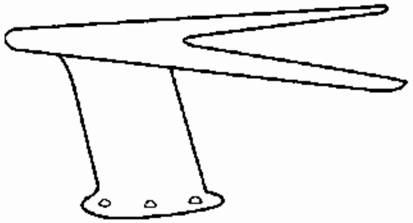
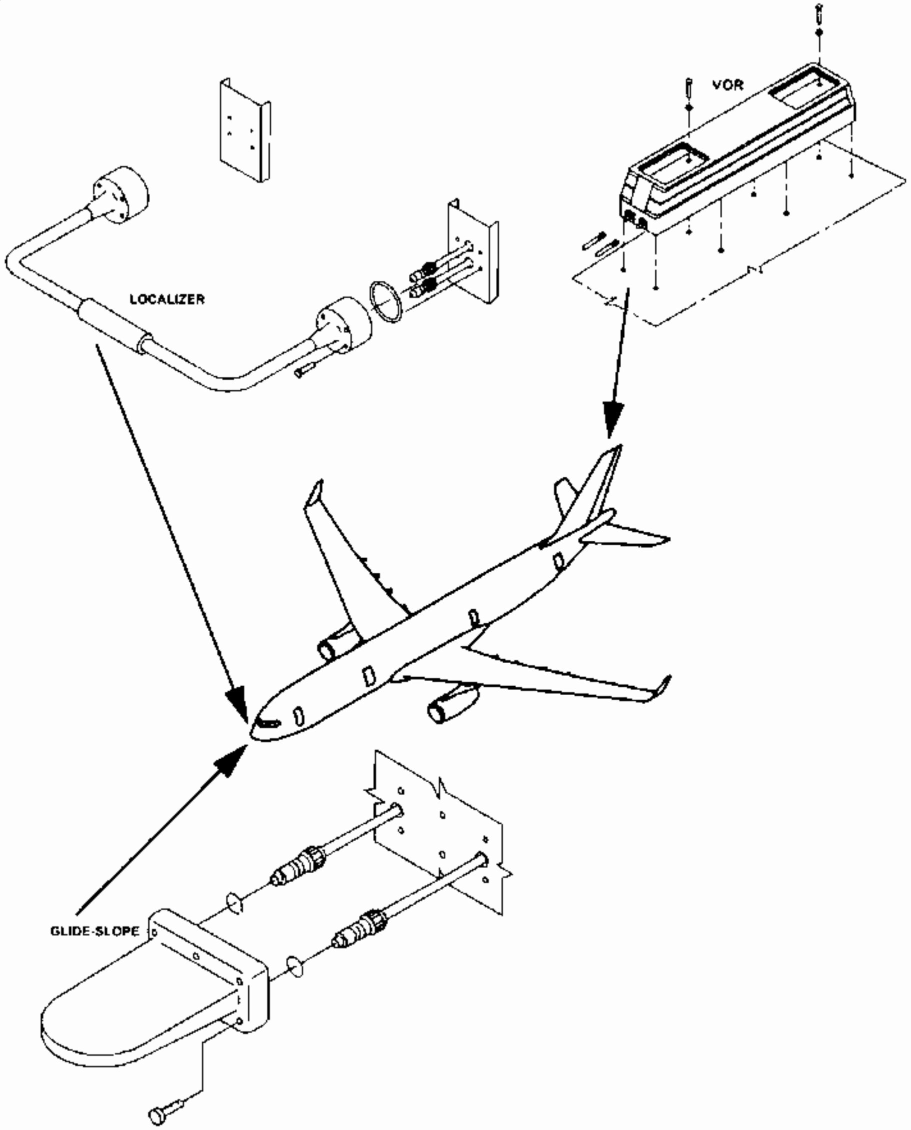


Figure 203: .Antenna Locations



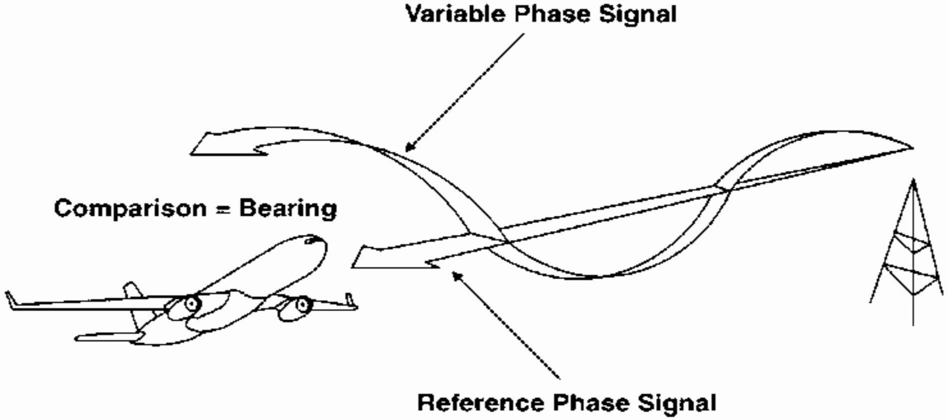
VOR VHF- Omnidirectional Range

Introduction

The Very High Frequency Omnidirectional Range system is a navigation aid, which receives, decodes and processes bearing information from the omnidirectional ground station.

The phase difference between the reference and the variable phase is function of the aircraft position which respect to the ground station.

Figure 204: VOR Signal



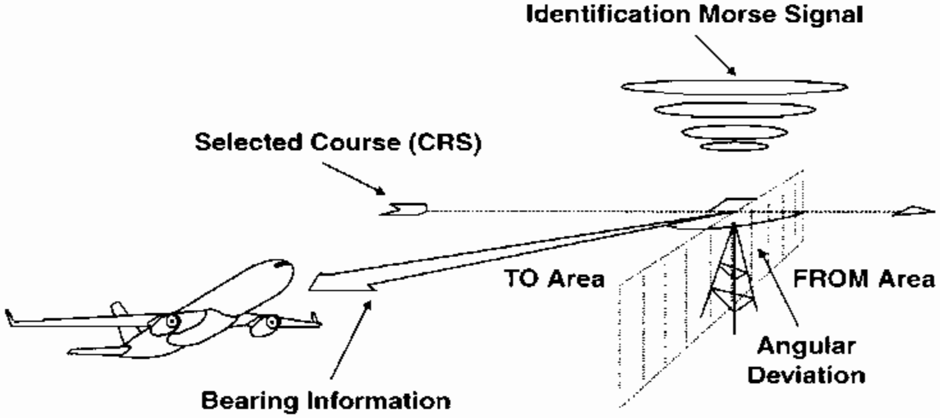
The VOR system provides:

- Bearing information from the difference between two phases transmitted by a ground station.
- Aircraft angular position which respect to a selected course.
- TO/FROM position which respect to a selected course.
- A Morse signal which identifies the station.

The Frequency is: 108.00 - 117.95 MHz

The VOR system is a medium range radio navigation aid.

Figure 205: VOR Information



VOR Indication

Radio Magnetic Indicator

This instrument is a compass repeater, fitted with two VOR pointers, one for each VOR system installed. When the frequency of a VOR station is tuned and valid signals are received, the respective pointer to bear automatically in the direction of the selected VOR station, showing QDM.

Figure 206: RMI

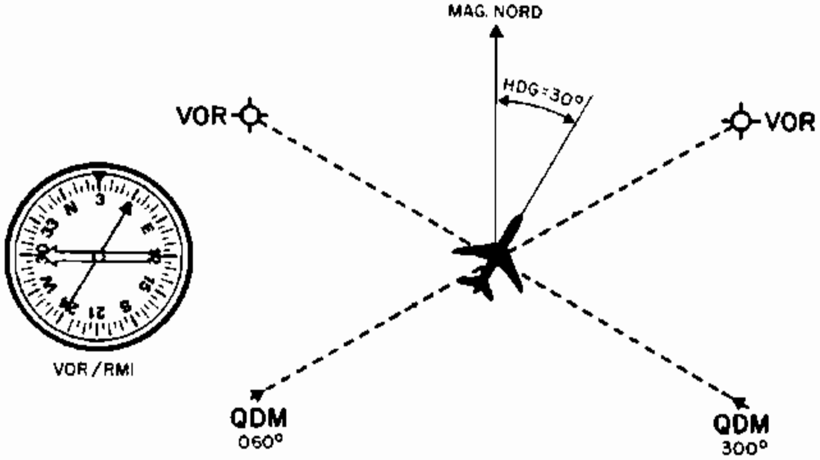
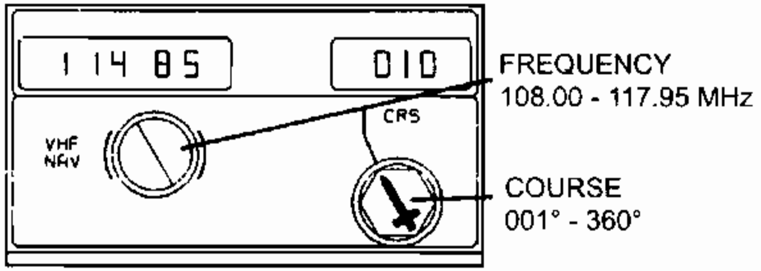


Figure 207: Frequency and Course Selector

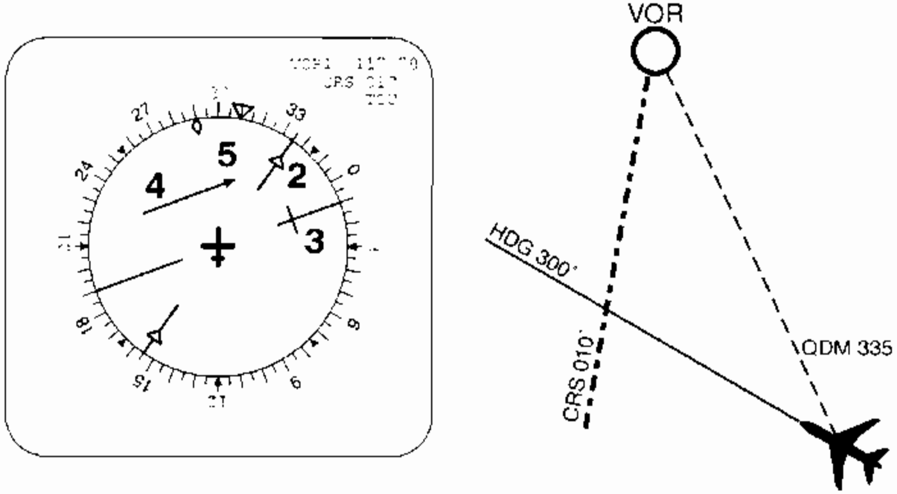


Navigation Display

The VOR Bearing pointer at the Radio Magnetic Indicator or Navigation Display (see below Nr. 2) shows always the direction toward the tuned VOR ground station.

The Pilot may select any desired VOR course at the shown course selector or MCDU. The indication at ND, Radio Direction or Horizontal Situation Indicator makes possible an accurate flight along any selected course, also with crosswind toward or from the VOR station.

Figure 208: VOR ND Indication and real Situation



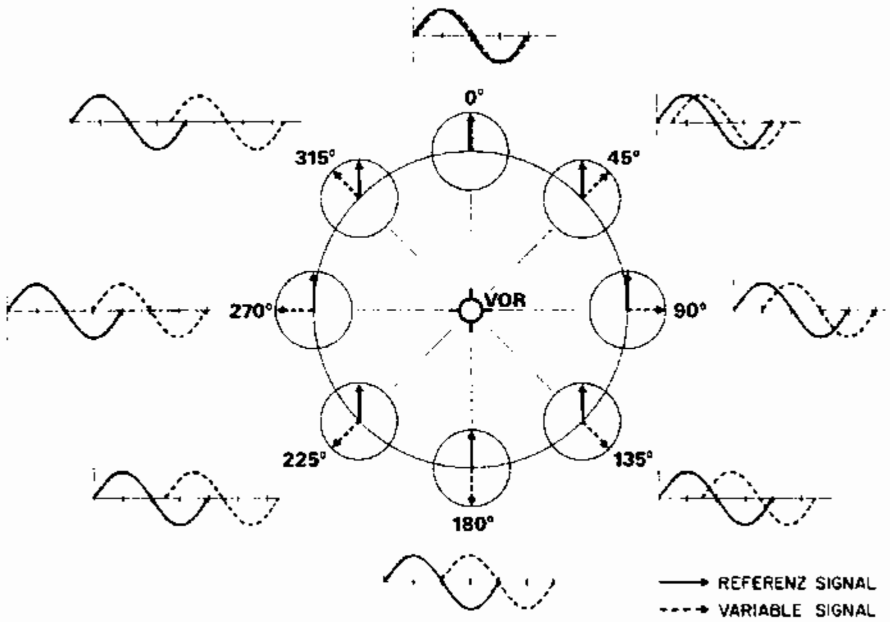
1. Information of selected VOR station
   Selected frequency, course and station identification.
2. VOR Bearing Pointer
   Magnetic bearing (QDM) toward selected VOR station.
3. VOR Course Pointer
   Represents selected VOR course.
4. Deviation Bar
   Each dot represents a lateral deviation of 5° against the selected course.
5. TO/FROM Indication
   The arrow shows toward (QDM) or from QDR the VOR station (QDR).

Ground Stations

A VOR is a VHF transmitter whose carrier is simultaneously frequency and amplitude modulated, FM and AM emission. The two modulation signals, called reference and variable signal differ in their phase position according to the direction in which they leave the station. The phase position difference between the reference and the variable signal is use to determine the lines of position.

- The reference signal (FM) is constant in all directions.
- The phase position of the variable signal (AM) differs from the reference signal according to the direction in which it leaves the station.

Figure 209: Phase Shift depending of Azimuth



Line of position

We differentiate the line of position in 2 terms, whether we mean the course leading TO a radio station, or FROM that radio station.

- The magnetic course to be flown TO a radiostation, (by no wind) is called track or QDM.
- The magnetic course leading away FROM a radio station is called radial or QDR.

Figure 210: Track QDM and Radial QDR

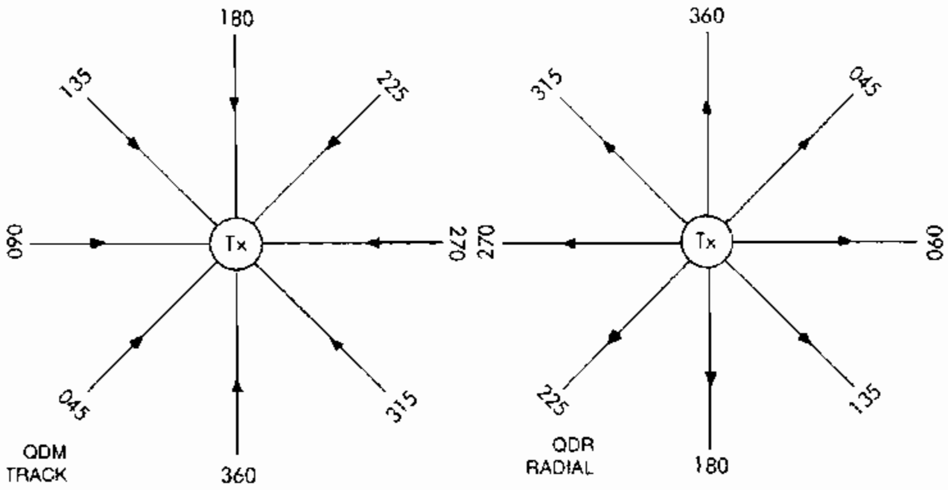


Table 5: Categories of VOR Stations ICAO

Type	Used for	Range NM	RF Power	Frequency MHz
High Power A - VOR	Airway Navigation	100 - 300	200 W	112.00 - 117.95 All Channels
Low Power T - VOR	Terminal Area	25 - 50	25 W	108.00 - 111.85 even 1/10 MHz Steps

Emissions Classic VOR

The carrier antenna radiates a nonrotating, circular pattern around the station. This consists of the rf-carrier amplitude modulated by 9960 Hz subcarrier which is frequency modulated (+/- 480 Hz) by the 30 Hz reference phase signal.

The sideband antenna radiates a lobe pattern of unmodulated carrier, rotating at the rate of 30 revolutions per second producing the 30 Hz variable phase signal.

In the receiver the variable phase and reference phase signals are exactly in phase at the magnetic north of the station. Accurancy: 3 . . 5°

Figure 211: Variable and Reference Signal

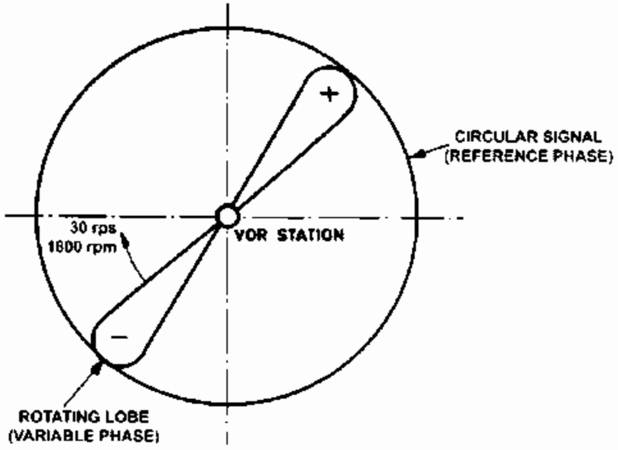


Figure 212: Frequency Spectrum of Classic VOR

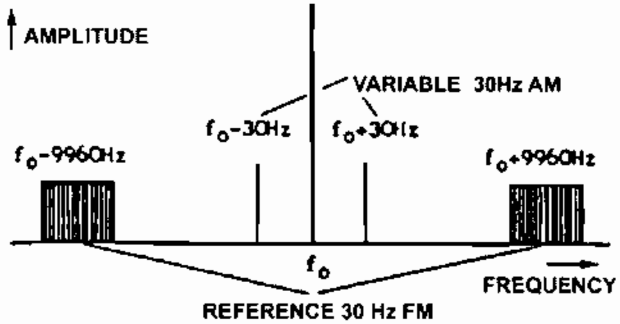
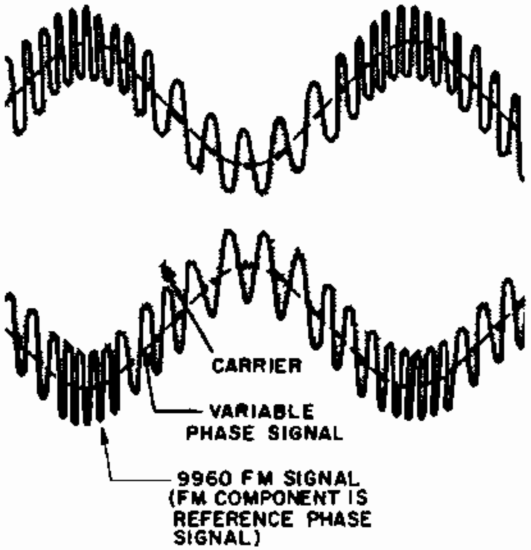


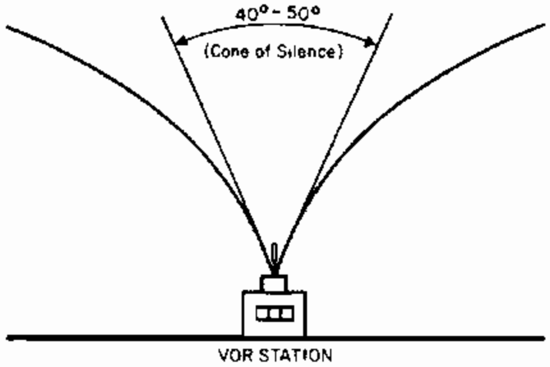
Figure 213: Variable and Reference Signal at Receiver



Cone of Silence

Directional component of the radiated signal above the VOR station are not useable to determine the directions. Overflying the "cone of silence" or also called "zone of confusion" results in a unusable reception and navigation guidance.

Figure 214: Cone of Silence



Emissions Doppler VOR

To increase the accuracy of the navigation, today many VOR stations working as Doppler-VOR. Doppler effect means rising of the reception frequency if the signal source approaches toward the receiver, or decreases if the source moves away.

The reference phase consists of the rf carrier amplitude modulated by 30 Hz.

The variable phase is received as a 30 Hz FM signal produced by doppler effect. The ground station has 39 dipols arranged in a circle sending the carrier modulated with a subcarrier 9'960 Hz rotating around 360° in 1/30 second. Due of continuously changing the distance between rotating antenna and receiver 30 Hz FM is produced at the receiver.

The aircraft equipment is identical as for the classic VOR. Accuracy: 0.5°

Figure 215: Rotating Radio-Beam, Producing 30 Hz FM at Receiver

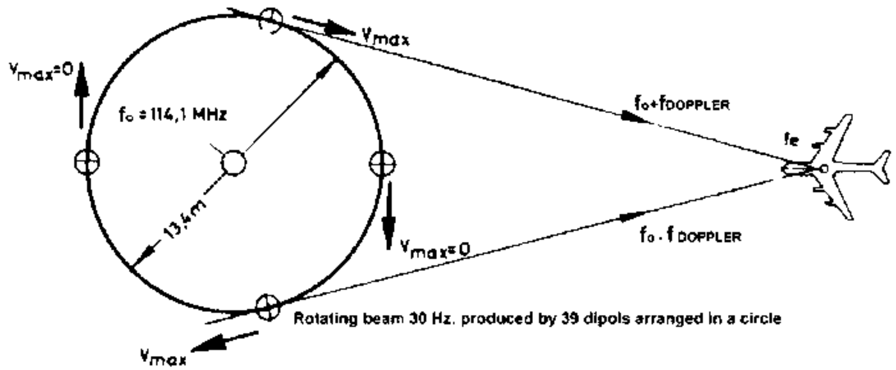


Figure 216: Frequency Spectrum of D-VOR

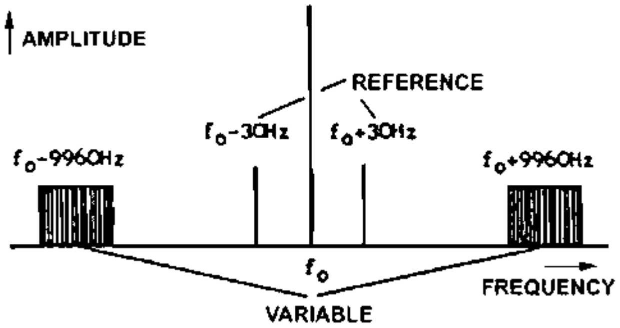


Figure 217: Doppler VOR Tx-Antenna

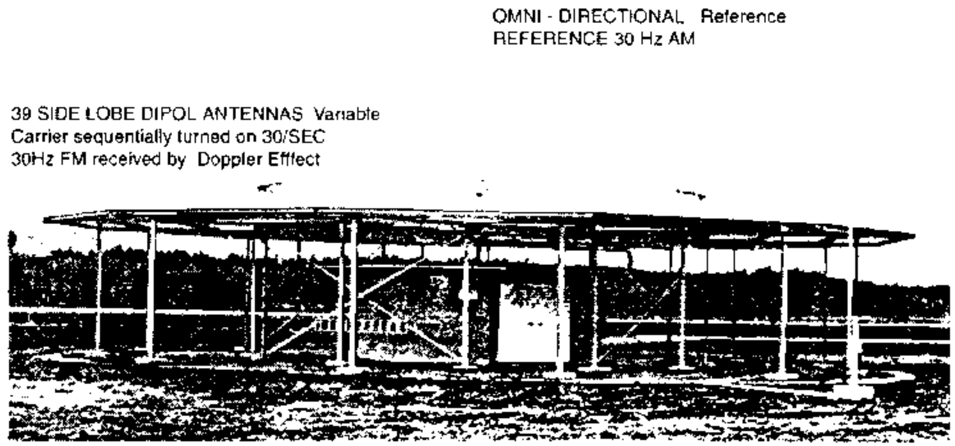
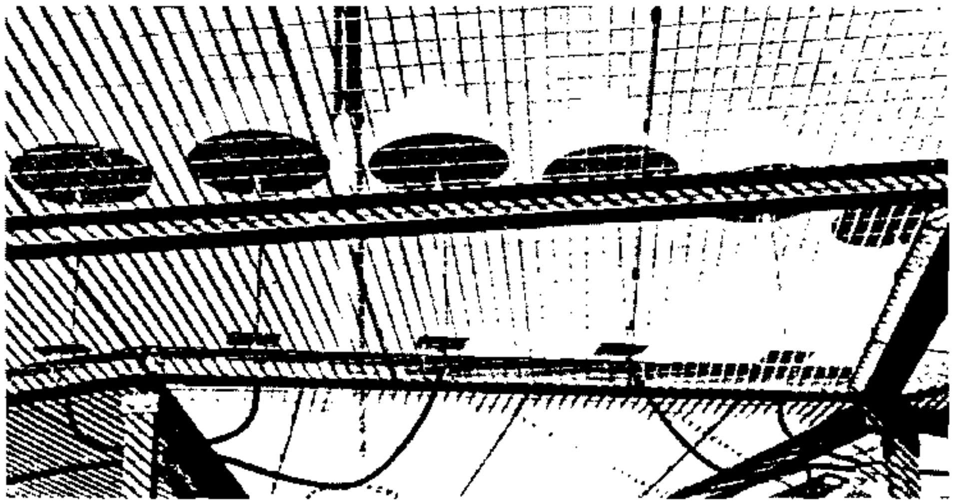


Figure 218: Side Lobe Dipols



Aircraft Equipment

The VOR receiver is a separate unit or is build as a VHF-navigation receiver Some light aircraft uses the VHF-communication receiver with additional circuitry to process the VOR and ILS signals.

The output can be divided into two groups:

Automatic VOR

The pilot has just to select a operating VOR stations frequency. The Radio Magnetic Indicator RMI or Navigation Display ND shows **automatically** the actual VOR bearing (QDM).

Manual VOR

The pilot selects **manually** at the course selector a desired VOR COURSE.

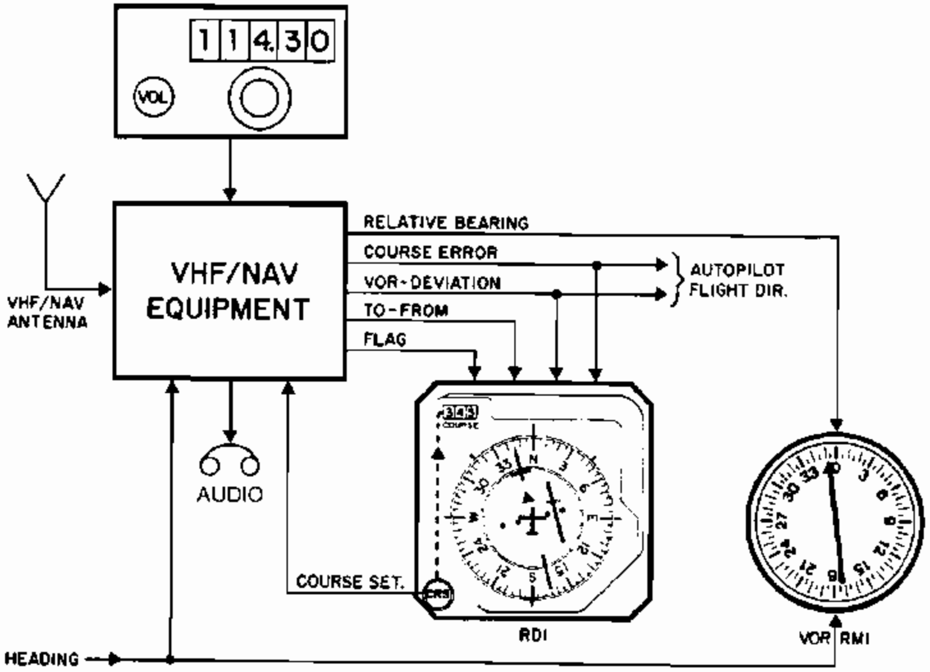
One of the 360 possible position lines around the tuned VOR station.

The:

RDI (Radio Direction Indicator) or
HSI (Horizontal Situation Indicator) or
PDI (Pictorial Deviation Indicator)or
ND (Navigation Display)

shows VOR-DEVIATION, TO-FROM and COURSE ERROR between actual aircraft situation to the selected station.

Figure 219: VOR Aircraft Equipment



Automatic VOR

The VHF NAV receivers pick up both reference and variable signals of the VOR. A phase detector automatically shifts the phase position of the reference signal to correspond with the phase position of the variable signal. This phase shift corresponds with the position line on which the aircraft is in respect to the selected VOR station.

The combination of position line (Relative Bearing) and compass information (Magnetic Heading) inside VOR RMI results as Absolute Bearing QDM.

Figure 220: VOR Rx and RMI

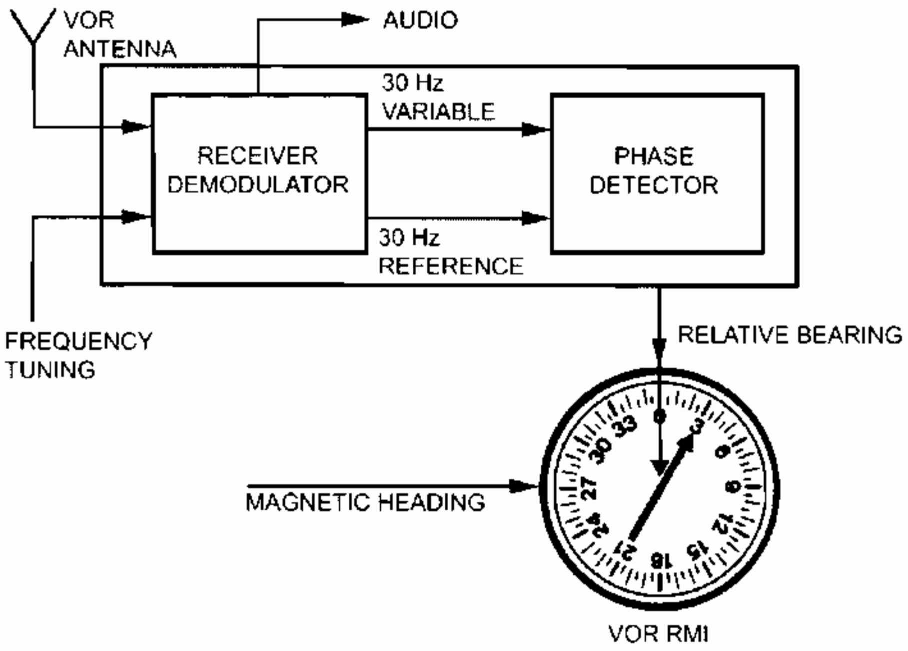


Figure 221: VOR Receiver with RMI

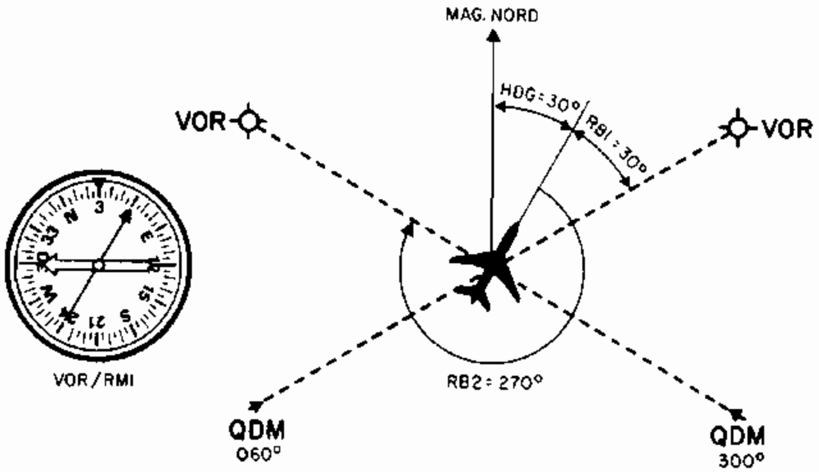
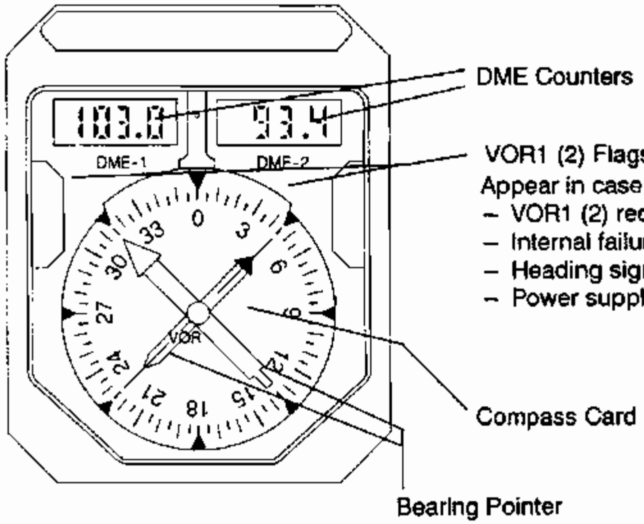


Figure 222: Radio Magnetic Indicator



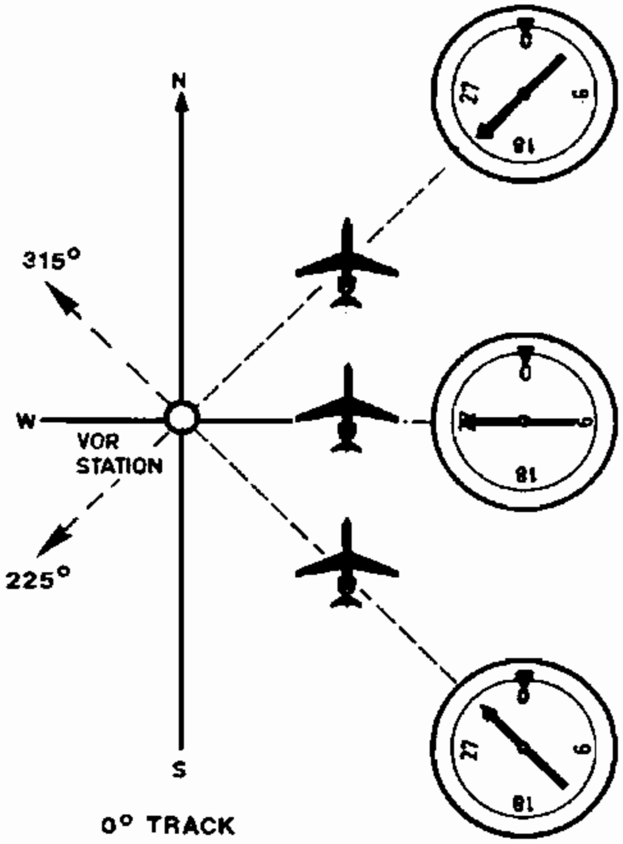
VOR1 (2) Flags
Appear in case of:
- VOR1 (2) receiver failure.
- Internal failure of RMI.
- Heading signal invalid.
- Power supply failure

Indicate the magnetic bearing to the station received by VOR 1 (dashed pointer) and VOR 2 (double pointer).

Function of RMI

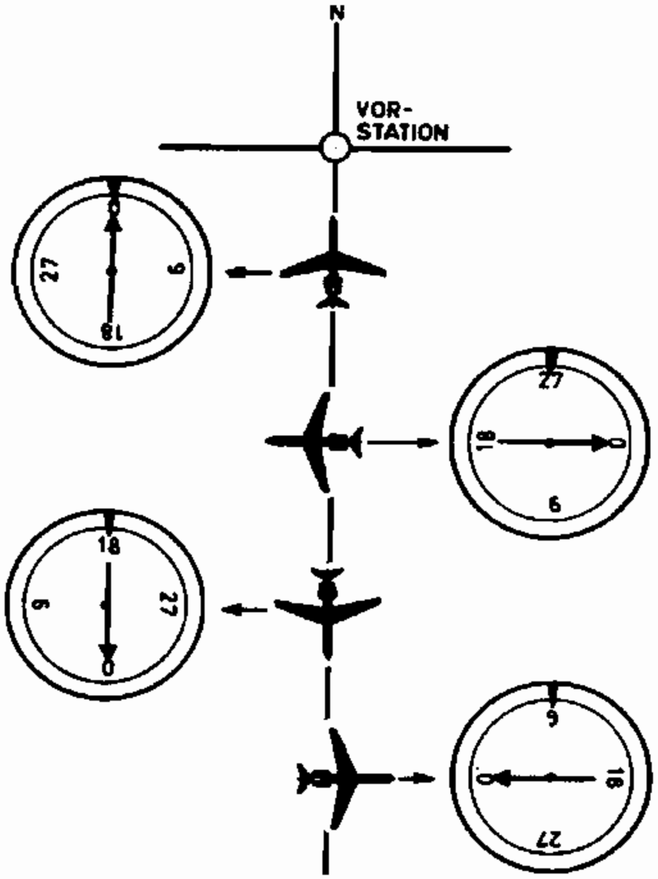
Left example shows the airplane flying toward north. The phase angle is continuously changing, so the VOR-pointer changes it's QDM.

Figure 223: QDM changing, Heading 360°



Right example shows the airplane is along VOR-track 360. The phase angle remains 180° The heading is continuously changing, so the pointer moves with the heading scale.

Figure 224: Heading changing, QDM 360°



Combined VOR / ADF Radio Magnetic Indicator

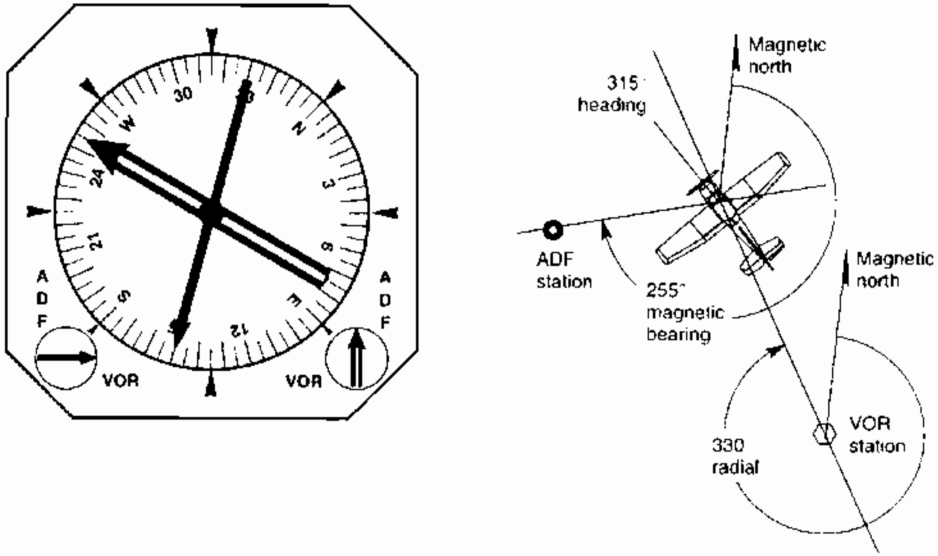
To minimize the number of instruments, the radio magnetic indicator, or RMI, has been developed and is now widely used. This instrument combines the remote indicating compass with the indicators for the ADF and VOR.

The single arrow that indicates for the VOR is pointing to 150° This is the TO bearing to the station (QDM), and if the aircraft were turned to a heading of 150° it would go to the station. This places the aircraft on the 330° radial
(180°+ 150° = 330°). VOR radials (QDR) are always numbered by the magnetic direction FROM the station.

The flux-gate compass has rotated the dial of the indicator to show that the aircraft is flying with a magnetic heading of 315° The dial has turned until 315° is under the marker at the top of the instrument, which is the lubber line.

The double arrow that indicates for the ADF shows that the station being received on the ADF is to the left of the aircraft between the wing and the nose. The station has a magnetic bearing (QDM) from the aircraft of 255°

Figure 225: VOR/ADF - RMI



Manual VOR

The display gives a image of the aircraft position in relation to a selected VOR course. Following information are shown:

- VOR deviation (left - right indicator),
- Course error (difference between aircraft heading and selected track),
- TO - FROM indication,
- Warning flag.

The phase shift is activated manually by selecting the desired track with the "course knob". When the aircraft is on the selected course (on track), there is no phase difference between reference and variable signals in the deviation discriminator. The deviation pointer of the indicator remains in the center

As soon as the aircraft leaves the selected track, the phase difference in the deviation detector brings the pointer to move across the instrument, showing where the selected track lies in relation to the aircraft heading.

The course error (also called WCA, Wind Correction Angle), shows the angle between the aircraft heading and the selected track. The selected course and the compass information are lead to a differential synchro, and the difference between the 2 pieces of information gives the course error. The course error signal-governs the Course Pointer in the indication.

The TO - FROM indicator shows whether the aircraft is in the TO or FROM area of the selected VOR station.

The warning flag is activated when the reception of VOR signals becomes too weak, for instance when the aircraft is out of the VOR working range, or by technical malfunctions either of the ground or aircraft equipment.

The reception frequency must be tuned and the desired course must be selected.

Figure 226: Receiver and Display

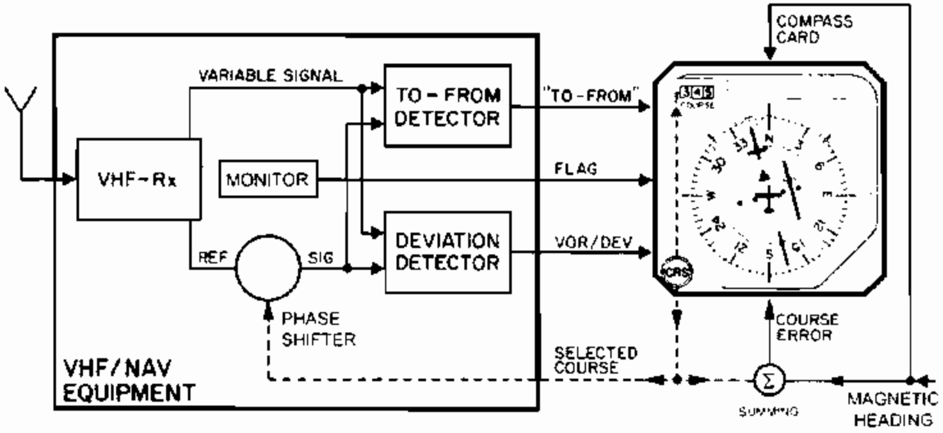
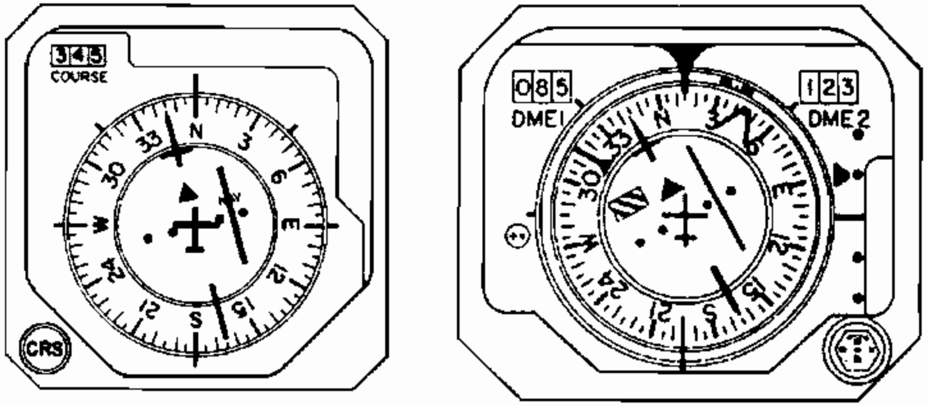
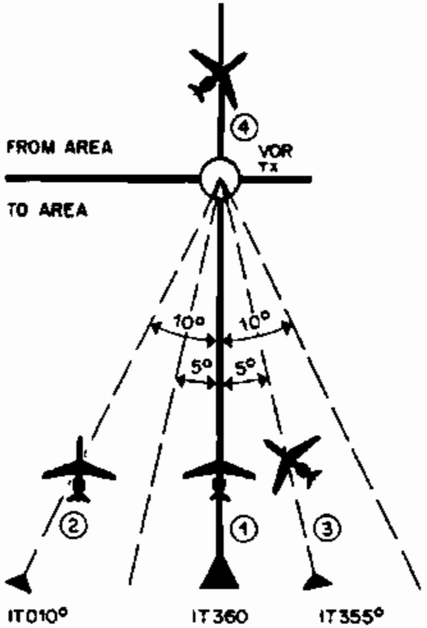


Figure 227: Radio Direction Indicator



Function of Manual VOR

Figure 228: Aircraft Position Situations toward and from a VOR Station



1 The aircraft is on the selected course. Deviation bar centred.
2. The aircraft is 10° left of selected course. Deviation bar is 2 dots right.
3. The aircraft is 5° right of selected course and the heading is not equal the selected course. Deviation bar is 1 dot left, course pointer shows the course error
4. The aircraft has over flown the VOR-Tx with a Wind Correction Angle. The TO/FROM pointer moved to the other end of the deviation bar and shows (FROM). The course error is shown.

Figure 229: Radio Direction Indicator

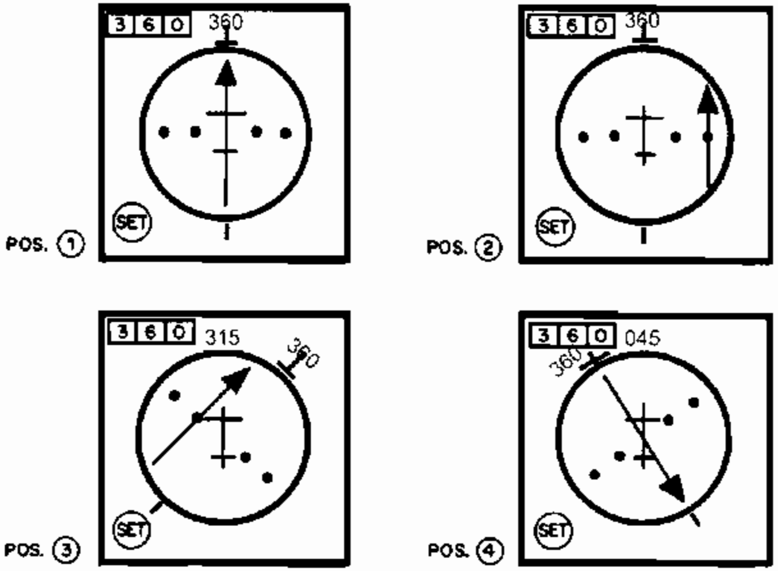
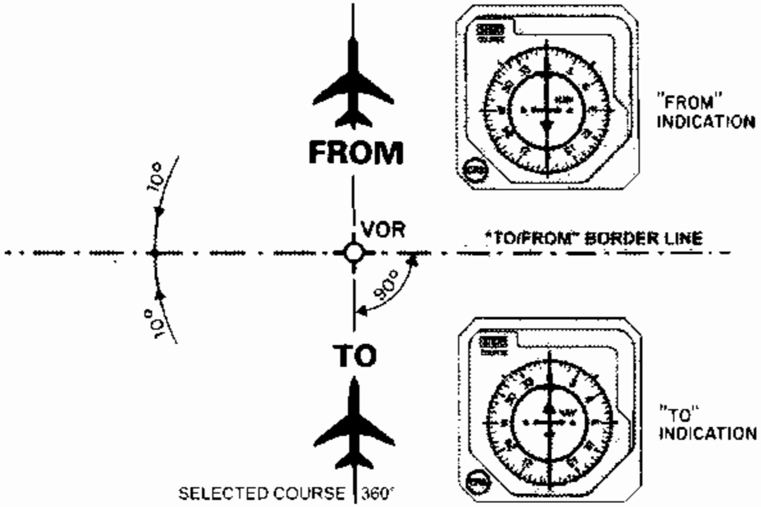


Figure 230: TO - FROM Indication



Control Panel and Automatic Tuning

A wide variety of control panels depending on system layout are present.

Figure 231: VOR/DME Control Panel

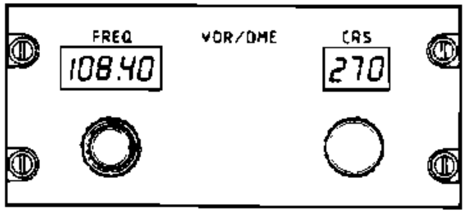
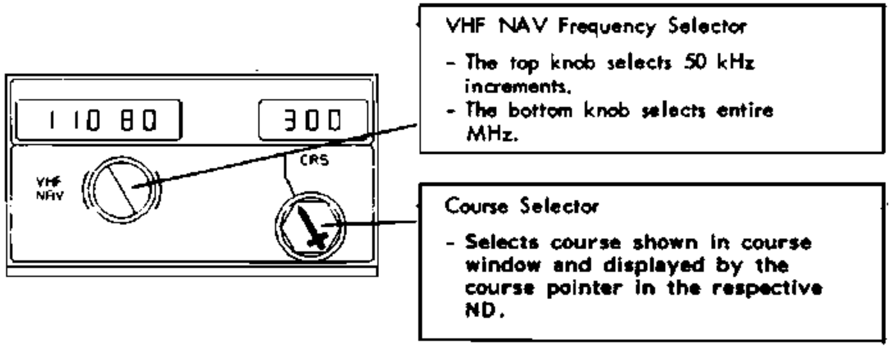


Figure 232: VHF NAV Control Panel (VOR, ILS and DME)



VHF NAV Frequency Selector

- The top knob selects 50 kHz increments.
- The bottom knob selects entire MHz.

Course Selector

- Selects course shown in course window and displayed by the course pointer in the respective ND.

Table 6: Categories and VOR Frequencies

Type	Used for	Frequency MHz
High Power A - VOR	Airway Navigation	112.00 - 117.95 All Channels 120 Channels 50 KHz spacing
Low Power T - VOR	Terminal Area	108.00 - 111.85 Even 1/10 MHz Steps 40 Channels

The Flight Management System automatically tunes the VOR Receivers. The pilots may tune the VOR via MCDU's. Backup tuning is possible via RMP.

Figure 233: Automatic and MCDU Remote Tuning

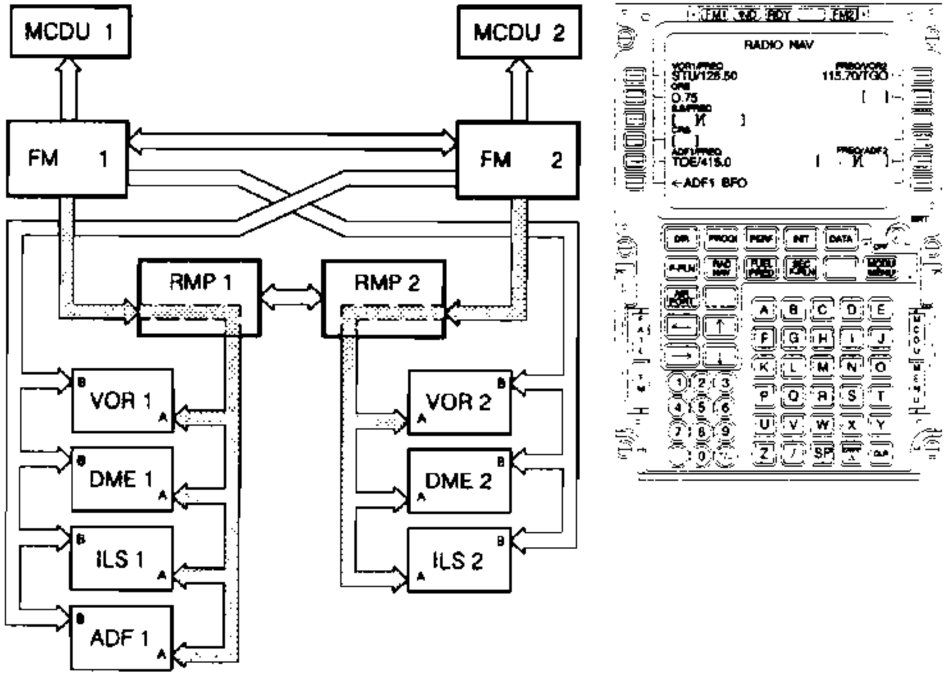
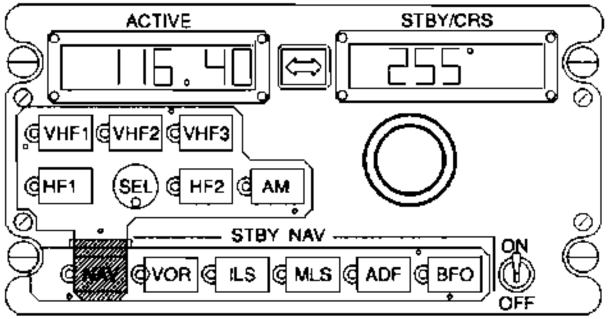


Figure 234: Radio Management Panel



Marker Beacon

Fundamentals

The Marker system is a radio navigation aid which determines the distance between the aircraft and the runway threshold. When the aircraft overflies one of these Marker transmitters, the system provides aural and visual indications to the flight crew.

Frequency: 75 MHz

Beacons

Marker radio beacons are transmitters whose antenna systems are designed to propagate vertical beams.

Two types of Markers are used, the Z- and the Fan-Marker

The Z-Marker whose vertical beam is cone shaped is used to mark a certain crossing point of airways, or to fill the cone of silence over a NDB.

The Fan-Marker propagates a fan shaped beam and is used to mark important positions along airways and to give distance to threshold information on the approach and landing path.

According to ICAO recommendations, Airway Markers should reach at least 20'000 ft and ILS Markers 6'000 ft in altitude.

Frequency and Emissions

All markers work on 75 MHz with A2 modulation. They are modulated with either one of 3 audio frequencies according to their implementation. The audio freqency can be keyed for identification purposes

MARKERS	AUDIO FREQ.	IDENT.	LAMP	IMPLEMENT.
OM	400 Hz	----	blue	ILS
MM	1300 Hz	.-.-.-	orange	ILS
IM	3000 Hz	.....	white	ILS
All other FM	3000 Hz	*	white	airways

* with or without identification (Morse code)

Figure 235: Airway Marker

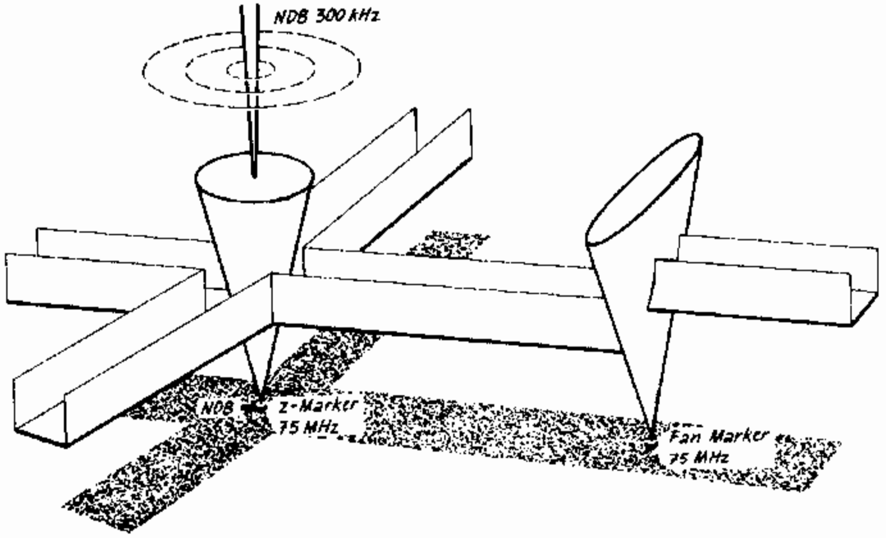
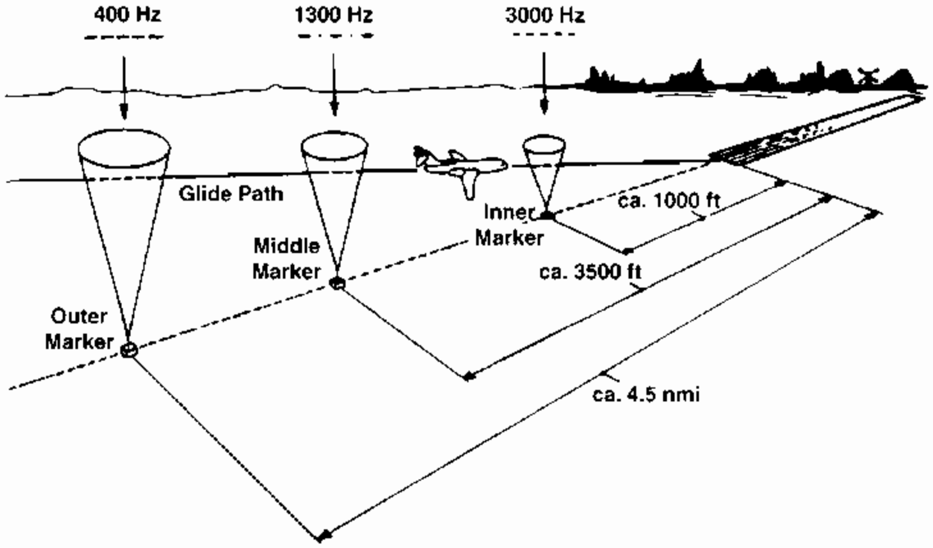


Figure 236: ILS Marker



System

A 75 MHz VHF receiver and a display unit in form of 1 or 3 lamps (one for each or one for all possible modulation frequency) are required.

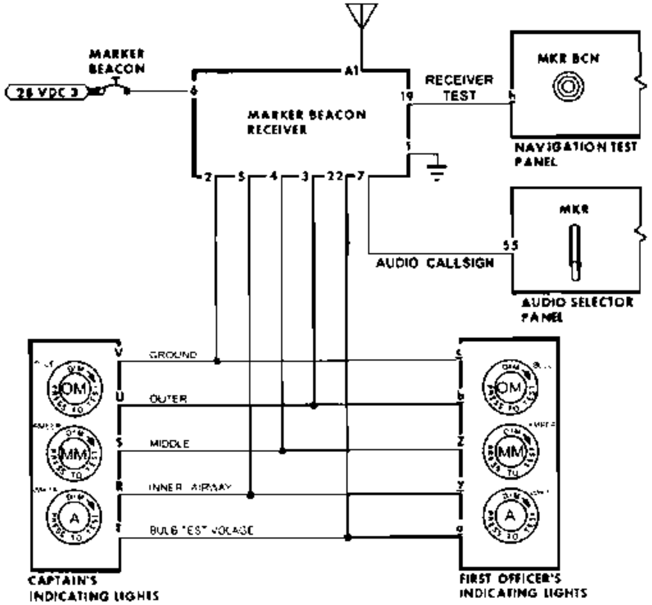
The output of the Marker receiver is lead to the headphones or loudspeakers and to the visual indicating system: lights or Primary Flight Display.

When the aircraft overflies a Marker beacon, the pilot hears the audio signal and sees the appropriate Marker visual indication.

Indications

Marker	Identification	Tone Hz	Light	Name
Outer	- - - - - - - - -	400	Blue	OM
Middle	. - . - . - . - . -	1300	Amber	MM
Inner- or Airway	Call sign / . . .	3000	White	IM or A

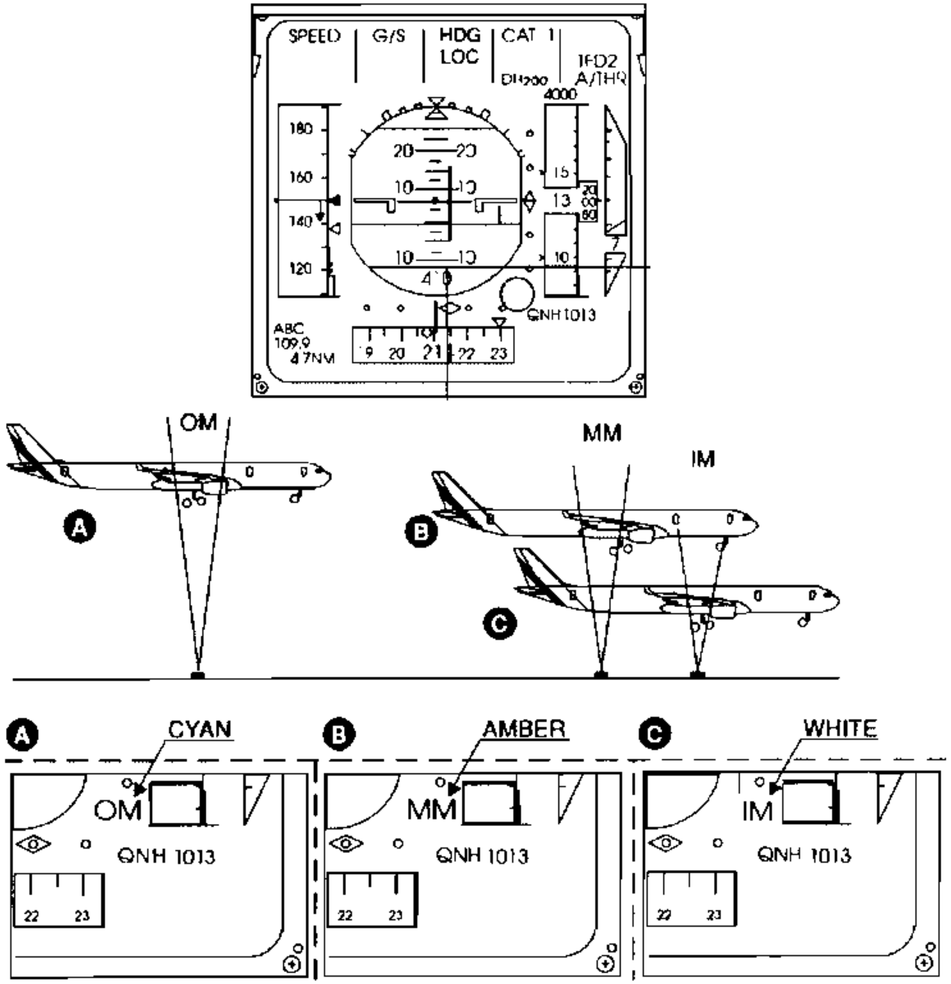
Figure 237: Marker System



Indicating on EFIS

When the aircraft overflies the Marker, the type of Marker is displayed in different colors at the PFD and is indicated by an aural identification via cockpit speaker or headphone.

Figure 238: Primary Flight Display



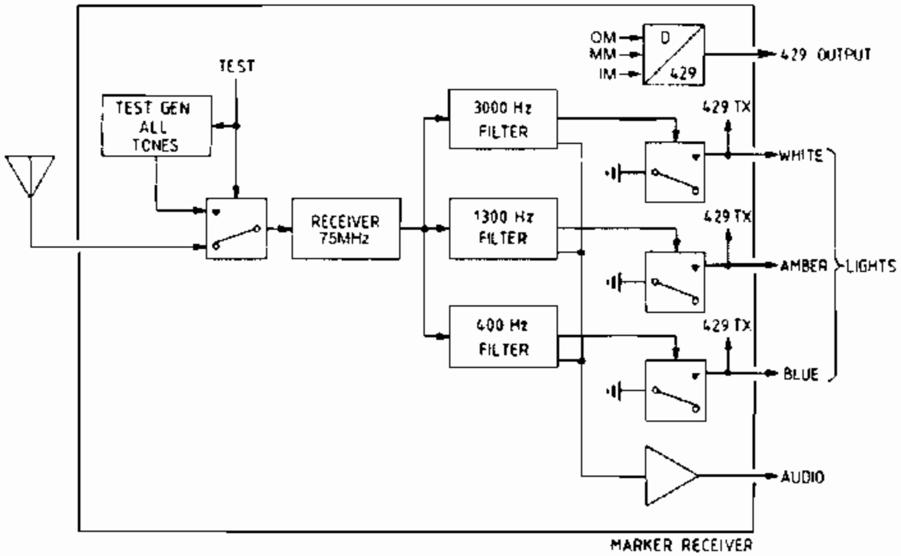
Receiver

The marker beacon receiver detects the audio modulation of the 75 MHz input The audio modulation of 400 Hz of 1300 Hz or 3000 Hz goes to the audio filters. If a marker beacon audio tone is present, it goes through the filter and closes the electronic switch to give a ground for a Marker light.

The Marker receiver can also be build inside the VOR or ILS receiver

To have the display at the EFIS this information also goes to the multiplexer and ARINC 429 transmitter in the VOR/MB receiver. The ARINC 429 transmitter puts the marker beacon information in the bits 11, 12 and 13 of label 222.

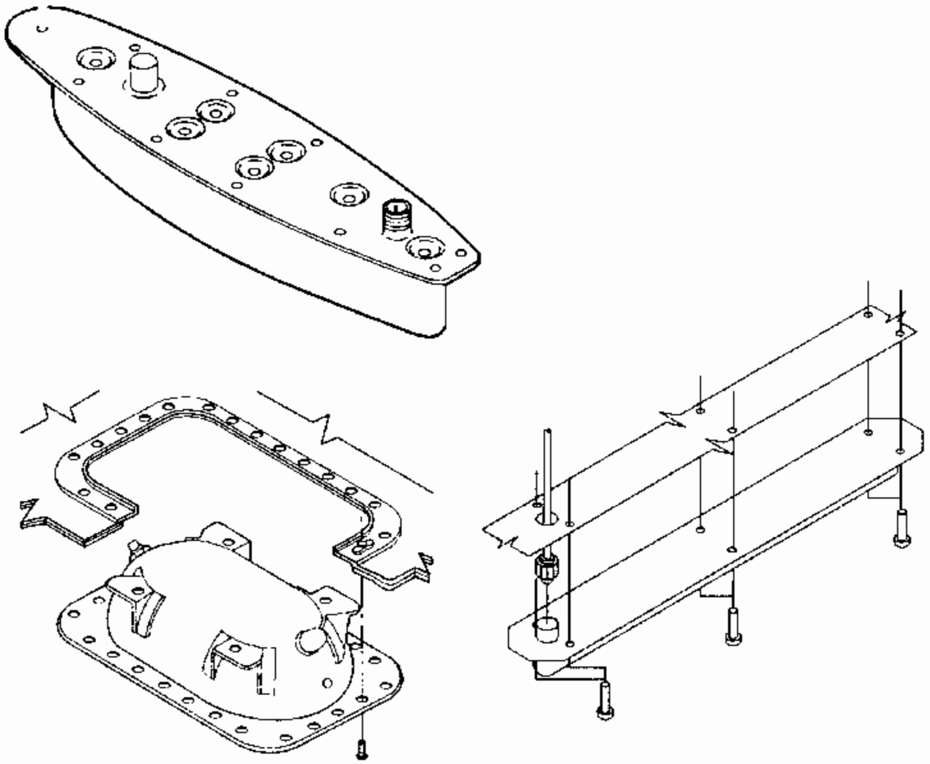
Figure 239: Blockdiagram Marker Receiver



Antenna

Marker beacons transmit horizontally polarized signals vertically upward on a frequency of 75 MHz. They are received in the aircraft by an antenna like the one in figure mounted on the bottom of the fuselage.

Figure 240: .Different Antenna Models



DME Distance Measurement

Principle

The Distance Measuring Equipment (DME) provides digital read-out of the aircraft slant range distance from a selected ground station. The system generates interrogation pulses from an onboard interrogator and sends them to a selected ground station. The ground station replies. The interrogator determines the distance in Nautical Mile (NM) between the station and the aircraft. The interrogator detects the Morse audio signal which identifies the ground station.

Frequency: Around 1 GHz 252 channels paired with VHF NAV frequencies.

At the same location as a VHF omnirange station (VOR) is generally also a DME station. The VOR gives bearing and the DME distance to that station.

DME ground stations located close to the ILS - runways are used to determine the distance between approaching aircrafts to the runway threshold. To compensate the distance between runway-threshold and the location of the ground-station, the internal delay of the station 50 µs is reduced to the corresponding value.

The DME gives the slant distance. The flight management systems use the distance information from the DME for position calculations. The distance is also available for indication in the flight compartment.

The DME in the aircraft is an interrogator which interrogates the DME ground station. The ground station gives a reply which the interrogator receives. From the time difference between interrogation and reply the interrogator calculates the distance. The interrogation and the reply are on a different frequency. These frequencies are:

- 1025 to 1150 MHz for the interrogator transmitter
- 962 to 1213 MHz for the ground station transmitter.

The frequency for the ground station transmitter is always 63 MHz above or below the interrogator frequency (when below and when above depends on the selected channel). The DME frequency has a fixed relation with the collocated VOR, so when you select a VOR frequency you automatically select the DME frequency.

Figure 241: Distances

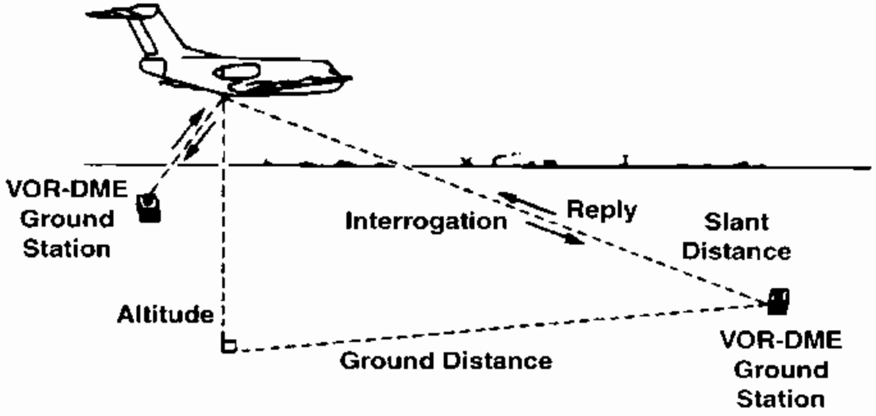
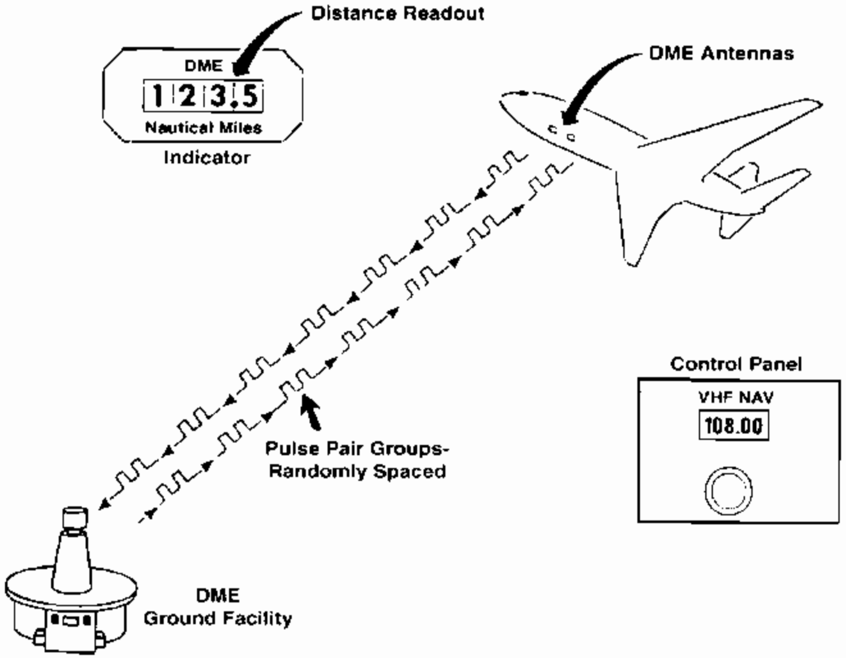


Figure 242: Interrogation and Reply

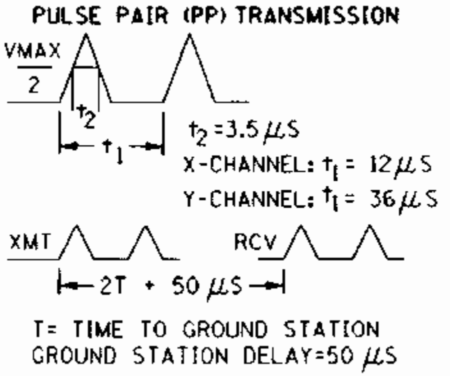


Interrogation Pulses

The interrogator transmits 2 RF pulses, which is the interrogation. The ground station retransmitts the same pulses on the selected frequency. The interrogator varies the repetition rate of the transmission at random, which gives each DME interrogator a unique repetition rate. This is to make sure that the aircraft recognizes its own reply pulses. The interrogator looks for replies with its own repetition rate and ignores other replies which are for other aircraft. The time between the two pulses depends on the channel type

The DME ground station also transmits identification tones to identify the selected station. The systems tune either automatically or manually. The flight management system does the automatic tuning. You tune manually when you select a VOR frequency on a VOR/DME control panel. When the FMS tunes the DME the DME interrogator can give the distance to up to 5 DME stations.

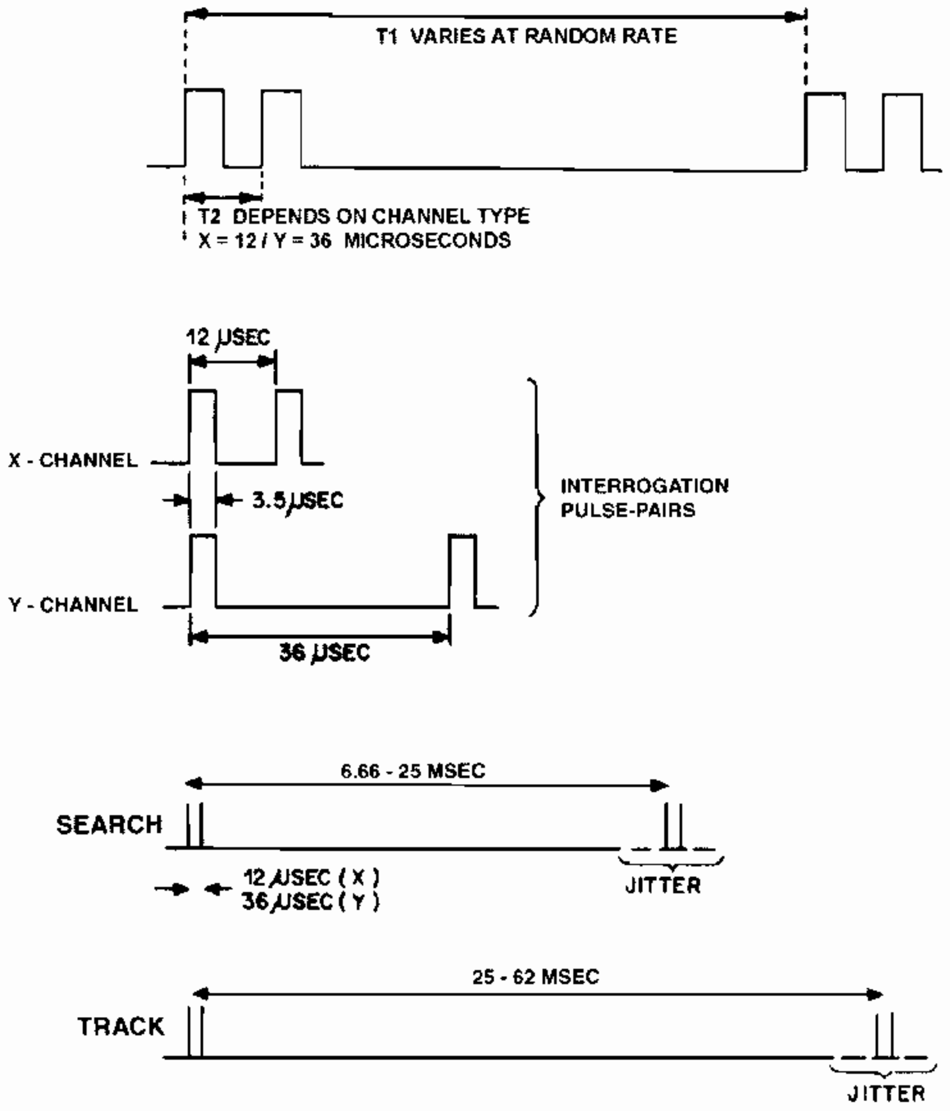
Figure 243:



SEARCH MODE: NORMALLY < 40 PP/SEC
MAX = 150 PP/SEC
TRACK MODE: NORMALLY < 16 PP/SEC
MAX = 40 PP/SEC

TIME BETWEEN XMSN OF PULSE PAIRS VARIES RANDOMLY.

Figure 244:



Operation

The DME interrogator transmits and receives matched pulse pairs. The ground station receives and echoes the twin pulses back. With no interrogating aircrafts around, the ground station sends continuously pulse pairs (PP) with a constant rate of 2'700 PP/s filler and identification pulses. Called squitter.

If there is an interrogating aircraft in the beacon range, filler (squitter) PP's are replaced by reply pulse pairs.

If the interrogator receives PP's from a ground station, the interrogator changes from standby to search mode.

During search, a counter inside interrogator-computer runs through the range of the range and searches for the actual distance.

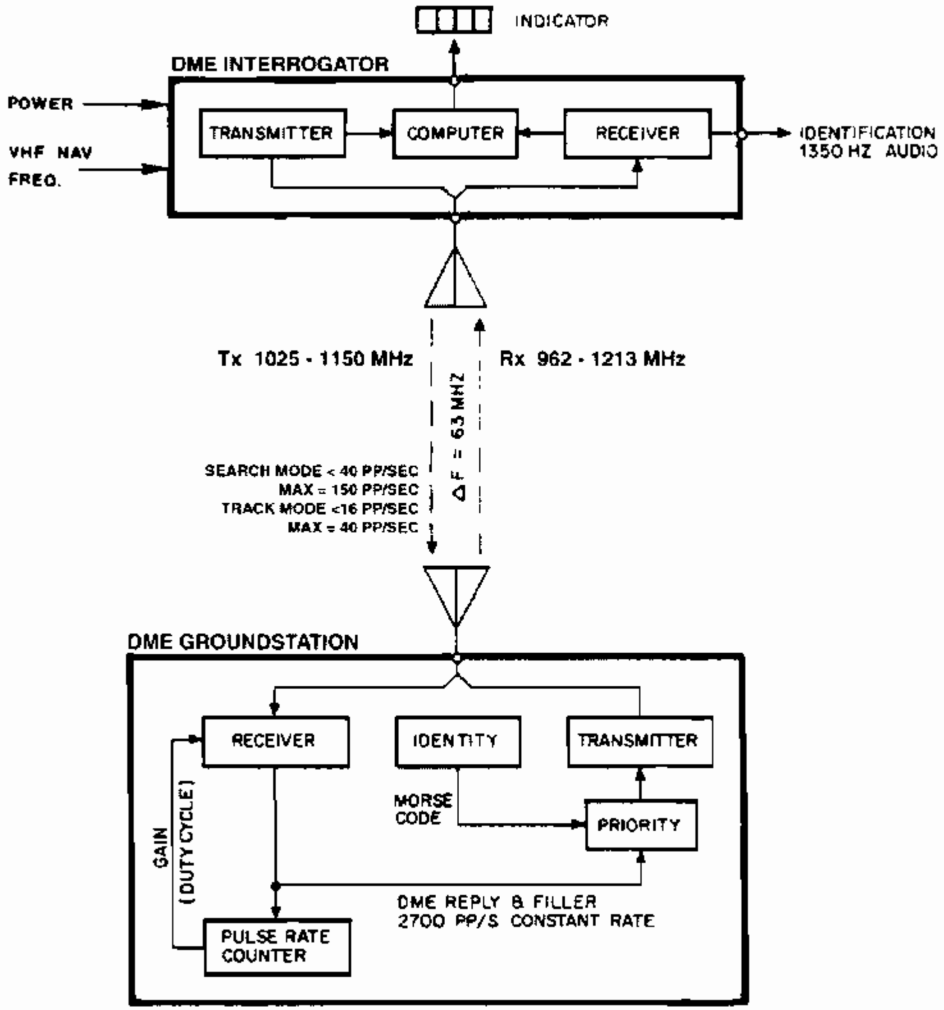
If the computer of the interrogator has tracked to the actual distance, the rate of PP's are reduced. The indication follows the actual distance.

TACAN

TACtical Air Navigation is a military rho-theta (distance-angle) navigation system. Range and bearing can be determined from a single TACAN station. The distance measuring part of, is identical in operation of DME.

A civil aircraft equipped with DME can use any TACAN station for distance determination.

Figure 245: Interrogator and Ground Station



DME Interrogator Modes

There are four modes of DME operations are summarized as follows:

Standby

No reception of any active or squittering randomly transmitting DME groundstation. Dashes - - - - are in view

Search

When the system is first turned on, a controlled variable delay counter system begins count. It counts from zero delay to maximum delay, until it matches the delayed transmitted signal to the received signal

This running through delay and distance indications is called "Signal Controlled Search" or just `SEARCH". During this time, dashes in the DME indicator are in view, showing that the DME system is not yet operative. The transmitter is periodically transmitting and the receiver is periodically receiving. When the matching circuits see that the received signal is the same as the delayed transmitted signal, it causes the distance counter/memory to lock on to that particular delay. The pulse repetition rate is between 40 and 150 pulse-pairs/sec.

Track

"Locking on" means that the counter stops its relatively rapid search. It runs slowly after "lock-on" as it sees a signal from the matching circuits calling for a move in one direction or the other to maintain the matched condition.

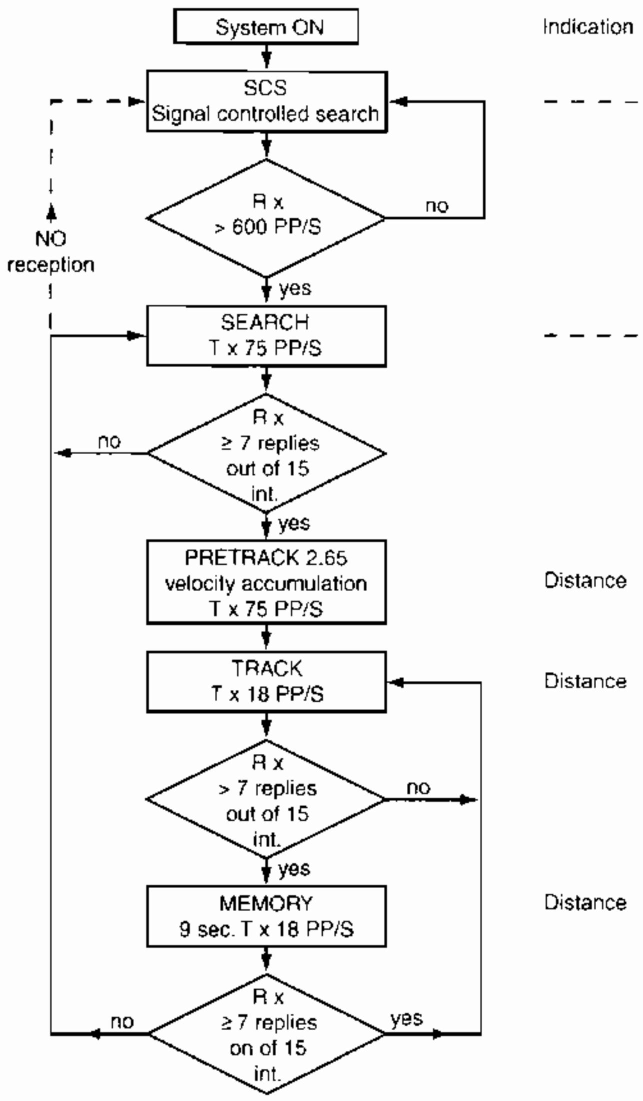
As long as the delayed transmitter signal matches the signal received, the distance indication is correct. When a difference occurs, the counter has to be driven one way or the other to increase or decrease the delay, depending upon whether the airplane is approaching or receding from the ground station.
The pulse repetition rate is between 16 and 40 pulse-pairs/sec.

Memory

If replies are lost an interrogator will not immediately revert to search or auto standby but will enter its memory condition; this may be one of two types, either static or velocity.

With static memory the readout is maintained steady, whereas with velocity memory the readout continues to change at its last known rate. Memory time will normally be between 4 and 12 seconds. The interrogator tries to track the DME station again.
The pulse repetition rate is between 40 and 150 pulse-pairs/sec

Figure 246:



Frequencies

The Interrogator transmits a pulse-pair signal on any one of 126 frequencies within the range of 1025 MHz to 1150 MHz. One hundred of the DME transmit frequencies are automatically selected by tuning the NAV control to a frequency between 108.00 and 117.95 MHz.

The other 26 frequencies can be selected by tuning the NAV control to frequencies between 133.30 and 135.95 MHz, these channels are normally used for military TACAN stations.

The signals transmitted by the airborne DME are received by the ground station assigned to the selected channel frequency. After a built-in delay of 50 microseconds, a reply pulse-pair is automatically transmitted on the channel frequency assigned to the ground station. There are 252 channels within the frequency band of 962 to 1213 MHz set aside for DME ground stations.

Station Identification

Once every 30 seconds the beacon transmits its identity, which is detected by the pilot as a Morse code burst of three letters at an audio tone of 1350 Hz. These Morse identifiers are contained in the onboard navigation cards.

Figure 247:

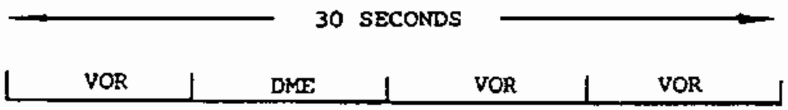


Figure 248: .VHF NAV to DME frequency conversion chart

NAV	DME		NAV	DME		NAV	DME		NAV	DME		NAV	DME	
	XMTR	REC		XMTR	REC		XMTR	REC		XMTR	REC		XMTR	REC
108.00	1041	978	109.00	1051	988	110.00	1061	998	111.00	1071	1008	112.00	1081	1018
108.05	1041	1104	109.05	1051	1114	110.05	1061	1124	111.05	1071	1134	112.05	1081	1144
108.10	1042	979	109.10	1052	989	110.10	1062	999	111.10	1072	1009	112.10	1082	1019
108.15	1042	1105	109.15	1052	1115	110.15	1062	1125	111.15	1072	1135	112.15	1082	1145
108.20	1043	980	109.20	1053	990	110.20	1063	1000	111.20	1073	1010	112.20	1083	1020
108.25	1043	1106	109.25	1053	1116	110.25	1063	1126	111.25	1073	1136	112.25	1083	1146
108.30	1044	981	109.30	1054	991	110.30	1064	1001	111.30	1074	1011	112.30	1094	1157
108.35	1044	1107	109.35	1054	1117	110.35	1064	1127	111.35	1074	1137	112.35	1094	1031
108.40	1045	982	109.40	1055	992	110.40	1065	1002	111.40	1075	1012	112.40	1095	1158
108.45	1045	1108	109.45	1055	1118	110.45	1065	1128	111.45	1075	1138	112.45	1095	1032
108.50	1046	983	109.50	1056	993	110.50	1066	1003	111.50	1076	1013	112.50	1096	1159
108.55	1046	1109	109.55	1056	1119	110.55	1066	1129	111.55	1076	1139	112.55	1096	1033
108.60	1047	984	109.60	1057	994	110.60	1067	1004	111.60	1077	1014	112.60	1097	1160
108.65	1047	1110	109.65	1057	1120	110.65	1067	1130	111.65	1077	1140	112.65	1097	1034
108.70	1048	985	109.70	1058	995	110.70	1068	1005	111.70	1078	1015	112.70	1098	1161
108.75	1048	1111	109.75	1058	1121	110.75	1068	1131	111.75	1078	1141	112.75	1098	1035
108.80	1049	986	109.80	1059	996	110.80	1069	1006	111.80	1079	1016	112.80	1099	1162
108.85	1049	1112	109.85	1059	1122	110.85	1069	1132	111.85	1079	1142	112.85	1099	1036
108.90	1050	987	109.90	1060	997	110.90	1070	1007	111.90	1080	1017	112.90	1100	1163
108.95	1050	1113	109.95	1060	1123	110.95	1070	1133	111.95	1080	1143	112.95	1100	1037

NAV	DME		NAV	DME		NAV	DME		NAV	DME		NAV	DME	
	XMTR	REC		XMTR	REC		XMTR	REC		XMTR	REC		XMTR	REC
113.00	1101	1164	114.00	1111	1174	115.00	1121	1184	116.00	1131	1194	117.00	1141	1204
113.05	1101	1038	114.05	1111	1048	115.05	1121	1058	116.05	1131	1068	117.05	1141	1078
113.10	1102	1165	114.10	1112	1175	115.10	1122	1185	116.10	1132	1195	117.10	1142	1205
113.15	1102	1039	114.15	1112	1049	115.15	1122	1059	116.15	1132	1069	117.15	1142	1079
113.20	1103	1166	114.20	1113	1176	115.20	1123	1186	116.20	1133	1196	117.20	1143	1206
113.25	1103	1040	114.25	1113	1050	115.25	1123	1060	116.25	1133	1170	117.25	1143	1180
113.30	1104	1167	114.30	1114	1177	115.30	1124	1187	116.30	1134	1197	117.30	1144	1207
113.35	1104	1041	114.35	1114	1051	115.35	1124	1061	116.35	1134	1071	117.35	1144	1081
113.40	1105	1168	114.40	1115	1178	115.40	1125	1188	116.40	1135	1198	117.40	1145	1208
113.45	1105	1042	114.45	1115	1052	115.45	1125	1062	116.45	1135	1072	117.45	1145	1082
113.50	1106	1169	114.50	1116	1179	115.50	1126	1189	116.50	1136	1199	117.50	1146	1209
113.55	1106	1043	114.55	1116	1053	115.55	1126	1063	116.55	1136	1073	117.55	1146	1083
113.60	1107	1170	114.60	1117	1180	115.60	1127	1190	116.60	1137	1200	117.60	1147	1210
113.65	1107	1044	114.65	1117	1054	115.65	1127	1064	116.65	1137	1074	117.65	1147	1084
113.70	1108	1171	114.70	1118	1181	115.70	1128	1191	116.70	1138	1201	117.70	1148	1211
113.75	1108	1045	114.75	1118	1055	115.75	1128	1065	116.75	1138	1075	117.75	1148	1085
113.80	1109	1172	114.80	1119	1182	115.80	1129	1192	116.80	1139	1202	117.80	1149	1212
113.85	1109	1046	114.85	1119	1056	115.85	1129	1066	116.85	1139	1076	117.85	1149	1086
113.90	1110	1173	114.90	1120	1183	115.90	1130	1193	116.90	1140	1203	117.90	1150	1213
113.95	1110	1047	114.95	1120	1057	115.95	1130	1067	116.95	1140	1077	117.95	1150	1087

Navigation with DME

While DME on its own provides useful navigation information it is not, in itself, a complete navigation aid. It was intended from the start that for both approach and short-range en-route navigation DME would be used in conjunction with ILS and VOR respectively. DME works in conjunction with VOR and ILS beacons.

En-route Navigation

When a VOR and a DME beacon are at the same site the pilot can obtain range and bearing information thus the two systems together provide a Rho-Theta navigation system.

Since the pilot knows, from his charts, the location of the beacons, the range and bearing information allows him to obtain a position fix.

Use of DME with VOR

With VOR/DME beacons at selected waypoints such as airways crossing points are co-located DME groundstations installed. Of course large expanses of ocean cannot be served by the line of sight system we are discussing here. The maximum range of an airway DME is up to 300 NM. It should be enough to remind you that pilots are given left/right guidance to fly along selected VOR radials and while flying are given distance to go information courtesy of the DME.

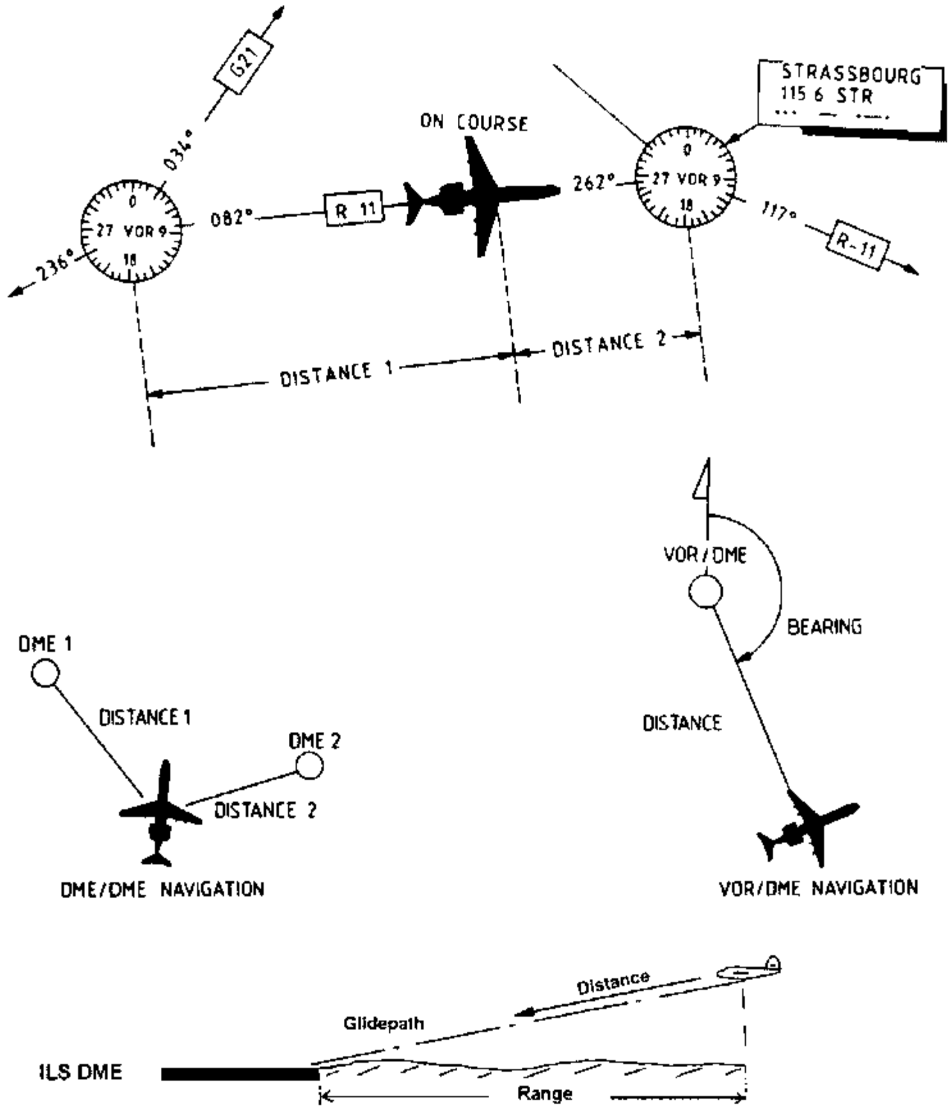
A further complication is that some VOR beacons are designated terminal beacons. These are situated at airfields and transmit low power thus giving restricted coverage. The DME beacons used with such VOR beacons similarly provide a restricted coverage. The range available is nominally 25 NM.

Approach

The use of DME with ILS is quite straightforward. ILS will provide its normal function of giving guidance information leading to touchdown, while DME will give distance to touchdown. Of course the localizer, glidepath and DME beacons must be suitably sited at the airfield.

Note that at glidepath angles of about 3 degrees, the slant range and ground range are nearly the same.

Figure 249:



Indicating

The DME distance is shown on the Primary Flight Display and on the Navigation Display. The DME distance is also shown on the two counters of the DDRMI.

ILS DME distance to runway threshold

Shown at the lower left corner of the PFD.

VOR DME distance to VOR station 1 and 2

Depending of the ND's display mode the slant distance is shown at the left DME 1 respective right lower corner for DME 2.

DME counters of mechanical indicator showing the DME distances as soon the interrogator has tracked to the actual distance.

No Computed Data

DME interrogator is not tracked to an actual distance, standby or search.
Dashes - - -. - are visible.

DME fault

DME interrogator is not powered or an internal failure exists.
Flag covers the display or the display is blank.

Figure 250: DDRMI

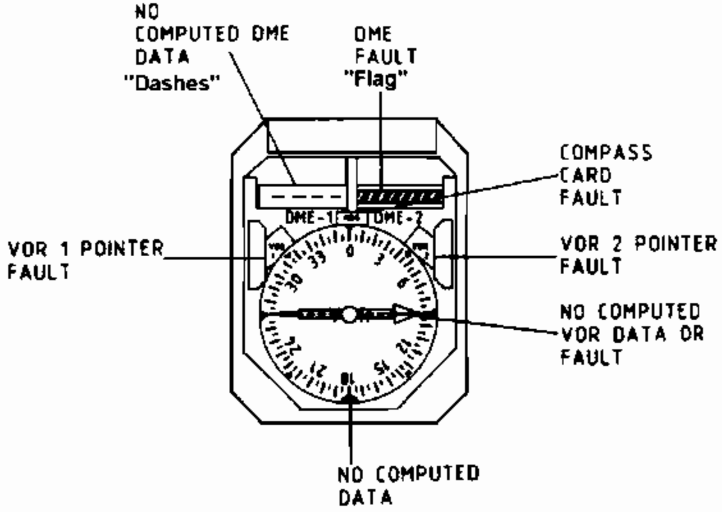
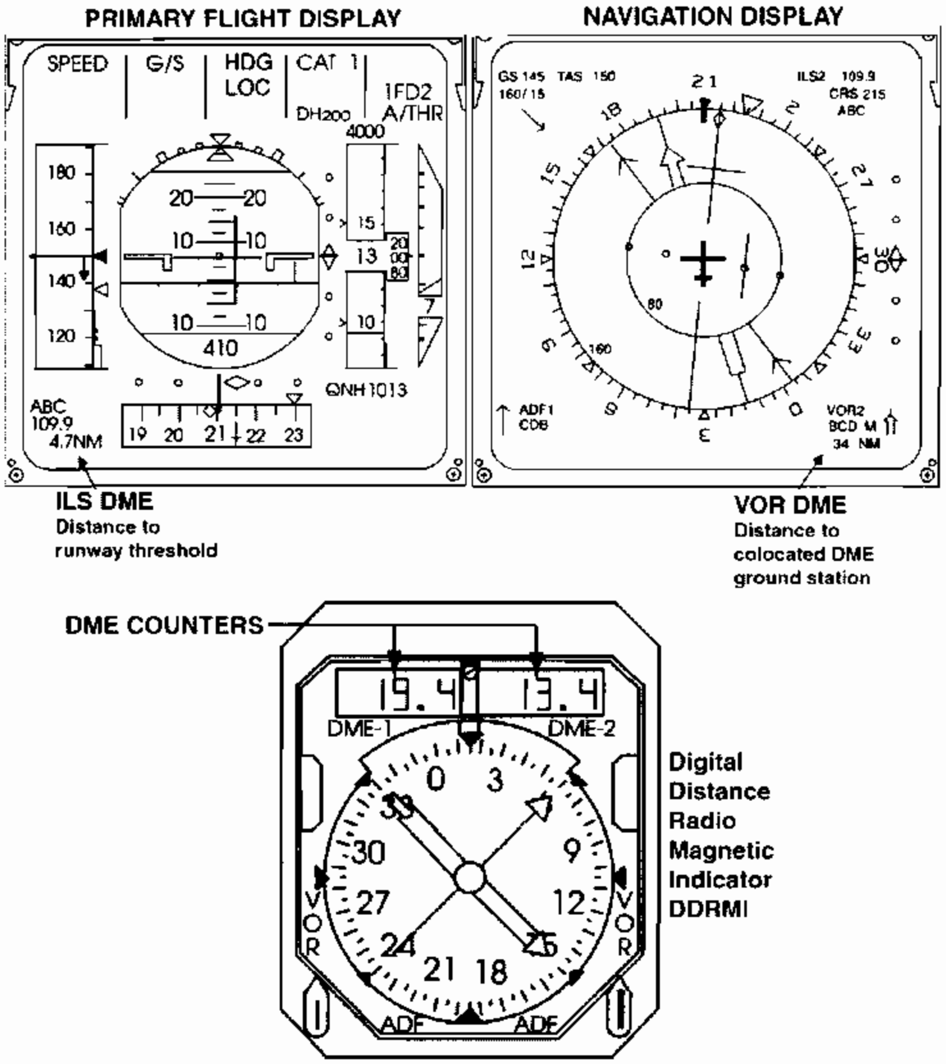


Figure 251:



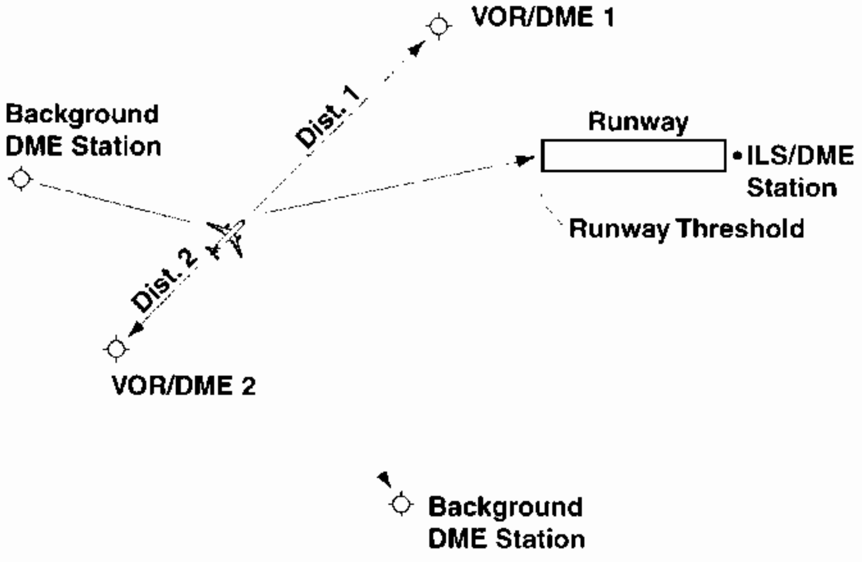
DME usage by Flight Management Systems FMS

If possible the FMS calculates the horizontal position (latitude and longitude) with distances from two DME stations (DME/DME). The FMS selects DME stations around the start position of the selected route from its internal data base. There must be an ideal angle between these stations (preferably 90°) to make an accurate two-dimensional navigation possible. The stations must also be strong enough and within a usable range. In areas with minimum radio coverage the FMS may be unable to find a suitable DME/DME pair. In these areas the FMS uses distance and bearing at a collocated VOR/DME station for its position calculations.

There are three ways to tune the VOR/DME systems:

- Automatic tuning by the FMS
  The FMS can tune the DME and VOR automatically. Although the FMS can tune the ILS, it tunes the DME to the ILS/DME frequency if the runway has DME installed.
  The FMS can automatically tune up to four VOR/DME stations and one ILS/DME station. The FMS uses two of the DME stations for its navigation. If the FMS cannot find two suitable DME stations, it selects the frequency of a collocated VOR/DME station.
- Manual tuning from the FMS Control Display Unit
  Through the CDU you manually select the identifier or frequency of a VOR/DME beacon for use in the DDRMIs.
- Manual tuning from Radio control panels
  You can tune the VOR/DME manually from its control panel on the pedestal. Information from this VOR/DME is shown on the CDU, ND's and DDRMIs.

Figure 252: Scanning DME 5 Channels



The Flight Management System uses all distance informations for aircraft position calculation.

- The DME slant distance to VOR/DME 1 and 2 is shown at DDRMI's and Navigation Displays.
- The slant distance to the both background stations are for FMS usage only.
- The slant distance to the ILS/DME station is shown on the Primary Flight Display.

DME System

Inputs

Each interrogator has 2 input busses (frequency input A and B) for frequency selections, one from the flight management system and one from the VOR/DME control panel. A test switch gives the possibility to test both DME systems.

Outputs

The interrogator has 2 output busses; distance data 1 and 2. One goes to the DDRMI's and to the EFIS. The second goes to the flight management system.

An audio output with the DME identification tones, goes to the audio management system. To listen to the DME you must select the associated potentiometer (VOR or ILS) at the audio control panel.

Suppression

When an interrogator transmits, it gives a suppression pulse to all other L-band equipment (other DME, ATC transponders and TCAS computer). This pulse protects these systems against high RF input power (up to 700 Watt) to their receivers and prevents distortions of their operation.

Antenna

A short, vertically polarized UHF whip or blade antenna is used. It is mounted on the center line of the bottom of the fuselage as far from any other antenna as is practical.

Figure 253:

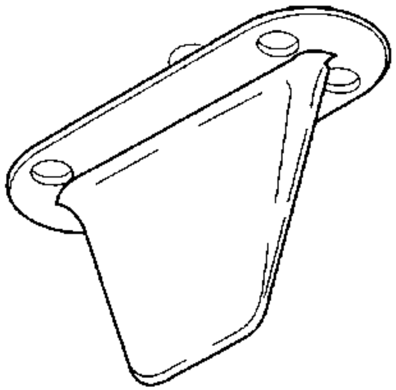
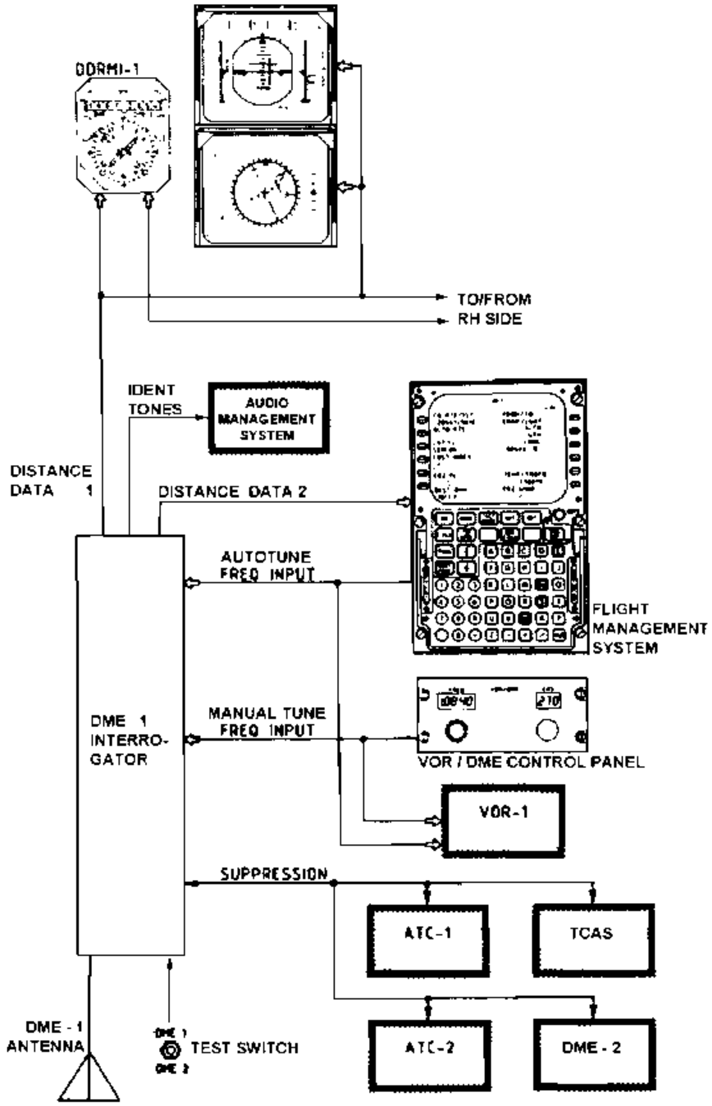


Figure 254: DME Interface



DME Interrogator

The DME interrogator has 3 modes of operation, which are:

- standby
- directed scan
- free scan

In the standby mode the distance displays on the DDRMIs and EFIS show 4 dashes because the ARINC 429 words is set to NCD. A system goes to standby when the frequency selection data is invalid.

In the directed scan mode there are 2 possibilities:

- manual
- automatic

In manual the VOR/DME control panel controls the frequency tuning. In this mode the DME measures the distance to only 1 DME ground station; the one you selected on the VOR/DME control panel.

In the automatic mode the DME can measure the distance of 1 up to 5 DME ground stations. On the output busses each frequency is followed by the associated distance to that station. Only the distance of one station is on the distance displays In the DDRMI and EFIS.

The FMS selects automatically the station which Is displayed. On the FMS display control unit, it is also possible to select manually a DME station for display on the DDRMI and EFIS. The information which station to display is in the DME frequency word.

The free scan mode is basically the same as the automatic directed scan mode. The difference is that the DME automatically selects 5 stations and gives the distance to these stations. The DME scans through all the 252 DME ground stations, and separates them in a foreground and a background loop. In the foreground loop are the 5 closest stations, which the flight management system can use for navigation. The rest of the stations within the range of the system is in the background loop. (The maxim range is 320 NM)

The flight management system selects between directed scan or free scan.

The power amplifier (PA) of the DME interrogator transmits 700 W pulses. The modulator and synthesizer take care of the proper frequency and pulse spacing. The frequency information comes through 2 ARINC 429 receivers. Which receiver is in use depends on the AUTO/MAN discrete from the cockpit selection.

In the frequency data word is also information about the mode of operation of the DME: for example free scan, directed scan 1 or 2 or 3 stations. The selected frequency goes to the synthesizer while channel Information (X or Y) goes to the interrogation coder, which takes care for the proper spacing between the pulses. The frequency information also goes to the output coder, because the frequency word (035) is retransmitted on the ARINC 429 output busses, paired with the associated distance.

The synthesizer also supplies the receiver, because the reply from the ground station is always 63 MHz above or below the interrogator frequency. During transmission of a pulse a suppression pulse detunes the input filter in the receiver The suppression pulse also goes to the other systems which operate in the same frequency band (the other DME, TCAS and the ATC transponders)

The receiver filters mixes, amplifies and detects the incoming signals. The ident detector applies the DME ident (1350 Hz) to the audio management unit. The threshold detector and pulse pair decoder detect valid pulse pairs. The pulses next go to the range counter, where the distance to the DME ground station is calculated.

Figure 255:

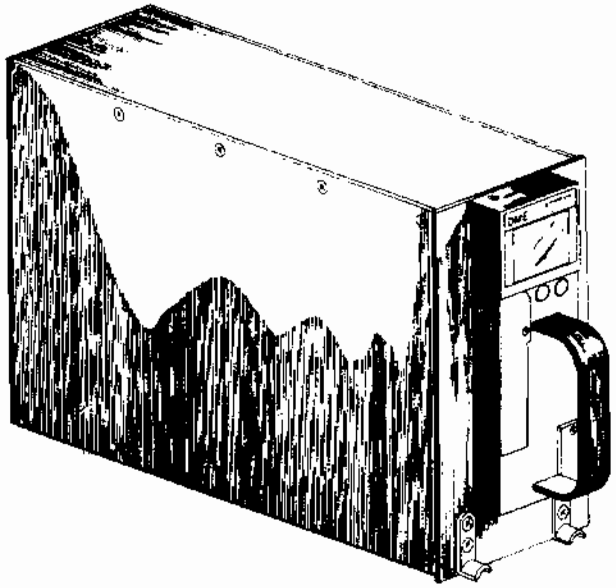
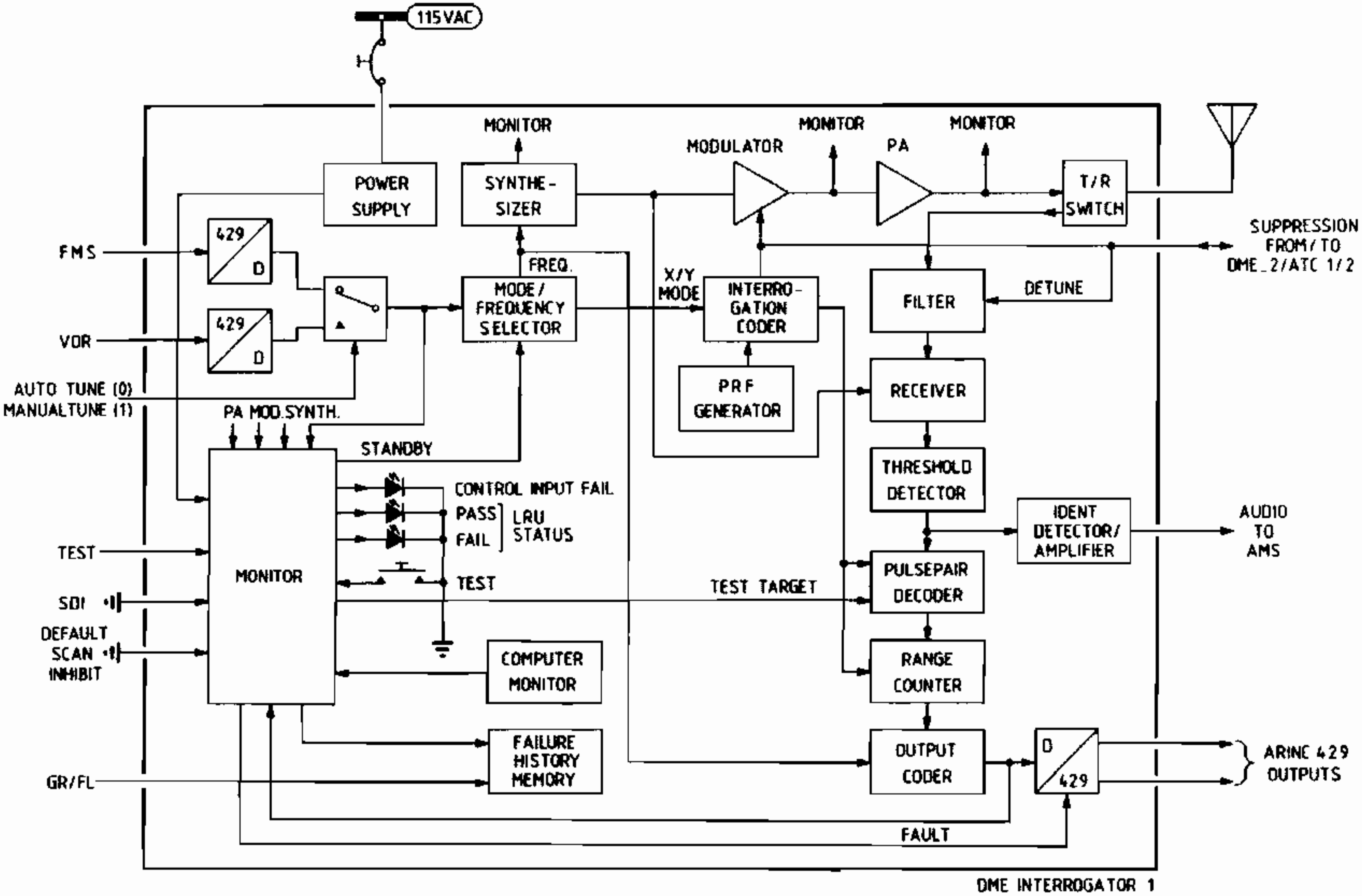


Figure 256: DME InterrogatorFunctional Block Diagram



Area Navigation

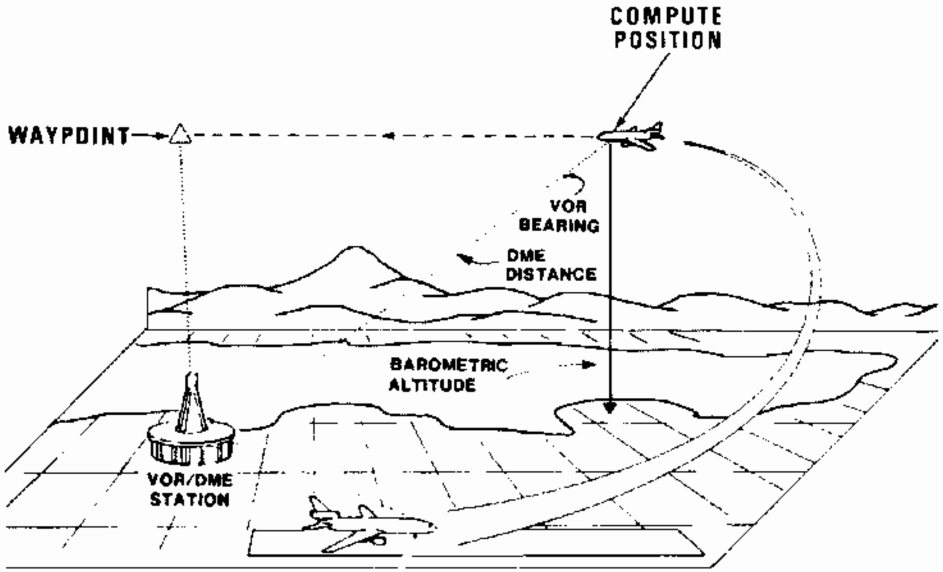
Introduction

Area navigation (RNAV) is a navigation and guidance system which uses VOR bearing, DME slant ranging, and barometric altitude as its basic signal inputs to compute course and distance to a waypoint. Since the system can only function within the service area of a VOR/DME station, it cannot be used for overseas navigation.

To fly over uncovered regions like oceans, deserts and unpopulated areas, the input of the inertial reference system and or global positioning system is needed.

The next devlopment step is the Flight Management System, covering also profile (vertical) navigation and engine thrust management.

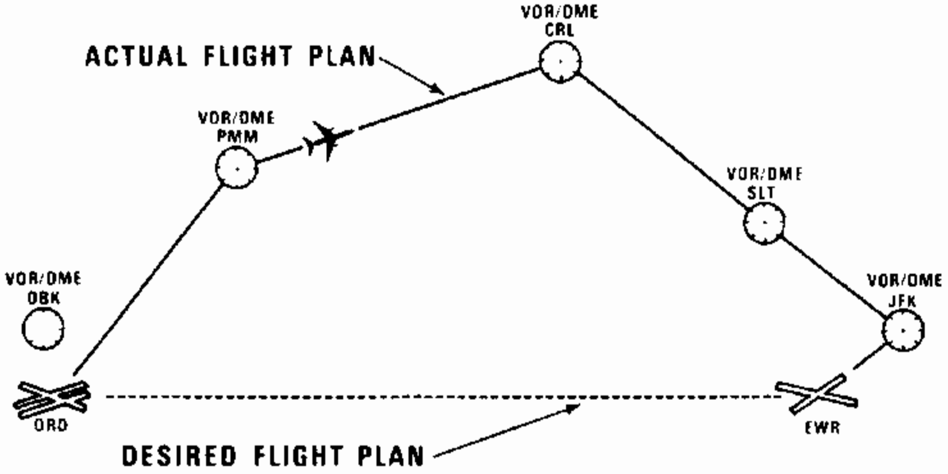
Figure 257: RNAV



VOR/DME flight

For example this is a flight plan between Chicago's O'Hare airport and Newark. The flight takes from one VOR station to another until, by a round about path, we arrive at Newark.

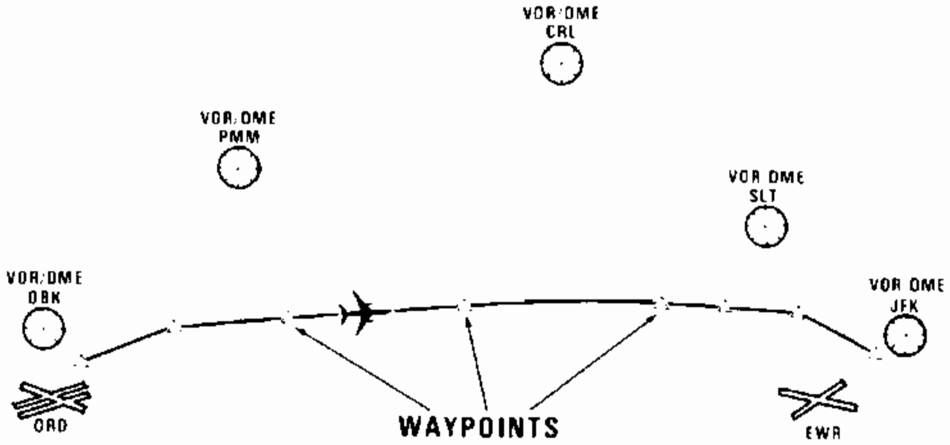
Figure 258: VOR Flight



Using Area Navigation RNAV

The area navigation concept provides direct routes between airports. Along each route there are waypoints towards which the airplane flies. The waypoint locations are established when the route is designed. Each waypoint is associated with a specific NAV aid or VOR/DME station.

Figure 259: RNAV Flight



Waypoint Characteristics

The navigational data base stored in the computer contains the following characteristics of each waypoint: latitude and longitude, altitude, frequency of its NAV aid, distance from the NAV aid, and magnetic bearing from the NAV aid.

If the VHF navigation system is tuned to the proper NAV aid, the area navigation computer will receive the information regarding the position of the aircraft in respect to the NAV aid.

Rho-Theta Mode

Knowing the DME distance, the bearing of the aircraft and the bearing of the waypoint, the system can compute the distance to the waypoint; and the course or track angle to the waypoint.

This combination is referred to as the Rho-Theta mode of area navigation, where Rho is the DME distance, and Theta is the VOR angle.

Rho-Rho Method

An improvement over Rho-Theta is possible using two DME distances. The navigation data base would be expanded to provide each waypoint with two NAV aid references.

Improved position accuracy is achieved along with improved navigational accuracy. Rho-Rho is the preferred method of area navigation.

Figure 260: Rho - Theta

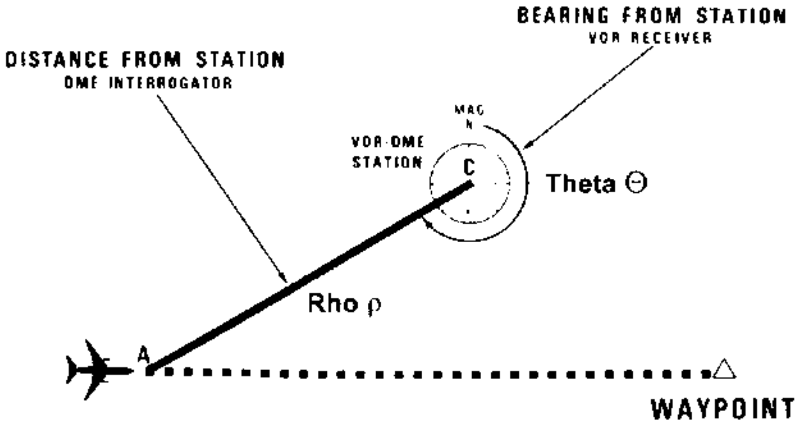
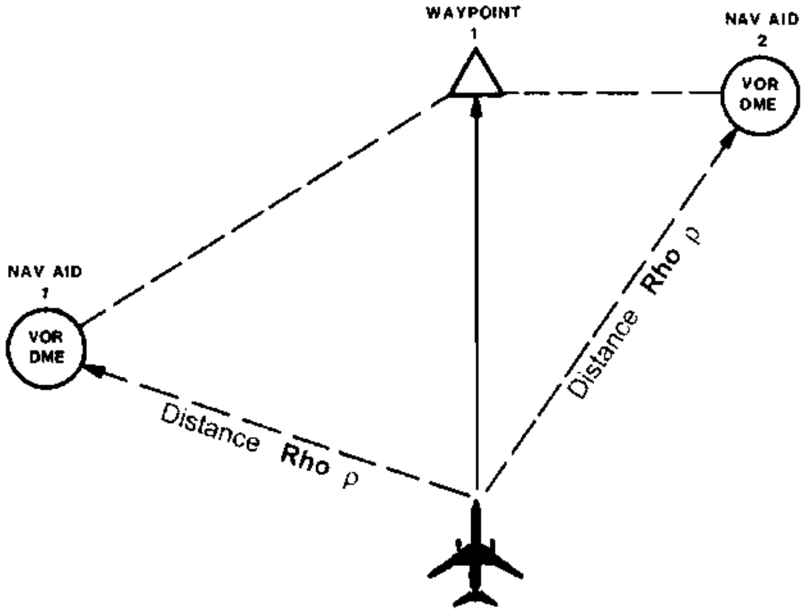


Figure 261: Rho - Rho



Block Diagram

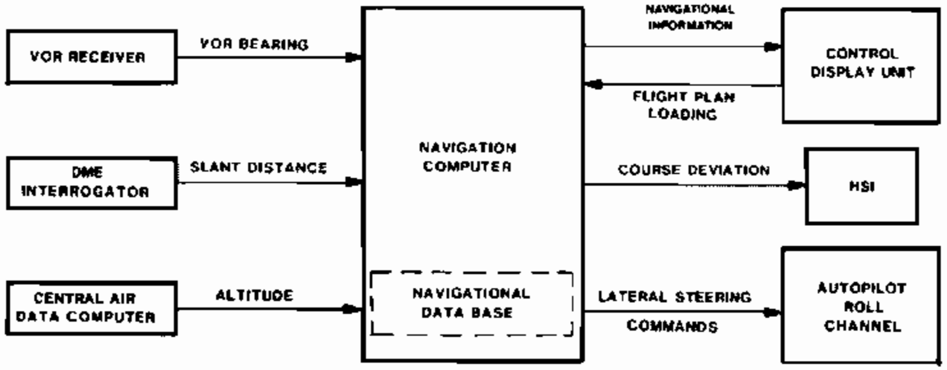
The navigation computer receives a VOR bearing from the VOR receiver, DME distance from the DME interrogator, and altitude from the central air data computer.

A navigational data base is stored either within the navigation computer or in an external storage unit. The navigational data base contains all information needed regarding the routes between cities, the navigation aids (VOR/DME stations) and waypoints.

The control display unit is used to enter information into the computer and to display navigation information. In a typical commercial airplane installation, the computer may also send course deviation signals to the course deviation indicator, and lateral steering commands to the autopilot.

Other inputs from Inertial Reference System IRS or Global Positioning System GPS provides further navigation data to fly over all regions over the world.

Figure 262:

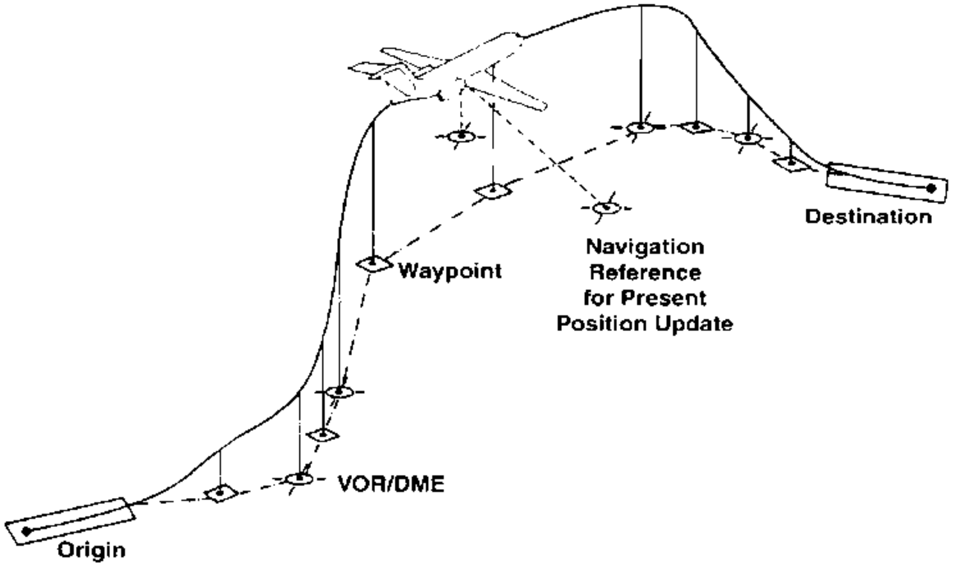


Flight Management

Introduction

The Flight Management System (FMS) compares a pilot selected flight plan with the actual horizontal and vertical aircraft position. In case of a difference between the selected flight plan and the aircraft position the FMS makes a steering and a thrust command.

Figure 263: Flight Route

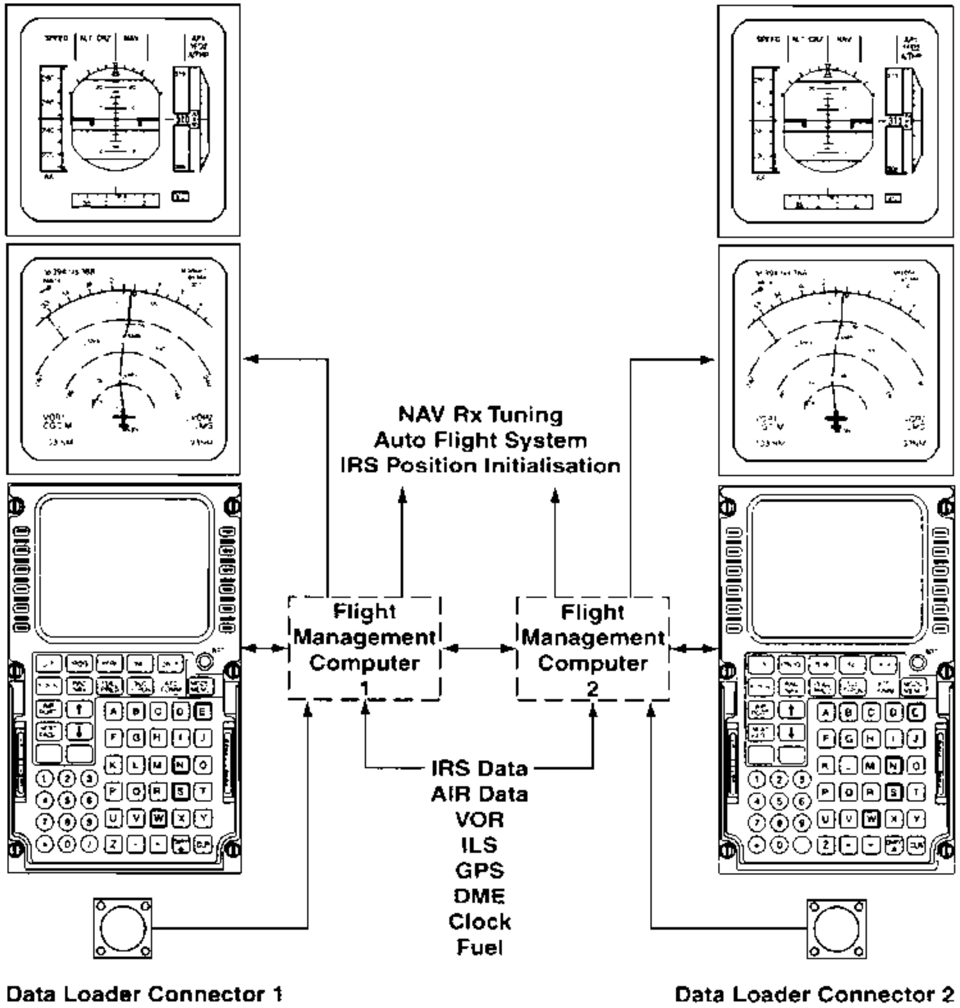


The FMS shows the information about the selected flight plan on the Control Display Unit (CDU). Through the keyboard of the CDU the crew can change the flight plan.

The FMS gives the steering and thrust commands to the AFS. The AFS can use the commands to fly the aircraft automatically on the flight plan. The AFS can also use the commands to the crew through the flight director command cues.The FMS also gives information to the EFIS to show the flight plan on the navigation display.

AFS = Auto Flight System (Autopilot/Autothrottle)

Figure 264: FMS Interface



The FMS uses information from various aircraft systems and from a data base.

Navigation. The FMS uses information from its data base to automatically tune the navaids (ILS, VOR and DME). With these navaids, the FMS measures the aircraft's position, direction, and velocity.

Performance. The FMS calculates a vertical profile that gives the shortest possible flying time at the lowest fuel consumption. The FMS also can give predictions of fuel quantities and arrival times at future points in the flight plan.

Guidance. The FMS compares the position where the aircraft has to be according to the flight plan, with the actual aircraft position. If there is a difference, the FMS gives guidance commands to the AFS to bring the aircraft back to the flight plan.

EFIS display. The FMS is the primary source of information for the displays.

In the FMS data base there is information about flight plans, navaids, aircraft aerodynamics and engine data. The flight plan and navaid data must have an update every 28 days. To start the FMS the crew has to select a flight plan on the CDU. After the selection, the FMS takes the flight plan out of the data base and puts it in the flight plan memory for use in that flight. The crew adds Standard Instrument Departures (SID) and Standard Arrival Routes (STAR) when traffic control gives these procedures.

After these selections the FMS knows the horizontal path that the aircraft must follow from the origin airport to the destination airport. With information from the data base about navaids that give the best result for navigation, the FMS tunes the ILS VOR and DME automatically. The FMS uses information from the IRS, GPS, DME and VOR to calculate the aircraft position, direction and velocity.

To calculate the optimum vertical path of the aircraft the crew give the FMS more information, such as the:

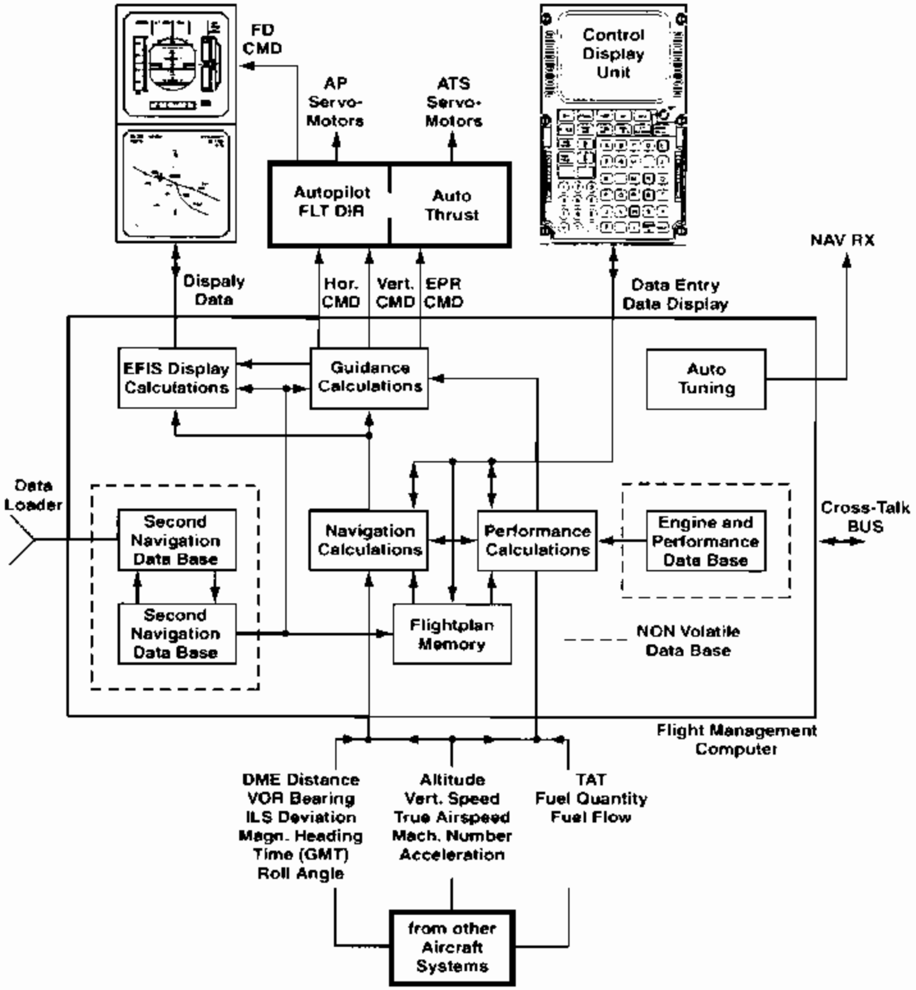
- cruise altitude (traffic control)
- aircraft weight
- standard instrument departure (traffic control)

Before the FMS starts to calculate the optimum vertical path the crew must select an overall target for the flight economy. There are three targets for the whole flight profile; minimum cost, minimum fuel, or minimum flight duration. When the FMS has this information it calculates the optimum vertical path in combination with the horizontal path.

The crew can change the horizontal and vertical path through the CDUs. In most cases, the crew does not change the horizontal path but the vertical path.

The reason for this is traffic control. When there are many aircraft in the same airway section traffic control puts these aircraft above each other in the airway.

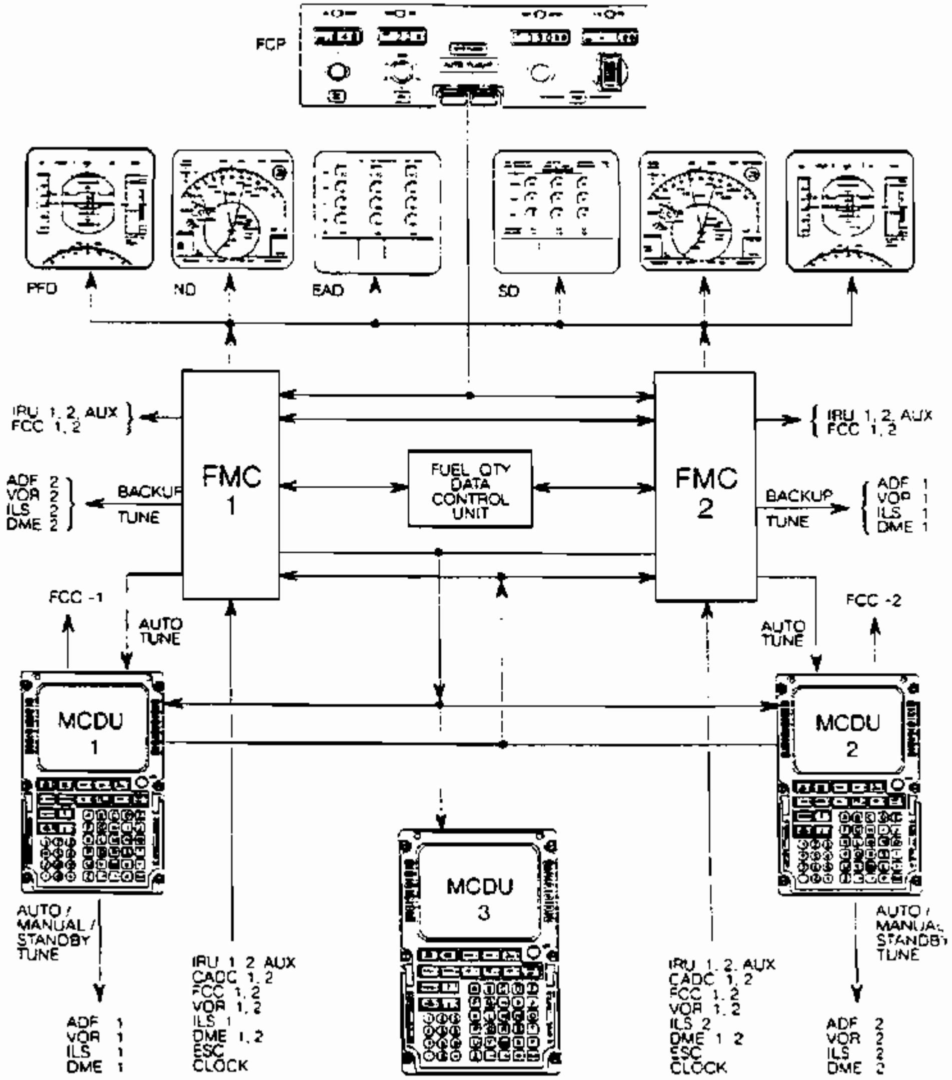
Figure 265: FMS Blockdiagram



Flight Management System MD-11

Notes:

Figure 266: Flight Management System MD-11



Computation of Position

The Flight Management Computer or Area Navigation Computer computes its aircraft position (called the "FM position") from a MIX IRS position and computed radio position or a GPS position. The computer selects the most accurate position considering the estimated accuracy and integrity of each positioning equipment. GPS/INERTIAL is the basic navigation mode provided GPS data are valid and successfully tested. Otherwise navaids plus inertial or inertial only are used.

Mix IRS Position

The FMS or ANS receives a position from each of the three IRS and computes a mean weighted average called the "MIX IRS" position. If one of the IRS fails, the computer uses only one IRS. Each IRS position and velocity is continuously tested. If the test fails, the corresponding IRS is rejected. (Accuracy: 2 NM/h)

Radio Position

The FMS or ANS uses the navaids to compute its radio position. The navaids it can use are: DME/DME, VOR/DME, LOC, DME/DME/LOC, VOR/DME/LOC. It uses LOC to update the lateral position using LOC beam during ILS approach. LOC is also used for quick update when in GPS/IRS mode (if GPS installed). (Accuracy: 0.3 NM)

GPS Position

If the GPS data comply with integrity criteria, GPS data are used to calculate the FMS position. (GPS Primary) (Accuracy < 0.3 NM)

FM Position

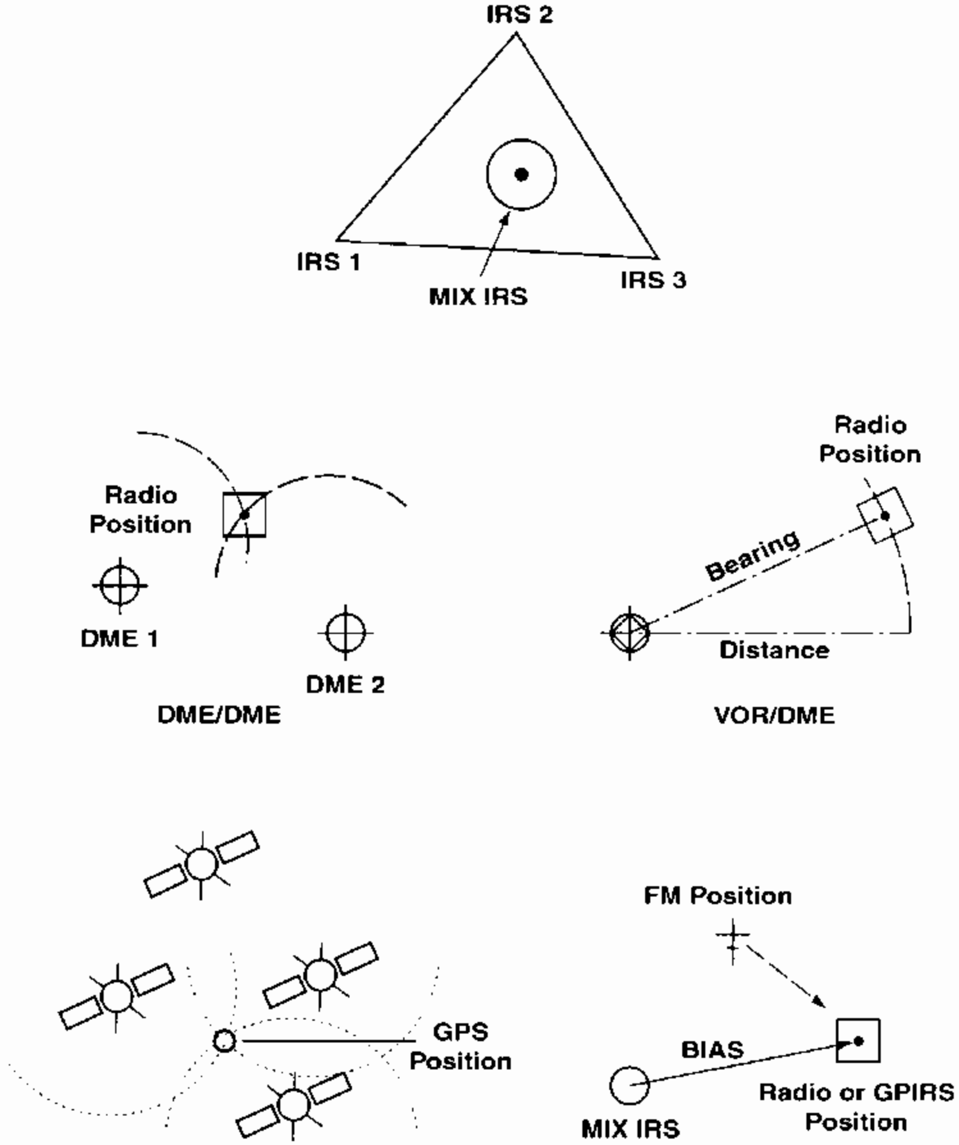
At takeoff, the FM position is updated to the runway threshold position as stored in the data base. In flight, the FM position approaches the GPS position (or the radio position if the GPS is not valid) at a rate depending upon the aircraft altitude. Accuracy: Enroute 3.5 NM, Terminal 2 NM, Approach 0.36 NM)

Bias

Each FMGC computes a vector from its MixIRS position to the radio or GPIRS position. This vector is called the "bias". The FMS updates the bias continuously if a radio position or a GPS/IRS position is available.

If an FMGC loses its radio/GPIRS position, it memorizes the bias and uses it to compute the FM position, which equals the mix IRS position plus the bias.

Figure 267:



FMS Functions

The Flight Management System combines lateral and vertical navigation control with full performance management. Not only can it quickly define a desired route from the aircraft's current position to any point in the world. The definition will be based on the operating characteristics of the aircraft.

FMS navigation provides highly accurate and automatic long range capability by blending available inputs from both long range and short range sensors such as IRS, VLF/Omega, GPS (Global Positioning System), VOR and Scanning DME, to develop an FMS position more accurate than any single sensor can provide. The FMS performs flight plan computations, displays the total picture on the EFIS, and provides signals to the autopilot and autothrottle for automatic tracking.

The Flight Management System (FMS) makes a flightplan. This flightplan is a lateral flightplan to the selected destination and a vertical flightplan to the selected cruise altitude.

The lateral flight plan exists of flight legs. Speeds and altitudes are added to these flight legs. The total of the speeds and altitudes is the vertical flightplan.

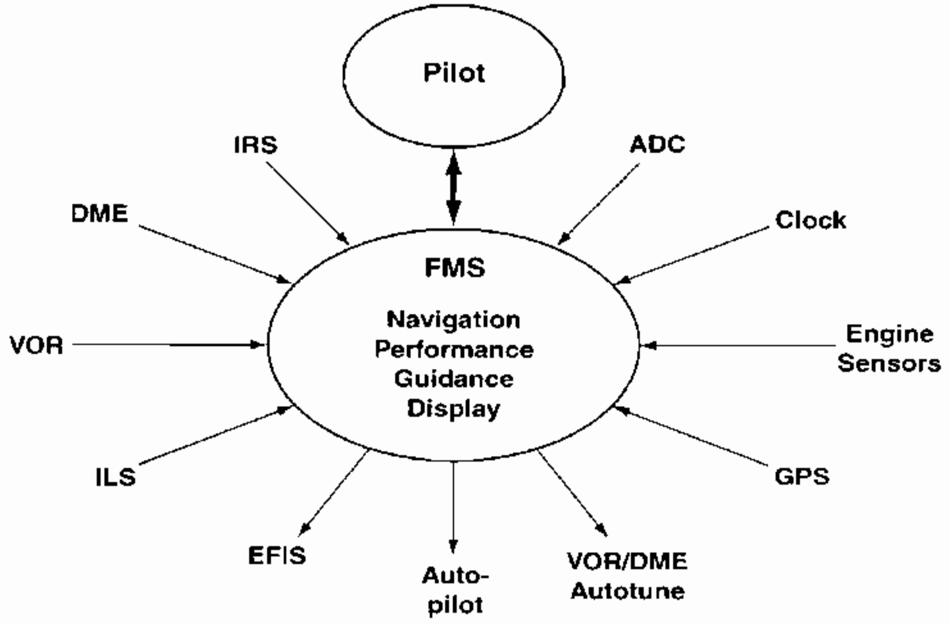
After a lateral flightplan selection additional data (i.e.; weight, cruise altitude) is inserted to calculate the vertical flightplan.

During aircraft operation FMS updates the aircraft position. This present position in relation to the flightplan is shown on the Electronic Flight Instrument System (EFIS).

The FMS makes steering commands to maintain the aircraft on the lateral and vertical flightplan. The Automatic Flight Control and Augmentation System (AFCAS) accepts the steering commands to follow the flightplan path.

These functions of the FMS take over many routine tasks and computations normally done by the flight crew.

Figure 268: FMS Tasks



The Lateral Flightplan

The lateral flightplan comes from a navigation database in the FMS. This navigation data base contains company routes (lateral flightplans), navigation station information and navigation references (waypoints). Before each flight the crew selects the lateral flightplan from this navigation database.

The navigation database information changes from time to time. It changes because of introduction of new company routes. The navigation stations are not always available because of periodic maintenance on these stations. The navigation database in the FMS is updated with the latest information every 28 days.

In addition to the flightplan selection the crew also has to tell the FMS what the start position of the aircraft is. The FMS gives the start position from the selected flightplan as a present position. When the crew confirms this present position to the FMS, the FMS accepts this present position information.

The flightplan is a route from airport to airport. In addition to this flightplan the crew must specify a take-off procedure and an approach procedure. The Standard Instrument Departure (SID) is the route from the take-off runway to the begin of the flightplan. The Standard Arrival Route (STAR) is the route from the end of the flightplan to the runway of the destination.

When the flightplan is inserted and the position of the aircraft is confirmed the FMS starts to navigate. During the navigation operation the present position of the aircraft is updated by the FMS. The FMS updates the present position with the IRS (senses motions and attitude changes) and the VOR, DME, ILS and GPS systems (senses direction and distances to navigation ground stations).

The present position of the aircraft is compared with the position of the flightplan. Any deviation from the flightplan results in a deviation indication on EFIS.

Roll steering commands are generated to follow the lateral flightplan if the Autopilot operates in the NAV mode.

SID	Standard Instrument Departure
STAR	Standard Arrival Route

Figure 269: Flight Plan

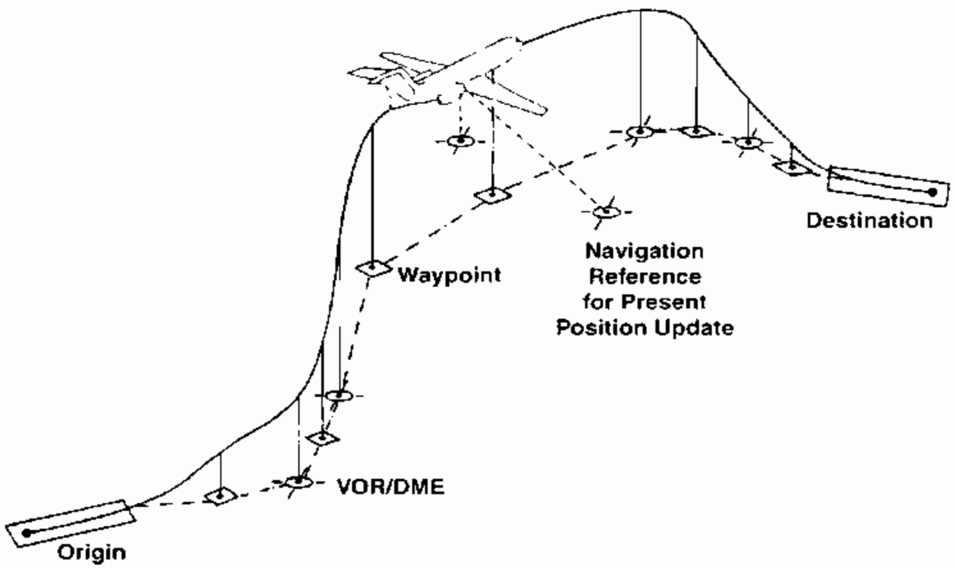
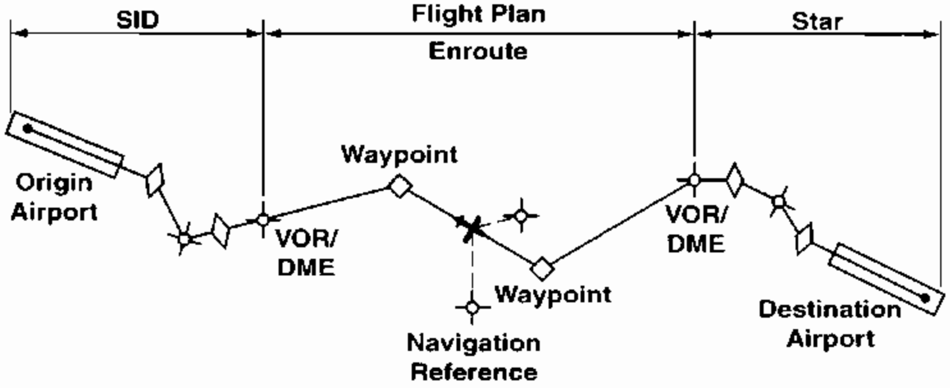


Figure 270: Lateral Flight Plan



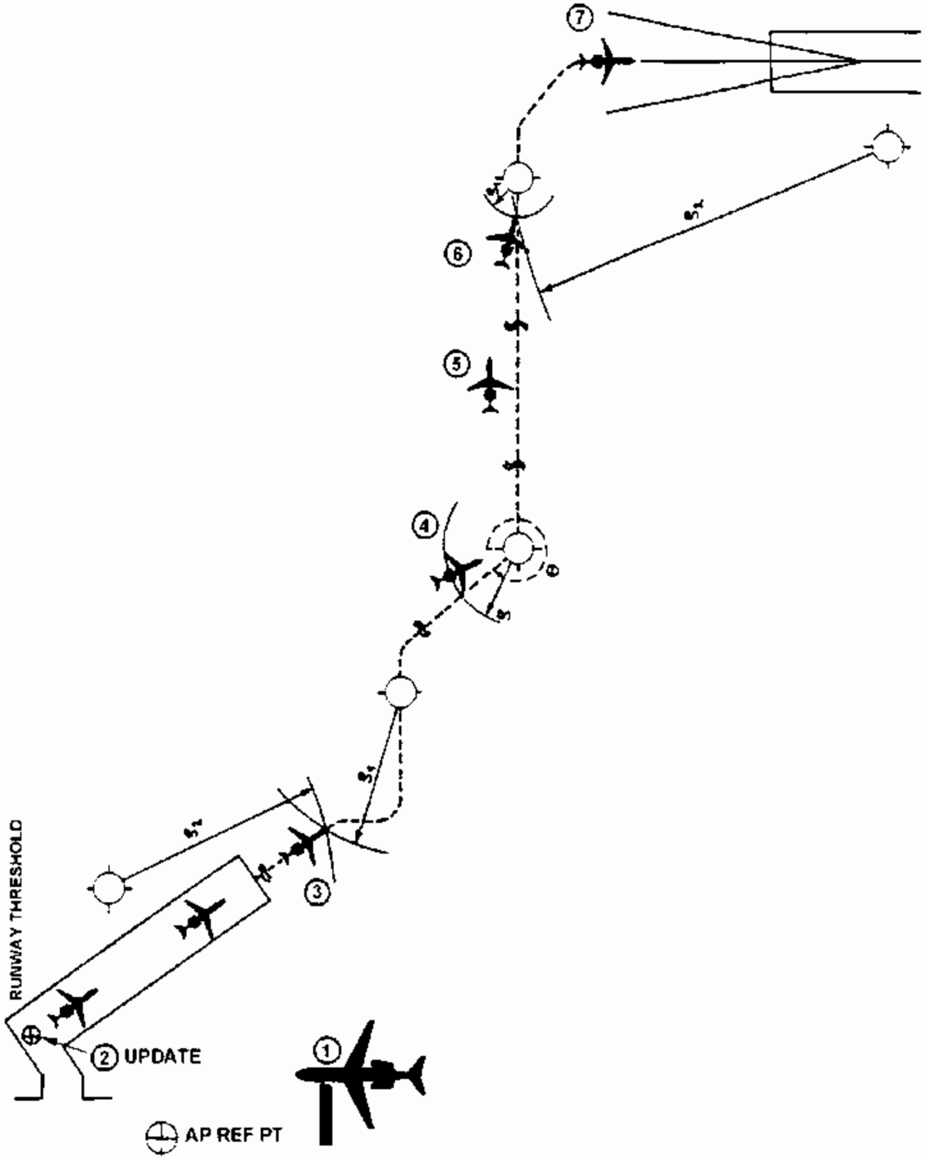
AREA Navigation System RNAV

The RNAV system is identical to the Flight management system, containing the lateral (horizontal) navigation part. The VOR/DME stations can be located besides of the route. The routes and its waypoints are calculated and based on the radio navigation aids.

Example of a FMS or RNAV guided flight See next drawing.

1. FMS Position at Airport Reference Poin
2. FMS Position updated by Take Off initiation
3. Dual DME update (ρ/ρ) R/I Mode
4. VOR/DME update (Θ/ρ) R/I Mode
5. No VOR/DME coverage I Mode
6. Dual DME update (ρ/ρ) R/I Mode
7. Dual DME and Lateral update by Localizer R/I Mode

Figure 271: FMS or RNAV guided flight



Performance Management

Speeds, altitude and engine thrust computed in the flight plan. The total weight and altitudes must be inserted to calculate the flight plan and optimization of the aircraft performance.

The perfomance computation reduces the fuel consumption. Via selection of the best strategy, between 1 and 2 % of energy can be saved.

How the Performance management saves fuel:

- Calculation of the flight profile (Vertical Flight Plan) and optimization of speed and altitude depending aircraft weight, fuel weight and time.
- Computation of Engine thrust limits for all flight phases.
- Direct coupling of engine thrust demand to the engine fuel control device. auto throttle system or electronic fuel control.
- Controlling the engine thrust with a minimum of change the demanded thrust.
- Indication of the recommendations to the pilots for optimum climb, cruise and descent.

The vertical flight plan is calculated in the FMS. For these vertical flight plan calculations the FMS uses:

- the aircraft model database (this database contains the aerodynamic specifications of the respective aircraft type)
- the engine database (this database contains performance specifications of the engine)
- the inserted weights of the total aircraft (including passengers, luggage and fuel)
- the selected altitude
- the windspeed and winddirection information.

After the vertical flight plan calculation the FMS shows predictions of time, speed and altitude the aircraft will have on the different reference points in its flight plan.

During flight the FMS updates the aircraft altitude with the ADC (altitude) and IRS (inertial vertical speed and inertial altitude) inputs. Any deviation from the vertical flight plan results in a vertical deviation indication on EFIS.

Figure 272: Performance Computation

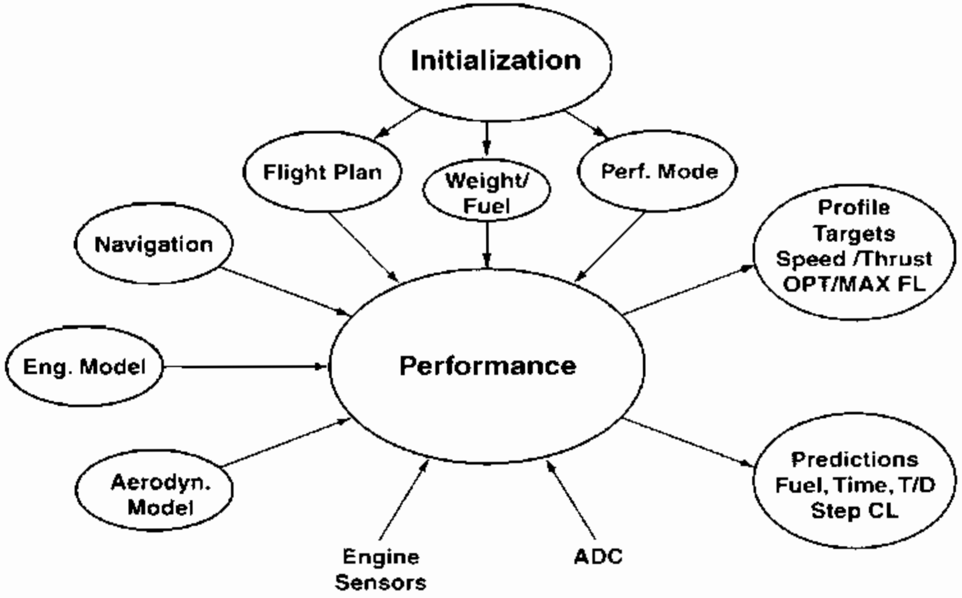
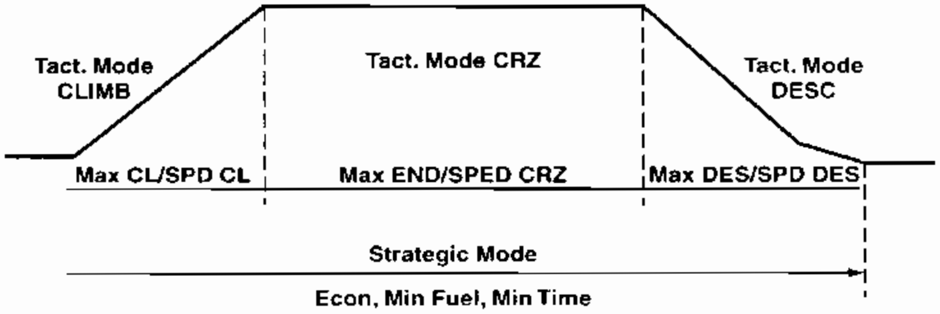


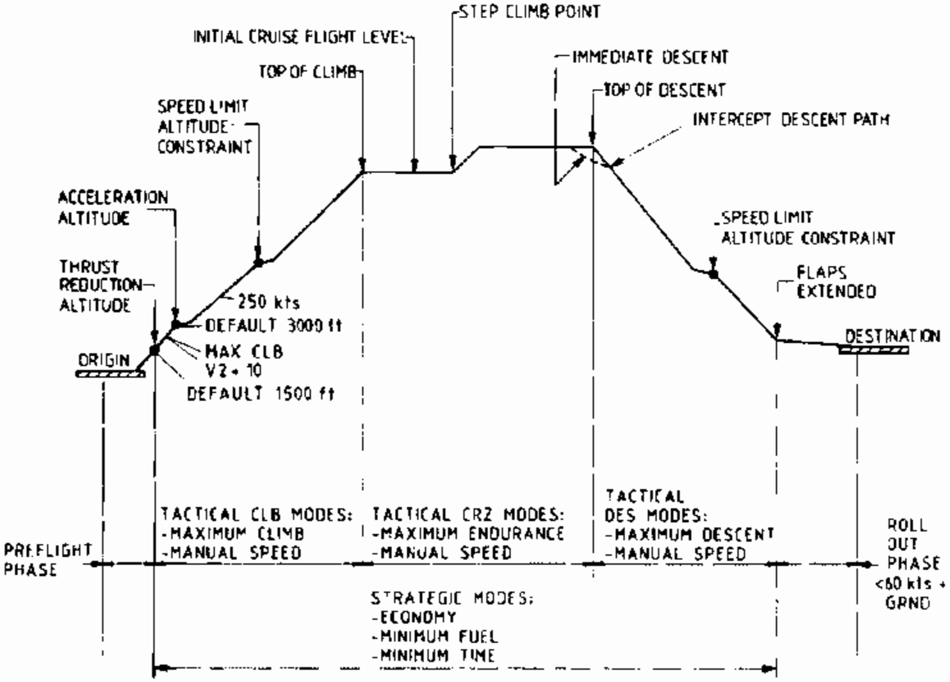
Figure 273: Tactical Modes



The Vertical Flight Profile

- Thrust and pitch steering commands are generated to follow the vertical flight plan if Auto Flight System operates in the PROFILE mode.
- A vertical flight plan from origin to destination exists of a takeoff phase, a climb phase, a cruise phase, a descent phase and an approach phase.
- The takeoff phase starts when takeoff thrust is developed by the engines on the takeoff runway.
- The climb phase starts at the thrust reduction altitude (1500 feet according IATA profile). At this thrust reduction altitude the takeoff thrust is reduced to climb thrust.
- At 3000 feet above the airport level (acceleration altitude) the speed is increased to 250 kts. This is the maximum allowable speed below 10,000 feet.
- At 10,000 feet the aircraft accelerates to a higher speed.
- The cruise phase starts at the top of climb and ends at the top of descent.
- The descent phase starts at the top of descent and ends at the time the crew selects the flaps down. At 10,000 feet the speed is decreased to 250 kts. (maximum allowable speed below 10,000 feet).
- The approach phase starts after flap down selection and ends at runway touch down.

Figure 274: Flight Profile



Navigation Database

The dataloader connectors located in cockpit or avionics bay is used to update the navigation database once in the 4 weeks. Each FMC has its own data-load connector. With a portable dataloader the new navigation database is loaded from a tape or diskette into the FMC. Any dataloader fullfilling the specification can be connected to the dataload connector.

- New data base content will be uploaded every 28 calendar days

Figure 275: FMS Blockdiagram

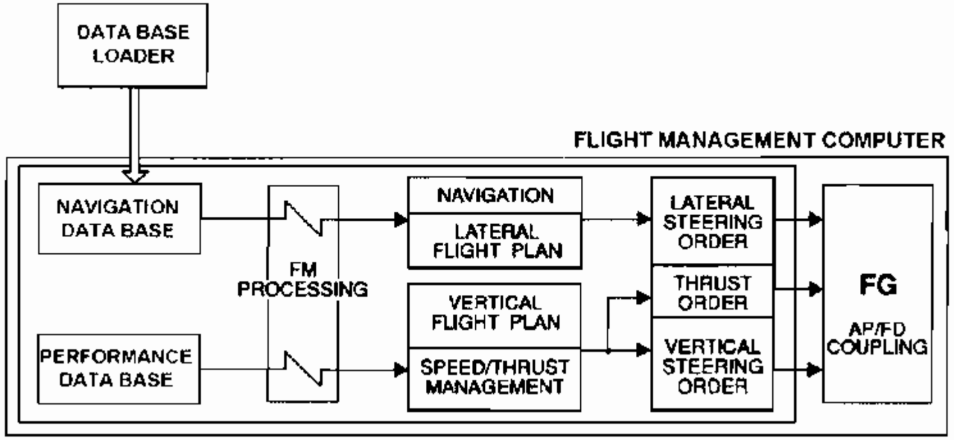


Figure 276: Data Base Loader

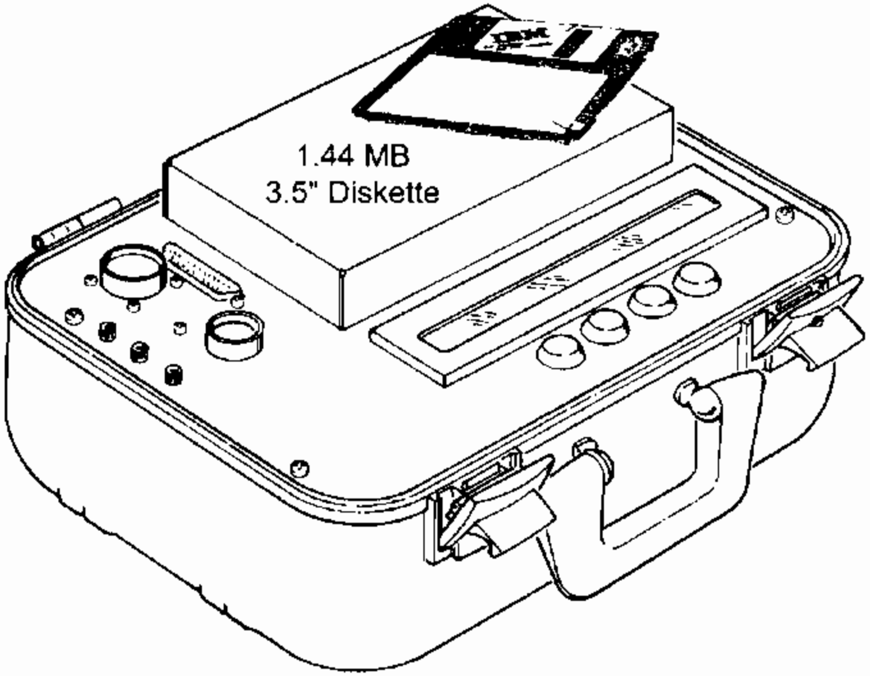
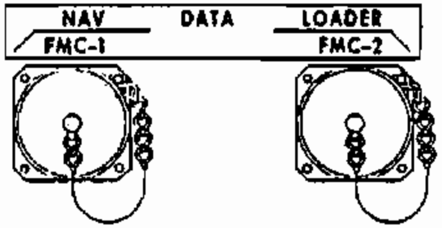


Figure 277: Receptacles for Data Base Loader



Radio Altimeter

Fundametals

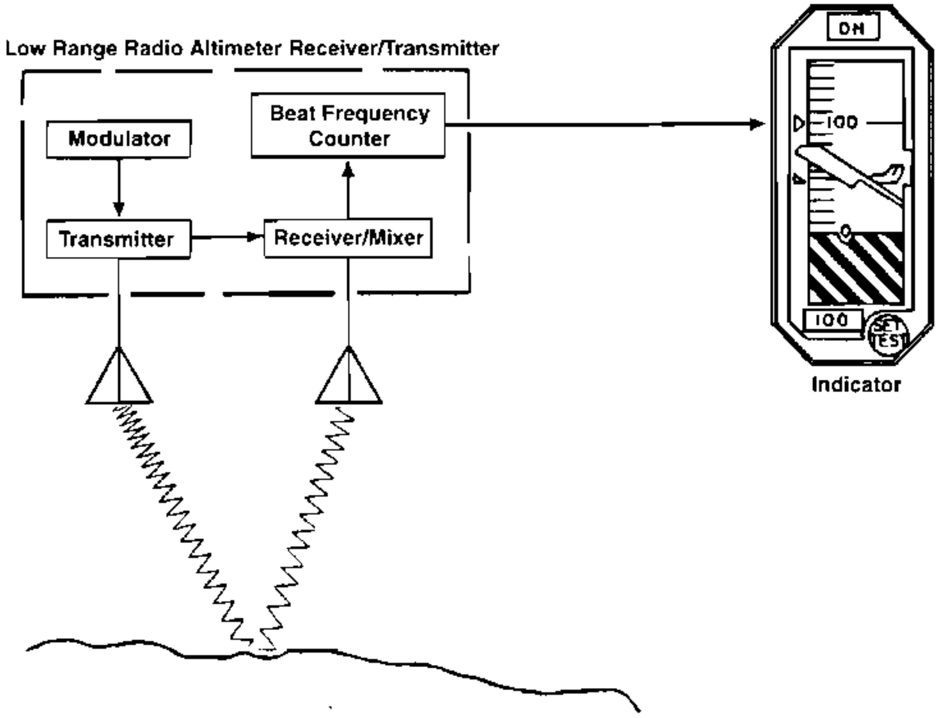
The Radio Altimeter System determines the height of the aircraft above the terrain during initial climb, approach and landing phases.

The principle of the radio altimeter is to transmit a frequency modulated signal, from the aircraft to the ground, and to receive the ground reflected signal after a certain delay. The time between the transmission and the reception of the signal is proportional to the A/ C height.

Frequency: 4.3 GHz

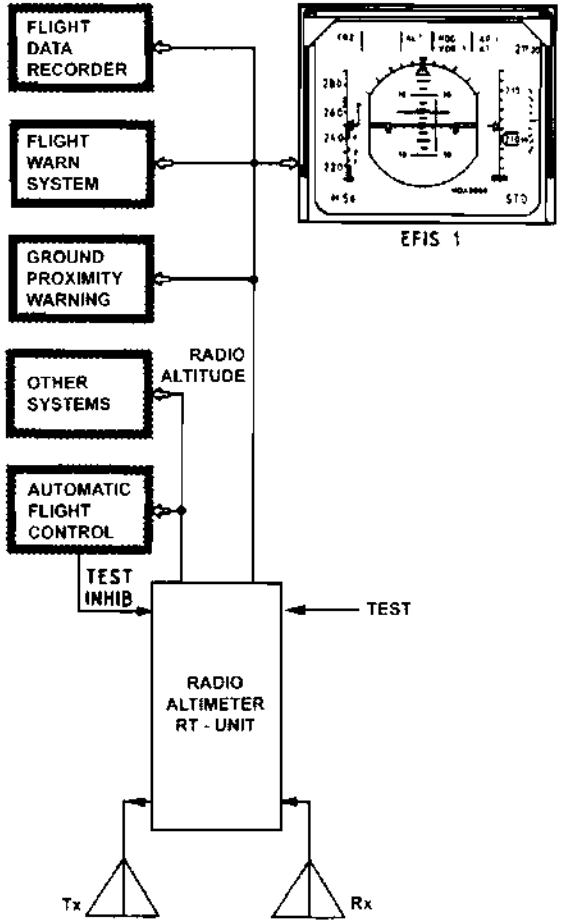
Maximum height: 2500 feet

Figure 278: Principle



The RT Unit send the radioaltitude to the indicator system (EFIS or conventional instruments) and to other systems. Flight data recorder for investigations. Flight warn system for altitude call out during approach and failure monitoring. Ground proximity warning for pilot alerting. The automatic flight control system (Autopilot) uses the height for automatic landings. During this phase of flight the selftest of the RT Unit is inhibited to prevent a false maneuvre. The selftest can be initiated from the cockpit or at the RT Unit.

Figure 279: System



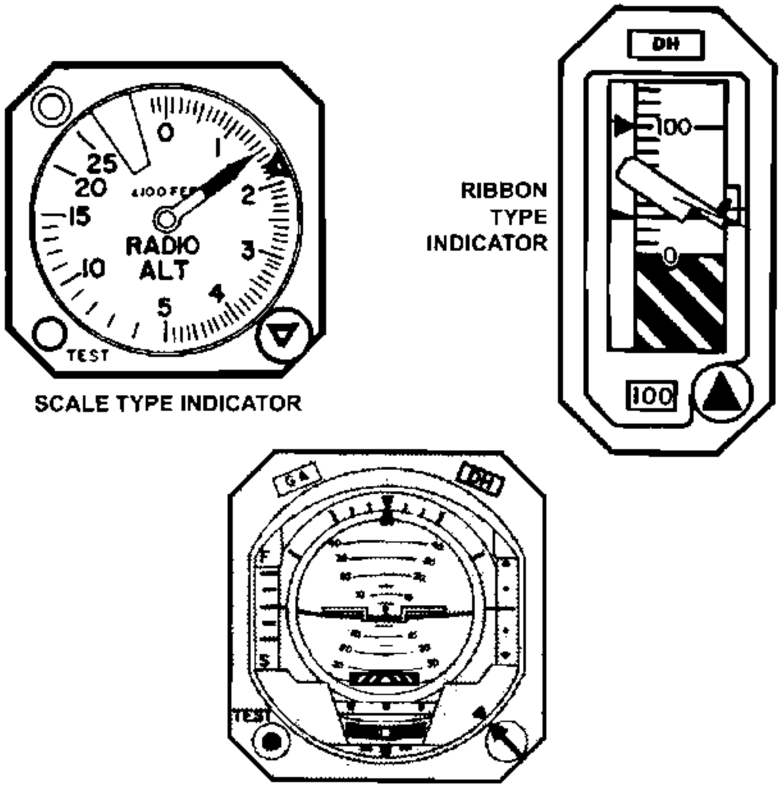
Radio Altimeter Indication

Analog instruments showing the aircraft height during take off and approach. Above 2500 feet the poiner is not visible respective the tape with the scale shows blank.

The DH light illuminates when the aircraft height is equal or lower than the selected decision hight. A sound is audible when the light turns on.

The rising runway represents the height below 200 feet during approach. At ground it is close to the aircraft symbol.

Figure 280: Radio Altimeter Indicators and Rising Runway



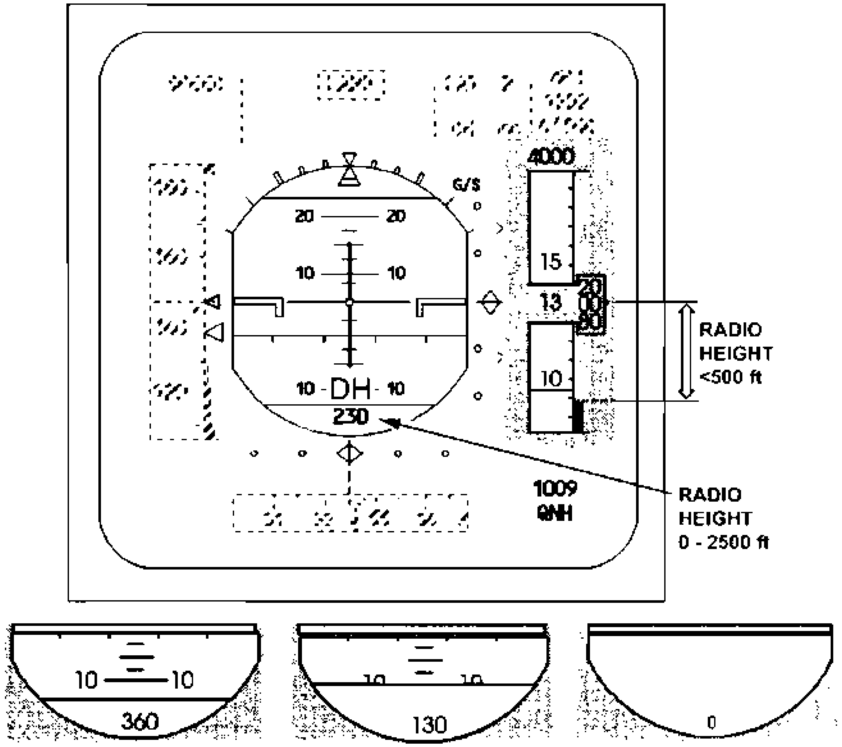
SCALE TYPE INDICATOR

RIBBON TYPE INDICATOR

FLGHT DIRECTOR HORIZON WITH RISING RUNWAY

The PFD shows the radio height in digital form. DH is shown when the aircraft decents under the selected decision height.

Figure 281: Primary Flight Display



Final phase of approach

Final phase of approach below 150ft

On ground

In the final phase of an approach below 150 feet, the lower limit on the attitude sphere moves up as the aircraft approaches the ground. The distance between the lower limit and the horizon line is proportional to the aircraft height.

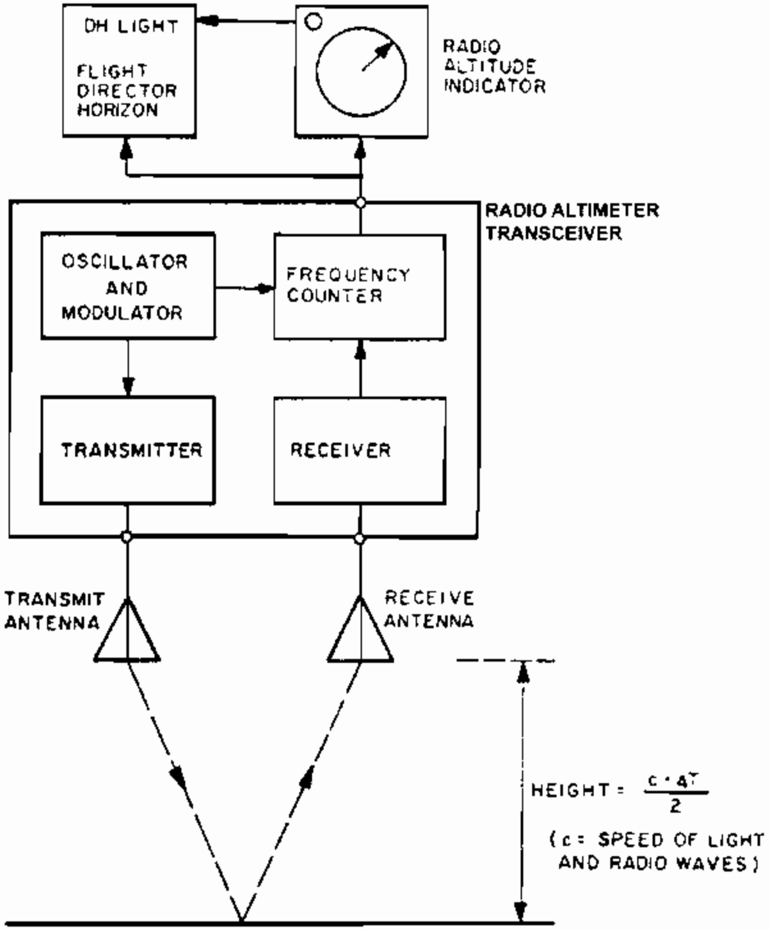
Automatic Call Out

Below 400 feet, the radio altitude is announced by a synthetic voice generated by the Flight Warning Computer.

Principle

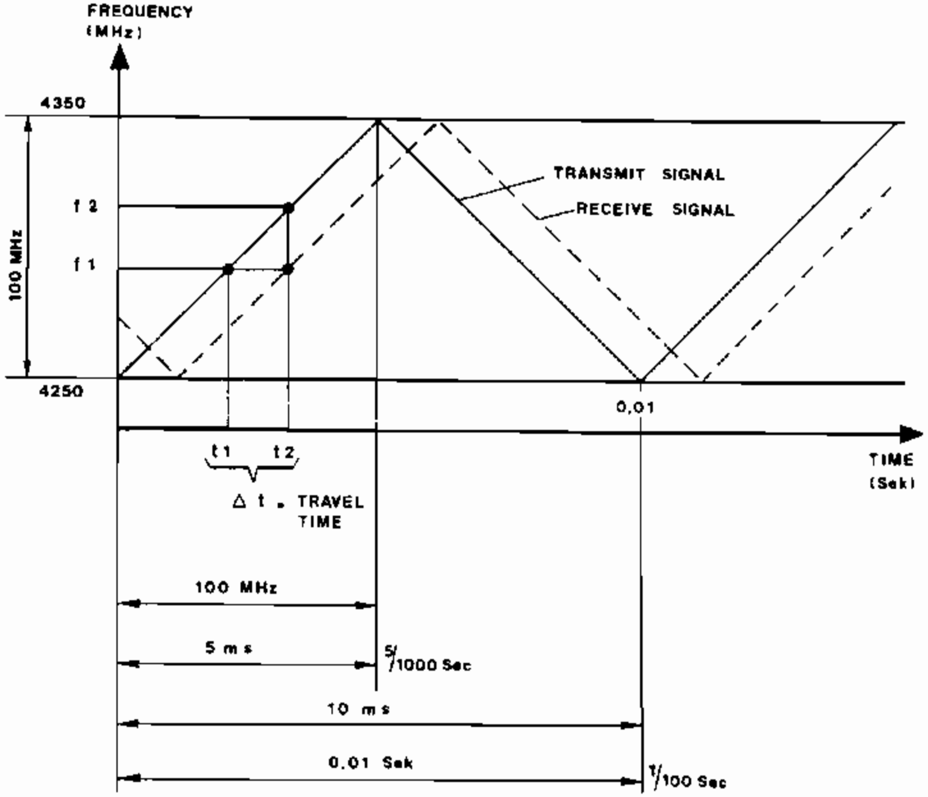
The system continuousliy transmits radio signal to the ground. The ground reflects this signal and it comes back in the aircraft after a delay. This delay depends on the height of the aircraft above terrain. The system processes this delay into altitude information. A visual presentation of the altitude is on the EFIS or at the radioaltimeter indicator with flightdirector horizon for the final approaches.

Figure 282:



The transmitter sends a signal that changes from 4'250MHz to 4'350 MHz and back 100 times per second (FM/CW). The transmit frequency changes 100 times per second around 100 MHz. Between the ground reflected signal and the actual transmit signal, there is a frequency difference proportional of the traveltime. Out of the difference frequency the system computes the height.

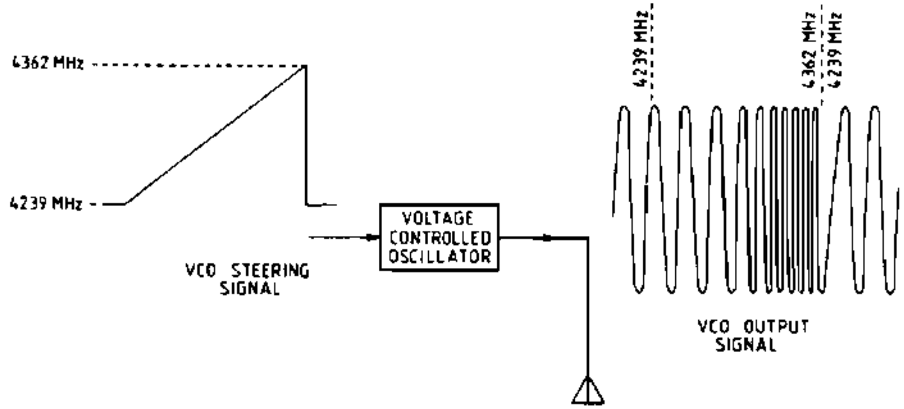
Figure 283: Tx Rx Signal



Transceiver

The radio altitude transmitter is a Voltage Controlled Oscillator (VCO). The control signal is a sawtooth voltage. This sawtooth signal causes the VCO to make a sweep through a frequency band from 4239 MHz to 4362 MHz (FM sweep of 123 MHz). The output of the VCO (75 mW) goes to the TX antenna, which transmits it to the ground. The delay time between transmission and reception depends on the height of the aircraft. The received signal goes to the mixer together with a sample of the transmitter signal. The frequency of this sample changes during the delay time (TX sweep). The mixer gives now a difference in frequency, which goes to a 25 kHz detector. The output of the 25 kHz detector goes to the track control circuit. This circuit gives a positive or negative control signal to the sawtooth generator, when the output of the detector is higher or lower than 25 kHz (higher or lower altitude).

Figure 284: VCO Signal



This signal controls the slope of the sawtooth. The length of this sawtooth is a measure of the height of the aircraft. The pulse to hight converter changes the sawtooth in a digital altitude signal. If the 25 kHz detector gives no output, a search switch comes on. The sawtooth generator makes a sweep through the full range of the system from the lowest altitude up to the highest limit. One search cycle takes about 0,6 sec and goes on for as long as there is no output from the detector. This occurs when we switch the system on or when aircraft altitude becomes more than the system range. During a search cycle the SSM goes to NCD.

Figure 285: Low and high Altitude Oscilator Signal

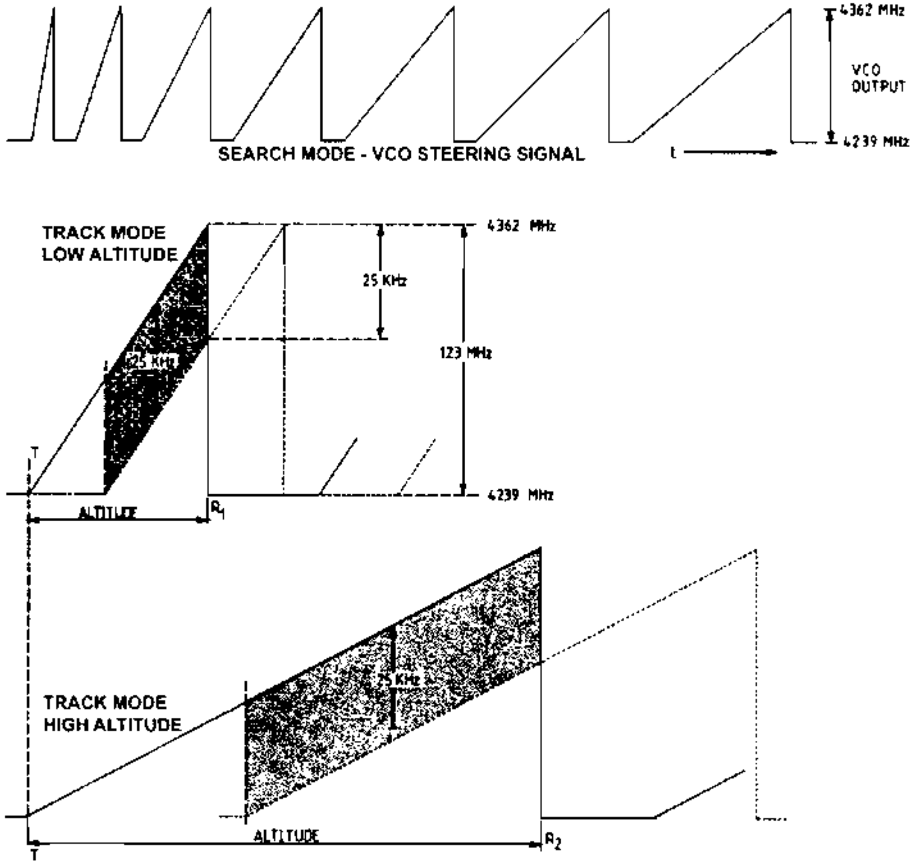
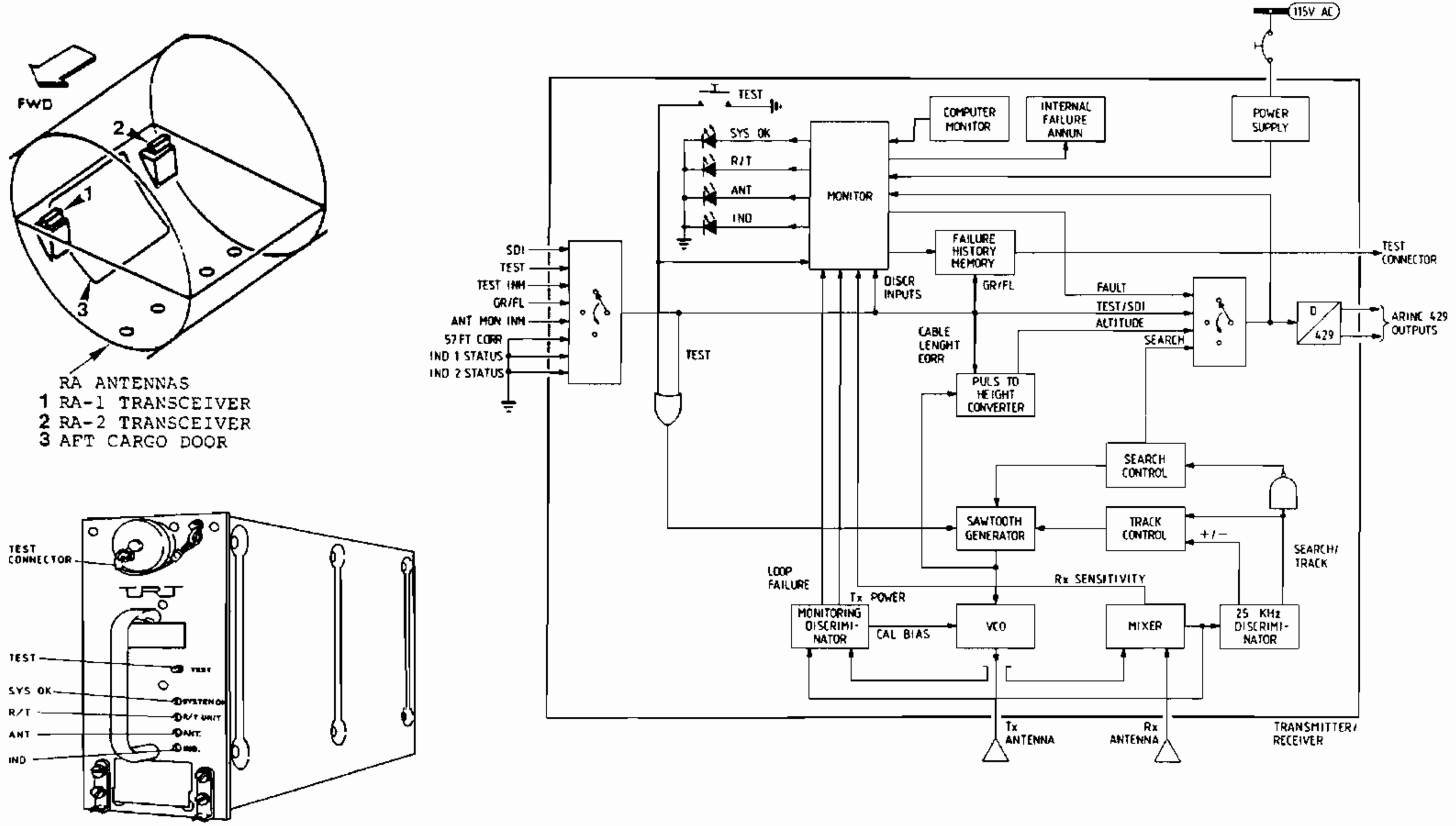


Figure 286: Transmitter/Receiver



Antenna

Radio altimeters transmit vertically downward and receive their reflected signal from the surface beneath them. This system requires two antennas mounted on the bottom of the fuselage. In most installations these antennas are flush with the skin.

Figure 287:

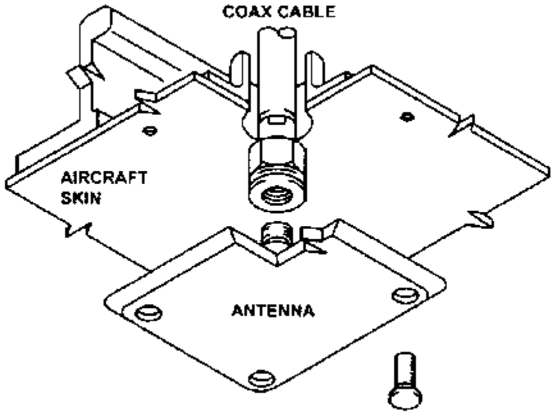
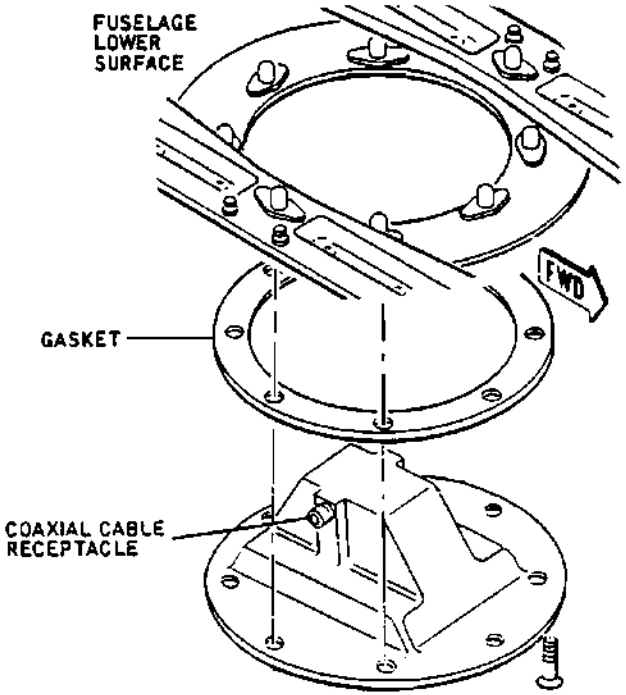


Figure 288:



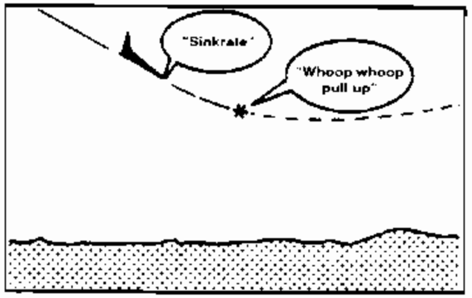
Ground Proximity Warning

Warnings

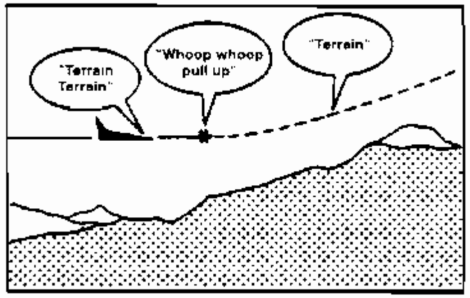
It has been proven that a human voice can attract a person's attention more than a warning light or other visual indication. For this reason aural warnings are used in the GPWS when the aircraft is in a dangerous position relative to the ground.

During operation, a GPWS senses the nearness of the ground and warns the pilot if the aircraft has gotten too near the ground when it is not in a configuration for landing. It does this by monitoring the radio altimeter to determine the actual height above the ground. It also monitors the air data computer, instrument landing system, and landing gear and flap position to determine if the aircraft is properly configured for its distance from the ground. If it is too near the ground for its location or configuration, the system will warn the pilot.

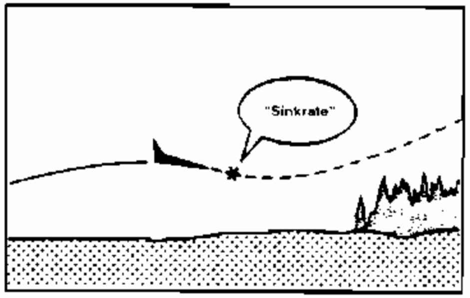
A typical GPWS in a aircraft will warn the flight crew of 5 types of hazards:



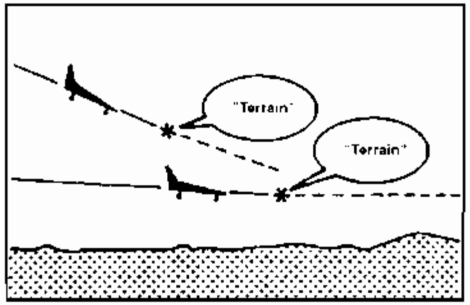
Mode 1 warnings occur when the aircraft is below 2,450 feet radio altitude and the barometric altimeter shows an excessive rate of descent. When excessive descent rate is detected, the warning light will illuminate and the aural warning sounds. "SINKRATE" or "WHOOP! WHOOP! PULL UP!"



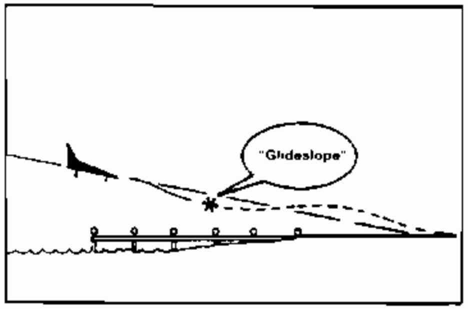
Mode 2 warnings occur when the terrain is rising at an excessively fast rate. When this is encountered the light illuminates and the aural warning says the word "TERRAIN" or "WHOOP! WHOOP! PULL UP!"



Mode 3 warnings occur when the aircraft has initiated a climb after takeoff or after a missed approach. If there is a loss of altitude under these conditions, the GROUND PROXIMITY light will illuminate and the aural warning will say "DON'T SINK. "



Mode 4 warnings occur during the landing phase of a flight. If there is insufficient terrain clearance when the landing gear is up or the flaps are not in land configuration. The warning will sound TOO LOW GEAR or TOO LOW FLAPS and the GROUND PROXIMITY light illuminates.



Mode 5 warnings occur when the aircraft is on ILS approach. If the aircraft sinks below the glide slope, the amber GS light will illuminate and the aural warning will repeat "GLIDE SLOPE GLIDE SLOPE."

Figure 289: Warnings Mode 1 - 5

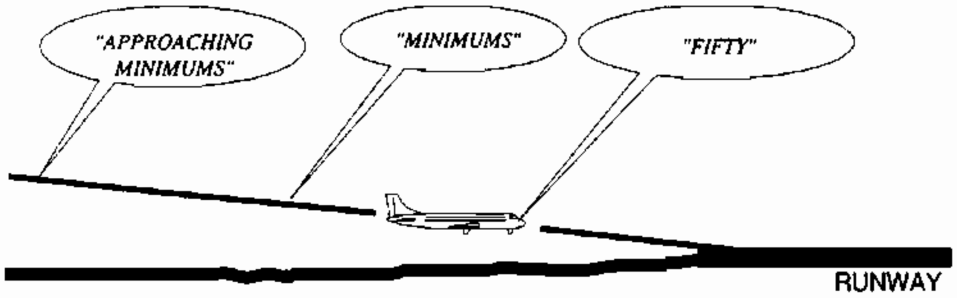
Call-Outs

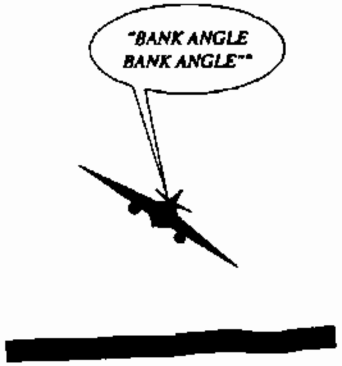
Mode 6 provides alerts and callouts for descent below predefined altitudes, Decision Height (DH), Minimums and Approaching Decision Height, Approaching Minimums.

Alerts for excessive roll or bank angle are also provided as part of this mode. The "Excessive Bank Angle" aural alerts are given twice, and then suppressed unless the roll angle increases by an additional 20%.

Specific callouts are selected via program pin from predefined menus. Mode 6 alerts and callouts produce aural and ARINC 429 output indications, but do not produce visual indications.

Figure 290:





Windshear Alerting

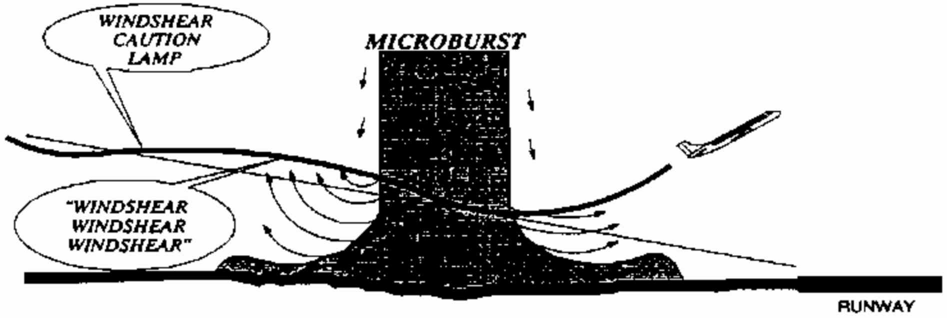
Mode 7 produces optional alerts for flight into an excessive Windshear conditions during takeoff or final approach. The Windshear warning produces aural, visual and ARINC 429 output indications.

Windshear detection is active during the initial takeoff and final approach phases of flight. Alert and warnings are provided when the level of windshear exceeds predetermined threshold values.

The actual windshear value measured represents the vector sum of inertial acceleration versus air mass accelerations along the flight path and perpendicular to the flight-path. These shears result from vertical winds and rapidly changing horizontal winds.

Windshear warnings are given for decreasing head wind (or increasing tail wind) and severe vertical down drafts. Windshear alerts are given for increasing head wind (or decreasing tail wind) and severe up drafts. The windshear microburst phenomenon and windshear caution and warning levels are illustrated below.

Figure 291:



EGPWS Terrain Alerting and Display

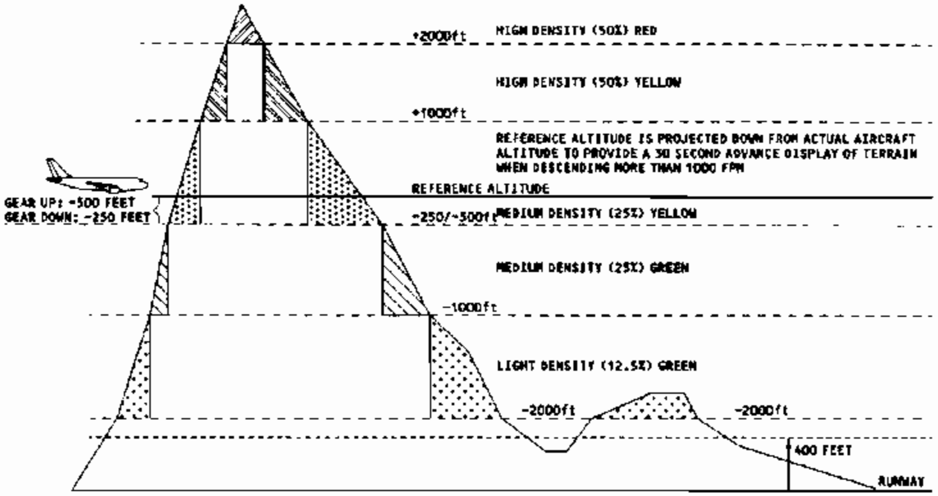
The Enhanced Ground Proximity Warning System (EGPWS) incorporates terrain alerting and display functions. These functions use aircraft geografic position, aircraft altitude, and an internal terrain data base to predict potential conflicts between the aircraft flight path and the terrain, and to provide grafic displays of the conflicting terrain.

The Caution and Warning envelopes use the Terrain Clearance Floor as a baseline, and virtually "look ahead" of the aircraft in a volume which is calculated as a function of airspeed, roll attitude and flight path angle.

If the aircraft penetrates the Caution Envelope boundary, the aural message *"Caution Terrain. Caution Terrain"* is generated, and alert discretes are activated for visual annunciation. Simultaneously, the conflicting terrain areas are shown in solid yellow color on the Terrain Display.

If the aircraft penetrates the Warning envelope boundary, the aural message *"Terrain Terrain. Pull Up!"* is generated, and alert discretes are activated for visual annunciation. Simultaneously the conflicting terrain areas are shown in solid red color on the Terrain Display.

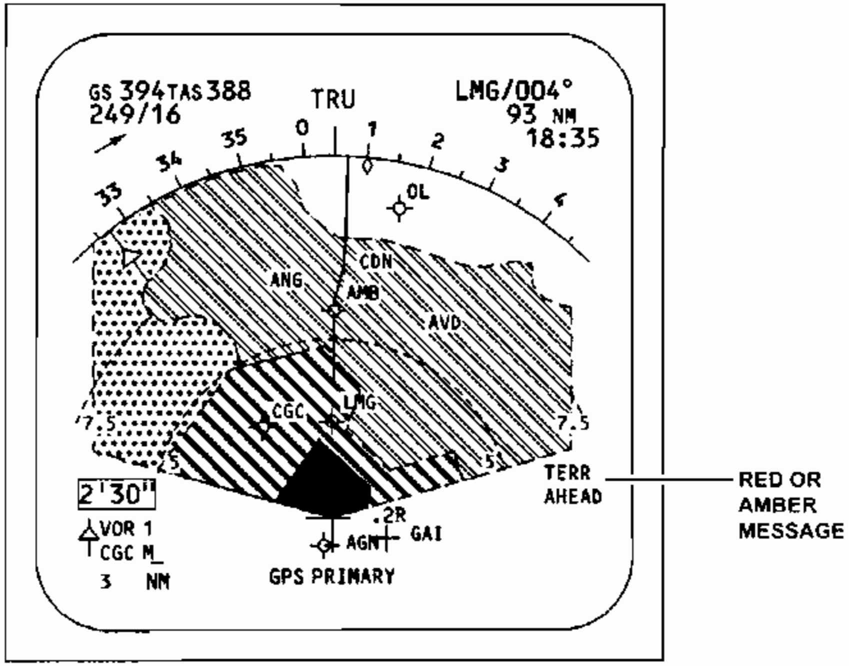
Figure 292:



EGPWS Terrain Picture

The ND presents the terrain picture. The terrain appears in different colours and densities according to its relative height.

Figure 293:



Solid Red Warning Terrain (approximately 30 seconds from impact)

Solid Yellow Caution Terrain (approximately 60 seconds from impact)

50% Red Dots More than 2000 feet above reference altitude

50% Yellow Dots 1000 to 2000 feet above reference altitude

25% Yellow Dots 500 feet below to 1000 feet above reference altitude

25% Green Dots 500 feet below to 1000 feet below reference altitude

12.5% Green Dots 1000 to 2000 feet below reference altitude

Black No close terrain

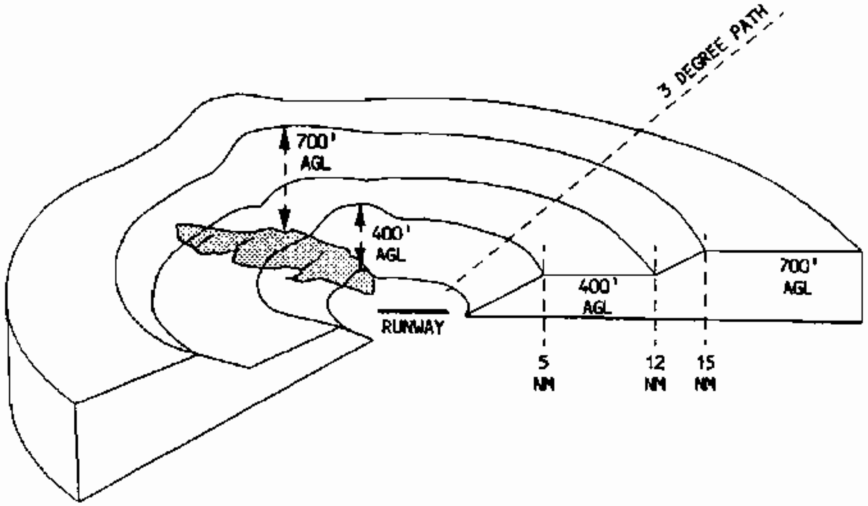
Magenta Unknown Terrain

Terrain Clearance floor

A number of airports throughout the world have approaches or departures that are not entirely compatible with standard GPWS operation. These airports are identified in the database in such a way that when the GPWS recognizes such an airport, it modifies the profile to avoid nuisance warnings.

The Terrain Clearance Floor (TCF) creates an increasing terrain clearance envelope around the intended airport runway directly related to the distance from the runway it is active during takeoff, cruise and final approach.

Figure 294:



Terrain Database

Local Terrain Processing extracts and formats local topographic terrain data from the EGPWS Terrain Database. This Database divides the earth's surface into grid sets referenced horizontally on the geographic (lat/long) coordinate. Elements of the grid sets record the highest terrain elevation . Grid sets vary in resolution depending on geographic location. Because the overwhelming majority of "Controlled Flight into Terrain (CFIT)" accidents occur near an airport, and the fact that aircraft operate in closer proximity to terrain near airports, higher resolution grids are used around airports. Lower resolution grids are used outside of airport areas where enroute aircraft altitude makes accidents unlikely and for which detailed terrain features are not of importance to the flight crew.

Digital Elevation Models (DEMs) are available for most of the airports around the world today.The global EGPWS Terrain Database is organized in a flexible and expandable manner. Using digital compression techniques, the complete database is stored in non-volatile memory of 20 MByte within the LRU. Updates and additions are easily done by inserting a single PCMCIA card in a card slot on the LRU front-panel. Status LEDs on the LRU front-panel allow the operator to monitor the database load progress and completion.

Obstacle Database

Provisions are also made for future use of an Obstacle Database providing obstacle data in the vicinity of major airports. This database will provide altitude data for man-made obstacles or groups of obstacles that protrude above the EGPWS terrain protection floors.

System Block Diagram

The Enhanced Ground Proximity Warning System (EGPWS) generates aural voice and visual warnings when one of the following conditions occurs between radio altitudes 30 feet and 2450 feet for modes 2, 4, 5 and between 10 feet and 2450 feet for modes 1 and 3.

- Mode 1 : excessive rate of descent
- Mode 2 . excessive terrain closure rate
- Mode 3: altitude loss after takeoff or go around
- Mode 4 : unsafe terrain clearance when not in landing configuration
- Mode 5 . excessive deviation below glide slope.

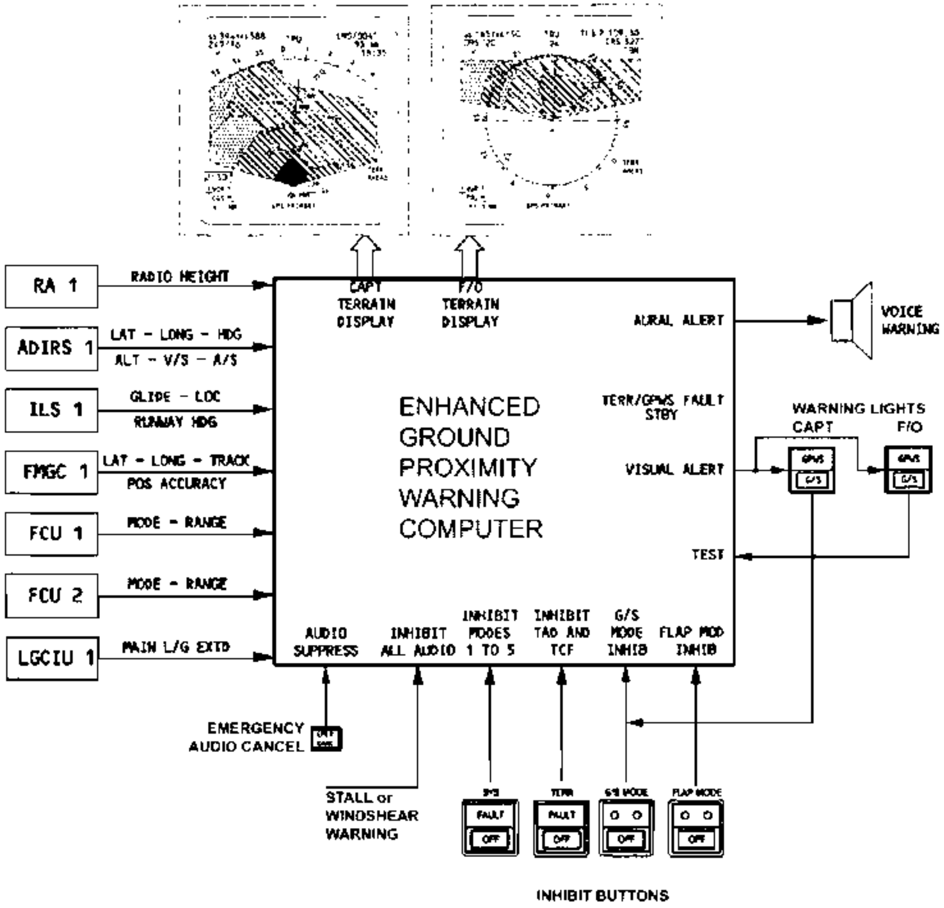
In addition to the basic GPWS functions the GPWS has an enhanced function (EGPWS) which provides, based on a world wide terrain database .

- A Terrain Awareness Display (TAD), which predicts the terrain conflict, and displays the terrain on the ND.
- A Terrain Clearance Floor (TCF), which improves the low terrain warning during landing.

The cockpit loudspeakers broadcast, even if turned off, the aural warning or caution messages associated with each mode. The audio volume of these messages is not controlled by the loudspeaker volume knobs. (These knobs allow the adjust audio volume for radio communication only).

GPWS lights come on to give a visual warning for modes 1 to 4. For mode 5 the glide slope (G/S) lights come on on the captain and first officer instrument panel.

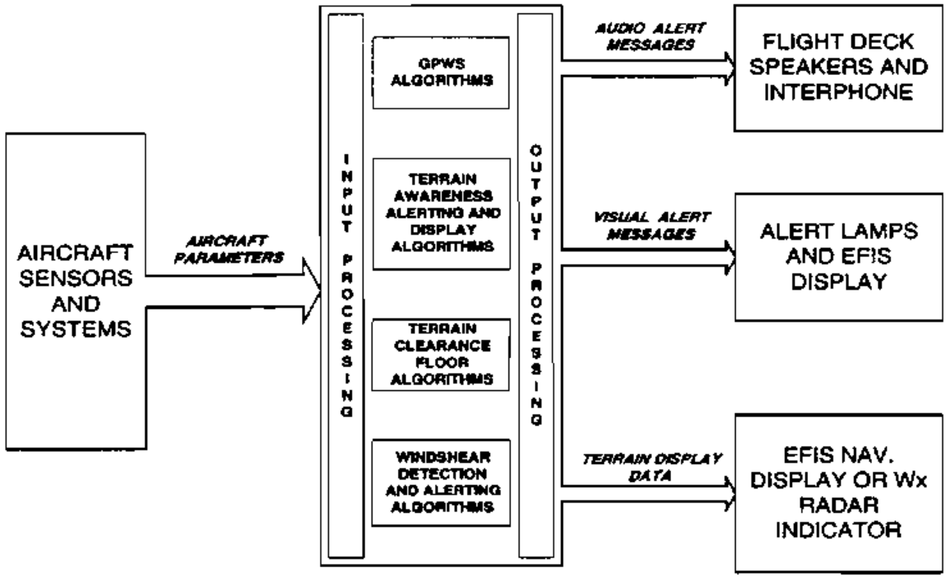
Figure 295:



System Overview

The purpose of the Enhanced Ground Proximity Warning System is to help prevent accidents caused by Controlled Flight into Terrain (CFIT) or severe Windshear. The system achieves this objective by accepting a variety of aircraft input parameters, applying alerting algorithms, and providing the flight crew with aural alert messages, visual annunciation, and displays. The system comprises the following groups of components:

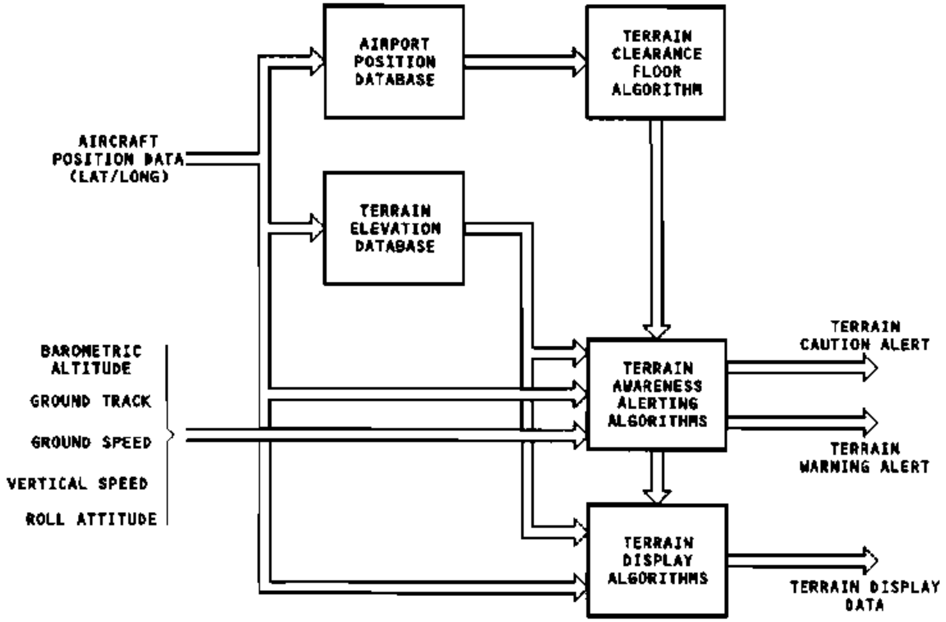
Figure 296:



Terrain Alerting

Terrain awareness alerting algorithms continuously compute terrain clearance envelopes ahead of the aircraft. If the boundaries of these envelopes conflict with terrain elevation data in the terrain database, then alerts are issued. Two envelopes are computed, one corresponding to a Terrain Caution Alert level and the other to a Terrain Warning Alert level. The algorithms are designed to meet the following criteria:

Figure 297:



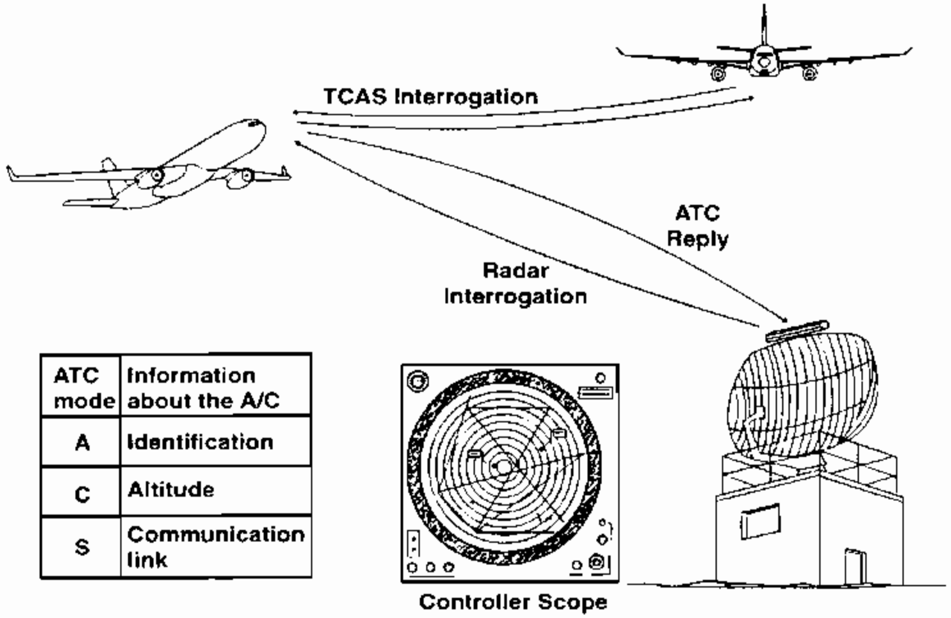
ATC Transponder

Principle

The Air Traffic Control (ATC) transponder is an integral part of the Air Traffic Control Radar Beacon System. The transponder is interrogated by radar pulses received from the ground station. It automatically replies by a series of pulses. These reply pulses are coded to supply identification and automatic altitude reporting of the aircraft on the ground controller's radar scope. These replies enable the controller to distinguish the aircraft and to maintain effective ground surveillance of the air traffic.

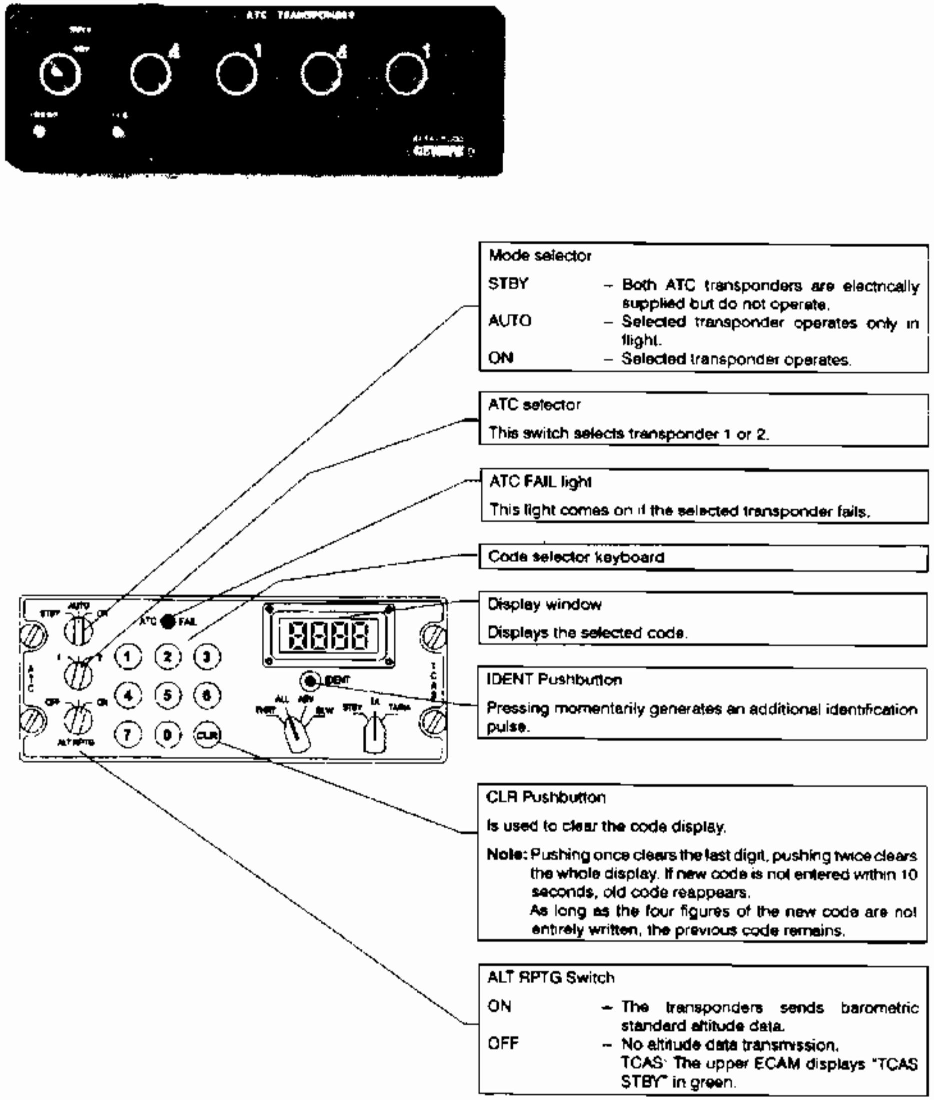
The ATC transponder also responses to interrogation from aircraft equipped with a Traffic Collision Avoidance System.

Figure 298:



ATC mode	Information about the A/C
A	Identification
C	Altitude
S	Communication link

Figure 299: Transponder Control



Mode selector
STBY – Both ATC transponders are electrically supplied but do not operate.
AUTO – Selected transponder operates only in flight.
ON – Selected transponder operates.

ATC selector
This switch selects transponder 1 or 2.

ATC FAIL light
This light comes on if the selected transponder fails.

Code selector keyboard

Display window
Displays the selected code.

IDENT Pushbutton
Pressing momentarily generates an additional identification pulse.

CLR Pushbutton
Is used to clear the code display.
Note: Pushing once clears the last digit, pushing twice clears the whole display. If new code is not entered within 10 seconds, old code reappears.
As long as the four figures of the new code are not entirely written, the previous code remains.

ALT RPTG Switch
ON – The transponders sends barometric standard altitude data.
OFF – No altitude data transmission.
TCAS: The upper ECAM displays "TCAS STBY" in green.

Primary and Secondary Surveillance Radar (PSR/SSR)

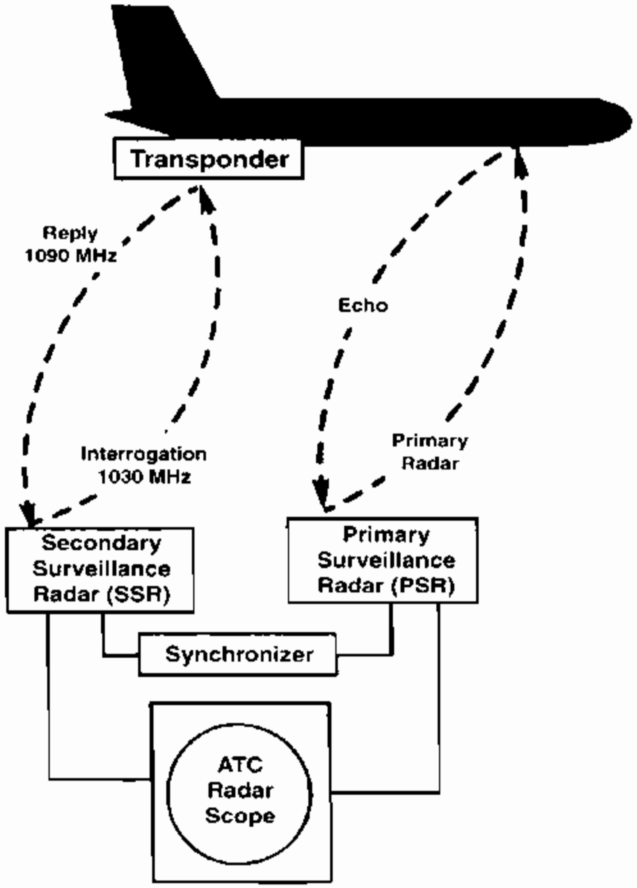
The air traffic control radar beacon system (ATCRBS) consists of airborne and ground based equipment that operate together to locate and identify the aircraft operating in the systems airspace. The airborne equipment consists of a transponder (receiver-transmitter), a control unit, and an antenna. The ground based equipment consists of a primary surveillance radar (PSR) system and a secondary surveillance radar (SSR) system. The PSR consists of an antenna, a receiver-transmitter, and an indicator The SSR system consists of an antenna, a receiver-transmitter and interface and control equipment used by the air traffic controller.

The PSR provides the bearing and range of the aircraft within the airspace. The SSR system provides the altitude and identification information of the aircraft within the airspace. The primary radar system uses a narrow RF beam, transmitted through a rotating antenna to illuminate aircraft in the path of the beam. By calculating the elapsed time between transmission of the RF beam and reception of the reflected RF beam, the distance to an aircraft is determined. By noting the bearing angle of the antenna, when reception occurs, the bearing to the aircraft is determined.

The secondary surveillance radar (SSR) system interrogates the aircraft about its identity and altitude by transmitting two sets of pulses. The interrogation mode is determined by the P1-P3 interrogation pulse spacing. There are two modes of interrogation used. Mode A for the basic ATC identity interrogation, and Mode C for requesting the transmission of digitally coded altitude information. The Mode A pulses are spaced 8 microseconds apart and interrogate the aircraft transponder about the identity of the aircraft. The Mode C pulses are spaced 21microseconds apart and interrogate the aircraft transponder about the altitude of the aircraft. The pulses in both modes are identical except for the spacing of the pulses. There also exists two alternate modes for interrogating the aircraft transponder. These optional modes are Mode B and Mode D.

Figure 300: Surveillance Radar Antenna (Primary with secondary)

Figure 301: PSR with SSR Principle



Interrogation Mode A or C

The ground station assumes that the reply signal it receives after an interrogation signal, is in response to that interrogation, because of a third pulse in the interrogation set that prevents aircraft transponders replying to a side lobe transmission of the SSR. The interrogation set of pulses consists of three pulses, the rotating directional antenna transmits two pulses, designated P1 and P3. The P1 and P3 pulses are spaced according to the SSR mode of operation. A pulse, designated P2, is radiated by an omnidirectional antenna 2 microseconds after the P1 pulse is transmitted from the directional antenna.

The transponder contains circuits for detecting the amplitude of P2 relative to P1, in order to prevent the transponder from replying to a sidelobe transmission. The radiated power level of P2 is nominally 18 dB below the peak level of the directional beam.

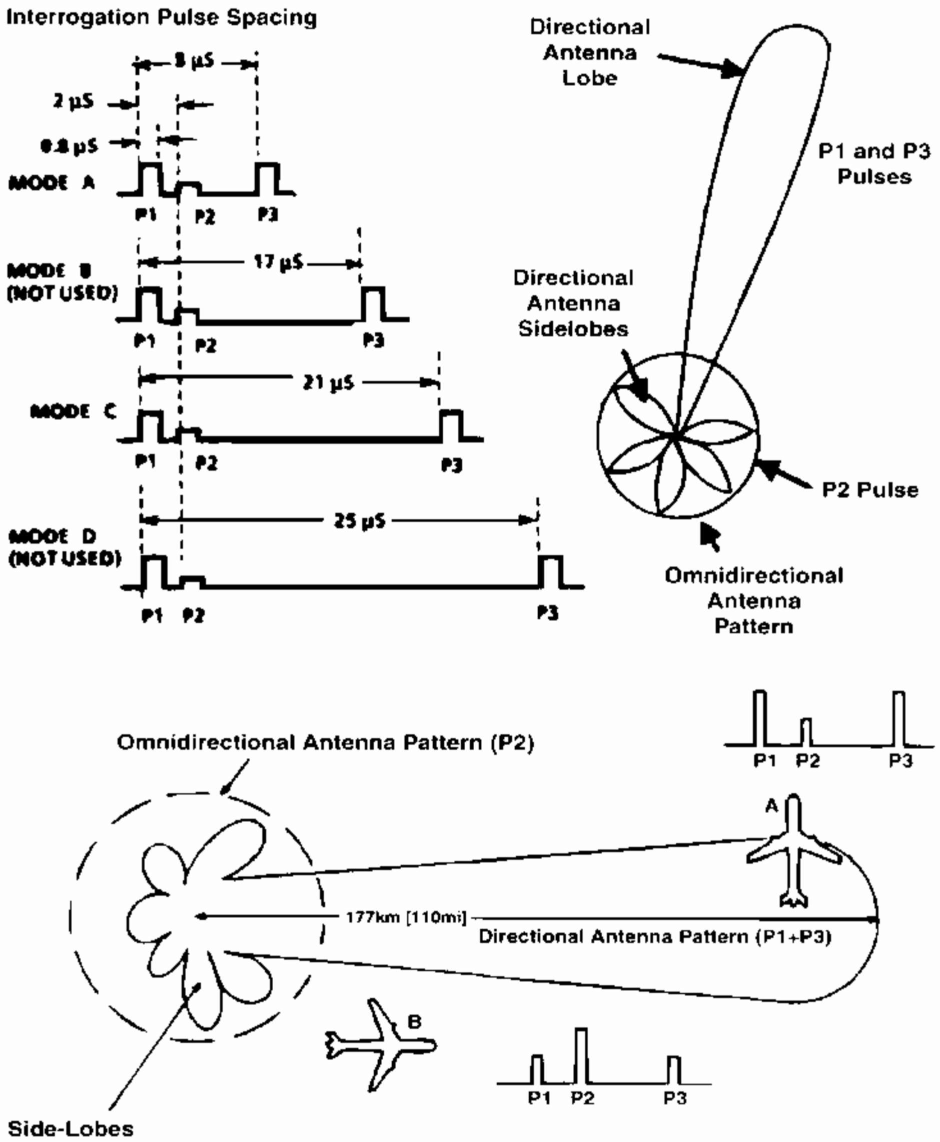
Aircraft A, flying in the main beam, will receive the P1 pulse at a higher amplitude than P2. The transponder of aircraft A will detect this amplitude difference and determine the interrogation to be a valid interrogation.

For aircraft B, the transponder detects that P2 is within 6 dB of P1, in amplitude and determines that the interrogation is not valid. The transponder will inhibit or suppress replies to further interrogations for 35 microseconds when P2 is equal or greater than P1.

All pulses are 0.8 microseconds wide. The received interrogations from the ground station are at a frequency of 1030 MHz. The transmitted reply signals to the ground station is at a frequency of 1090 MHz with about 600 Watt.

The received signal from the airborne transponder is electronically encoded so it can be displayed on an air traffic controllers radar screen. The replies processed by the SSR system will produce clear readable target on the air traffic controllers radar screen. Next to this, the air traffic controller may also display the aircraft identification number (selected by the aircrew) and the aircraft altitude.

Figure 302: Interrogation Pulses and Antenna Pattern



Reply Mode A or C

There are two framing pulses P_1 P_2, nominally spaced 20.3 microseconds apart. Within these framing pulses are thirteen information pulses (the X pulse is reserved for future use). These pulses are used to make up the $4096 = 2^{12}$ identification code selected by the pilot. The code designation will consist of digits 0 through 7.

The digits will be defined by the sum of the postscripts of the information pulse numbers. The first digit will be defined by pulse group A, the second digit will be defined by pulse group B, the third digit will be defined by pulse group C, and the fourth digit will be defined by pulse group D.

As an example, let assume the identification code is 2534. This identification code would consist of pulses A2, pulses B1 and B4, pulses C1 and C2, and pulse D4.

An IP (Identification Pulse) is transmitted upon interrogator request, following the last framing pulse of a Mode A reply. The IP pulse is activated by the IDENT switch (of the controller), and is transmitted for a period of 18 seconds.

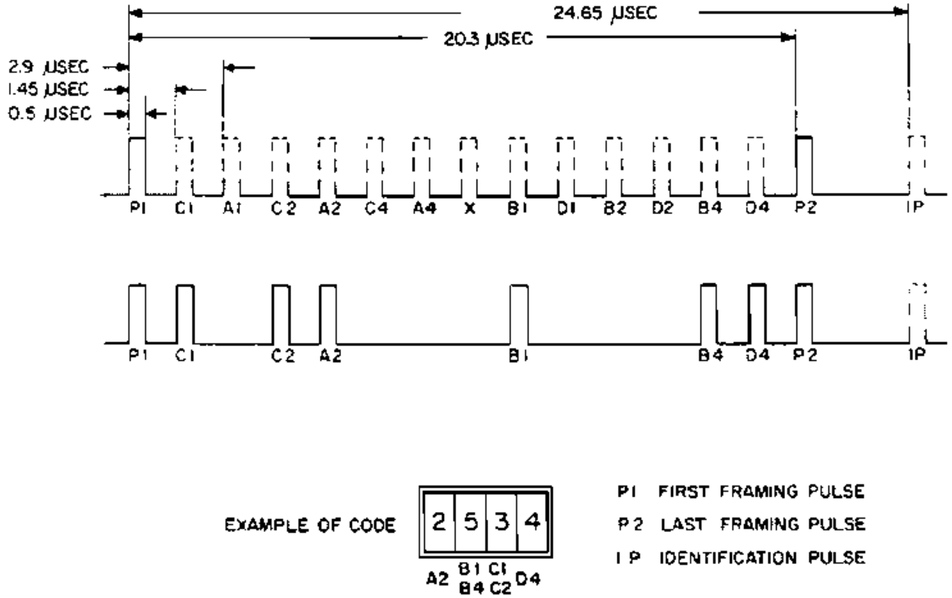
If the interrogation of the transponder occurred in mode C the encoded altitude is replied to the ground.

Some codes have been laid down internationally and are decoded automatically by the ground station. these are:

- 7700 Emergency
- 7600 Communication failure
- 7500 Hijacking

These codes may not be used while testing the system.

Figure 303: Transponder Reply and Altitude Reporting Codes



ALTITUDE (FEET)		A_1	A_2	A_4	B_1	B_2	B_4	C_1	C_2	C_4	D_1	D_2	D_4	CODE
9750 - 10250	9750 - 9850	0	1	1	1	0	1	0	0	1	0	0	0	6540
	9850 - 9950	0	1	1	1	0	1	0	1	1	0	0	0	6560
	9950 - 10050	0	1	1	1	0	1	0	1	0	0	0	0	6520
	10050 - 10150	0	1	1	1	0	1	1	1	0	0	0	0	6530
	10150 - 10250	0	1	1	1	0	1	1	0	0	0	0	0	6510

Mode S

The Mode S transponder equipped aircraft and ground station enhance the operation of ATCRBS by adding a data link feature for performance improvements in determining the aircraft location. The Mode S transponder data link capabilities include bidirectional air-to-air information exchange, ground-to-air data uplink, air-to-ground data downlink. The Mode S transponder may also function as part of a airborne separation assurance system when interfaced with a Traffic Alert and Collision Avoidance System (TCAS).

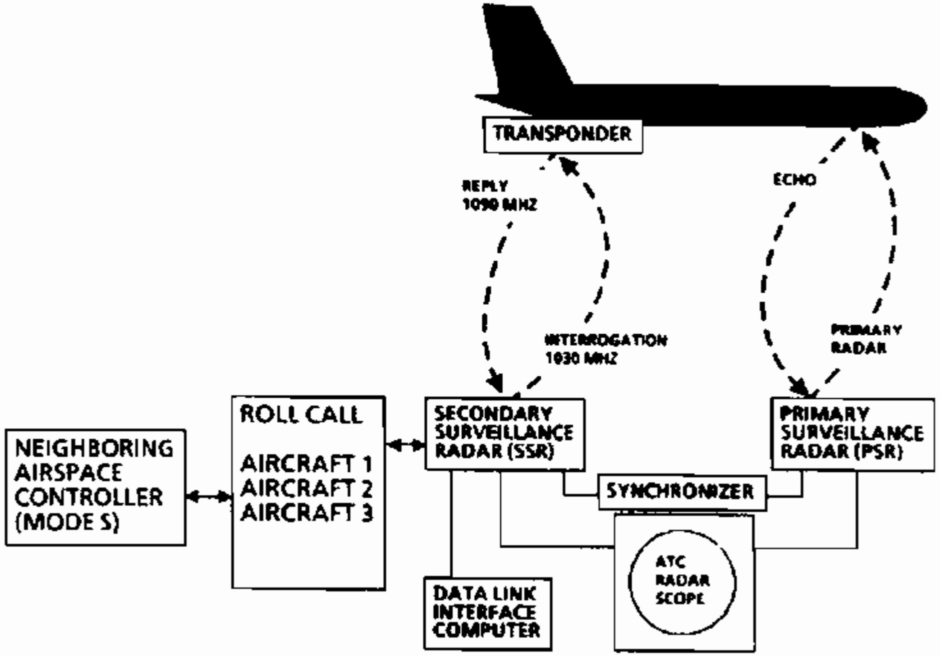
The ATCRBS/Mode S system operates in a similar fashion as ATCRBS. As a transponder equipped aircraft enters the airspace, it receives the ATCRBS/Mode S all-call interrogation, which can be identified by both ATCRBS and Mode S transponders.

The Mode S transponder replies with a Mode S format that includes the discrete 24-bit Mode S address. The address and the location of the Mode S aircraft is entered into a roll-call file. On the next scan, the Mode S aircraft is discretely addressed. The discrete interrogations of a Mode S aircraft contain a command field that may desensitize the Mode S transponder to further Mode S all-call interrogations. This is called Mode S lockout. ATCRBS interrogations (from ATCRBS interrogators) are not affected by this lockout. Mode S transponders reply to the interrogations of an ATCRBS interrogator under all circumstances.

As a Mode S aircraft flies into the airspace served by another Mode S interrogator, the first Mode S interrogator may send position information and the aircraft's discrete address to the second interrogator via ground lines.

In regions where Mode S interrogators are not connected via ground link, so if the aircraft enters an airspace served by a different Mode S interrogator, the new interrogator may acquire the aircraft via the reply to an all-call interrogation.

Figure 304: .Mode S Principle



Interrogation Mode S

Aircraft are tracked by the interrogator throughout its assigned airspace. A Mode S aircraft reports in its replies either its altitude or its ATCRBS 4096 code depending on the type of interrogation received. During each scan, interrogations of ATCRBS aircraft are made in both Mode A and Mode C. The Mode S interrogation is transmitted using binary differential phase-shift keying (DPSK) The modulation of the downlink transmission from the transponder is pulse position modulation (PPM). Each Mode S interrogation contains a 24-bit discrete address that allows a very large number of aircraft to operate in a air traffic control environment without the occurrence of a redundant address.

When an interrogator does not receive a valid reply, as it scans through a Mode S aircraft's location, the interrogator can re interrogate a limited number of times. Normally, interrogators interrogate at low power "whisper" and re interrogate at high power "shout" if the low power interrogation fails.

The Mode S transponder receives an interrogation from the ground. The transponder will initiate a reply to an ATCRBS ground station, until the presence of the P4 pulse is detected.

If the width of the P4 pulse is 0.8-microseconds (ATCRBS Mode A or Mode C only all-call), no reply is transmitted.

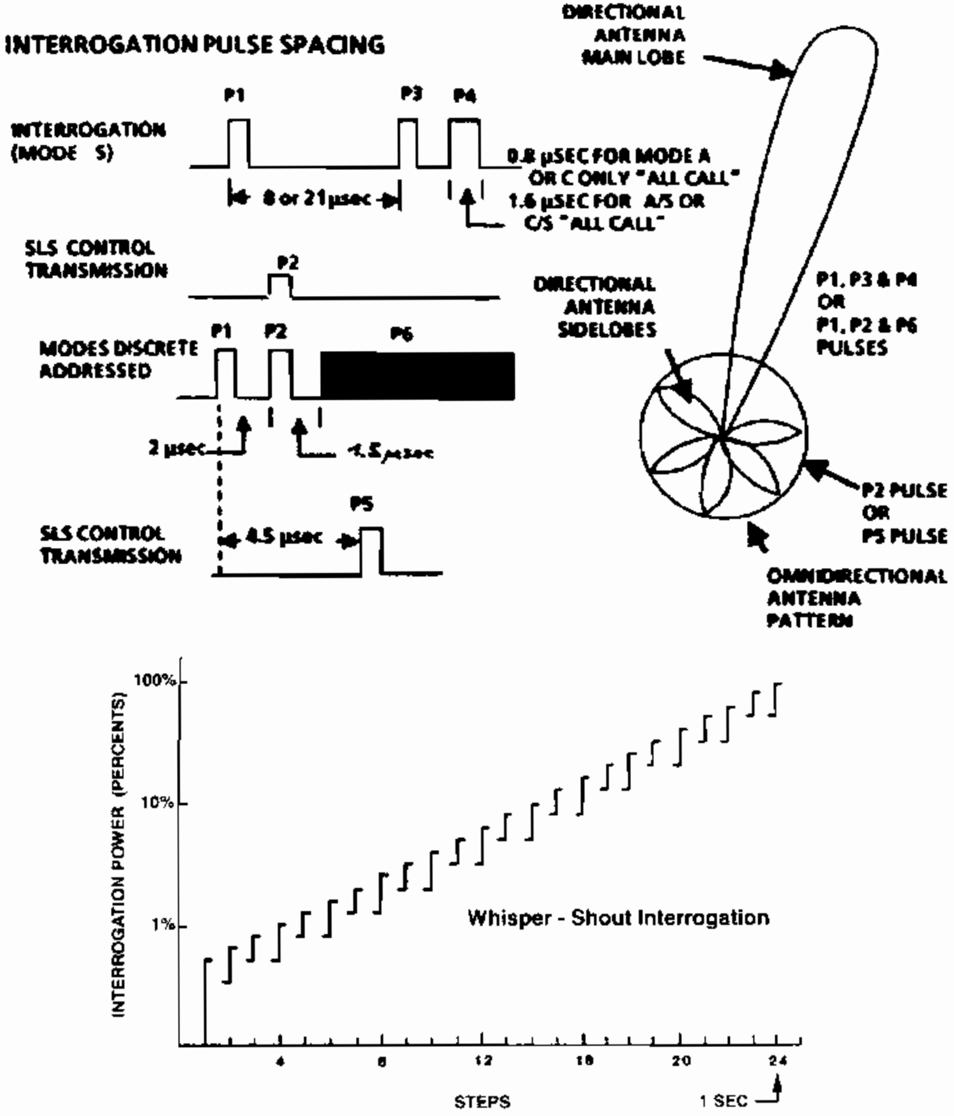
If the width of the pulse is 1.6 microseconds (ATCRBS/Mode S all-call), a Mode S reply is generated 128 microseconds after the leading edge of the P4 pulse.

The Mode S reply is the same reply generated in response to the Mode S all-call interrogation. The standard replies are discussed in later paragraphs.

Side lobe suppression for Mode S is accomplished by overlaying a pulse (P5) on the P6 pulse, the transponder will not reply.

The aircraft system is equipped with two antennas. One of the antennas is mounted on the top of the aircraft, and the other antenna is mounted on the bottom of the aircraft. The Mode S transponder will have automatic selection of antenna, based on the relative strength of detected interrogation signals.

Figure 305: ATCRBS / Mode S Interrogation Pulses and Antenna Pattern.



Interrogations

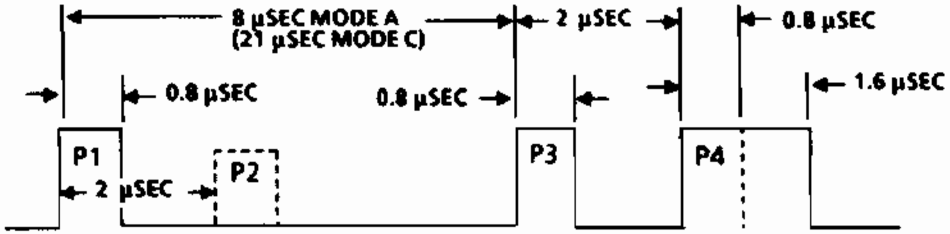
The Mode S transponder supports all surveillance functions, in addition to bidirectional air-to-air data exchange, ground-to-air data uplink (Comm A), air-to-ground data downlink (Comm B), uplinked extended length messages (Comm C), downlinked extended length messages (Comm D), and multisite message protocol.

Pulse Amplitude Modulation

The Mode S PAM (pulse amplitude modulation) interrogations are shown below. The following six interrogations are exclusively PAM signals:

ATCRBS Mode A, C,
Mode A / Mode S all-call, Mode C / Mode S all-call,
Mode A only all-call, and Mode C-only all-call

Figure 306: Mode A, C and S - All Call



P4 is not present for ATCRBS mode A and mode C interrogations.
P4 is long (1.6 microsec) for Mode A/Mode S all-call and Mode C/Mode S all call.
P4 is short (0.8 microsec) for Mode A only all call and Mode C only all call
P2 pulse amplitudes will vary from P1 amplitudes.
P4 amplitudes are equal to P3 amplitudes

Binary Differential Phase Shift Keying (DPSK)

All Mode S interrogations are binary differential phase shift keying (DPSK) signals. The P1-P2 pulse pair preceding P6 suppress replies from ATCRBS transponders to avoid synchronous garble (caused by the random triggering of ATCRBS transponders). A series of "chips" contain the information within P6.

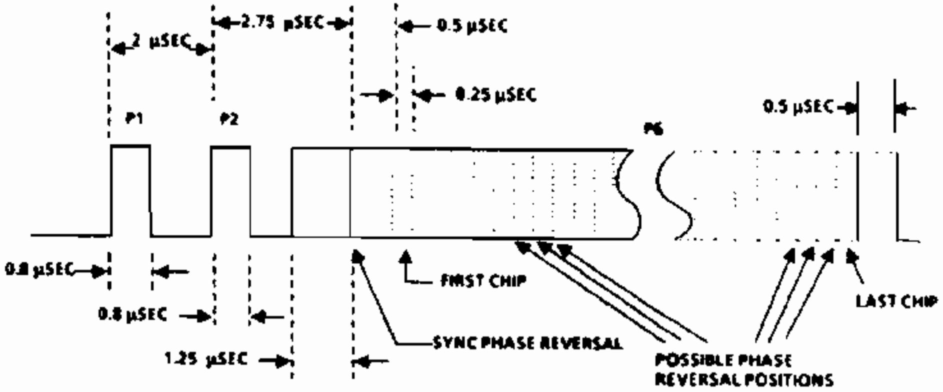
There are either 56 or 112 chips within each P6. The last chip is followed by a 0.5-microsecond guard interval to prevent the trailing edge of the P6 from interfering with the demodulation process. P5 may be overlaid on P6 by the interrogator as a side lobe suppression signal in any Mode S interrogation.

Uplink Messages

The formats of uplink messages contain either 56 or 112 bits, with the last 24 bits being used for address or parity, and the remaining bits used for information.

Each Mode S transmission contains two essential fields: one describes the format, and the other (24-bits) carries parity information and contains either the address or the interrogator identity overlaid on the parity. The format descriptor is the field at the beginning of the transmission and the 24-bit field ways occurs at the end of the transmission.

Figure 307: Mode S Selective Interrogation



Mode S Replies

The Mode S replies to a Mode S interrogation are in a much different format, so the reply can contain much more information than previous generations of transponders. The Mode S reply consisting of a preamble and data block.

The reply data block is formed by pulse position modulation (PPM) encoding of the reply data. The first preamble pulse will also occur 128 microseconds after the P4 pulse of an ATCRBS/Mode S all-call interrogation.

Bidirectional air-to-air data exchange, ground-to-air data uplink (Comm A), air-to-ground data downlink (Comm B), and multisite message protocol. In addition, the transponder is capable of receiving extended length messages (ELMs) from the ground. ELMs are received in the Comm C format. ELM transmittals to the ground use the Comm D format. All discrete Mode S interrogations and replies (except the all-call reply) contain the 24-bit discrete address of the Mode S transponder.

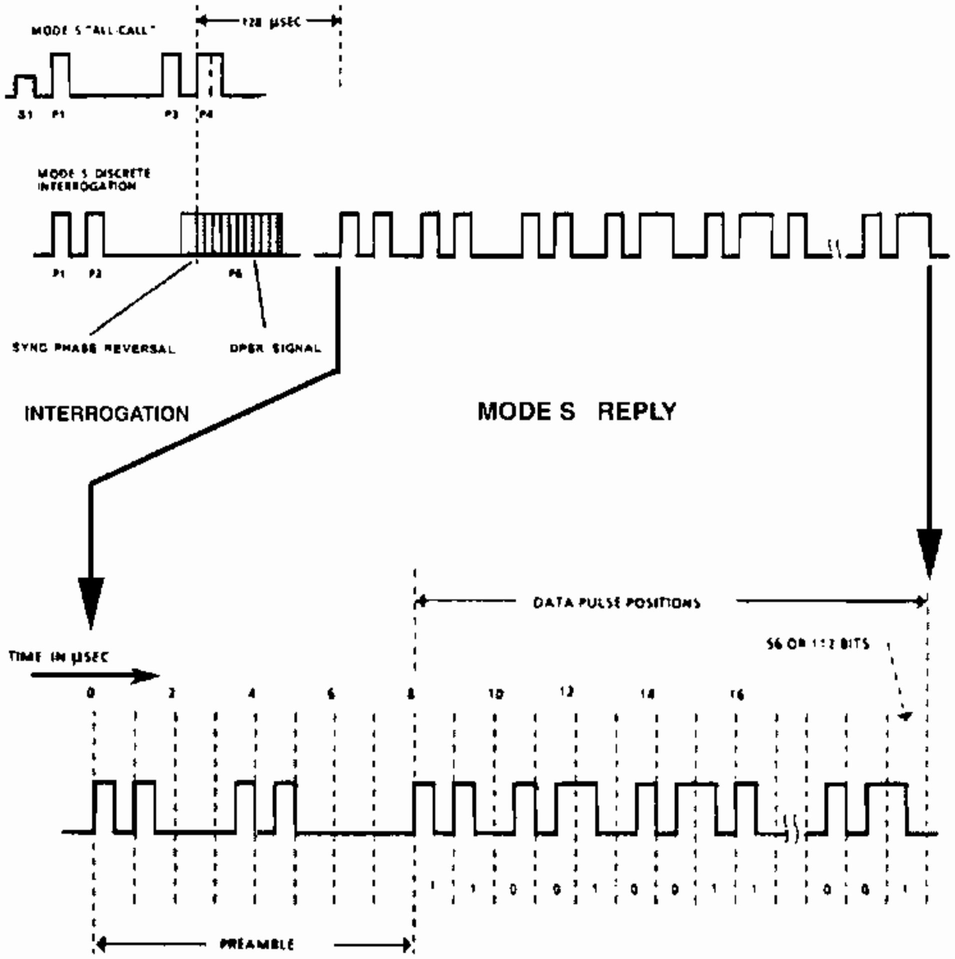
The primary function of Mode S is surveillance. To accomplish this function, the Mode S transponder uses the 56-bit transmissions (in each direction). In the 56-bit transmissions, the aircraft reports its altitude or ATCRBS 4096 code, and the flight status (airborne, on-ground, alert, special position identification (SPI), etc.

The squitter transmission is an all-call reply which is transmitted by a transponder approximately once every second. The squitter signal is observed by aircraft equipped with airborne collision avoidance systems. Special surveillance interrogations from airborne collision avoidance systems are addressed to Mode S equipped aircraft. These interrogations are used for Mode S target tracking and collision threat assessment.

The Mode S transmissions permit their use as a digital data link. The interrogation and reply formats contain sufficient coding space to permit the transmission of data. These data transmissions may be used for air traffic control purposes, air-to-air data interchange for collision avoidance, or to provide flight advisory services such as weather reports, or automated terminal information system (ATIS).

Most Mode S data link transmissions will be handled as one 56-bit message included as part of a long 112-bit interrogation or reply. These transmissions include the message in addition to the surveillance data. Longer messages are transmitted using the extended length message (ELM) capability. The ELM is capable of transmitting up to sixteen 80-bit message segments, either ground-to-air or air-to-ground.

Figure 308: Reply Signal from Transponder to SSR



Transponder System

The interrogation signal on 1030 MHz is received by the antenna, passed through the coupler to the receiver. It then passes into the decoder which is set to respond only to the interrogation pulse selected by the pilots control.

The trigger output of the decoder starts the encoder to produce a series of pulses appropriate to the code selected. The transponder is capable replying to the ground interrogator in any of 4096 = 2^{12} codes.

These transponder pulses modulate the 1090 MHz of the transmitter carrier CW, which passes the coupler to the antenna. The coupler prevents any of this signal from entering the receiver

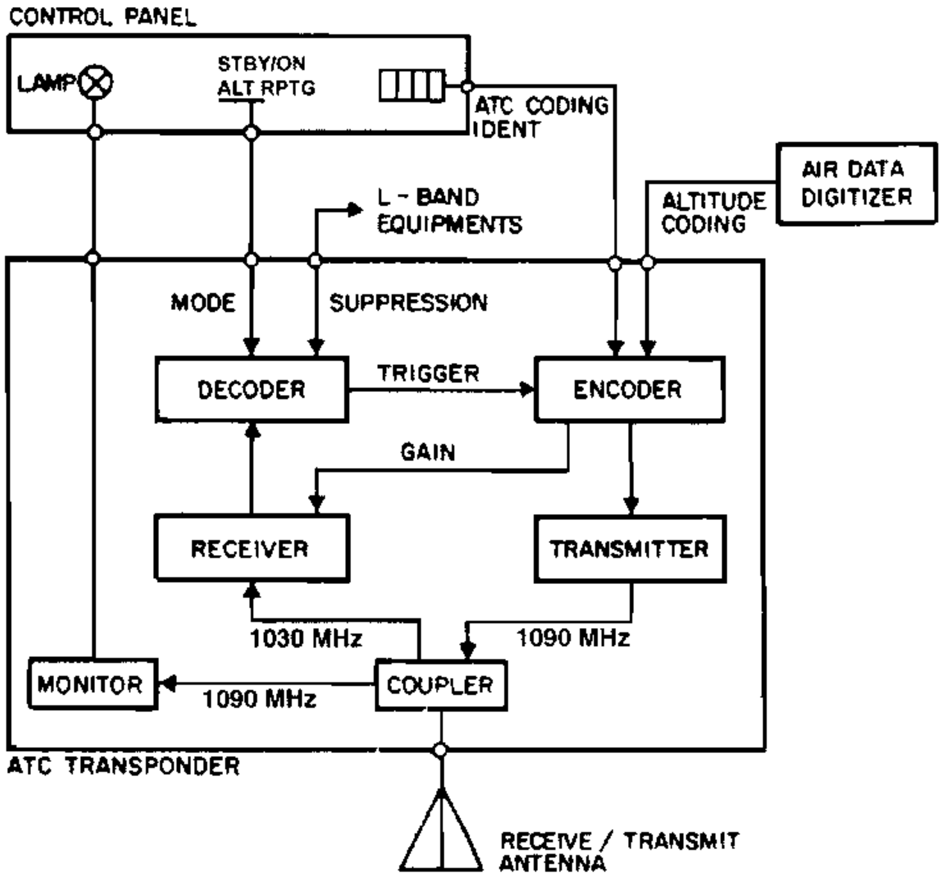
When the transponder is operating in mode A, it provides identification information only. If the interrogation is in mode C, the interrogation is answered by a code produced in the encoding altimeter and responds with information that produces a read-out on the controller's scope showing the altitude of the aircraft in one-hundred-foot increments. On many corporate or commercial-type aircraft, the altitude information is sent to the ATC transponder from the central air data computer.

The only indication the pilot has of the transponder operating is the winking light on the face of the control head. This light blinks each time the transponder responds to an interrogation from the ground radar.

Some small transponders fit into the instrument panel, and others have only the control head on the panel and the actual unit itself is remotely located in the avionics equipment rack. The antenna is a short blade or stub and is located on the belly of the aircraft as far as practical from any other antenna, and in a position that will not be shielded by the landing gear when it is extended.

Transponder installations are interconnected with the DME and TCAS system by a suppressor bus. This prevents simultaneous transmissions of the L-Band (about 1 GHz) and inhibits the reception during transmission.

Figure 309:



Interface

A single ATC control unit enables system selection. It provides the selected transponder with code and function data and, in return, receives status data.

Altitude information from airdata computer or altimeter-digitizer transmits altitude information to ATC 1 and 2 transponders to allowing altitude reporting operation.

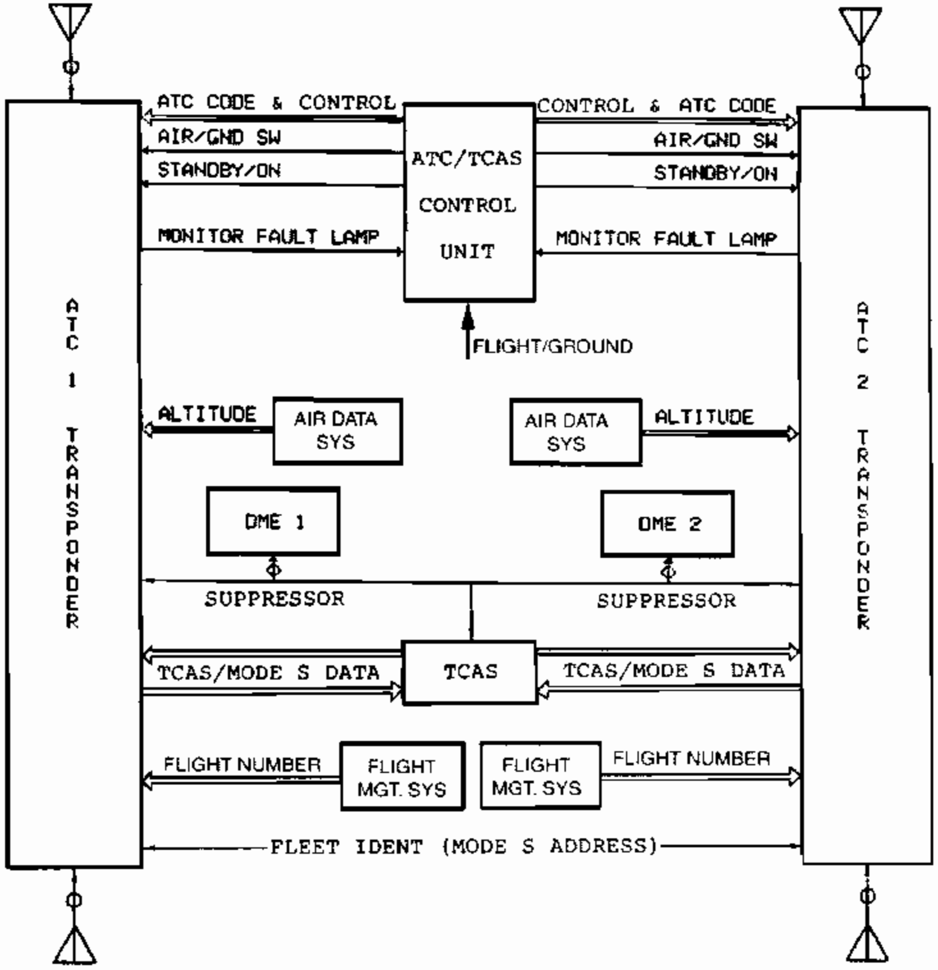
The antenna receive the Interrogation coming from the ground station and transmit the reply. The transponder selects the top- or bottom antenna, depending on signal strength. The antenna is a blade antenna used for transmission and reception. It is identical to the DME antenna. (same part number).

The Aircraft Ground/Flight information disables the transmit function of the transponder if the aircraft is on ground and the mode selector in AUTO position.

A coaxial suppressor connects the ATC' s and TCAS to the DME interrogators to prevent reception from one system while the other is in transmission mode. This is necessary because the ATC, TCAS and DME systems operate in the same frequency band.

The ATC Mode S transponder receives the fleet identification, by pin-programmed mode S address plug and flight number from the Flight Management System. With the TCAS the transponder exchanges control- and coordination data for TCAS operation.

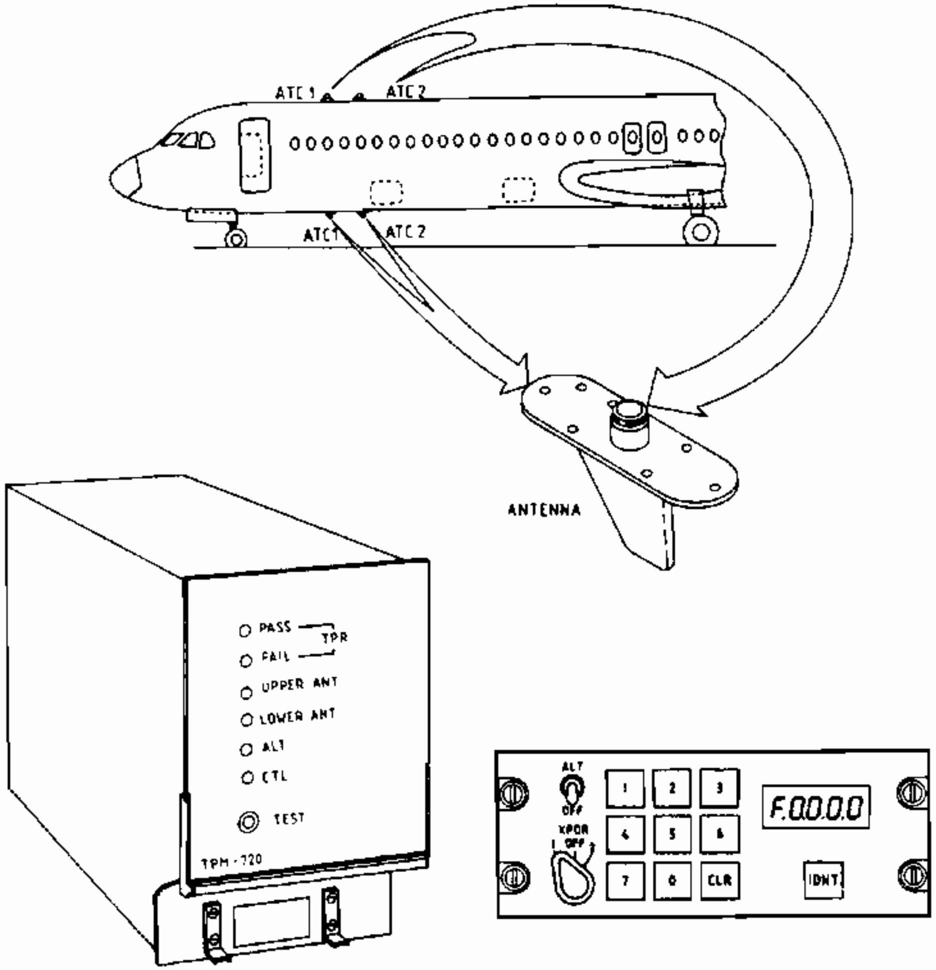
Figure 310:



Components

The air traffic control transponder uses the same type of antenna as the DME. It is also mounted on the bottom center line of the fuselage. It and the DME antenna must be as far apart as practical. Both installations require that the coax between the equipment and the antenna be as short as possible.

Figure 311: Transponder, Control Panel and Antennas



Fleet identification

Mode S transponder system allows the individual addressing for all airplanes of the world. By pin programming the country is assigned
i. e. Switzerland 0100 10 110.

The remaining 15 Bit of the 24 available Bit allows to individually assign 32'768 airplanes.

Figure 312: County Codes Example

Country	No. of Addresses	Bit Allocations (24)
Australia	262,144	0111 11
Brazil	262,144	1110 01
Canada	262,144	1100 00
Egypt	32,768	0000 00 010
France	262,144	0011 10
Germany	262,144	0011 11
Ireland	4,096	0100 11 001 010
Israel	32,768	0111 00 111
Japan	262,144	1000 01
Jordan	32,768	0111 01 000
Monaco	1,024	0100 11 010 100 00
New Zealand	32,768	1100 10 000
Saudi Arabia	32,768	0111 00 010
Switzerland	32,768	0100 10 110
UK	262,144	0100 00
USSR	1,048,576	0001
US	1,048,576	1010

Assigned
by
each country

Secondary Surveillance Radar display

Today the technology of display differs from in a wide way. Countries and regions using older ground facilities, others are using modern and advanced technology.

Figure 313: Plan Position Indicator former Technology

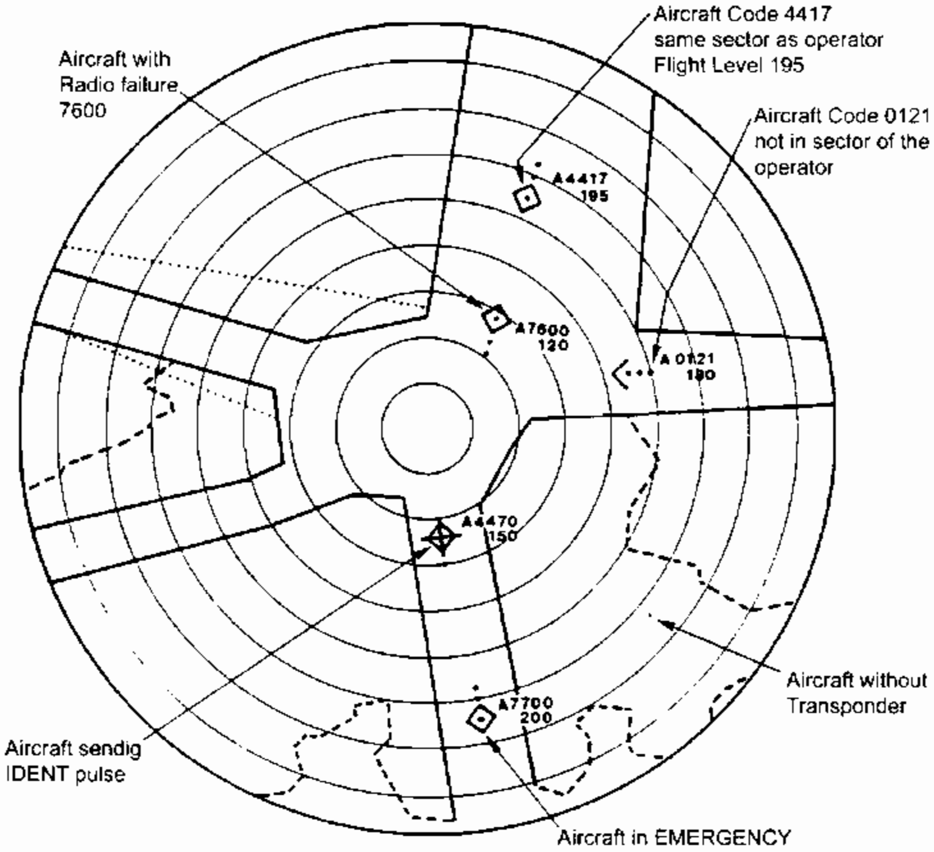
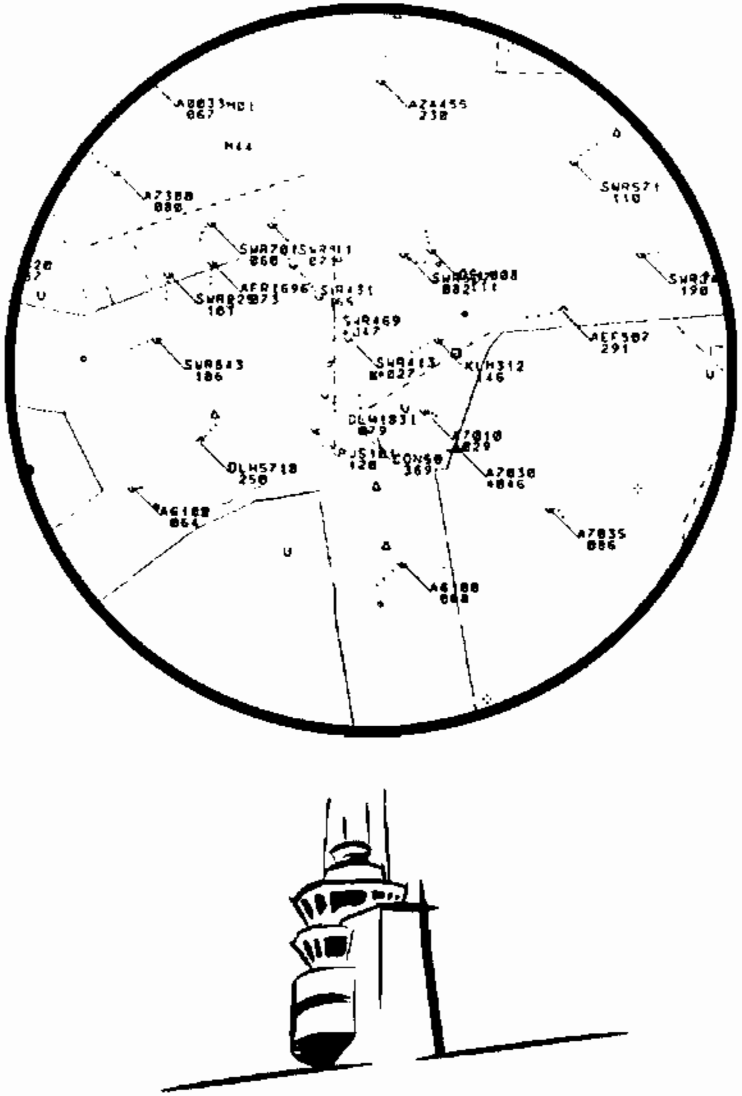


Figure 314: Plan Position Indicator advanced Technology



TCAS Traffic Collision Avoidance System

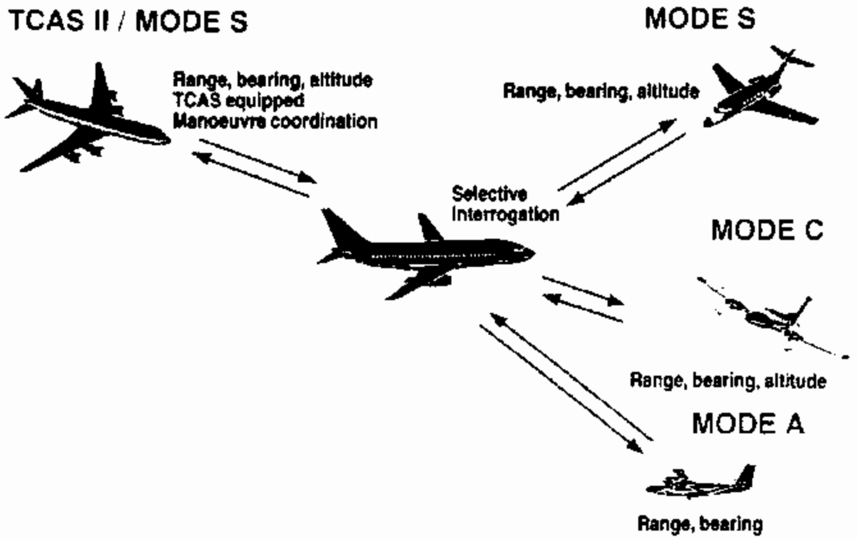
Introduction

The Traffic or Airborne Collision Avoidance System function is to detect and display aircraft in the immediate vicinity and to provide the flight crew with indications to avoid these intruders.

TCAS is a family of airborne devices that function independent of the ground based ATC system and provide collision avoidance protection for a broad spectrum of aircraft types.

- TCAS I provides proximity warning codes, to assists the pilot in the visual acquisition of intruder aircrafts. It is intended for use by smaller airplanes and by general aviation aircraft.
- TCAS II Provides traffic advisorys and resolution advisorys. (Recommended escape manoeuvres) in a vertical direction to avoid conflicting traffic. Airline AC and larger commuters and business AC will use TCAS II equipment.
- TCAS III Which is still under development, will provide traffic advisory and resolution advisory in the horizontal as well as the vertical direction to avoid conflicting traffic.

Figure 315:

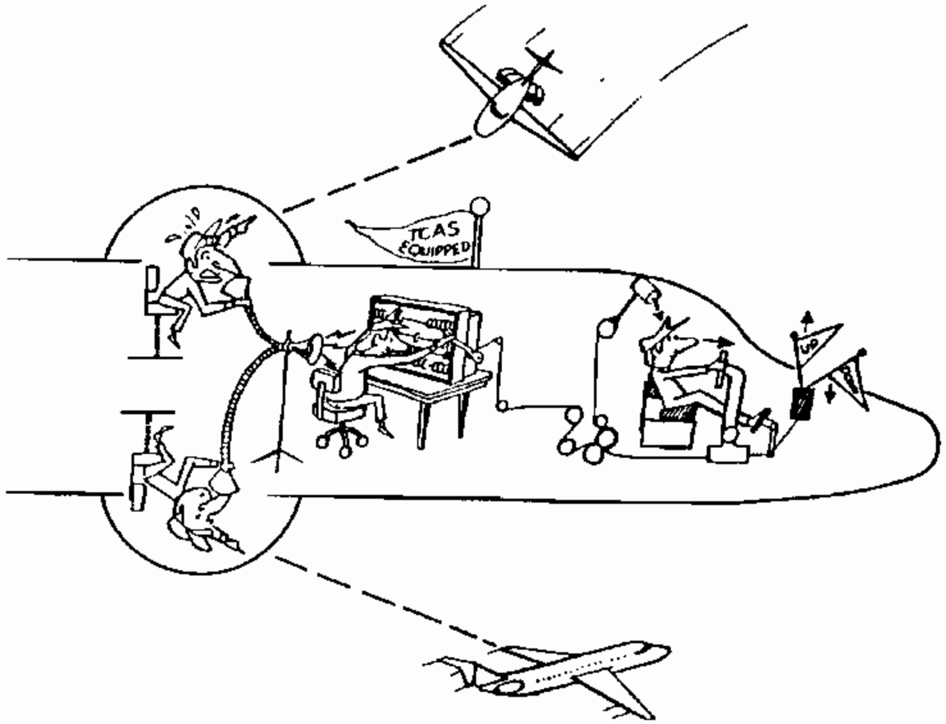


Principle

The TCAS interrogates ATC transponders of intruders. From the transponder replies the TCAS determines for each intruder:

- Its bearing.
- Its range and closure rate.
- Its relative altitude if available (ATC mode C or S).

Figure 316:



Function

The TCAS continually surveys the airspace around the aircraft utilizing ATC transponder replies from other aircrafts in the vicinity, determines range, relative bearing and relative altitude of those AC and predicts than their flight paths.

Intruder whose paths are predicted to penetrate protected collision area surrounding the TCAS equipped AC are annunciated by the TCAS on capt's and copi's VS/TRA display or respective EFIS displays and by spoken messages. In addition, the TCAS is capable of recommending evasive vertical manoeuvres intended to preserve or increase vertical clearance to intruder AC.

A traffic advisory (TA) is generated 40 to 45 seconds prior to a conflict and a resolution advisory (RA) 20 to 25 sec prior to a conflict. Once the flight path from the intruder no longer conflicts with the own AC, annunciation of all advisory ceases and the voice message "clear of conflict" will be broadcast.

TCAS provides no protection against aircrafts that do not have an operating ATC transponder. The TCAS cannot provide an RA when the intruder AC does not provide altitude information.

The TCAS computer performs airspace surveillance and intruder and own AC tracking, using ATC transponder infos and inputs from the TCAS antennas. If a tracked AC is a collision threat, it selects the best avoidance manoeuvres and if the threat AC is also equipped with TCAS, this manoeuvre is coordinated via the ATC transponder (Mode S) to ensure the selection of complementary advisorys.

Figure 317: Communications between Aircrafts

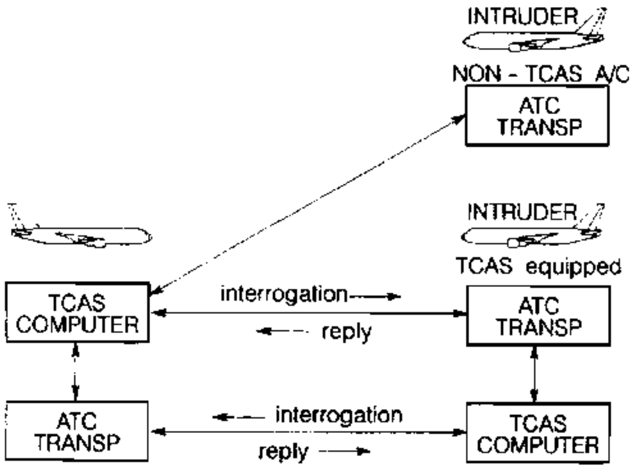


Figure 318: Caution, Warning and Resolution Areas

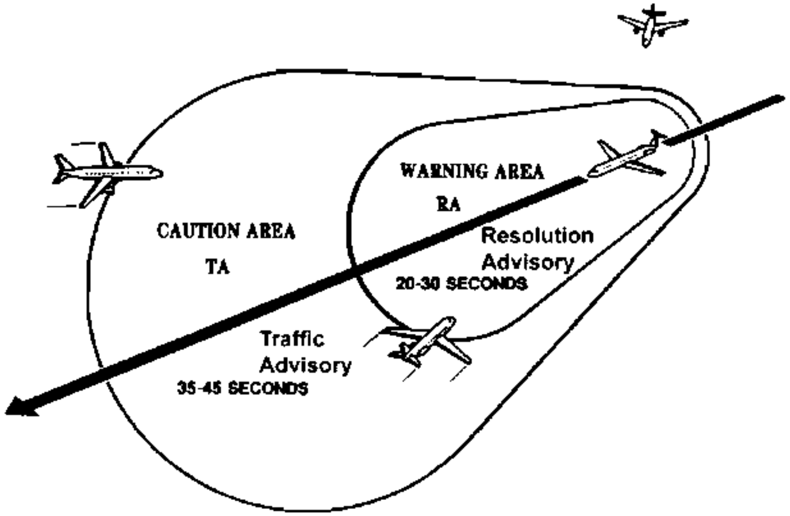
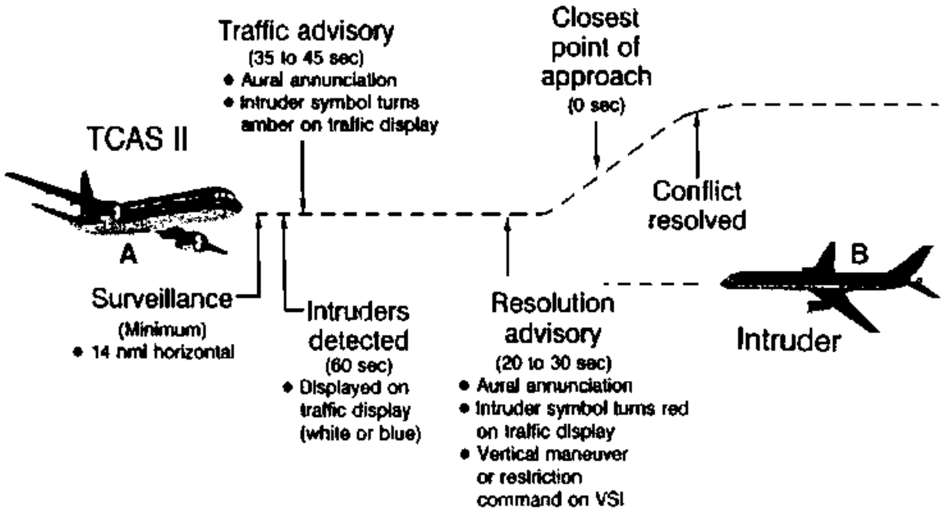


Figure 319: Collision Avoidance by vertical Maneuvre



Intruder Classification

The TCAS computes the intruder trajectory, the closest point of approach (CPA) and the estimated time (TAU) before reaching the CPA.

Each time the relative position of the intruder presents a collision threat, aural and visual advisories are triggered.

TCAS epitomizes vertical orders to ensure a sufficient trajectory separation and a minimal V/S variation considering all intruders.

Figure 320: Traffic and Resolution Advisory Areas

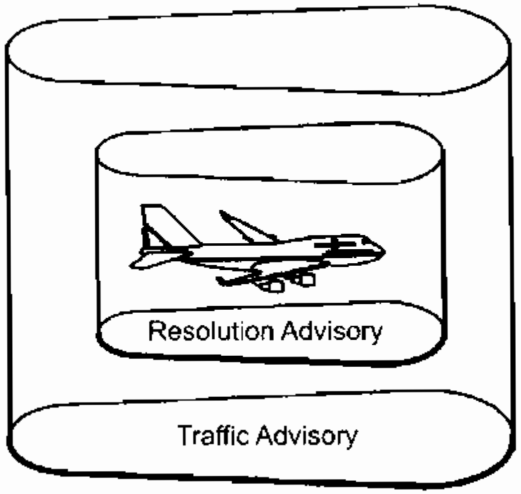


Figure 321: Closest Point of Approach

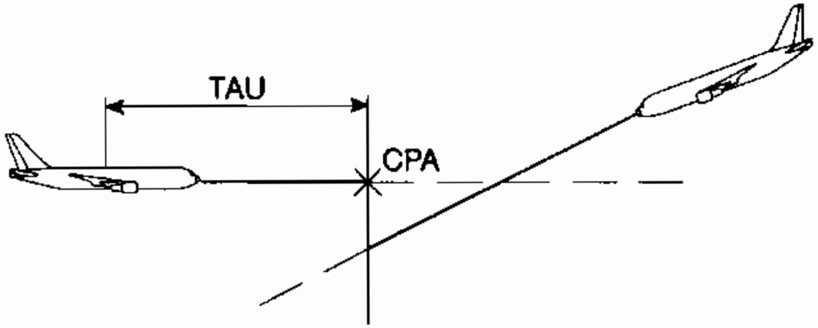
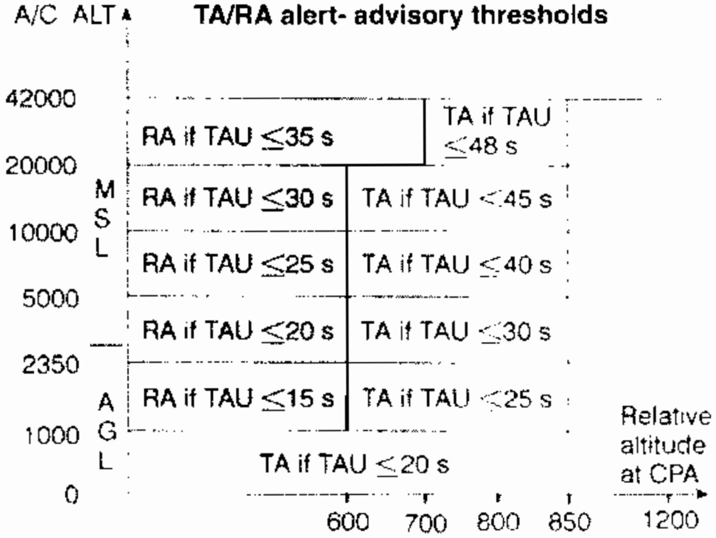


Table 7:

Level	Intruder position	Display information
Proximate	– No collision threat. – Closer than 6 NM and +/– 1200 ft.	– Intruder position
Traffic Advisory (TA)	– Potential collision threat.	– Intruder position. – Aural message.
Resolution Advisory (RA)	– Real collision threat.	– Intruder position – Aural message. – Vertical orders • Maintain actual V/S. (Preventive advisory) or • Modify V/S. (Corrective advisory)
Other Intruders	– No collision threat. – Any non proximate, TA, RA within surv. envelope.	– Intruder position.

Table 8:



Cockpit Presentation

There are various types of displays in the cockpit:

- VSI/TCAS Indicator
- Weather Radar Indicator
- ND and PFD

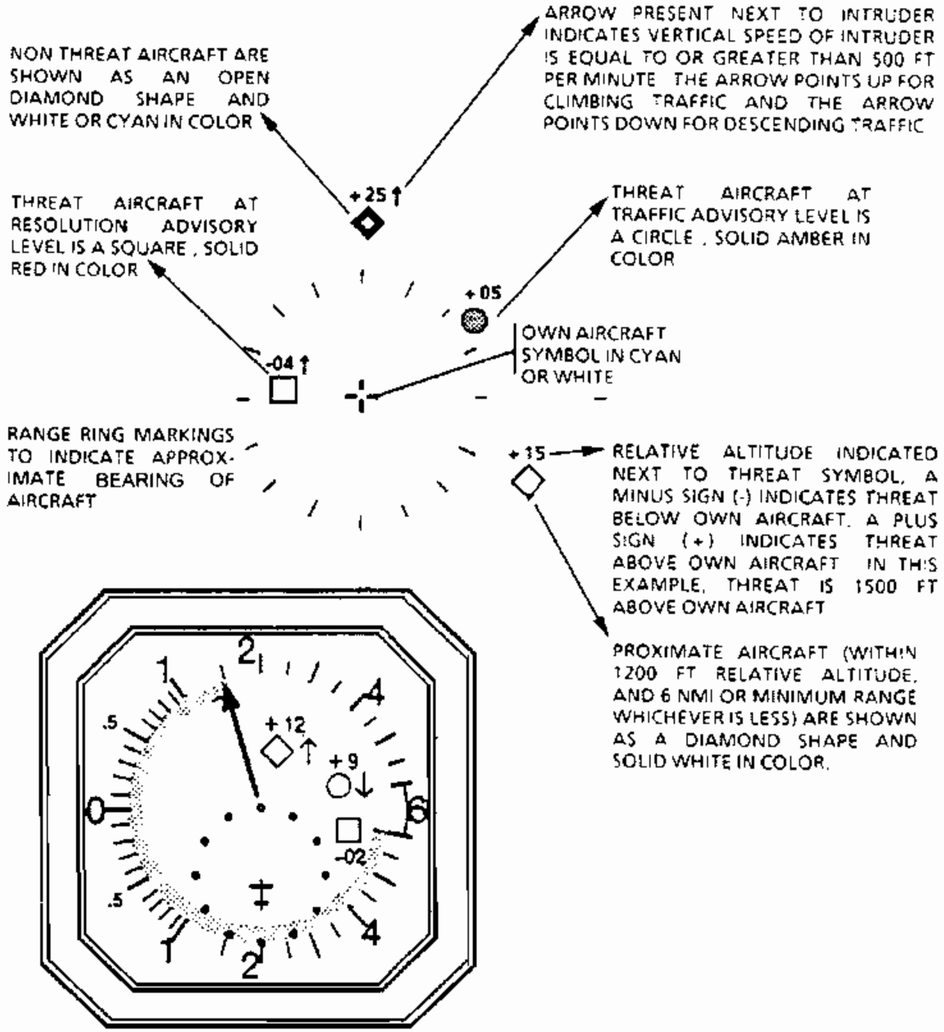
Traffic Advisory Display

The TA indication supports the pilot to make a visual search. The AC symbol on the display shows the pilot the distance and the relative bearing. The relative altitude in hundreds of feet, and as an arrow is displayed whether the aircraft is in climb or descent. Altitude information are only avail if the aircraft is equipped with altitude reporting. Update rate is once every second.

Resolution Advisory Display

The RA indication is the primary display to show the pilot the vertical speed correction to prevent a collision. The indication consists on red and green segments which can illuminate instead of the normal vertical speed indication. If the vertical speed pointer is in the red "stay-out-off" area, the pilot has to change the vertical speed until the pointer is in the green "fly to" area. That is designed as an corrective RA. If the pointer is out of the red area, the pilot has to maintain the actual vertical speed. That is designed as a preventive RA. Below 500 ft radio altitude, all resolution advisory are suppressed.

Figure 322: VSI with TA-RA Indication



Indication at ND and PFD

In today's EFIS equipped aircraft's traffic advisory (TA) and resolution advisory (RA) are superimposed in the navigation display. Vertical evasive manoeuvres is shown at the vertical speed scale on the primary flight display.

1. RA Intruder Immediate evasive manoeuvre required
2. TA Intruder Alert of traffic
3. Proximate Traffic within a range of 6 NM
4. Other traffic within a range of 8 NM
5. Relative altitude, climbing descending of the intruder
6. Red area. Forbidden vertical speed. High risk of conflict
7. Green area. Recommended vertical speed

The TCAS II indications for flight plan modifications are in the vertical plane only. The TCAS aural messages can be inhibited depending on higher priority aural messages. The Resolution Advisory (RA) informs the crew about an available avoidance manoeuvre.

Figure 323: ND

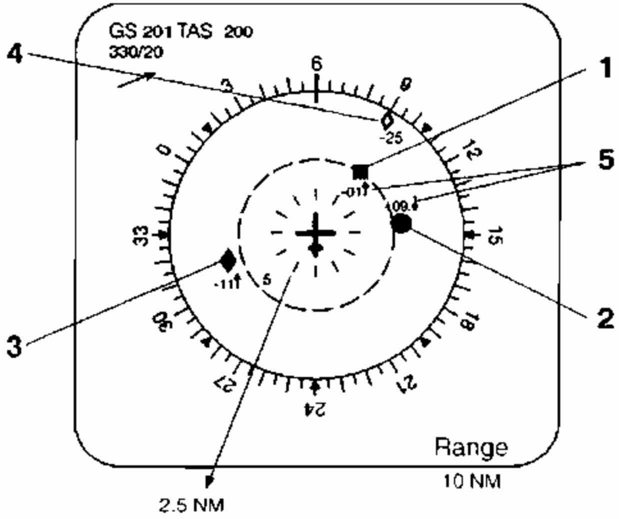
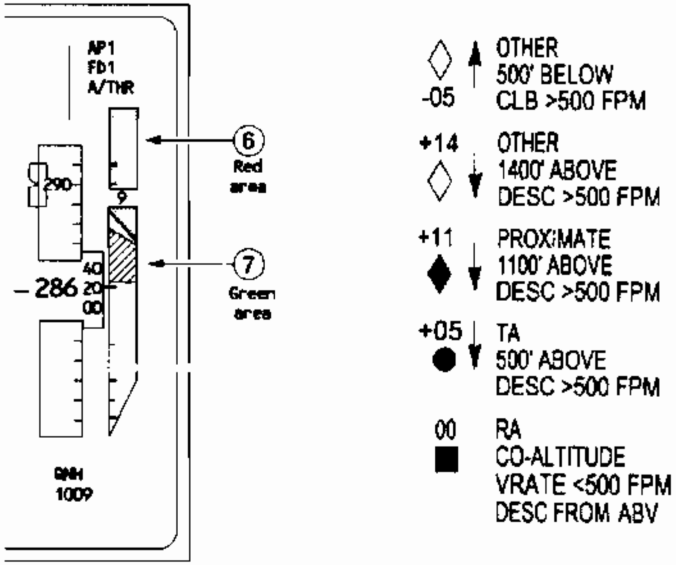


Figure 324: PFD



Aural Annunciation

Displayed traffic and resolution advisory are supplemented by synthetic voice advisory generated by the TCAS computer. The words "Traffic, Traffic" are annunciated at the time of the traffic advisory which directs the pilot to look at the TA display to locate the traffic. If the encounter does not resolve itself,. a resolution advisory is annunciated. The aural annunciations listed in the following example have been adopted as aviation industry standards.

The single announcement "Clear of Conflict" indicates that the encounter has ended (range has started to increase), and the pilot should promptly but smoothly return to the previous clearance.

To avoid confusion of pilots, by differend meaning of aural recommandations, following warnings and situations will **inhibit** the TCAS voice warnings:

- Stall warning
- Windshear warning
- Ground proximity warnings
- Low radio heights

Examples of aural annunciations

Traffic Advisory: TRAFFIC, TRAFFIC

Resolution Advisory:

Preventive:

MONITOR VERTICAL SPEED. MONITOR VERTICAL SPEED. Ensure that the VSI needle is kept out of the lighted segments.

Corrective:

CLIMB-CLIMB-CLIMB. Climb at the rate shown on the RA indicator; nominally 1500 fpm.

CLIMB, CROSSING CLIMB-CLIMB, CROSSING CLIMB. As above except that it further indicates that own flight path will cross through that of the threat.

DESCEND-DESCEND-DESCEND. Descend at the rate shown on the RA indicator; nominally 1500 fpm.

DESCEND, CROSSING DESCEND-DESCEND, CROSSING DESCEND. As above except that it further indicates that own flight path will cross through that of the threat.

REDUCE CLIMB-REDUCE CLIMB. Reduce vertical speed to that shown on the RA indicator.

REDUCE DESCENT -REDUCE DESCENT. Reduce vertical speed to that shown on the RA indicator

INCREASE CLIMB-INCREASE CLIMB. Follows a "Climb" advisory. The vertical speed of the climb should be increased to that shown on the RA indicator, nominally 2500 fpm.

INCREASE DESCENT-INCREASE DESCENT. Follows a "Descend" advisory. The vertical speed of the descent should be increased to that shown on the RA indicator, nominally 2500 fpm.

CLIMB, CLIMB NOW-CLIMB, CLIMB NOW. Follows a "Descend" advisory when it has been determined that a reversal of vertical speed is needed to provide adequate separation.

DESCEND, DESCEND NOW-DESCEND, DESCEND NOW. Follows a "Climb" advisory when it has been determined that a reversal of vertical speed is needed to provide adequate separation.

System

- 2 TCAS Antennas
- 1 TCAS Computer
- 2 TA/RA Displays
- 1 TCAS Mode S control- panel
- 2 Mode S Transponder with 2 Antennas

Top and Bottom Antenna
Each connected via 4 colour coded coaxial cables Tx. 1030 MHz. Rx. 1090 MHz.

Radio altimeter units (RA)
Modulation of system sensitivity 0 - 2500 ft. and triggering of inhibit orders.

Ground / Flight discrete
When Aircraft is on ground system operates in TA ONLY mode.

Attitude / Heading data
Used to compute the closest point of approach.

ATC mode S transponders
Air to Air coordination of own TCAS and detected TCAS equipped intruder aircraft. One transponder is active the other on stand-by.

Barometric Altitude via ATC Transponder
Modulation of system sensitivity above 2500 ft. and triggering of inhibit orders. I.e. inhibit climb order above 48'000 ft.

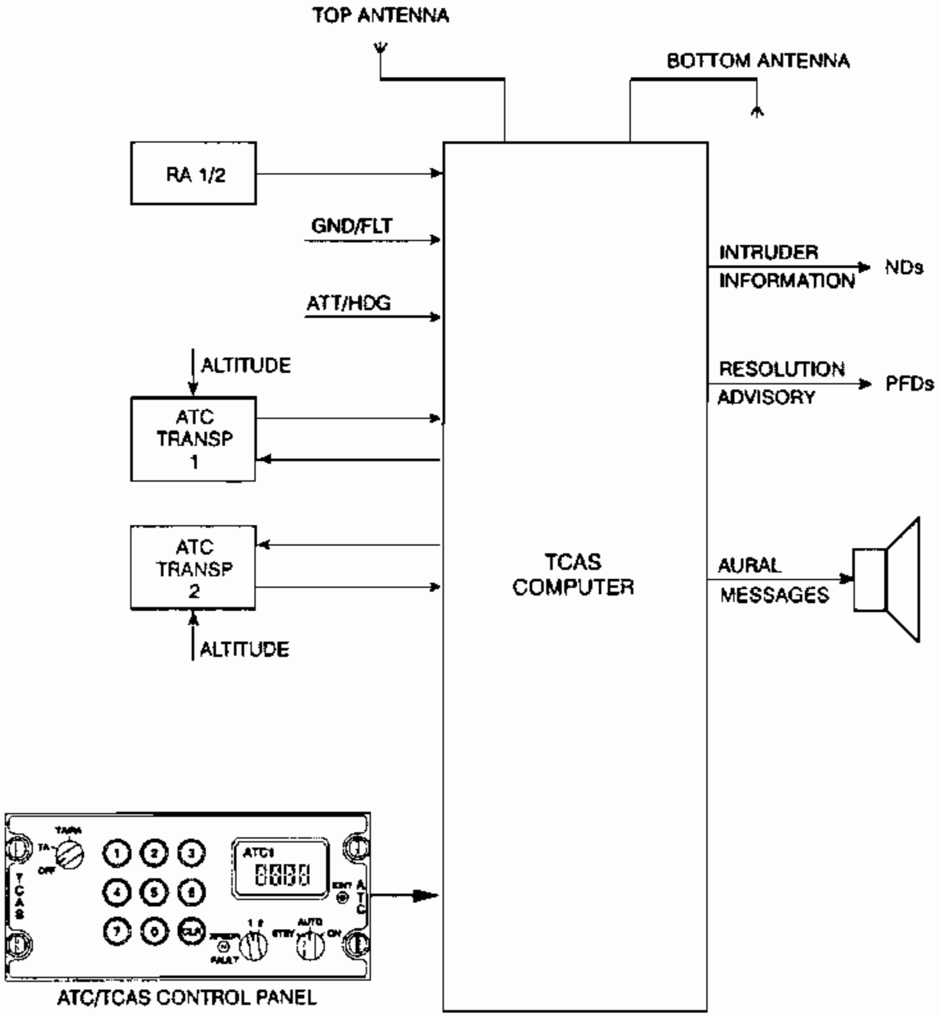
ATC / TCAS Control panel
Common to the ATC transponders and the TCAS. Enables the operating modes of these two items of equipment to be selected.

Navigation Display ND
Lateral display of intruders TA / RA.

Primary Flight Display PFD
Vertical display of resolution advisory RA.

Cockpit Speaker
Broadcasting aural TA and RA messages.

Figure 325:



Computer Unit

The heart of the TCAS II system, the computer unit, performs airspace surveillance, intruder tracking, traffic display, threat assessment, collision threat resolution and TCAS coordination. Using data from the airframe and other installed systems, it changes performance parameters to match varying altitudes and aircraft configurations.

The surveillance algorithms have been specially designed to reduce split tracks (multipath), and have been extensively tested under high density conditions.

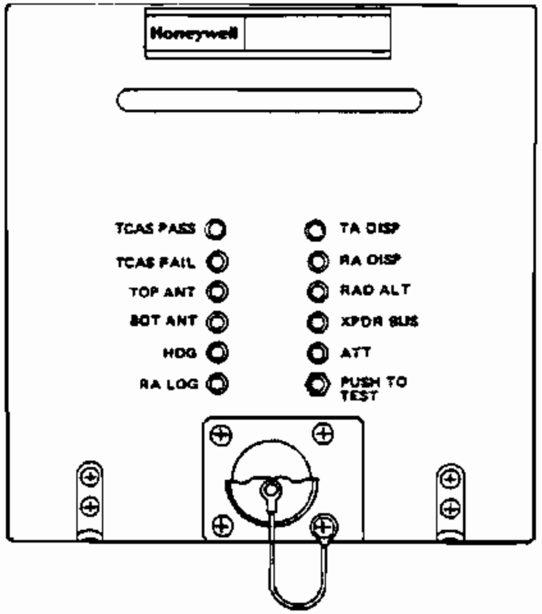
The unit uses collision avoidance algorithms to determine if a tracked aircraft is a collision threat and for selecting the best avoidance manoeuvre. It also uses logic to coordinate escape manoeuvres with other TCAS-equipped aircraft.

Future software changes are easily incorporated into the unit on board the aircraft via an ARINC 603/615 data loader port accessible from the unit front panel connector or rear connector aircraft wiring.

The TCAS computer is equipped with a built in test equipment (BITE). This program protects the power supply, the microprocessor, the memories, the transmitter and receiver and the antennas. This program is able to detect a wrong antenna connection.

At the computer front face a self test can be made by pressing the test button for a few seconds. All lights are on for 3 seconds and after the TCAS status is displayed for 10 seconds.

Figure 326:



TCAS Characteristics:

Pulse power 500 Watt

Transmit frequency 1030MHz

Reception frequency 1090MHz

Range 80 NM

Capable to handle 8 intruders simultaneously

Computer Block Diagram

The block diagram shows the received signals entering the TCAS receiver-transmitter through a beam steering network and a diplexer. The received signal is then applied to the signal processing circuits that remove the altitude and aircraft identification information from the received signal. This information is then sent to the CPU for use in the threat algorithms stored in program memory. The TCAS system uses the replies of transponder equipped aircraft to determine the potential threat of the aircraft. The TCAS system is capable of determining range, bearing to intruder and altitude of intruder if the intruder transponder is reporting altitude. from each reply.

The TCAS receiver-transmitter uses several replies from the intruder aircraft to determine the altitude rate and range rate of the intruder aircraft. In other words, the TCAS receiver-transmitter uses the reported altitudes to determine how fast the intruder aircraft is climbing or descending and uses the elapsed time between transmission and replies to determine whether the aircraft is approaching or leaving the surveyed area. The TCAS receiver-transmitter also uses the changing bearing positions to determine a probable flight path for the intruder.

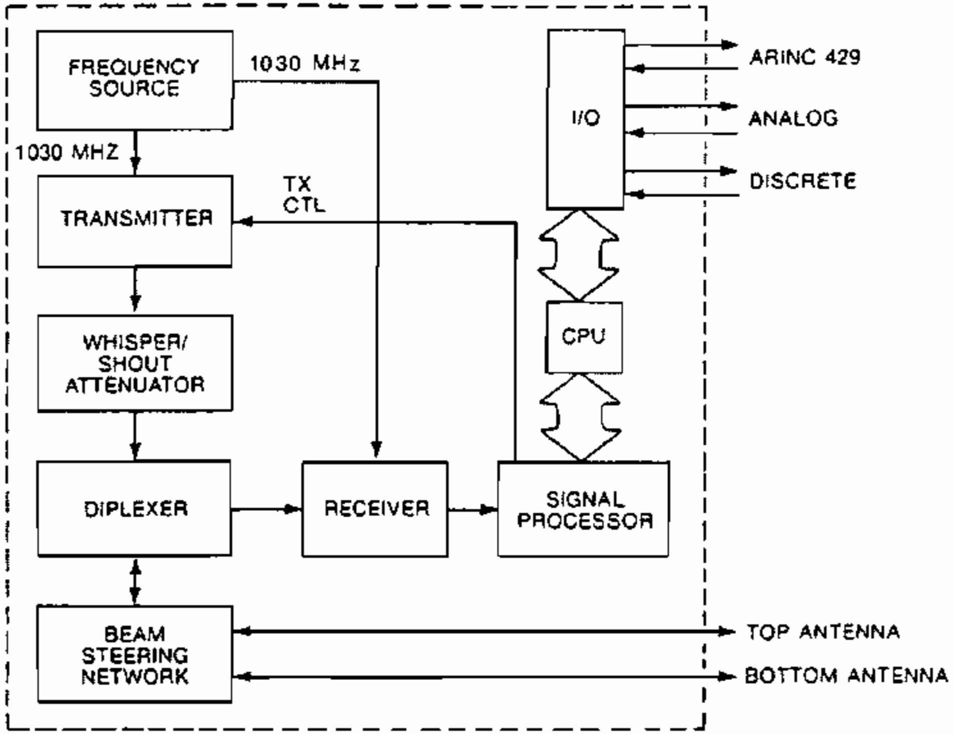
The TCAS receiver-transmitter contains the algorithms used for collision avoidance in TCAS II. These algorithms include tracking algorithms for intruder aircraft, threat detection algorithms. selection of resolution advisories algorithms, generating traffic advisory algorithms, and the algorithms for own aircraft altitude and sensitivity levels.

The receiver-transmitter also handles the Mode S data link transmissions that are TCAS related. The Mode S data link capabilities are only required when two TCAS equipped aircraft approach each other, in order to coordinate the manoeuvres of each aircraft.

From the transponder replies of intruder aircraft and if available the TCAS Mode S data link messages, the TCAS receiver-transmitter determines if the flight path and profile of the intruder aircraft will result in a conflict with its own aircrafts flight.

Based upon the TCAS own aircraft profile, the receiver-transmitter determines the appropriate resolution advisory.

Figure 327:



Antenna

The antennas, mounted on the top and bottom exterior fuselage, are extremely low-profile, four-element directional devices capable of transmitting in four selectable directions and receiving omnidirectionally with bearing information. The 4 antenna segments has an opening angle of 30 degrees and are vertically polarized. The TCAS computer's ability to receive omnidirectionally with bearing greatly simplifies surveillance algorithms for tracking nearby aircraft.

The antenna transmits pulses at 1030 MHz at varying power levels in one of four computer-selected segments. The computer receives at 1090 MHz from the directional antenna over four output coaxial cables to four receivers, one for each directional beam. The directional antenna permits sectorized interrogations for higher density operation.

The range of the replying aircraft can be calculated, using the speed of the returning signal and the amount of time elapsed

$$Distance = \frac{Elapsed\ Time}{12.359\mu s\ perNM}$$

Figure 328: Upper and lower Antenna

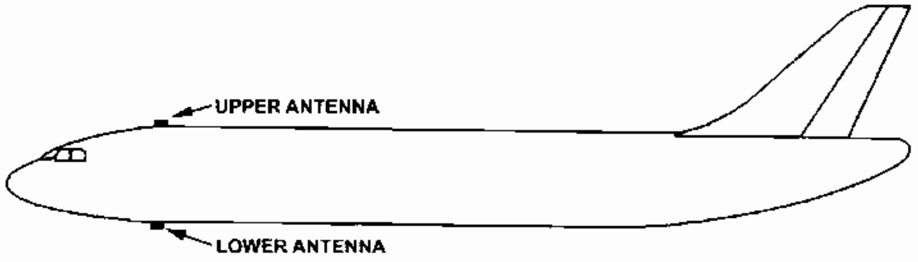
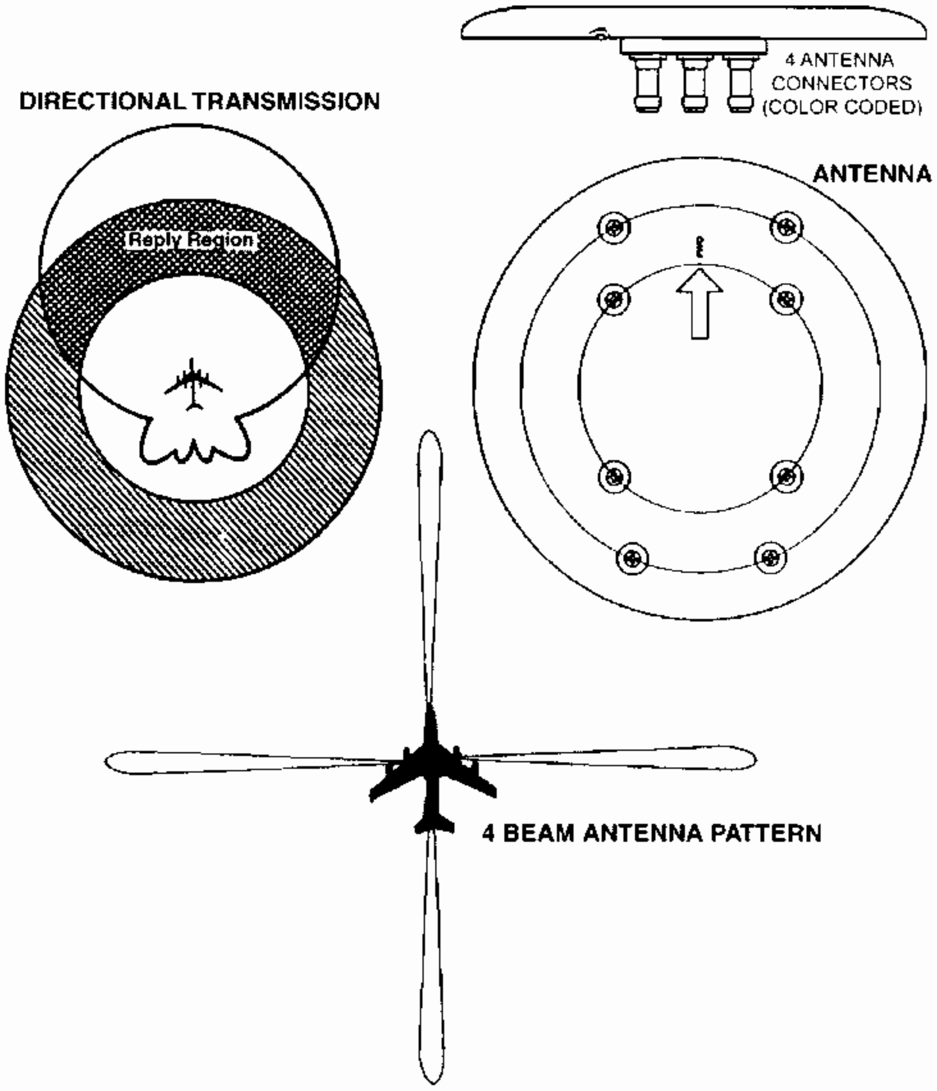


Figure 329: Antenna Beam Pattern



Communication between Aircrafts

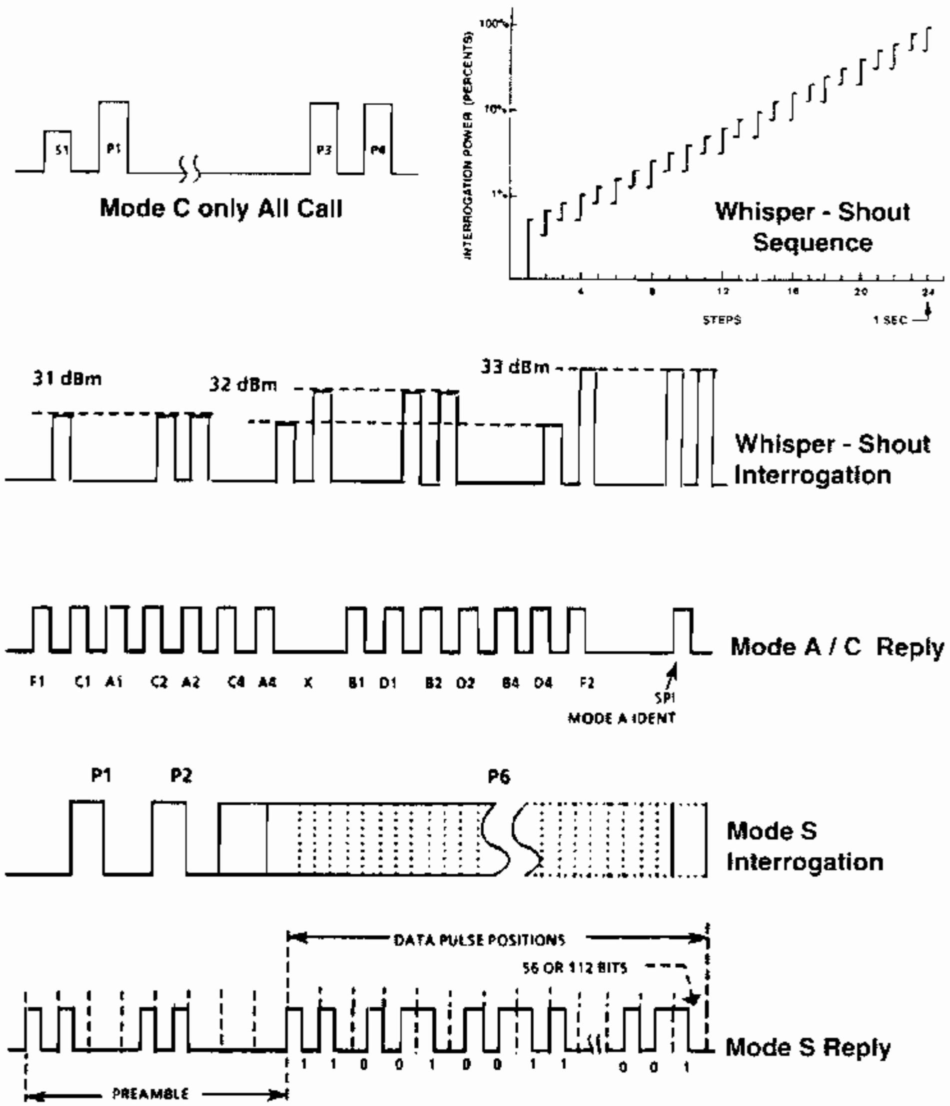
The TCAS receiver-transmitter transmits interrogations to the transponder equipped aircraft in the vicinity to generate transponder replies that the signal processing circuits of the TCAS will decode to identify the threat aircraft. Once each second, it transmits an interrogation for all ATCRBS and Mode S transponder-equipped aircraft. This one second period is referred to as the surveillance update period for all traffic within range of the TCAS-equipped aircraft.

ATCRBS interrogations from TCAS equipment employs the Mode C only All-Call three pulse format. Pulse S_1 is of lower amplitude than pulse P_1 and the two form a transponder suppression pair with a pulse separation of two microseconds. Only transponders that receive P_1 above a noise level of about S_1 pulse amplitude will respond to the TCAS II interrogation. The P_1-P_3 pulse spacing is the normal 21 microseconds for a mode C altitude reporting interrogation. Pulse P_4 is part of the format in order to suppress airborne Mode S transponders, which also would provide Mode S replies if not suppressed. The four pulse format group are repeated at increasing power levels over an approximately 20-dB range to generate a whisper-shout sequence. The transponder will reply if the amplitude of S_1 is below the noise level and P_1 is received at a greater level.

Between aircrafts different TCAS communication depending on the equipment:

- **Combined Mode A / Mode S-all-call or Mode C / Mode S all call interrogation:**
  All aircraft with ATC transponders reply this interrogation signals. To prevent signal overlapping from different aircrafts, the computer uses a whisper shout system. (different pulse group amplitudes). The whisper shout sequence is repeated every second.
- **Mode A or Mode C reply:**
  If the TCAS computer receives only mode A signals, only TA indication is possible. An evasive action coordination is impossible.
- **Selective interrogation (Mode S):**
  Aircrafts equipped with mode S transponders can be interrogate selective. (Coded pulse groups)
- **Mode S reply:**
  With this reply signals, the TCAS is able to display a TA and to calculate an RA.
- **Coordination of an evasive action:**
  Only possible between aircrafts equipped with TCAS II and mode S transponders.

Figure 330: TCAS Communication Pulses



Weather Radar

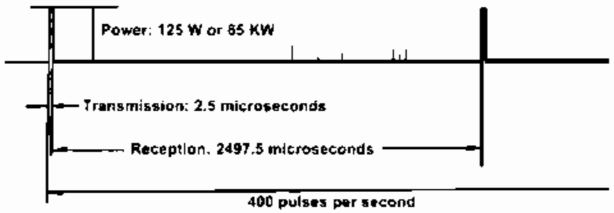
General

The Airborne Weather Radar System (WXR) allows the detection and display of severe weather areas. The WXR helps the pilot to avoid these areas and the associated turbulences by determining their range and bearing. It also provides a ground mapping.

The radar emits microwave pulses through a directive antenna which picks up the return signals. The range is determined by the time taken for the echo to return. The azimuth is given by the antenna position when the echo is received.

Frequency: Microwaves 9.4 GHz
Pulse power: 125 Watt - 65 kW 180 - 400 pulses per second

Figure 331: Tx with Rx Pulses



Observe the safety precaution if you operate the radar!

The high energy radiowaves are dangerous for human bodies and may ignite inflammable liquids!

Figure 332: Radar scanning a Cloud

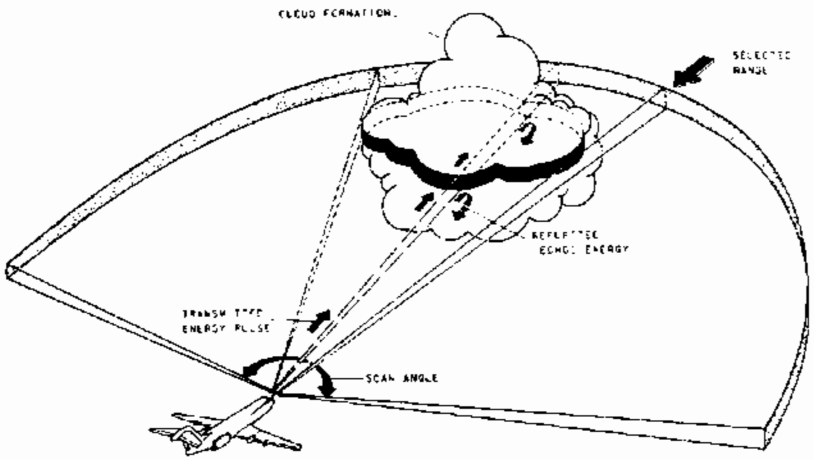


Figure 333: Transmission and Echo

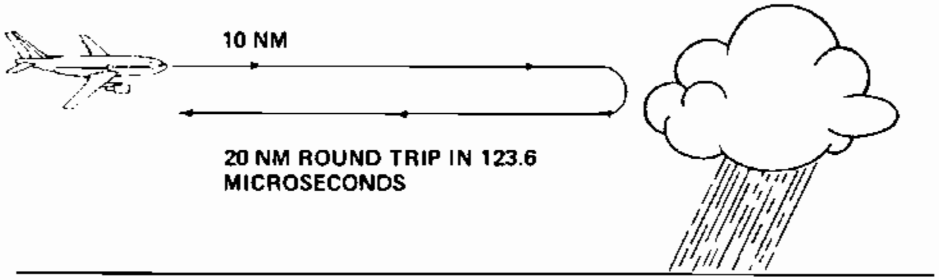
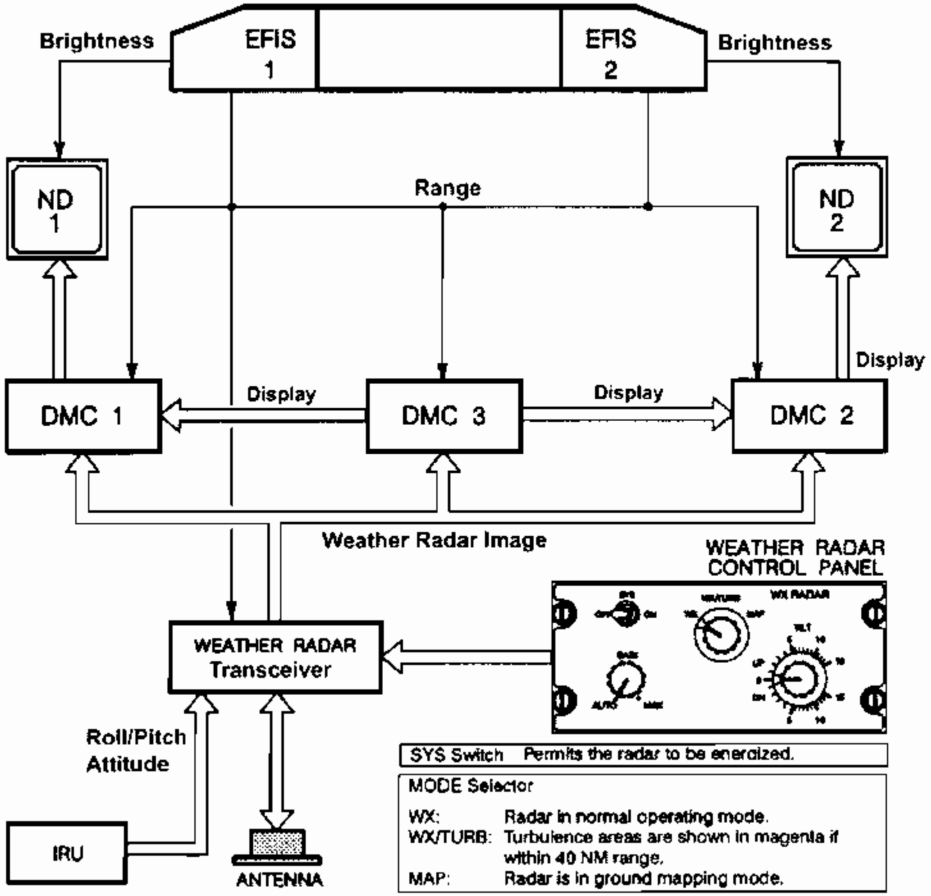


Figure 334: Weather Radar System Block Diagram



SYS Switch Permits the radar to be energized.

MODE Selector

WX: Radar in normal operating mode.
WX/TURB: Turbulence areas are shown in magenta if within 40 NM range.
MAP: Radar is in ground mapping mode.

TILT Knob

Allows manual control of antenna tilt. 0 refers to the horizon

GAIN Knob

Used to adjust the sensitivity of the receiver in ground mapping mode only.
AUTO: Gain is automatically adjusted to optimum setting.

Figure 335: Weather Radar Indication

Colour	Rainfall
Green	1 to 4 mm/hr
Yellow	4 to 12 mm/hr
Red	> 12 mm/hr
Magenta	Turbulence area

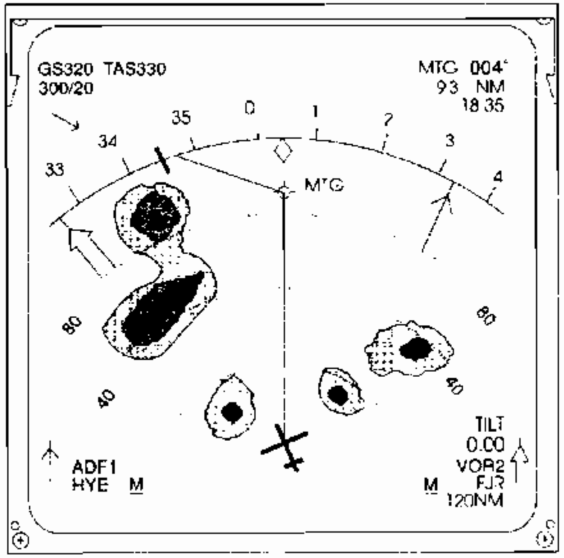
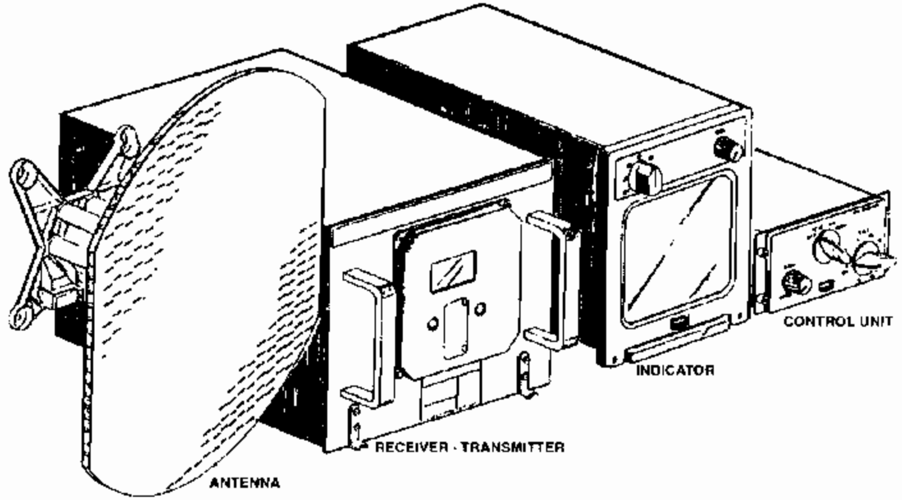


Figure 336: Components



How Radar detects Turbulences and Windshear

Conventional Radar: The transmitter emits a pulse which uses only the reflectivity of rainfall (droplets of precipitation) to return an echo to the receiver.

Turbulence Detection. Pulse waveforms show that the echo frequency differs from that of transmitted pulse. Caused by the Doppler effect. The frequency shift represents turbulence which imparted motion to the droplets. The received radar signal actually shifts over a spectrum of frequencies; the broader the band, the greater is the turbulence. When the spectrum exceeds a threshold defined moderate to heavy, the return is displayed on the screen as turbulence (a magenta-colored area). That threshold occurs when droplets move at the rate of 5 meters per second.

Figure 337: Pulses

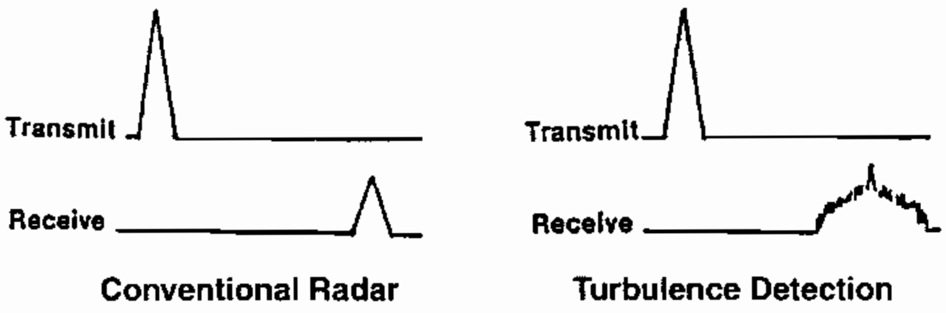
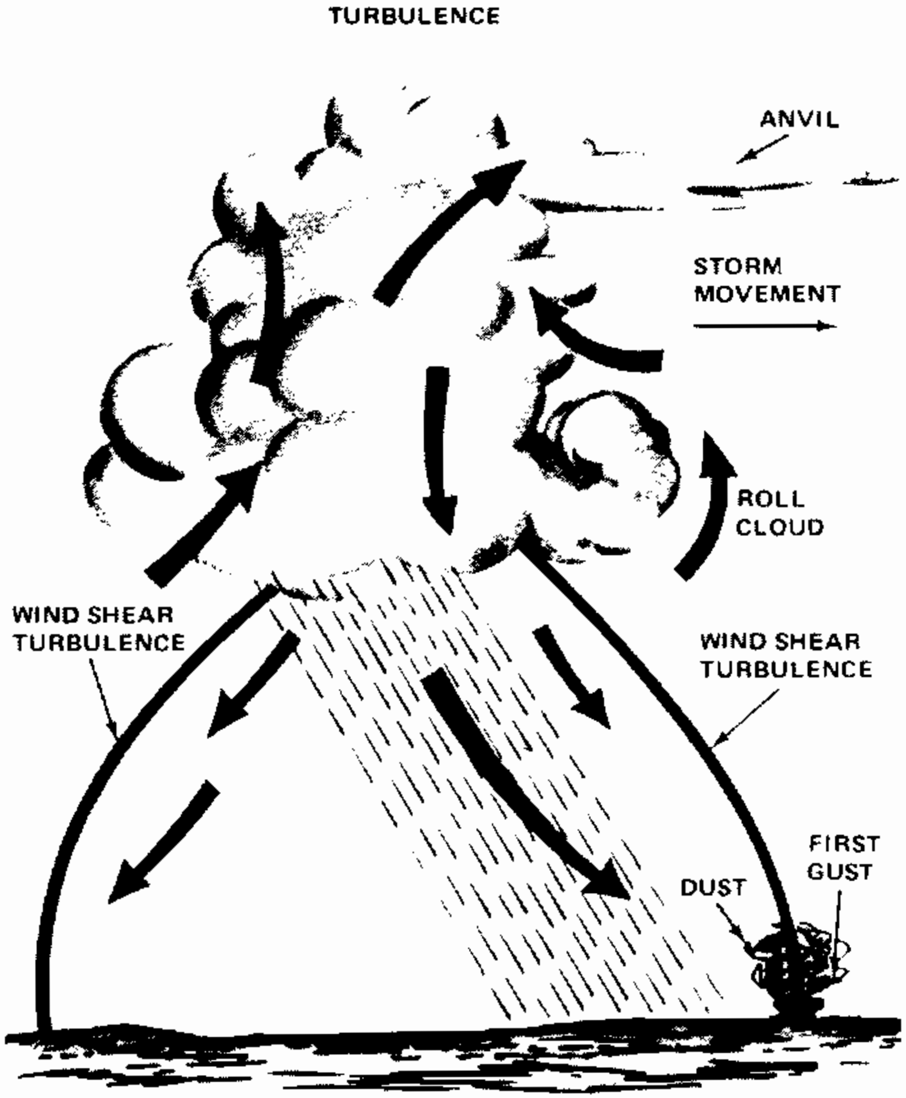


Figure 338:



Windshear Weather Radar (Microburst Detection)

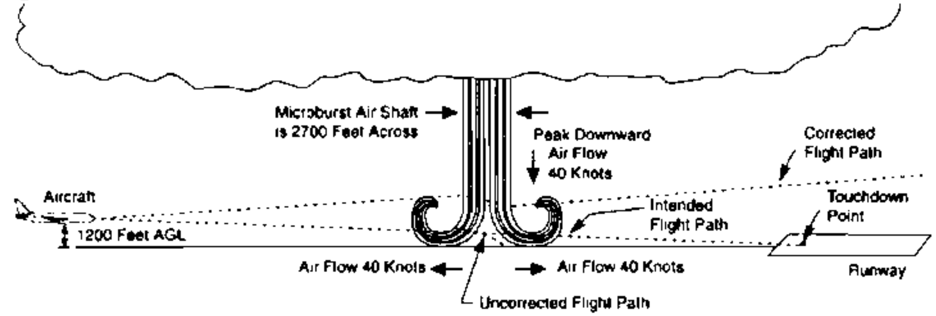
During both takeoffs and landings, microbursts have been the cause of numerous transport aircraft accidents. A Forward Looking Windshear Detection/Avoidance Airborne Weather Radar System has the capability to detect the presence of microbursts up to 5 NM ahead of the aircraft flight path when below 1500 feet AGL.

A microburst is a cool shaft of air, like a cylinder, between 1000 and 3000 feet across that is moving downward. When it encounters the ground the air mass mushrooms in a horizontal direction curling inward at its edges. The downward air velocities associated with these narrow air shafts range from 40 to 110 knots. When the downward moving air flow is translated to a horizontal flow at the base of the air shaft, the outflow winds have front-to-back velocities ranging from 80 to 220 knots.

Two types of microbursts exist, wet and dry. A wet microburst is characterized by the rain droplets within the air shaft failing all the way to the earth's surface largely intact. A dry microburst is characterized by a rain that exits from the cloud base, but substantially evaporates before reaching the ground. Virga occurs in high based rainstorms found in places like the high plains and western United States. Regardless of whether the microburst is wet or dry, the air shaft's wind characteristics are identical.

The air shaft of a microburst creates problems for aircraft for two reasons. The first problem is due to the downward air movement. Since the aircraft is flying within the air mass, as the air mass plummets earthward, so does the aircraft. Second, the lift that is generated by the wing is related to the relative velocity of air traveling over the wing. If the air velocity suddenly changes, so does lift. When the lift is reduced, the aircraft descends. As an aircraft enters a microburst, depending on the point of entry, it will experience at least one of these conditions and most probably both.

Figure 339: Microburst



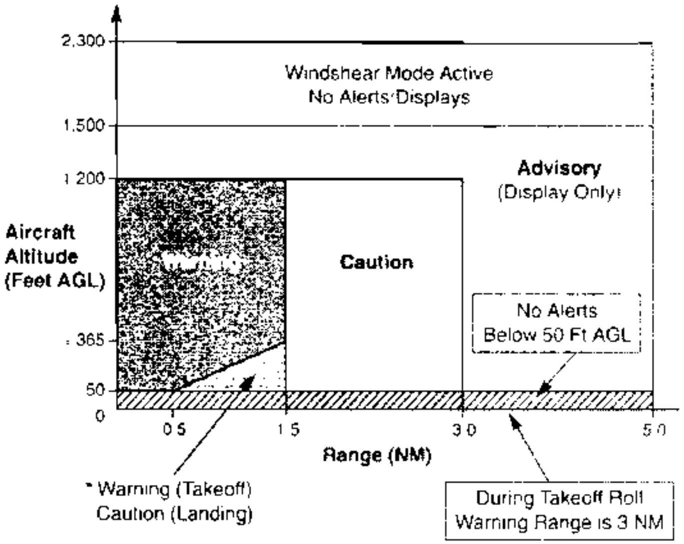
Detection Process

When the airshaft of a microburst encounters the ground, it mushrooms outward carrying with it a large number of the failing raindrops. By measuring the horizontal velocity of these water droplets the weather radar is able to infer the horizontal and vertical velocity of the winds carrying the raindrops.

The radar processor detects the doppler frequency shift imparted onto the reflected microwave pulses by a microburst. As the radar scans across the windshear event, it will detect raindrops moving toward it at one range and away from it at a slightly greater range.

The difference in the range between the raindrops moving toward and away is the width of the base of the microburst. After the radar detects this condition, it then proceeds to assess the severity of the event by measuring how fast the droplets are moving. If the assessment of the severity of the microburst exceeds a preset threshold value, a windshear alert is issued on the radar display and through the flight deck audio system.

Figure 340: Warning Thresholds



System

In short words:

Control Unit
Mode selection, Reception Gain, Range, Tilt.

Indicator
Separate CRT /TFT display unit or EFIS is used.

Attitude
Antenna stabilization.

RadioAltitude
For windshear alert computation.

Air Data Computer
True Airspeed for wind shear alert computation.

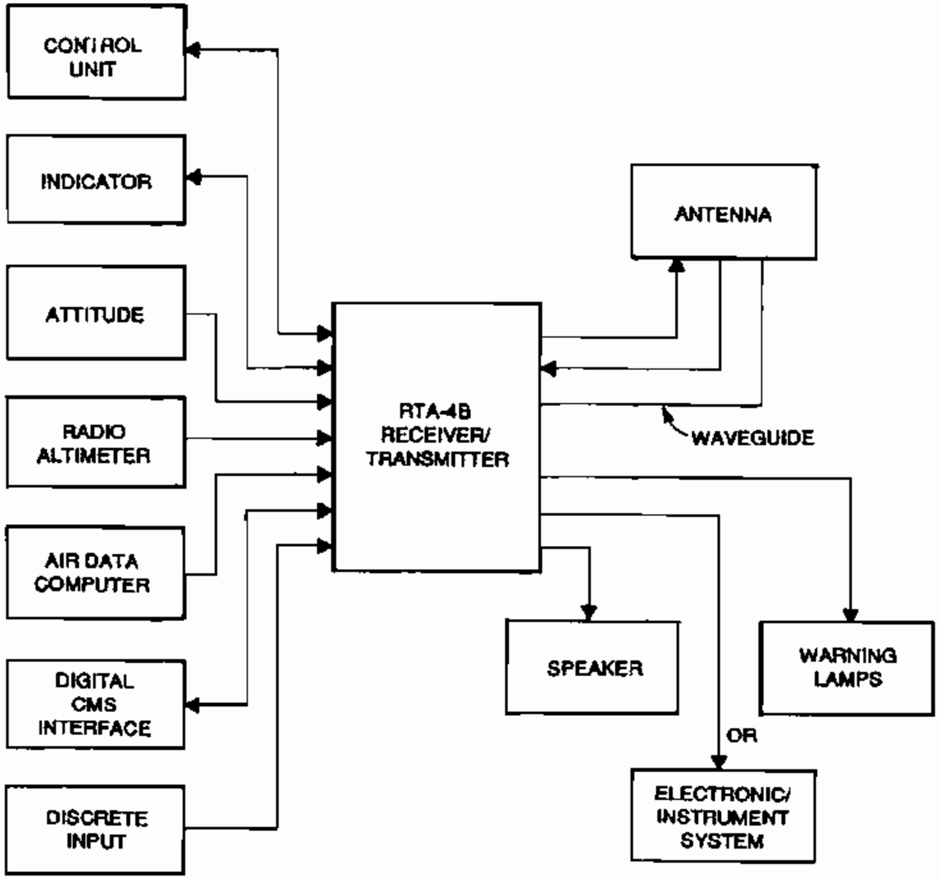
Digital CMS Interface
Central Maintenance System for maintenance. Test and malfunction logging.

Discrete Input
Warning inhibit, Gear up/down.

Antenna
Transmission and reception via wave guide.
Stabilisation in roll and pitch. Tilt control via selector. Azimuth movement contol.

Warning lamps (optional)
Wind shear alert.

Figure 341: Blockdiagram



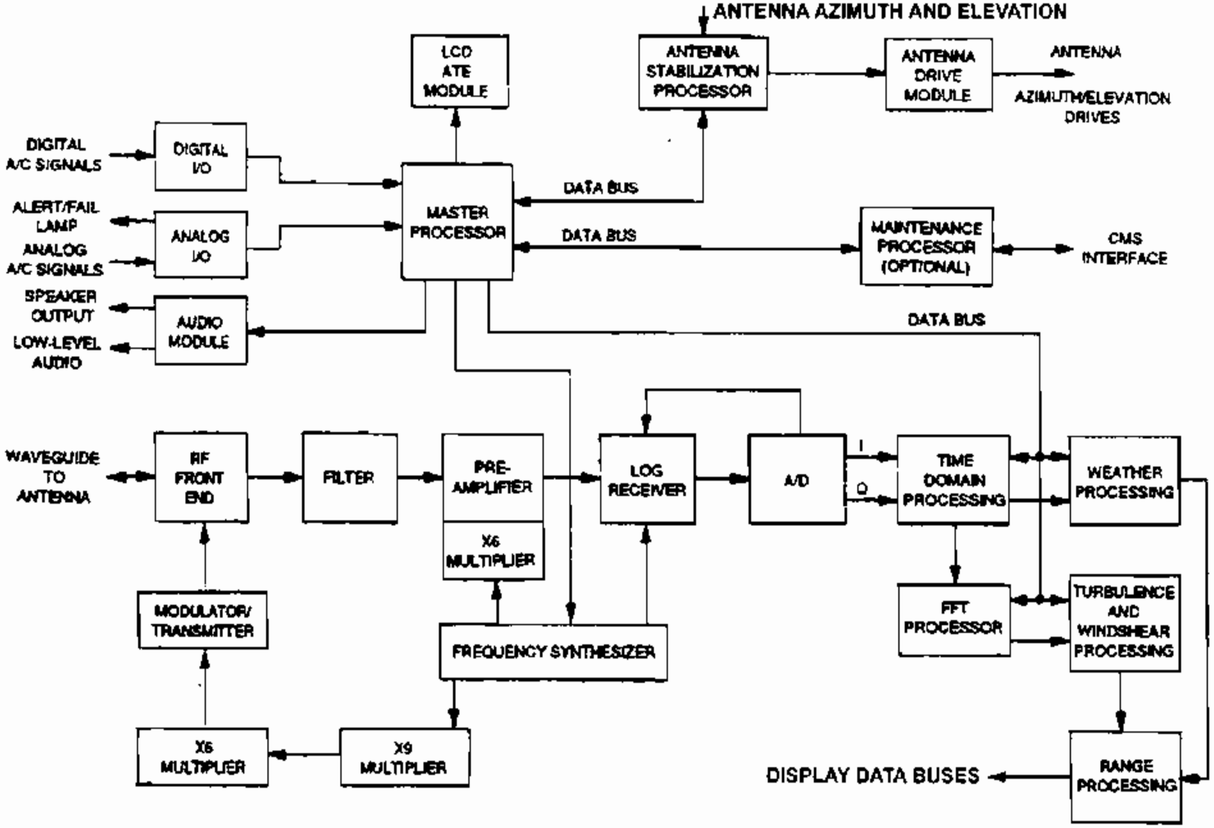
Electronic Instrument System EIS
Instead of separate Indicator.

Speaker
Aural warning for winshear alert.

Receiver - Transmitter Unit

- Master Processor Controls all functions of R/T - Unit
- Frequency Synthesizer, MultipliersModulator/Transmitter, RF Front End
  Transmission of pulses from aircraft.
- RF Front End, Filter Preamplifier, Logaritmic Receiver
  Reception of returning echo pulses.
- Digital and Analog Input/Output
  Attitude input for Antenna Stabilisation, Range and Mode selection, Interface to other avioncs system.
- Audio Module Voice warning Windshear.
- Analog/Digital Converter, Time Domain Processing, Weather Processing, Fast- Fourier Transform Processor, Turbulence and Windshear Processing, Range Processing
  Performance of all output computations to displays and alerts.
  Output to display unit: ARINC 453 1600 Bit/Word, 1MHz Clock, 6200 Words/ sec.
- Antenna Stabilisation Processor, Antenna Drive Module
  Performing antenna stabilization, tilt and azimuth control.

Figure 342: Block Diagram



Transmission Pulses

A timing diagram of the pulse transmissions in the weather and weather/turbulence operating modes is provided in next figure. In windshear detection/avoidance mode, frequency is 6000 Hz and the sequence of transmitted pulses consists of two interleaved pulse trains, each train with a different carrier frequency, A and B.

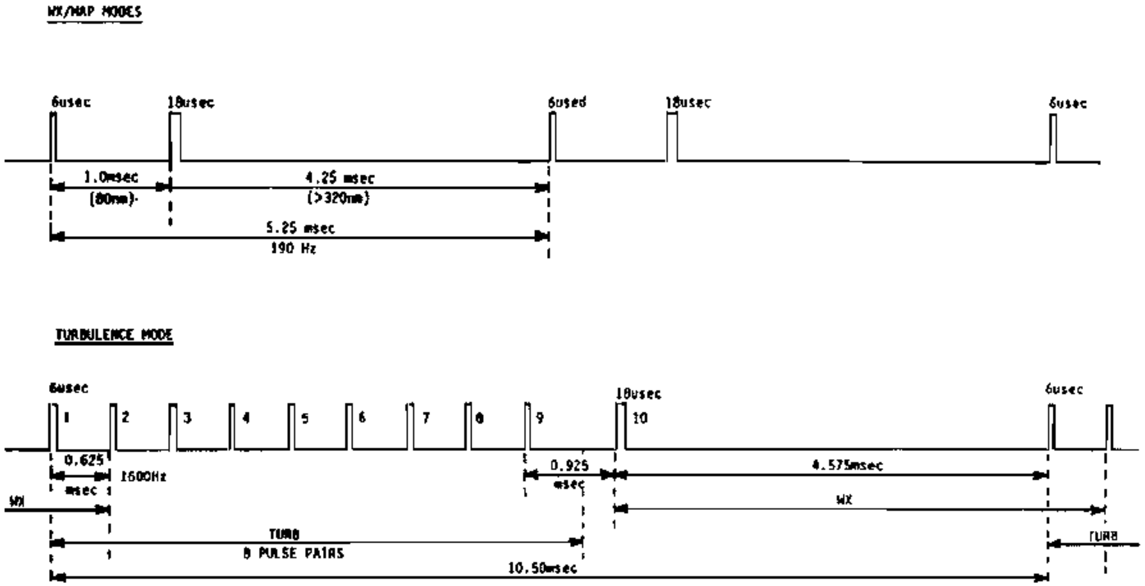
For the weather (WX) and terrain-mapping (MAP) modes, the basic transmit-receive period is 5.25 milliseconds. This results in a basic pulse repetition frequency (PRF) of 190 Hz. However since two pulses (6 and 18 microseconds wide) are transmitted, the PRF is specified as 380 Hz.

The received echoes from the 6-microsecond pulses are processed to produce targets ranging from zero to 20 nautical miles on the radar indicator. Received echoes from the 18-microsecond pulses are processed to produce the targets located at distances greater than 40 nautical miles. Received echoes from both the 6-microsecond pulses and the 18-microsecond pulses are processed to produce the targets located at distances between 20 and 40 nautical miles. The timing is varied slightly (jittered) between the 6- and 18-microsecond pulses.

When the turbulence mode is selected, the system shifts to an interlaced high and low PRF pattern to acquire intensity as well as turbulence information simultaneously. Pulses 1 through 9 (TURB) are transmitted at 1600 Hz and are used for turbulence detection. Pulse 10 is used for weather intensity determination. Pulses 1 through 9 are 6 microseconds wide and pulse 10 is 18 microseconds wide. The high PRF rate necessary for Doppler processing limits the turbulence detection range to 40 nautical miles.

When a range greater than 40 nautical miles is selected in turbulence mode, the indicator will display weather plus turbulence to a range of 40 nautical miles, and weather only beyond 40 nautical miles. In turbulence mode, interference is minimized by varying the timing between each PRF cycle.

Figure 343:



Antenna

The weather radar uses a narrow beam transmittet and received toward determined direction. The azimuth dive scanns the space ahead the aircraft for clouds, thunderstorm, hail and terrestic obstacles. Elevation- tilt- and rolldrives compensates the aircraft movements to obtain a stable weather radar image on the displays.

Parabolic Antennas

Older models using parabol antennas. The RF power 9,375 GHz about 65 kW is supplied via wave-guide and feeder toward the parabolic reflector. From there a narrow beem is directed into the space. The spoiler deflects the radiowaves toward the ground for ground mapping.

The Parabolic Reflector works on a similar principle to a car headlight reflector. Energy striking the reflector from a point-source situated at the focus will produce a plane waveform in a direction parallel to the axis to the parabola.

The feed is usual a dipole with a parasitic element. The consequence of a dipole feed is that the beam will have a main lobe and smaller side lobes, which usually means much higher powers are associated with these antennae than with the flat-plate types.

Figure 344:

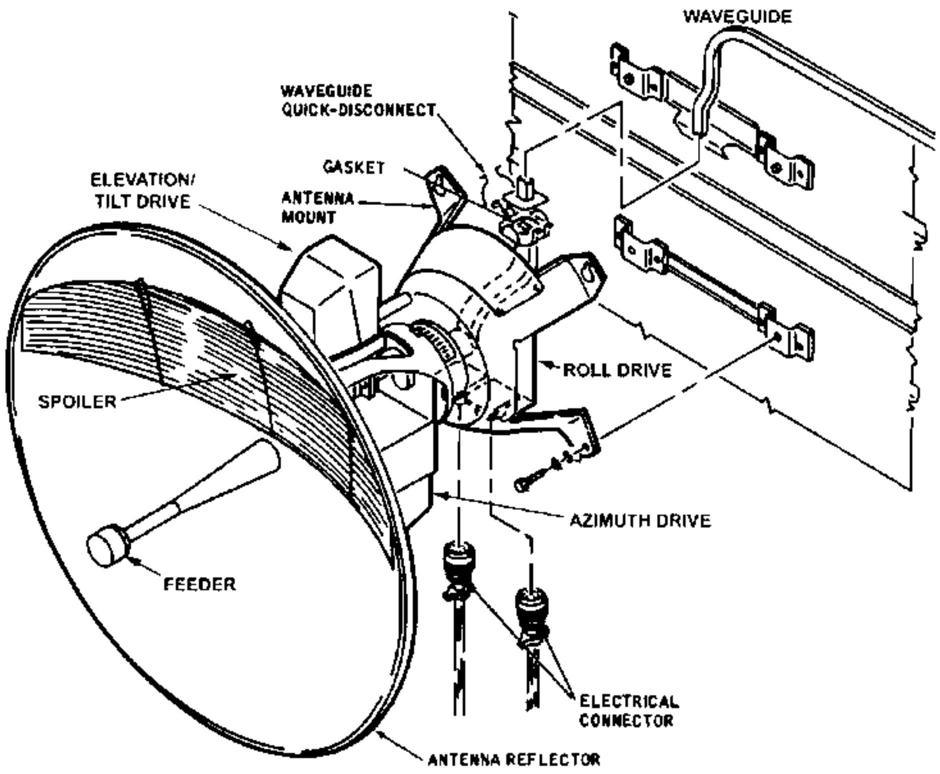
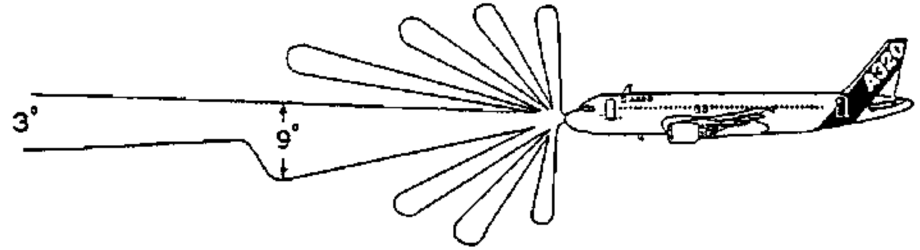


Figure 345: Antenna Pattern



Flat Plate Antenna

Newer systems uses flat plate antennas. Into a hollow plate many slots are arranged so, that each slots sends a narrow beam. The sum of all beams together builds up a pencil shaped narrow beam with an opening angle of only 3 degrees. This high efficient antenna makes possible, that the weather radar system operates with reduced transmisson power of only 125 Watt's.

The flat plate antenna consists of strips of wave guide vertically mounted side by side with the broad wall facing forward. Staggered off-centred slots are cut in each wave-guide so as to intercept the wall currents and hence radiate.

Several wavelengths from the antenna surface, the energy from each of the slots will be summed in space, resulting in a narrow beam radiation pattern.

The greater the number of slots the better the performance (narrower beamwidth), but since the spacing between slots is critical. We can only increase the number of slots by increasing the plate area.

It is mounted on a pedestal, which contains the necessary mechanisms and circuitry for scanning and tilting the antenna.

The weather radar system's R/T unit and antenna are interconnected by flexible and rigid wave-guide sections. The RF energy is routed directly to the antenna via the wave-guide. The reflected RF energy is also routed directly back to the R/T unit.

The wave-guide is connected to the antenna with a quick-disconnect so that the antenna may be easily removed and replaced when required. The wave-guide system is vented aft of the forward bulkhead, so that pressurised warm cabin air can be used to keep the wave-guide free of moisture, this eases the problem of wave-guide corrosion and reduces the risk of high-flashover at high altitudes.

Radome

The radome is usually a covered honeycomb structure, made of a plastic material reinforced with fibreglass. Lightning conductors on the inside of the radome will obstruct the beam, but their effect is minimised if they are perpendicular to the electrical field of the wave.

Figure 346:

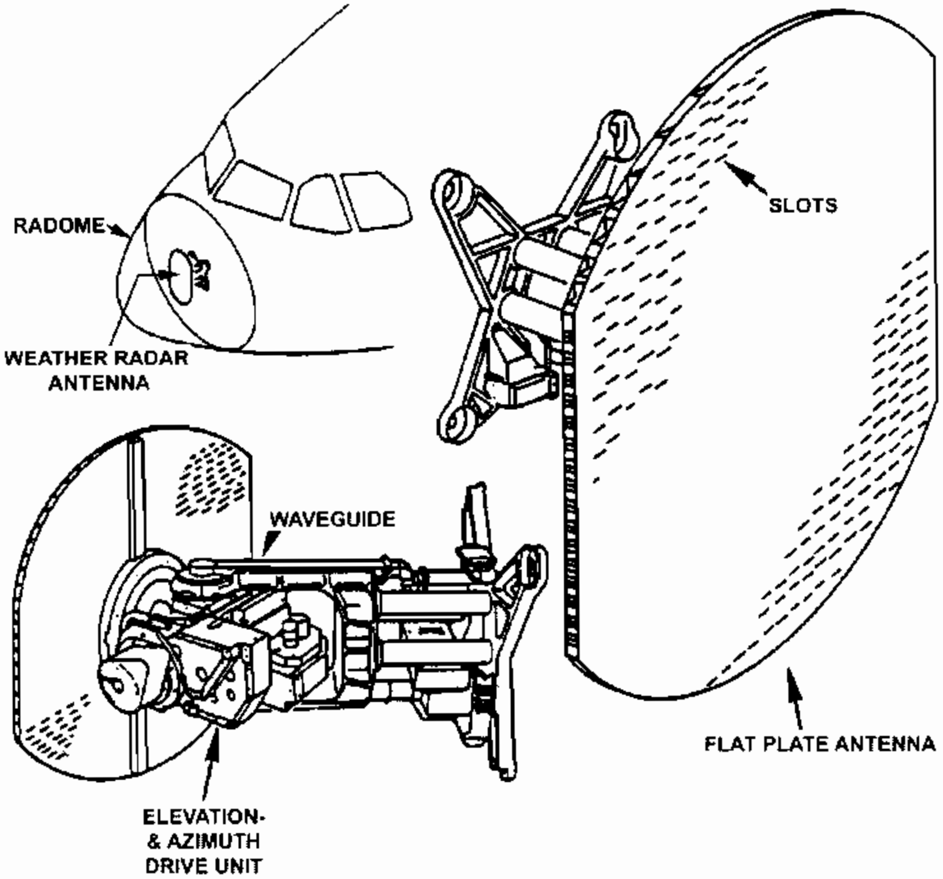
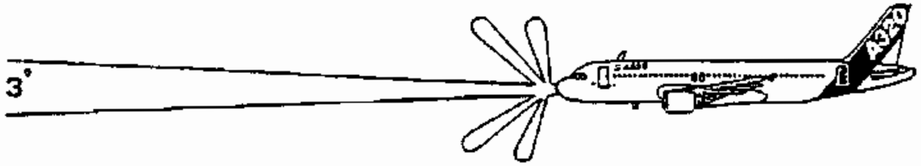


Figure 347: Antenna Pattern



Antenna Stabilization

Pitch and Roll

The antenna is stabilized in pitch and roll by inputs from the Attitude Reference System (IRS) or from the Vertical Gyros. The antenna is horizontally polarised and emits a narrow 'pencil' beam.

Antenna stabilization maintains antenna position relative to the earths horizon regardless of aircraft attitude variations incurred during turns and moderate maneuvers. To accomplish this, the Radar System receives roll and pitch stabilization input signals from either the aircraft's vertical gyro, or the Attitude Heading Reference System (AHRS). The AHRS is usually a part of the Inertial Navigation or Reference System.

The mechanical limit of the antenna is:

- Roll +/- 43 degrees
- Pitch +/- 25 degrees
- Tilt +/- 15 degrees

Azimuth Drive

The antenna is capable of scanning a total azimuth of +/- 45° to +/- 90°
20 times per minute.

Figure 348: Antenna Azimuth Scanning

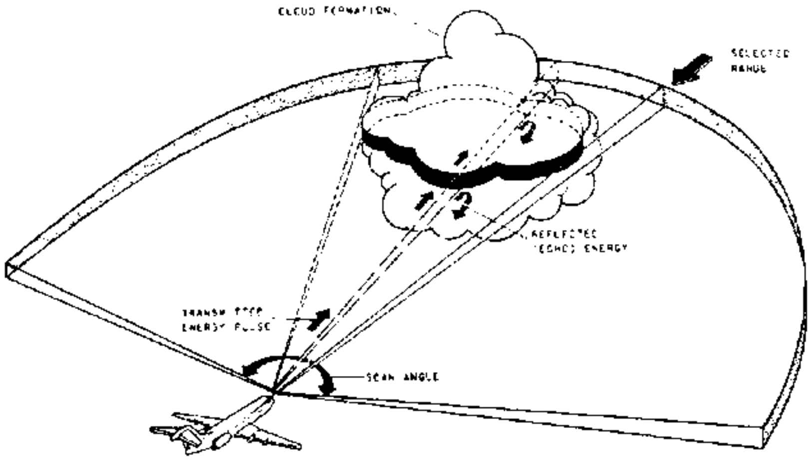


Figure 349: Roll and Pitch Stabilization

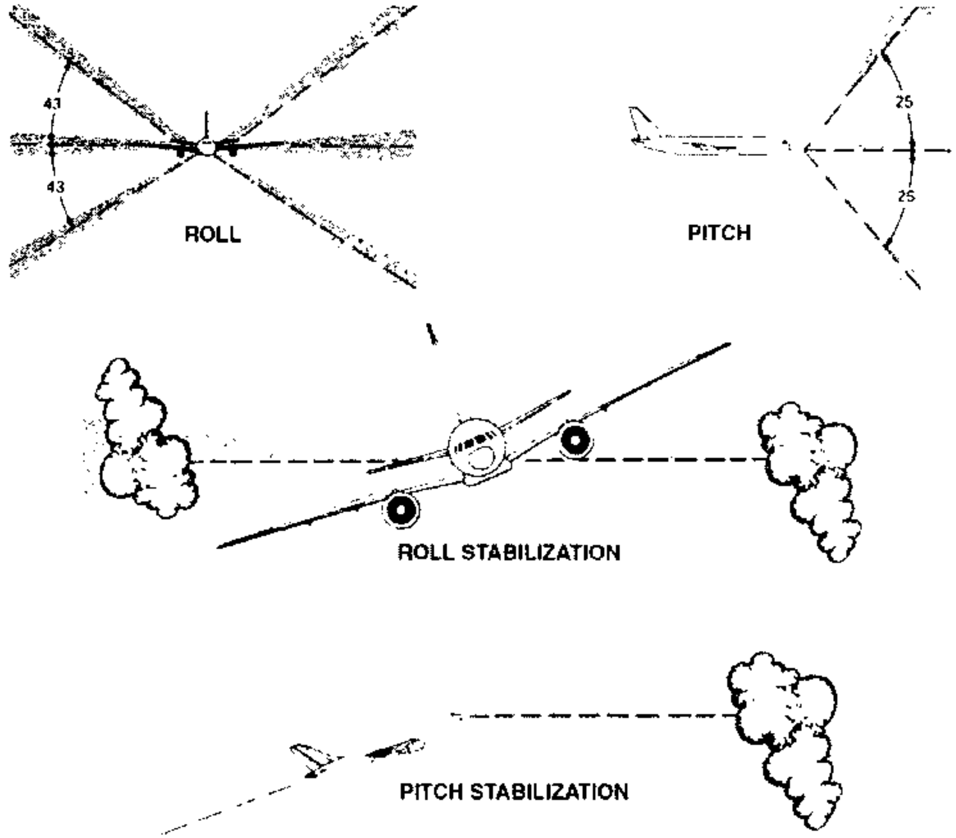
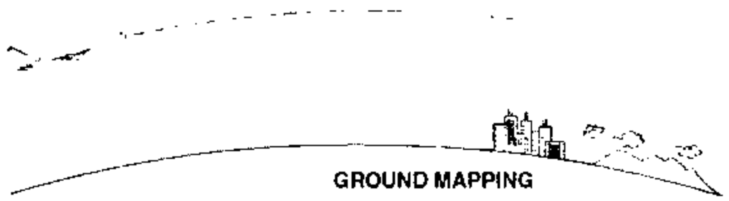


Figure 350: Antenna Tilt for Ground Mapping



Antenna Scan Pattern

Windshear Mode Antenna Tilt

In windshear mode, for the antenna scan dedicated to windshear detection, the antenna tilt is automatically adjusted achieve optimum windshear detection, regardless of the setting of the TILT control on the control unit. For non-windshear scans, the antenna follows the setting of the TILT control on the control unit.

Antenna Scan Patterns in Windshear Mode

The antenna scan pattern varies depending on the mode of operation. Above 1500 feet to 2300 feet, when the system is placed into alternate weather/windshear scan pattern, and no windshear is detected, the antenna scan pattern is as follows:

- Clockwise weather scan, with ±90 degrees of azimuth coverage and processing for weather.
- Counterclockwise windshear scan, with full ±90 degrees of azimuth coverage, but with windshear processing limited to the +/-45-degree sector

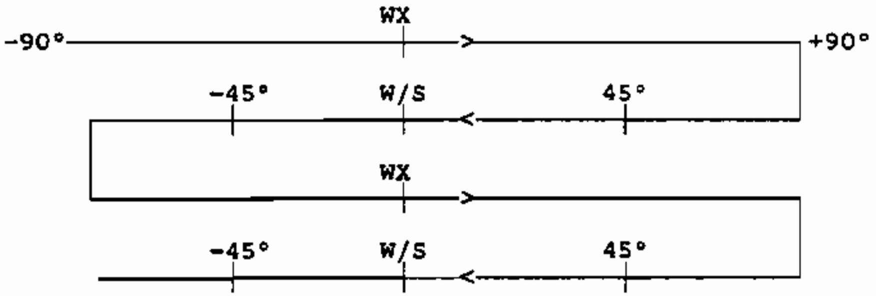
When the system is in windshear-only mode, the scan pattern is +/-45 degrees azimuth coverage on both the clockwise and counterclockwise scans. This mode occurs if the operator has a windshear-only control position on the control unit, or the system is in STANDBY or OFF mode. Windshear data is processed during both directions of antenna scanning.

When the system is in an alternate weather/windshear scan pattern, and the system detects a windshear event, the antenna scan pattern is as follows:

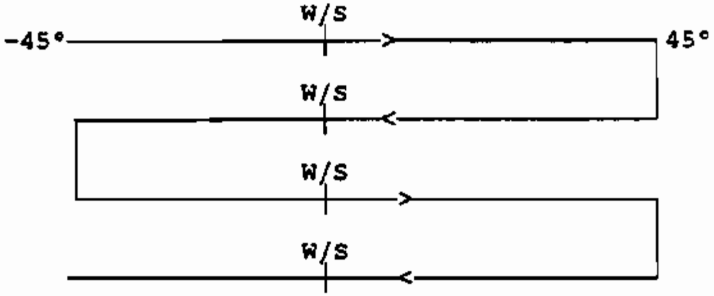
- Clockwise weather scan, from -90 degrees to +90 degrees.
- Counterclockwise windshear scan, from +90 degrees to -45 degrees, with windshear processing between +45 degrees and -45.
- The next clockwise scan is from -45 degrees to +45 degrees, to validate windshear.
- The next counterclockwise scan is from +45 degrees to -90 degrees, to validate windshear. No processing occurs between -45 degrees and -90 degrees.
- Clockwise weather scan, from -90 degrees to +90 degrees. The sequence is repeated as long as windshear event is detected.

If a windshear event is not validated, the system reverts to the alternating weather/ windshear scan pattern first described.

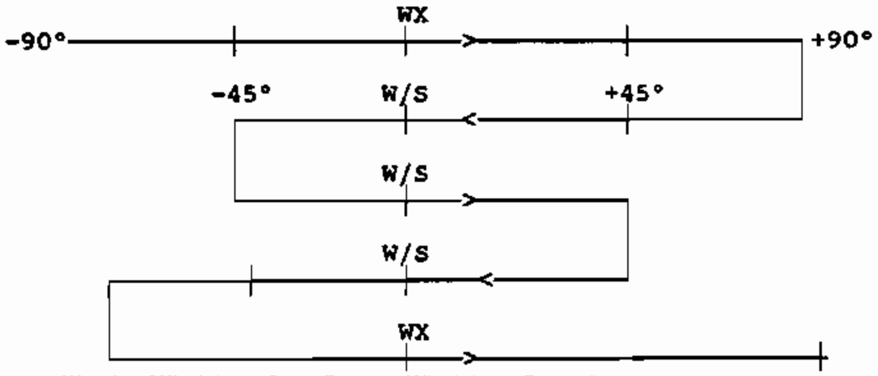
Figure 351:



Weather/Windshear Scanpattern, No detected Windshear



Windshear only Mode Scan Pattern



Weather/Windshear Scan Pattern, Windshear Event Detected

Magnetron

In previous generation of weather radars the high transmission pulse rf energy is generated by magnetrons.

The 13 kVolt, 12 ampere output pulse received from the magnetic modulator is applied to the cathode of the coaxial magnetron. This drives the magnetron Into oscillation producing a 9375 MHz, 65 kW peak power output signal.

The magnetron utilizes vane resonators which are slot-coupled to the stabilizing cavity surrounding the anode. Around the tube there is a permanent magnet with a strong magnetic field. Electrons travelling across this vane resonators stimmulates the resonace inside the cavities. The rf current on the inner wall of the stabilizing cavity flows into the output toward the waveguide and antenna.

The magnetic modulator turns the magnetrons high voltage power supply 200 times per second with a pulse duration of 5 microseconds on and for 4995 microseconds in off mode.

In domestic appliance microwave ovens containig also magnetrons with a frequency about 2.5 GHz.

Caution! The high radiating energy of magnetrons is dangerous.

Figure 352:

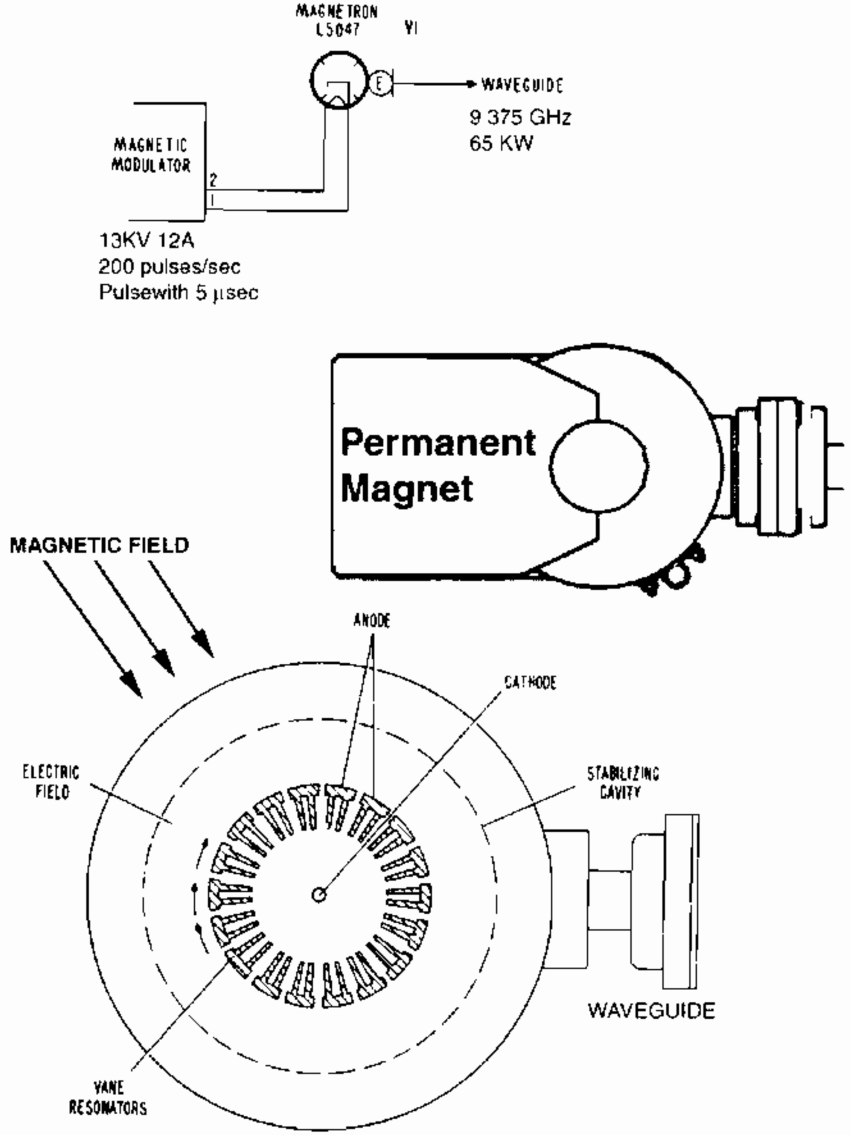
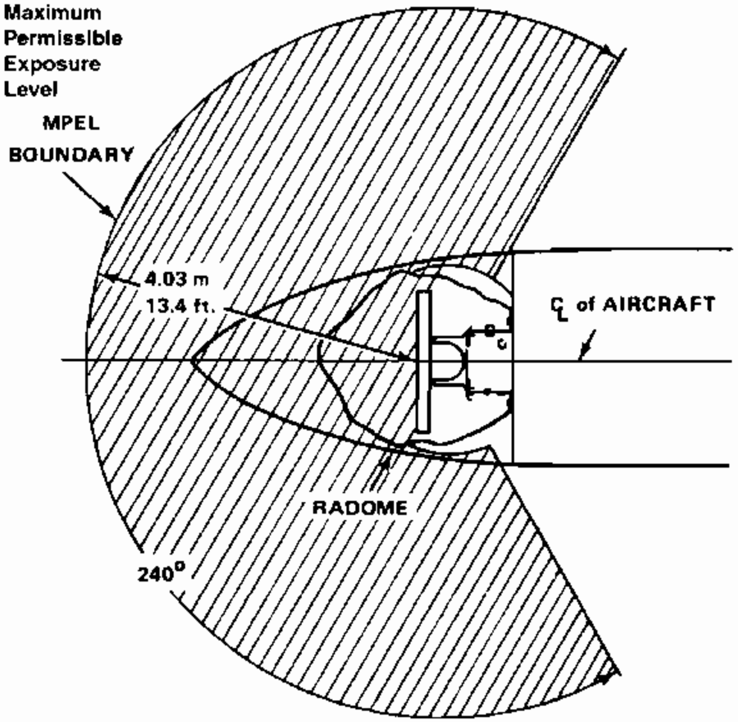


Figure 353: Warning



Radiation

WARNING

This instrument generates microwave radiation.

DO NOT OPERATE UNTIL YOU HAVE READ AND CAREFULLY FOLLOWED ALL SAFETY PRECAUTIONS AND INSTRUCTIONS IN THE OPERATING AND SERVICE MANUALS.

IMPROPER USE OR EXPOSURE MAY CAUSE SERIOUS BODILY INJURY.

Maintenance and Testing Safety Precautions

There are two hazards when operating weather radar, namely damage to human cells and ignition of combustible material. The greater the average power density the greater the health hazard.

A figure of 10 mWatts/cm^2 is a generally accepted "maximum permissible exposure level" (MPEL). Among the most vulnerable parts of the body are the eyes and testas.

The greater the peak power the greater the fire hazard. Any conducting material close to the scanner may act as a receiving aerial and have RF currents induced. There is obviously a risk, particularly when aircraft are being refuelled or defuelled.

The following rules should be observed when operating the weather radar on the ground:

1. Ensure that no personnel are closer to a transmitting radar scanner than the MPEL boundary, as laid down by the system manufacturer .
2. Never transmit from a stationary scanner.
3. Do not operate the radar when the aircraft is being refuelled or defuelled, or when another aircraft within the sector scanned is being refuelled or defuelled.
4. Do not transmit when containers of inflammable or explosive material are close to the aircraft within the sector scanned.
5. Do not operate with an disconnected wave guide.
6. Never look down in an open wave-guide of a installed system.
7 Fit a dummy load if part of the wave guide run is disconnected. (Workshop)
8. Do not operate close to large reflecting objects or in a hangar

An additional hazard, which does not affect safety but will affect the serviceability of the radar, is the possibility of very strong returns, if the radar is operated close to reflecting objects. The result of these returns is to burn out the receiver circuits.

In order to avoid the envelope in which the radiation level may exceed the standard of 10 milliwatt per square centimeter, all personnel should remain beyond the distance indicated in the illustration on the left side.

MLS Micro Wave Landing System

System Description

The time-referenced scanning beam Microwave Landing System (MLS) has been adopted by ICAO as the standard precision approach system to replace ILS. MLS provides precision navigation guidance for alignment and descent of aircraft on approach to a landing by providing azimuth, elevation and distance. The system may be divided into five functions:

1. Approach azimuth
2. Back azimuth
3. Approach elevation
4. Range
5. Data communications

With the exception of DME, all MLS signals are transmitted on a single frequency through time sharing. Two hundred channels are available between 5031 and 5090.6 Megahertz. By transmitting a narrow beam which sweeps across the coverage area at a fixed scan rate, both azimuth and elevation may be calculated by an airborne receiver which measures the time interval between sweeps. For the pilot, the MLS presentation will be similar to ILS with the use of a standard Course Deviation Indicator (CDI), Radio Direction Indicator (RDI), Horizontal Situation Indicator (HSI) or an Electronic Flight Instrument System (EFIS).

Figure 354: MLS Coverage

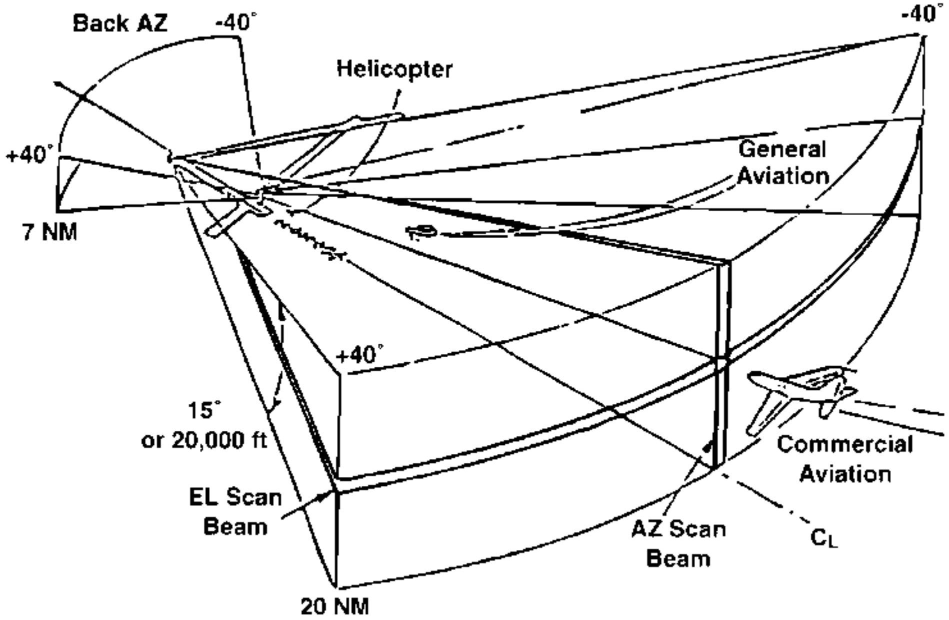
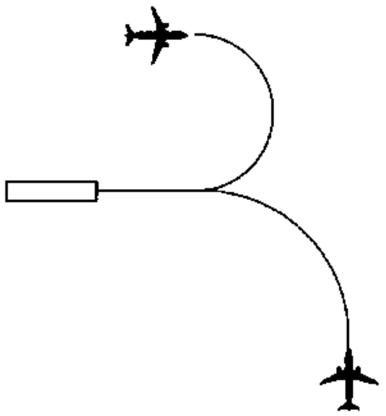


Figure 355: MLS Courved Approach



ILS Limitation

ILS has been the standard precision approach and landing aid since 1948, but it suffers from a number of limitations, which prompted research aimed at developing a new system. A new standard was adopted in 1978, which uses Microwave Frequencies and hence is known as the Microwave Landing System or MLS.

The Instrument Landing System (ILS) has served as the standard precision approach and landing aid for the last 40 years. During this time it has served well and has undergone a number of improvements to increase its performance and reliability. However, in relation to future aviation requirements, the ILS has a number of basic limitations:

1. Site sensitivity and high installation costs;
2. Single approach path;
3. Multi path interference; and
4. Channel limitations - 40 channels only.

MLS versus ILS

ILS ground antennas suffer from ground effects, in fact the glideslope beam is formed by using the ground in front of the antenna, which must be cleared and levelled. The use of relatively low frequencies means that the ILS installations at an airfield are much larger than those, needed for MLS. Site preparation for ILS is expensive and in some cases impractical. Reflections, interference and weather effects all have their part to play in degrading the performance of ILS due to the frequencies employed. In mountainous regions it may not be possible to install a reliable ILS because of reflection problems, although buildings within the vicinity of an airfield can also make life difficult. The shift-up to Microwave Frequencies has made possible, the use of many more channels. MLS will have 200 separate channels compared with the 40 available with the current ILS.

MLS Advantages

As previously mentioned, ILS has limitations which prohibit or restrict its use in many circumstances MLS not only eliminates these problems; but also offers many advantages over ILS including:

1. Elimination of ILS/FM broadcast interference problems;
2. Provision of all-weather coverage up to ±60 degrees from runway centerline, from 0.9 degree to 15 degrees in elevation, and out of 20 nautical miles (NM);
3. Capability to provide precision guidance to small landing areas such as rooftop heliports;
4. Continuous availability of a wide range of glide paths to accommodate STOL and VTOL aircraft and helicopters;
5. Accommodation of both segments and curved approaches;
6. Availability of 200 channels - five times more than ILS;
7. Potential reduction of Category I (CAT I) minimums;
8. Improved guidance quality with fewer flight path corrections required;
9. Provision of back-azimuth for missed approaches and departure guidance;
10. Elimination of service interruptions caused by snow accumulation; and
11. Lower site preparation, repair, and maintenance costs.

MLS Approach Characteristics

The Antennae needed at microwave frequencies are small enough to allow, narrow scanning beams to be generated. These allow a much wider region of cover, than with ILS and so, computed curved approach paths under MLS guidance can be followed. This greater flexibility in approach will lead to separate approach paths for commuter and scheduled flights at busy airports, high angle approaches for vertical and short takeoff and landing aircraft (VTOL and STOL) and curved approaches in mountainous regions. Of course the capability to follow curved or segmented approach depends on the carriage of sophisticated equipment in the aircraft. If an MLS beam is being used the bends, bumps, wiggles, false courses and false paths of the ILS system should not be experienced.

Guidance

Approach Azimuth Guidance

The approach azimuth antenna normally provides a lateral coverage of 40° either side of the center of scan. Coverage is reliable to a minimum of 20 NM from the runway threshold and to a height of 20,000 feet (ft). The ground station antenna is normally located about 1000 feet beyond the end of the runway.

Back Azimuth Guidance

The back azimuth antenna provides lateral guidance for missed approach and departure navigation. The back azimuth transmitter is essentially the same as the approach azimuth transmitter. However, the equipment transmits at a somewhat lower data rate because the guidance accuracy requirements are not as stringent as for the landing approach. The equipment operates on the same frequency as the approach azimuth but at a different time in the transmission sequence. On runways that have MLS approaches on both ends, the azimuth equipment can be switched in their operation from the approach azimuth to the back azimuth and vice versa.

Elevation Guidance

The elevation station transmits signals on the same frequency as the azimuth station. The elevation transmitter is normally located about 400 ft from the side of the runway between the threshold and the touchdown zone. It allows for a wide range of glide path angles selectable by the pilot.

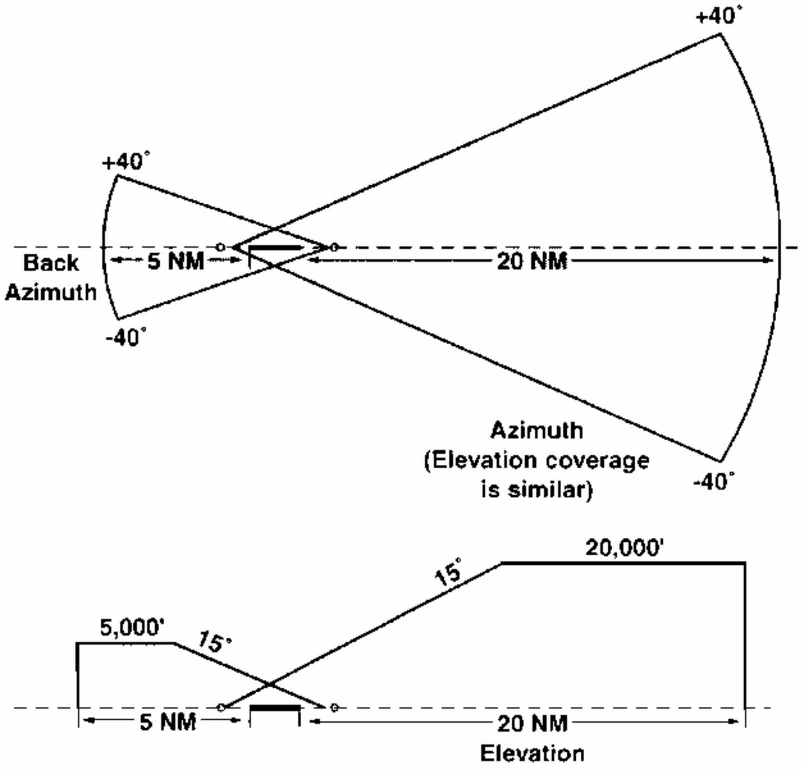
Range Guidance

Range guidance, consistent with the accuracy provided by the azimuth and elevation stations, is provided by the MLS precision DME (DME/P). DME/P has an accuracy of ±100 ft as compared, with ± 1200 ft accuracy of the standard DME system. In the future it may be necessary to deploy DME/P with modes which could be incompatible with standard airborne DME receivers

Data Communication

The azimuth ground station includes data transmission in its signal format which includes both basic and auxiliary data. Basic data may include approach azimuth track and minimum glide path angle. Auxiliary data may include additional approach information such as runway condition, wind-shear or weather.

Figure 356: MLS Azimuth and Elevation Coverage



The MLS Signal Format

The MLS system operates on 200 channels in the frequency band 5,031 MHz to 5,091 MHz. (C-band system) The signalling rate is 15,625 bits/sec, that is a 64 µs spacing between Pulses.

All components transmit on the single frequency allocated to an approach in a time multiplexed signal format. In addition to the elevation and azimuth transmissions, a burst of data is transmitted.

Angular Measurement

In fact what we have is a narrow beam, which is electronically swept, first in the TO direction and then in the FROM direction.

Any aircraft within the coverage of the scanning beam will thus receive Two-Pulses of energy, in one complete cycle of scan.

Left of Center

If the two received pulses are well spaced then the aircraft will be in the left hand half sector of the cover as is the case in Figure below.

Right of Center

On the other hand if the TO and FROM pulses are close together then the aircraft will be in the right hand half sector.

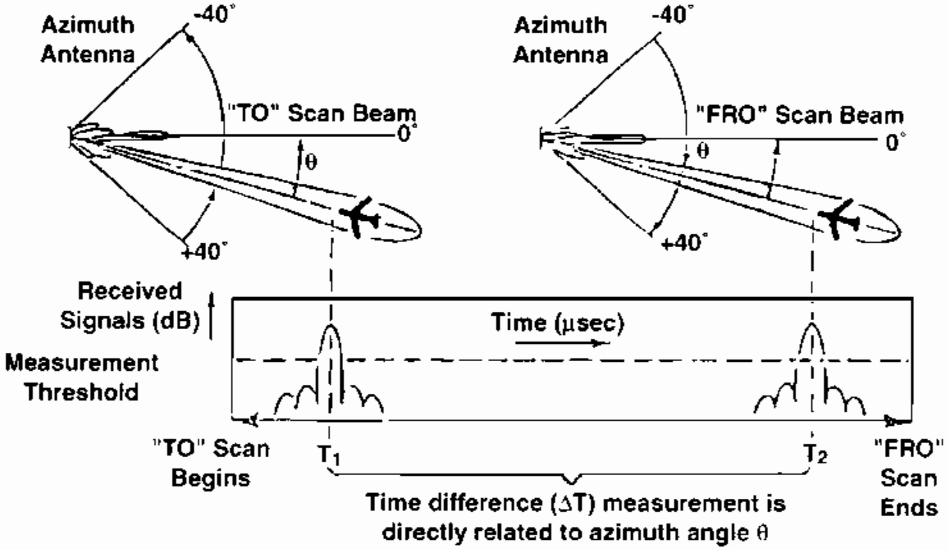
Note that, even if the aircraft is on the extreme right of the sector of cover, the TO and FROM signals will still be separated.

Processing

Once the angle has been measured it can be compared with the angle selected by the pilot on the control panel, the difference in angle being used as feed to indication system and to the autoflight system.

Alternatively, the angle can be fed to an external computer, which may be part of a FMS and there used, together with waypoint data, to compute appropriate segmented or curved paths.

Figure 357:



Aircraft Installation

The operational capabilities of MLS depend on the type of equipment installed in the aircraft. For full capability of the MLS system by being able to execute curved approaches under the guidance of the MLS following equipment is needed:

a) MLS Receiver,
b) DME/P,
c) Control Panel,
d) Flight Management System,
e) Flight Director Indicator or EFIS.

A popular installation is the Multi-Mode Receiver. This provides output deviation signals from ground or satellite facility which can be ILS, MLS or GPS. This installation gives great flexibility and cost savings, allowing for a single airborne instrument landing system installation with the capability of interfacing with all types of landing system ground facility used today.

MLS Aerials

A single MLS system requires two aerials along the aircraft fore-and-aft centre line for 360° coverage around the aircraft: one forward and one aft.

The Aircraft Aerials receive the C-band (5'031 - 5'061MHz) signals radiated by the airport ground station. The Receiver selects the antenna receiving the strongest signal or can be forced with external input to select the forward antenna.

Forward Aerial

A desirable location for the forward antenna is on the aircraft centre line above the cockpit in an area that slopes down toward the nose of the aircraft.

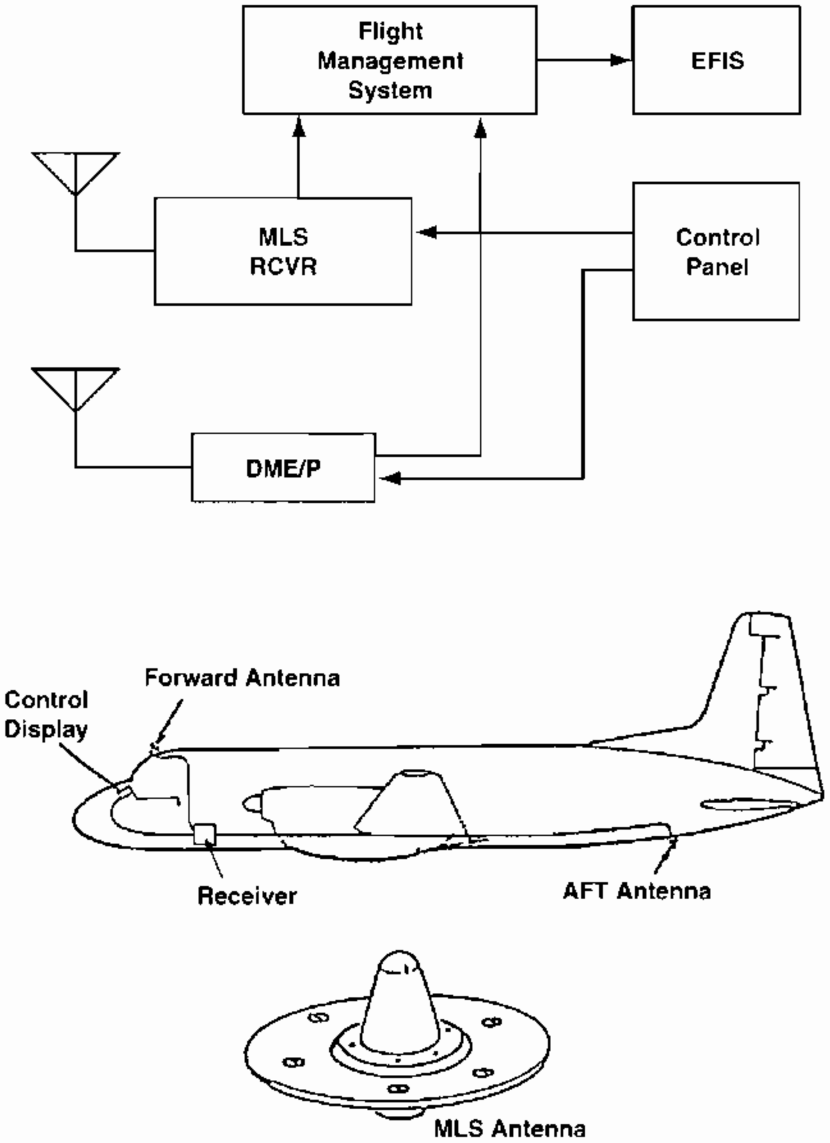
This location provides sufficient ground plane, minimum reflection and minimum shadowing effect. The area above the cockpit also provides exceptionally good signal reception on final approach and when making banked approaches to an airport.

Aft Aerial

The aft antenna may be located on the aircraft centre line on the belly of the aircraft, behind obstructions such as wings and landing gear and just after the aircraft belly begins to curve upward towards the tail section of the aircraft.

The antenna should be mounted on a flat metal surface to obtain a proper ground plane.

Figure 358:



Hyperbolic Navigation

Fundamentals

A hyperbolic navigation system works on a time comparison technique based on the fact that the propagation velocity of radio waves is constant (300'000 km/s or 6.18 µs per NM). The ground installations consist of 2 or more stations. MASTER and SLAVE - transmitting on very low frequency between 12 kHz and 2 MHz.

Following navigation systems are based on hyperbolic navigation:

- LORAN Long Range Navigation System
- OMEGA

Long wave transmitters covering a very long range, consuming to much energy. The systems are only used for submarines and replaced with satellite navigation system.

Working Principle

The MASTER and SLAVE stations are installed 200 to 400 NM apart and spread over the world. The MASTER Station transmits pulses of radio energy which are received at the SLAVE Station after a certain time depending on the distance between the 2 stations, e. g. if the 2 stations are 200 NM apart, the MASTER Signal will take 200 x 6.18 µs = 1'236 µs to reach the SLAVE Station.

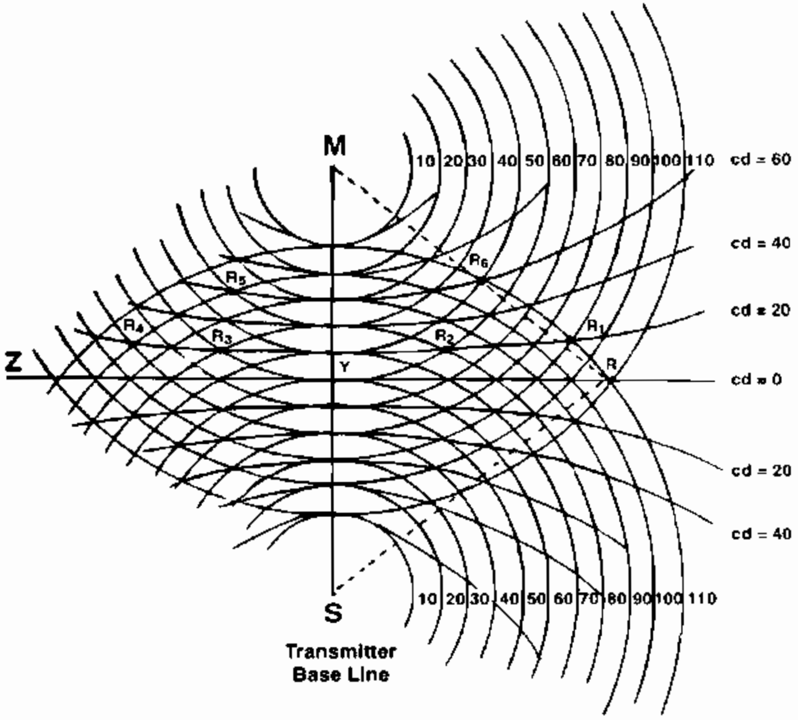
The airborne receiver picks up both, the MASTER and the SLAVE Signals, compares the incoming time difference between the 2 signals and computes based on the time-difference the aircraft or boat position.

M denotes the MASTER and S the SLAVE Station. The concentric lines surrounding the 2 stations represent time in microseconds. cd lines are - lines of constant time difference.

R_1 lies on the 90 µs line of the MASTER and the 110 µs line of the SLAVE Station. The time difference at this position is 20 µs. At positions R_2, R_3 and R_4 we also have a time difference of 20 µs. This allows to draw a hyperbolic position line having a constant time difference value of 20 µs.

In early systems the navigator in the cockpit had to read the time difference with an oscilloscope device and comparing it with a specific loran chart.With computers then the LORAN or OMEGA works automatically and displays all desired navigation parameters.

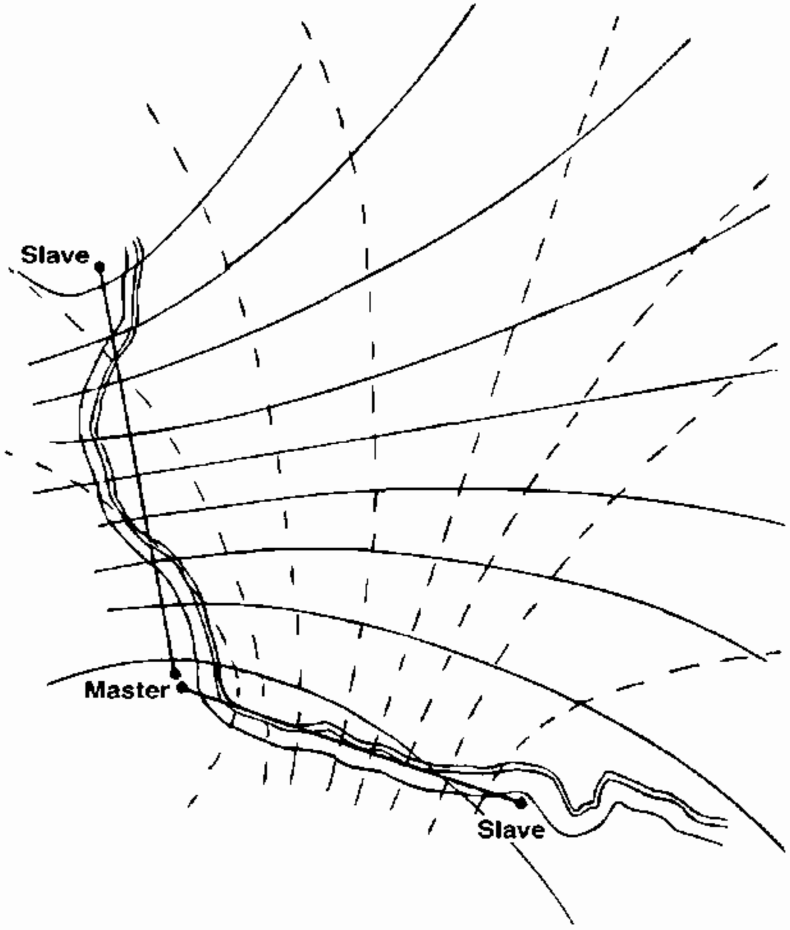
Figure 359: Two Transmitter sending Pulses



By moving the airborne receiver along a line of constant time difference, we describe an hyperbolic line of Position.

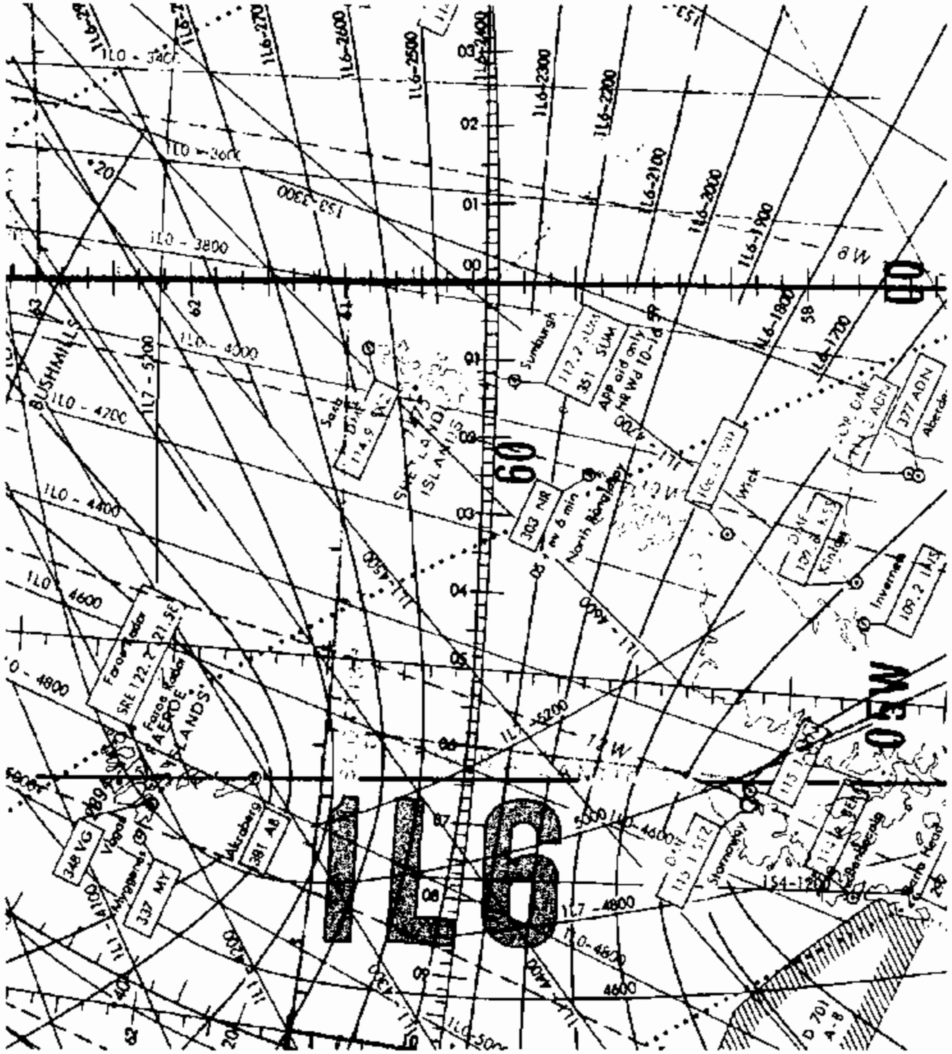
All LORAN chains consist of a pair of transmitters, although a MASTER Station may be common to 2 chains as seen below.

Figure 360: Two pairs of LORAN Transmitters was used



LORAN Charts are drawn with hyperbolic position lines of constant time difference in micro-seconds.

Figure 361: LORAN Chart used by Navigators



Doppler Radar

The Doppler Radar is an airborne self-contained long-range navigation aid requiring no ground installation. The Doppler works with great accuracy and provides the pilot with the following information:

- Ground Speed,
- Drift angle,
- Miles-to-go (to a preselected Position),
- Off-set miles (from a desired track).

Working principle

The basic principle, as the name implies, is the Doppler effect in conjunction with radar. When a receiver is moved toward a transmitter, the resulting frequency in the receiver will be higher than that of the transmitter. This because the moving speed of the receiver is added to the propagation velocity of the transmitted radio waves. By moving the receiver away from the transmitter, the opposite will occur.

Doppler-frequency-shift is a deviation in the signal frequency due to a change in the path length between the transmitter and receiver. This can be due to movement of any or all of the following: the transmitter, the receiver, or reflective surfaces along the path. The Doppler frequency shift is given by the following equation:

$$f_d = f_c * v/c$$

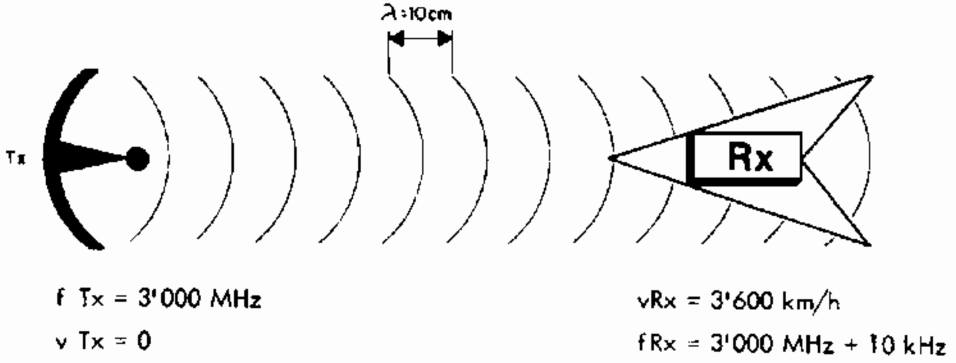
where v is the rate of change in path length between the transmit and receive antenna, c is the speed of light, f_c is the carrier frequency of the signal, and f_d is the Doppler frequency shift. The carrier frequency is shifted from f_c to f_c+f_d.

Example

In the example shown, the stationary transmitter transmitting on 3'000 MHz.
The wave length ($\lambda = c/f$) of 3'000 MHz (300'000 KHz) is 0.1 m
The moving speed of the receiver is 3'600 km/h or 1 km/s.
By adding the moving speed of the receiver to the propagation velocity of radio waves, we have a resulting speed of 300'001 km/s.
The resulting frequency in the receiver is thus 3'000'010 kHz. This is 10 kHz higher than that of the transmitter.

With a known transmitter frequency, the resulting frequency in the receiver gives us information about the speed at which the receiver is moving. In our example, the 10 kHz is known as the Doppler frequency shift.

Figure 362: Example of Doppler frequency shift

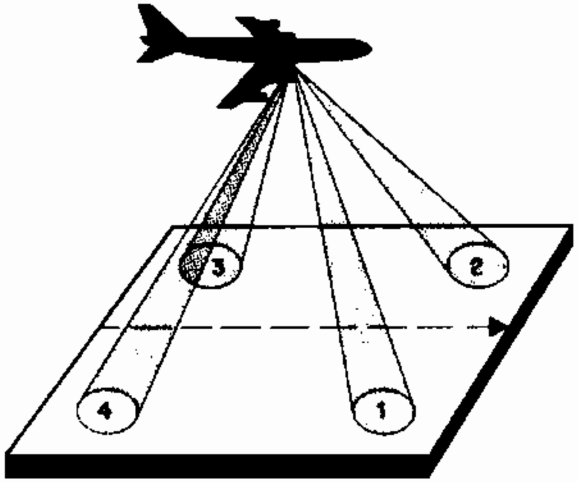


Doppler Sensor

The aircraft equipment consists of a transceiver unit and an antenna system emitting 4 beams. The beams are reflected by the surface of the earth, and the reflected signals provide 4 Doppler frequencies giving information about:

- Ground Speed (GS),
- Drift Angle (DA).

Figure 363: Four Beam Antenna



Doppler Navigation Computer

The **Drift Angle** and **Ground Speed** is shown to the pilots and used for further computations. A computer provides additional types of information like:

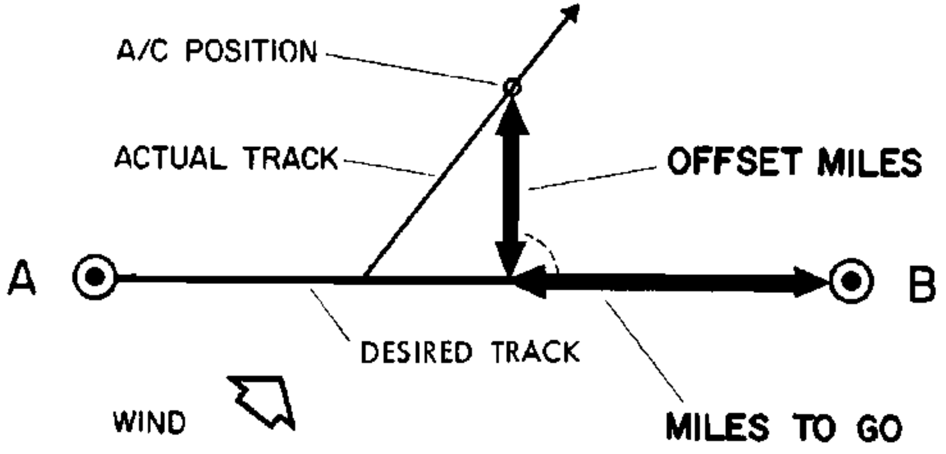
- Miles To Go
- Offset Miles
- Position

Today doppler systems are used in military airplanes. The system is very reliable and has a high accuracy and is independent from any other signal provider. The system is replaced for most cases by inertial navigation systems.

The accuracy of Doppler navigation is:

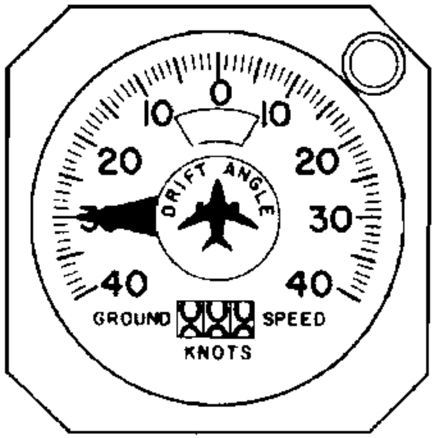
- Drift +/- 1/2 degree
- Ground Speed error +/- 0.5% plus 1 knot.

Figure 364: Navigation

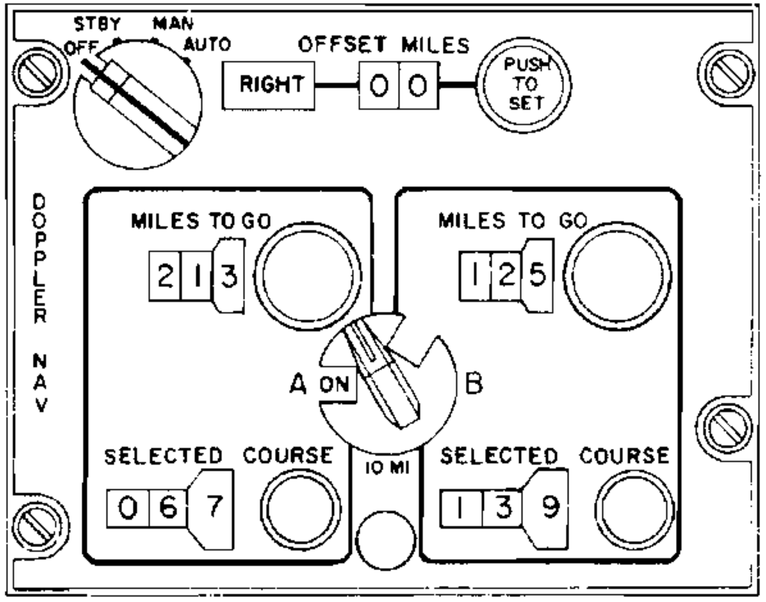


Doppler navigation systems are still used in helicopters. Because there is no interference with rotors. In opposite of a satellite navigation system, the doppler navigation is independant of any provider and ground installations.

Figure 365: Indication and Control



GROUND SPEED AND DRIFT INDICATOR



NAVIGATION COMPUTER

GPS Global Position System

Introduction

GPS is a space based radio navigation system which provides worldwide, highly accurate, continuous three-dimensional position, velocity and time information. GPS is generally regarded to be divided into three parts:

- Space Segment
- Control Segment
- User Segment

The Space Segment includes 21 operational satellites and 3 active spares.

The Control Segment includes a master control station in Colorado, in the United States and 4 linked monitor stations located around the world.

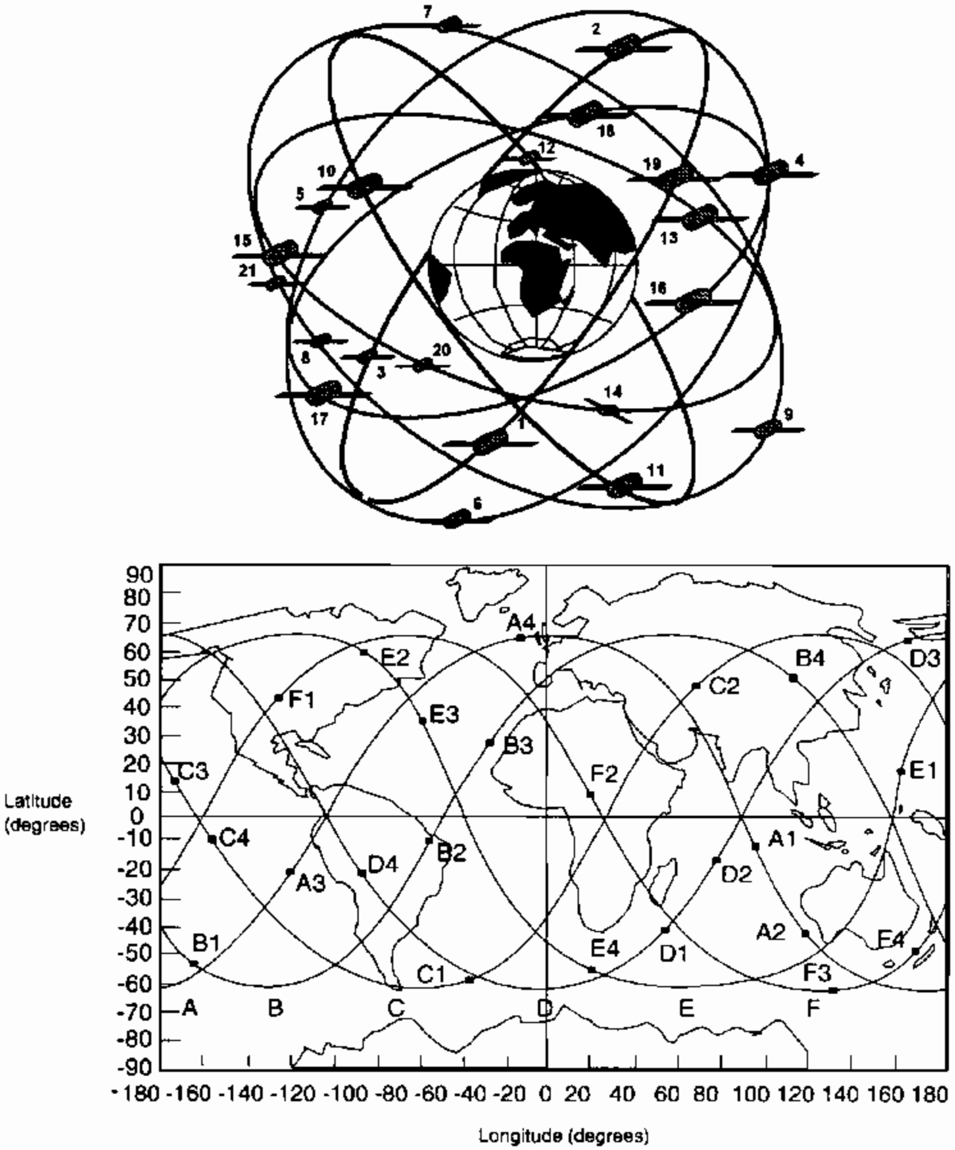
The User Segment consists of all the receivers that provide position, velocity and time data for aircraft, ships, trains, trucks, etc.

There are two levels of accuracy within the system. A precision mode for the military and a coarse/acquisition mode for civilian use. The precision mode has an accuracy of ±16 meters both laterally and vertically, while the coarse/acquisition mode has an accuracy of ±100 meters.

As is the case with much of the new technology in the field of aviation, GPS was created by the military for purely military functions and is still under the control of the United States Air Force. Certain features of the system are strictly reserved for the exclusive use of U.S. and allied military services. However, GPS is available to a large degree for civilian usage.

The European Space Agency and EU transport ministers released the development for the Galileo program. The total project cost for development and deployment is forecast to reach 3.4 billion Euros, with a 2008 operational date. The Galileo system is based on civilian use.

Figure 366: Earth orbiting Satellites



Space Segment

The space segment consists of 24 satellites (21 + 3 spares), in six orbital planes with four satellites in each plane. Orbiting the earth every 12 hours, at an altitude of approximately 11,000 nautical miles, each of the satellites has a 28° view of the earth. From any point on the earth, at any given time, there will be six to ten satellites in view. This provides redundancy, since only four satellites are required for three dimensional position determination.

Satellites

The architecture of the system is composed of a constellation of 25 satellites (21 always available).

Time of life: 7. 5 years
Mass: 815 kg.

Boarded Power: 700 watt at the end of life.
Operation frequency:1515.42MHz

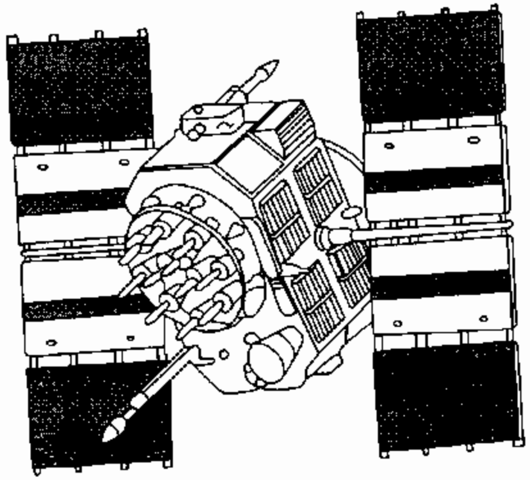
Operating clock: 2 caesium and 2 rubidium clocks.

The satellites are dispatched on 6 circular orbits of 4 satellites each.

Orbit altitude: 20231 km

Orbit recurrence: 12 sidereal hour (1 sidereal day equals 23 hours 56 min. 4.1s)

Figure 367: Satellite



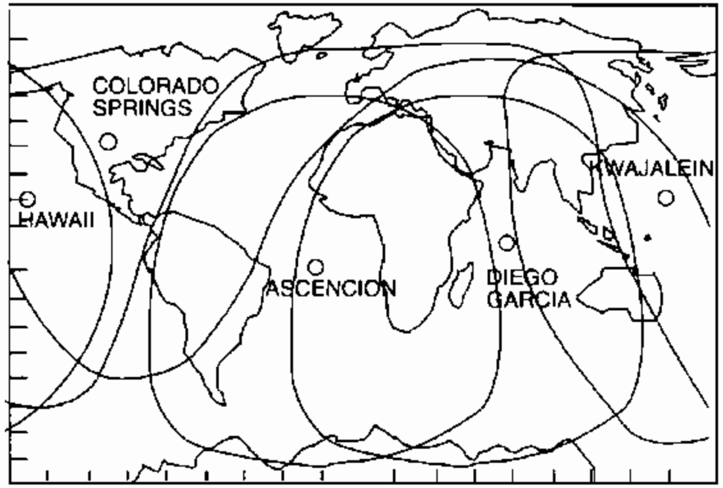
Control Segment

All 24 satellites will be controlled by the control segment on the ground. The control segment is composed of 4 monitor stations and 1 master control station which pursue the satellites, compute the ephemerides and clock corrections, and transmit at regular intervals an information message for the GPS users. The 4 monitor stations are located at: Kwajalein, Hawaii, Ascension Island and Diego Garcia. The master control station is located at Colorado Springs.

The spacing of the monitor stations provide a nearly continuous "ground" visibility of every satellite. All of the monitor stations track the satellites, determine their operational performance and validity and relay this information back to the Master Control Station. The Master Control Station can then determine the current satellite orbital parameters, the current clock parameters and then transfer correction data back to the satellites, three times a day.

Through the concept of the number of satellites circling the globe, plus the orbital planes of the satellites, along with the command and control structure, GPS will ensure that at least four satellites will always be available to a receiver at any time of the day or night, anywhere over the surface of the earth, to obtain a precise navigational fix. This concept will also ensure that the exact position of each satellite will be known at all times and that each satellite will have a very precise time standard. These two factors are necessary to ensure accurate three dimensional position determination.

Figure 368: Monitor Stations



User Segment

The principle of GPS position computation is based on the measurement of transmission time of the GPS signals broadcast by a minimum of 4 received satellites. For a boat, only 3 satellites would be enough to obtain its position, while, for a user on the move in the air, a fourth satellite is necessary to because of altitude of the aircraft. The GPS data are:

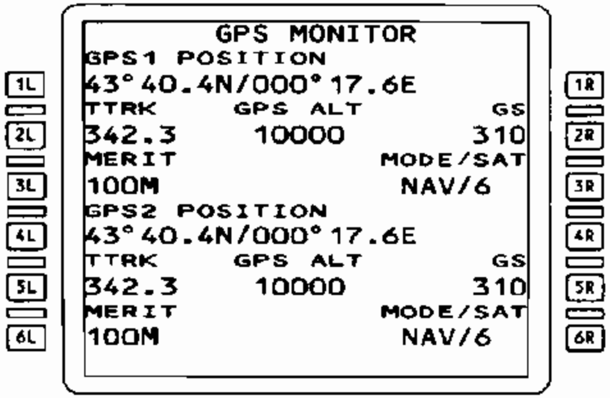
- GPS position (Latitude and Longitude)
- Ground Speed
- True Track
- Altitude
- Figure of merit (Position error can be up to 500 meter)

While the concept of navigation via GPS can include ships, trains, cars, etc. GPS designed for aircrafts are expandable to include CAT III precision approach guidance, position reporting and flight following, as well as aircraft conflict reporting and resolution.

Derived Information

GPS is primarily a position determining system, it is possible to derive certain data by taking into account the change in position over time. Actual track can be obtained by looking at several position fixes. Ground speed can be calculated by measuring the distance between two fixes, then measure the amount of time required to travel between the fixes, to obtain a rate of travel.

Figure 369: Display of GPS Data at MCDU screen



```
           GPS MONITOR
GPS1 POSITION
43°40.4N/000°17.6E
TTRK      GPS ALT          GS
342.3      10000          310
MERIT                MODE/SAT
100M                    NAV/6
GPS2 POSITION
43°40.4N/000°17.6E
TTRK      GPS ALT          GS
342.3      10000          310
MERIT                MODE/SAT
100M                    NAV/6
```

Figure 370: Receiver counting the Travel time of Satellite transmitted Signal

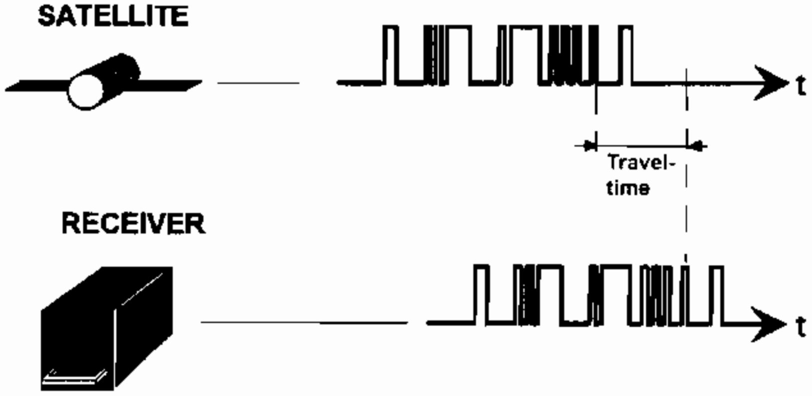
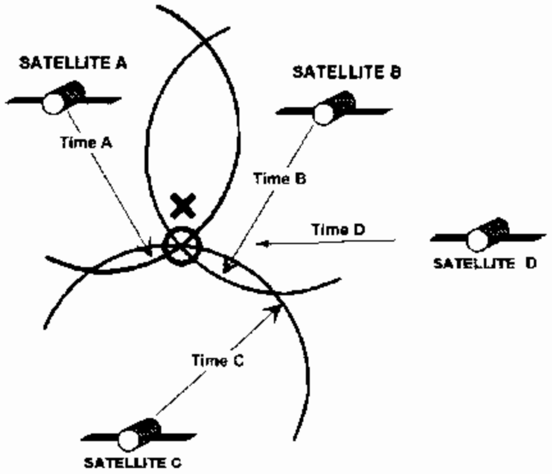


Figure 371: Position Determination with 3 Satellites



Theory of Operation

GPS works like DME in principle, with one important difference. DME measures the elapsed round trip time for a signal that is transmitted to a DME ground station from an aircraft and then dividing that time in half and multiplying the result by the speed of light. The result equals the slant range distance from the aircraft to the ground station.

GPS measures the amount of time it takes a signal to travel from a satellite to a receiver. That time is then multiplied by the speed of light to obtain a distance measurement. This distance results in a line of position (LOP). Just as DME determines a position fix by the intersection of two or three DME arcs, GPS uses four distance measurements from four satellites to determine latitude, longitude, altitude and time difference.

A significant difference in the operation of DME versus GPS is that DME is an active system, while GPS is a passive system. For DME to operate, an interrogation signal from the user must be initiated. GPS required no interrogation signal. As a passive system, it is always operational. The orbiting satellites continually transmit data, without the need of being interrogated. An additional advantage to a passive system is that it can have an unlimited number of users at any one time, where an active system such as DME is limited to approximately 100 users per station at any one time.

GPS is a expensive system to put into operation. If we forget about the cost of putting the satellites into orbit for the moment, direct measurements of elapsed time require exact synchronization between the satellites and the receivers onboard the aircraft. To achieve this synchronization, extremely stable clocks are required. Extremely stable in this case is on the order of 10^{-13} seconds per second. This equates to a drift rate of 0.003 seconds per thousand years. To achieve this stability, atomic clocks must be used. For redundancy four atomic clocks installed on each satellite!

The GPS is working with time differences. By using a quartz oscillator to set the timing at the receiver (aircraft) end, the cost of operation is greatly reduced. Using a quartz oscillator provides less accuracy. However, by anticipating this loss in accuracy, compensation can be applied in the form of a fourth line of position from a fourth satellite. This is why with GPS, four satellites should be in view at any given time for a precise navigation fix.

Figure 372: Distance measurement with one satellite (LOP)

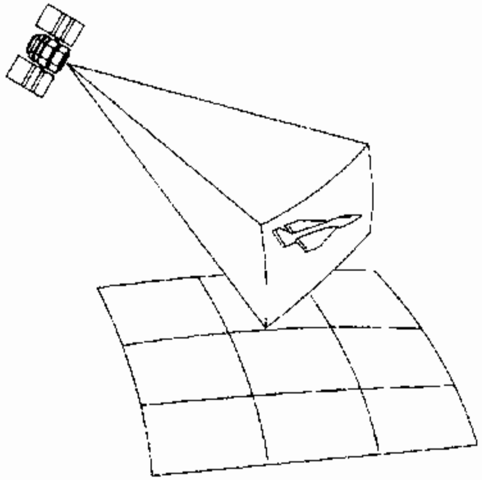
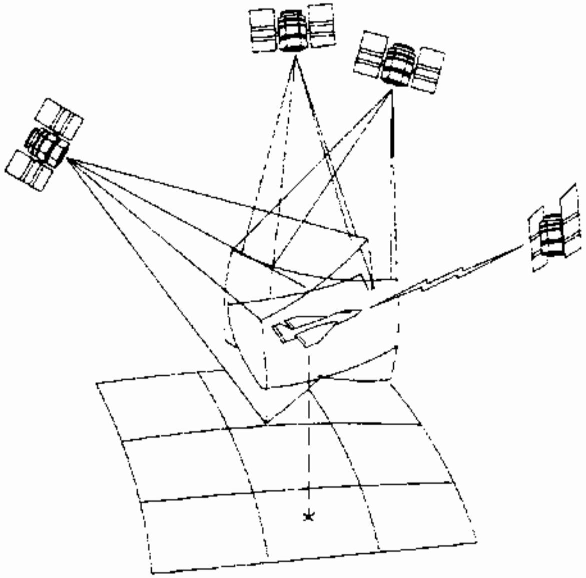


Figure 373: Position determination with 4 satellites



Position Fixing

If a distance from a specific point in space (satellite) is known, then it follows that the receiver is located somewhere on the surface of sphere, with a radius of that distance. The first distance measurement establishes the first line of position LOP.

The addition of a second satellite and a second distance measurement further refines the position calculation as the two LOPs intersect each other. The addition of a third distance measurement from a third satellite further refines the position calculation as we now have three LOPs intersecting at a specific point in space. This point in space represents the distances measured between the aircraft and the three satellites.

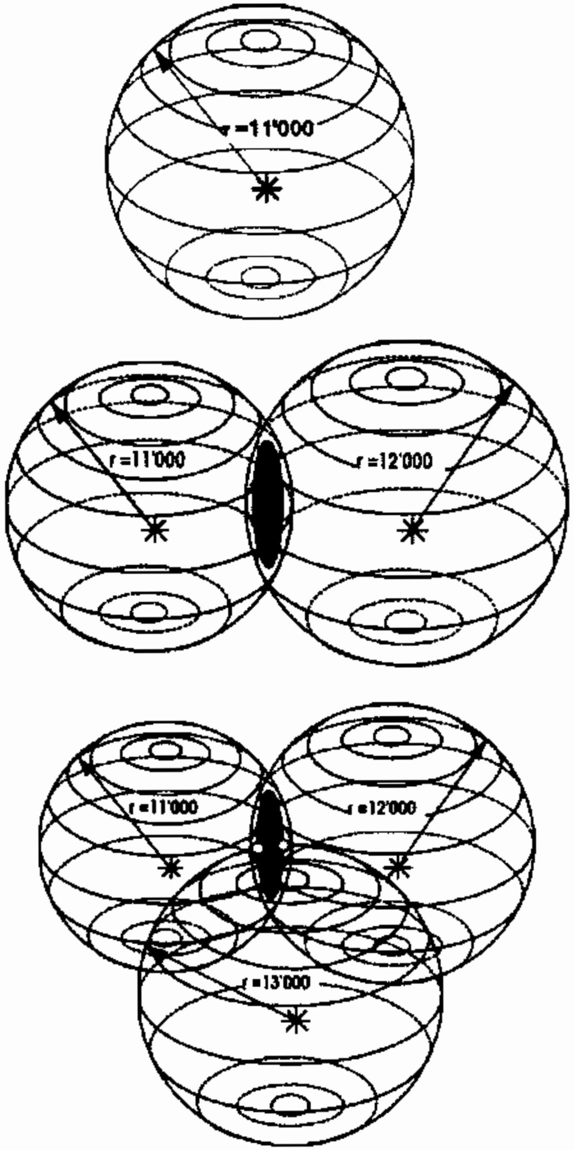
This, all by itself, is not very helpful. If you consider that you are:

- 11,000 nautical miles from satellite No. 1 and
- 12,000 nautical miles from satellite No. 2 and
- 13,000 nautical miles from satellite No. 3 and
- that these satellites are moving through space at 7,500 miles per hour,

this means that they are not in the same position they were in a second ago. To overcome this problem, each satellite transmits its position (ephemeris) to the receiving computer. The computer in turn can apply matrix algebra and the solution of simultaneous equations with four unknowns (longitude, latitude, altitude and time) into useful information.

For terristic navigation at the sphere with 3 satellites, the elevation is not determined. For elevation or altitude determination, the reception of a fourth satellite is necessary.

Figure 374: Position fixing with 1, 2 and 3 satellites



Receiver Clock Corrections

GPS satellites are equipped with atomic clocks, GPS receivers, there is a recognizable error in the measurement of the elapsed time between signal transmission and reception. Because of this time bias error, distance measurements are termed pseudo range estimates as opposed to true range estimates. To correct for this time bias error 3 satellites and for altitude, a fourth satellite is used.

Signal Structure

GPS satellites transmit on two frequencies and in two modes in the UHF band. The first is precision mode (P) and the second is coarse/acquisition mode (C/A).

The P mode is for military use only and is not available to civilian applications. In each mode, signals are transmitted that appear to be random in nature, but are not. The signal pattern is computer generated in a repeatable pseudo random code. Since the P mode is for military applications only, we will not discuss it here. The C/A code is transmitted at a rate of 1,023,000 bits per second and repeats itself every millisecond. This code is simple in that it contains only 1023 bits and can be deciphered quickly.

The GPS receiver on-board the aircraft has the same program as that which is on the satellite for generating the pseudo random code. By matching the two code patterns, the satellite and the receiver can be synchronized, which is the first step in determining a LOP. This is commonly referred to as initial acquisition.

Time Measurements

Once the GPS receiver has synchronized with the satellite code, it can then measure the elapsed time since transmission by comparing the phase shift between the two codes. The larger the phase shift, the longer the length of time since transmission. The length of time since transmission times the speed of light equals distance. For instance, if the GPS receiver determines that the two codes can be synchronized to within 0.08 seconds, multiplying 0.08 by the speed of light (162,000 nautical miles per second = 300'000 km per second), results in a distance of 12,960 nautical miles between satellite and receiver. So, it is easy to see that by measuring phase shifts in the code, distance calculated are between satellite and aircraft. As a point of interest, because the P code for military use is 10 times more precise than the C/A code, its phase shift can be measured 10 times more accurately and more precise distance measurement is obtainable.

- A time error of one micro second represents a LOP-difference of 300 meter!

Figure 375: Time Bias Error

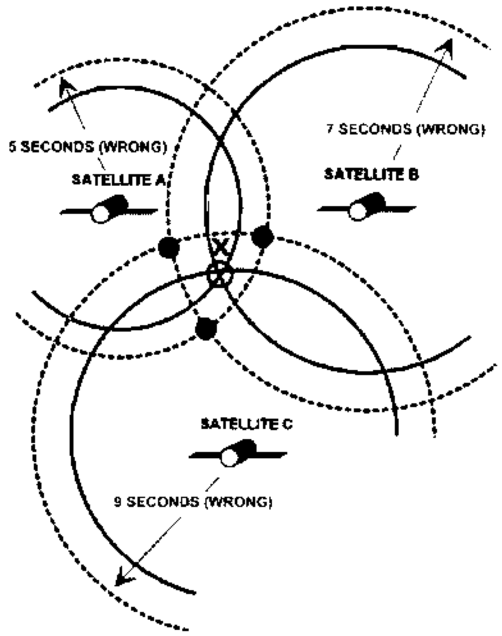
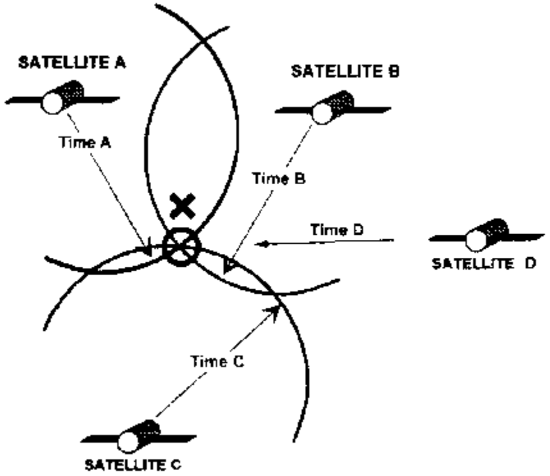


Figure 376: Accurate Time

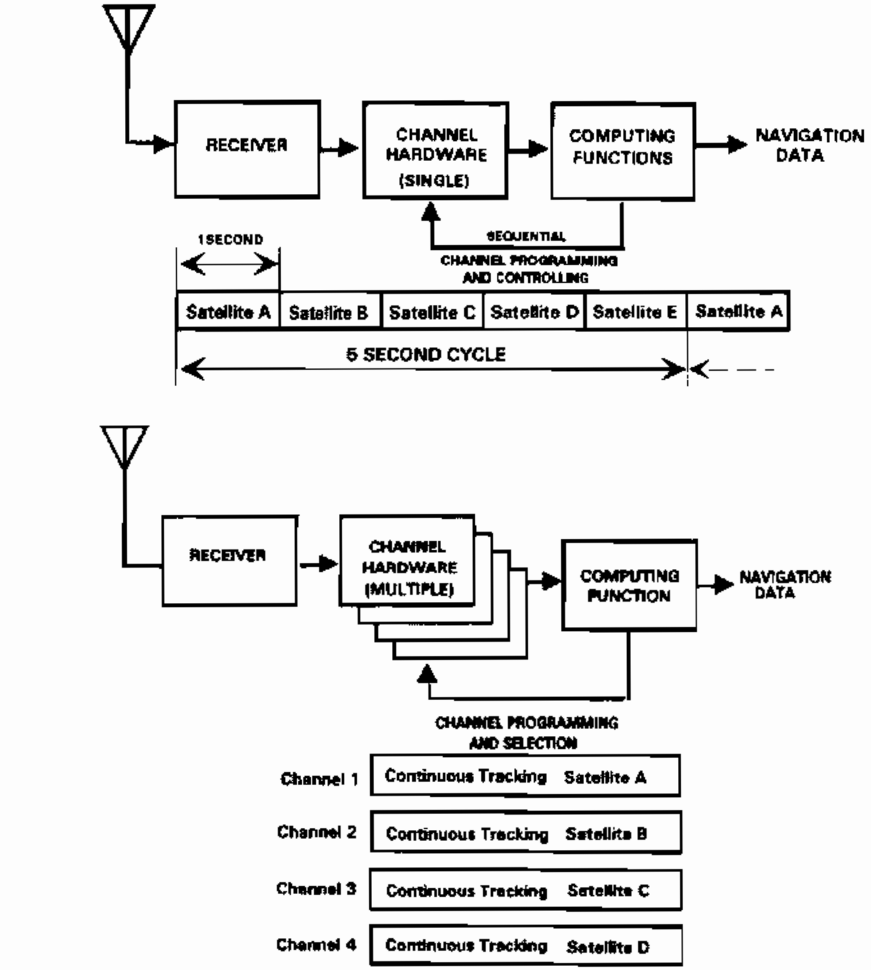


Serial/Parallel Processing

Smaller systems are using one hardware channel. Time-sharing this channel allows to track with several satellites.

Commercially used or more advanced system using for up to 12 channel a separate hardware. A better reliability and faster response is the result.

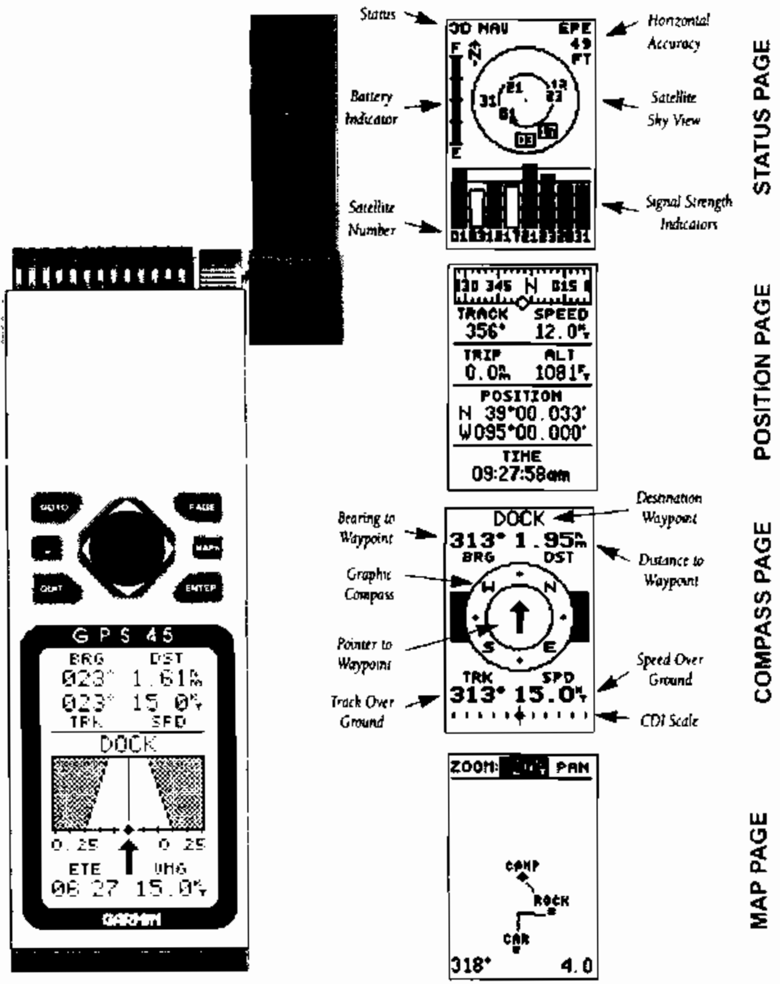
Figure 377: Serial and parallel processing



Example of a Hand-held GPS Navigator

GPS navigation systems are spreaded over a wide field of usage. For sailors, fisherman, general aviation pilots, hikers etc. a variety of models are existent.

Figure 378: GPS Navigator



Differential GPS

To increase the position accuracy on local places like airports a reference station is installed. The ground station compares the GPS computed position with the true (surveyed) position of the ground receiver. This determines the errors resulting from any error source common to the ground station and GPS equipped airplanes operating in the vicinity. The appropriate error corrections are transmitted to the airplane by way of a data link.

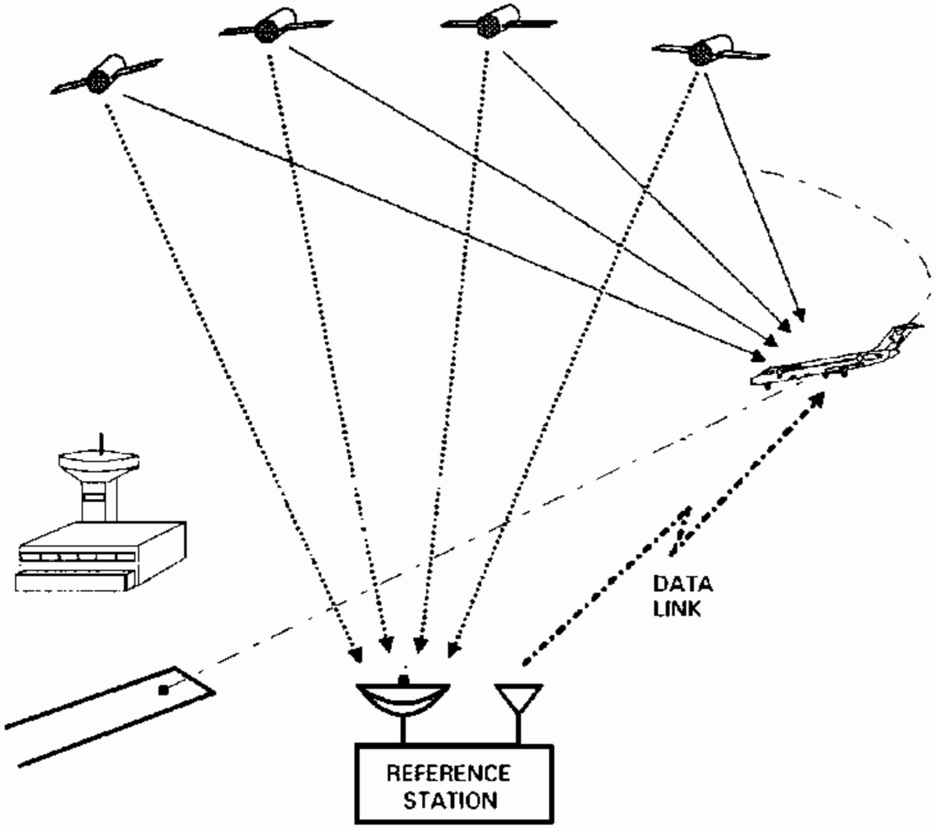
Differential GPS capability may allow curved approaches and other standardized instrument approaches assuming appropriate technical evaluations and crew procedures are developed. Departure navigation in very low visibility may be improved by providing guidance on takeoff roll, initial climb out, noise abatement and climb to enroute navigation.

GPS may provide improved ground control for accurate airplane and vehicle positioning. Low visibility taxi operations and emergency services are enhanced. Coordination of airline ramp activities and runway incursion prevention are possible. A major consideration in this application will be use of a data link system with sufficient data capacity to coordinate aircraft and ground based vehicles.

Other Applications

A portion of the navigation signal transmitted by each satellite has been reserved for future use. This could mean that the signals could also give ATC clearances, or weather data, just to name a couple

Figure 379: Approaching Aircraft with Differential GPS Guidance



Aircraft Systems

Different system layout are possible:

- GPSSU as a stand alone unit, located in the cabin ceiling close to its antenna.
- GPS Sensor Module as a circuit board located inside IRU or FMC.
- Multi mode receiver.

The GPS Sensor Unit (GPSSU) has twelve channels, each capable of tracking NAVSTAR GPS satellite signals. The primary function is to track the RF signal received from the antenna, determine the signal code phase and carrier phase, compute the antenna position and output the navigation data to the aircraft's navigation system.

GPS satellite orbits do change, there are times every day when the geometry of the satellite positions is not optimum. During these times, the position accuracy of the system will be slightly degraded. By integrating the GPS position information with that of other long-range navigation (IRS) or flight management systems, the overall positional accuracy of the system can be maintained.

In normal operation, the GPSSU data is used by ADIRU. In order to reduce GPSSU initialization time, ADIRU's sending data to GPSSU (IR position, Altitude, Date, UTC).

Multi Mode Receiver MMR

The primary function of the MMR is to receive and process ILS and GPS signals. The ILS receiver and the GPS receiver make up two of the sub assemblies.

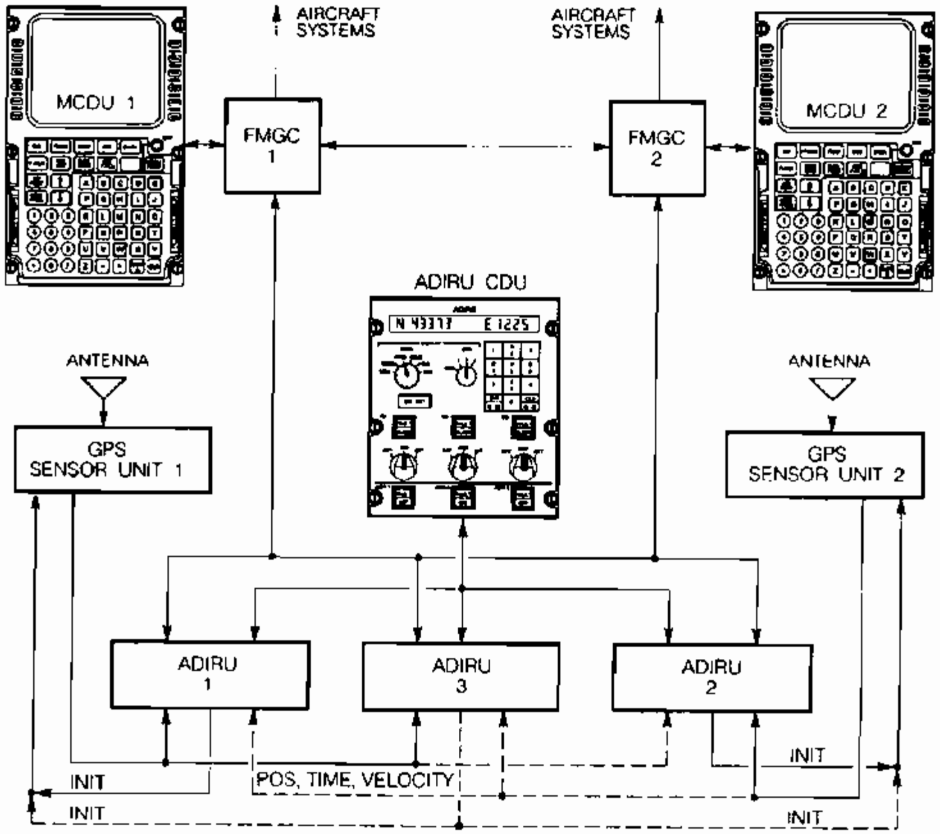
ILS

The ILS signals, including both localizer and glide slope, are used to determine flight path deviations during precision approach and landing, and are supplied to the aircraft flight control and instrument systems. These deviations are based on radio frequency signals that the unit receives from a ground-based instrument landing system.

GPS

The MMR receives RF signals through an active GPS antenna (preamplifier implemented within the antenna). The GPS receiver filters, mixes and performs A/D conversions. The resulting data is processed by microprocessors that output position, velocity, time, and integrity data to the system processor. The system processor transmits ARINC 743A-compliant data for use by other aircraft systems.

Figure 380: Interface



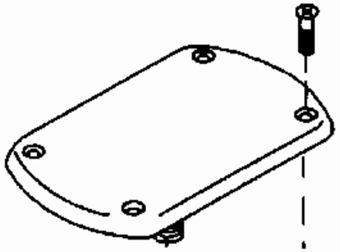


Figure 381: Antenna

The GPS antenna is a L- band antenna. The GPS antenna is designed to operate at 1575.42 MHz with a right hand circular polarization and to provide an omnidirectional upper hemispheric coverage.

Inertial Navigation

Fundamentals

Inertia

In order to understand an inertial navigation system, both the definition of "inertia" and the basic laws of motion as described by Newton over 300 years ago has to be taken into account.

- Inertia can be defined as follows: "A body continues in a state of rest, or uniform motion in a straight line, unless acted upon by an external force." This is also known as Newton's first law of motion.
- Newton's second law of motion states: "The acceleration of a body is directly proportional to the sum of the forces acting on the body."
- Newton's third law of motion states: "For every action, there is an equal and opposite reaction."

With these laws we can mechanize a device which is able to detect minute changes in accelerations and velocity, an ability necessary in the development of an inertial system. Newton's second law states that the acceleration (that is rate of change of velocity) is directly proportional to the force acting on the body. Velocity and distance are computed from sensed acceleration by the application of basic calculus. The relationship between acceleration, velocity and displacement are shown below.

Note that velocity changes whenever acceleration exists and remains constant when acceleration is zero.

Figure 382: Accelerometer as base of Inertial Navigation

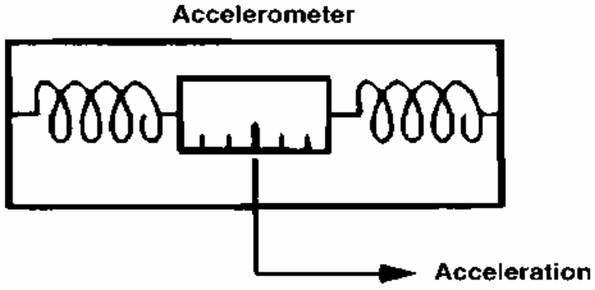
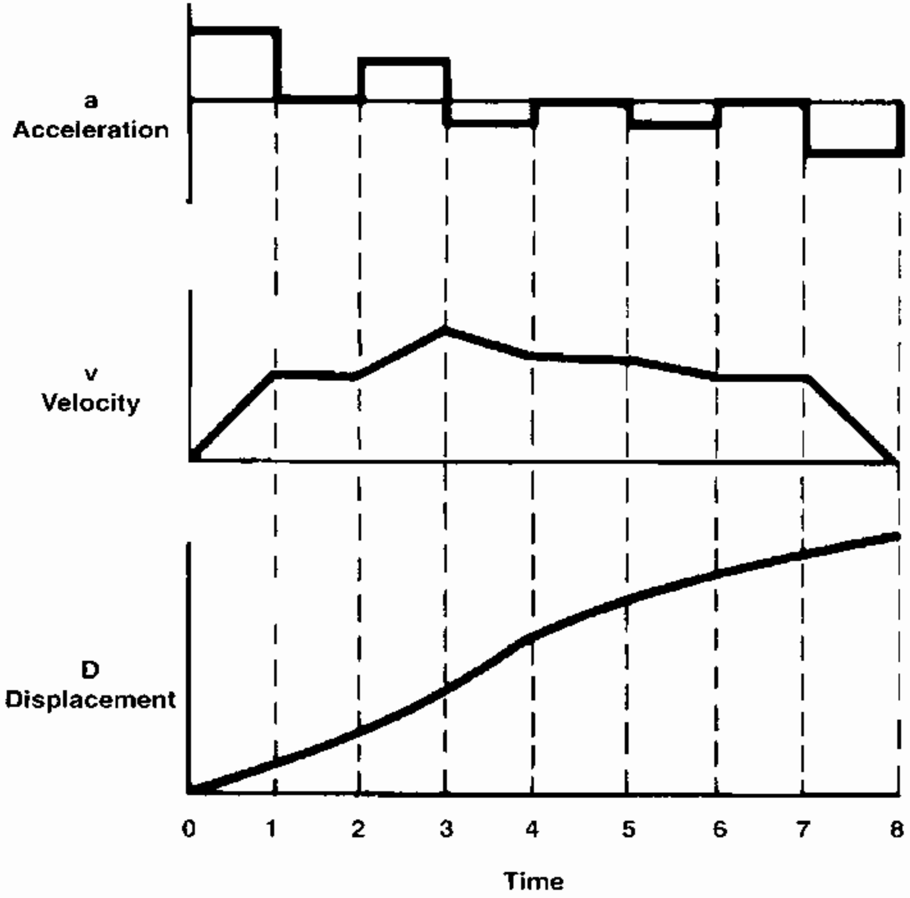


Figure 383: Integration of Acceleration



Velocity = acceleration * time $v = a * t$

Displacement D = velocity * time = $v * t$

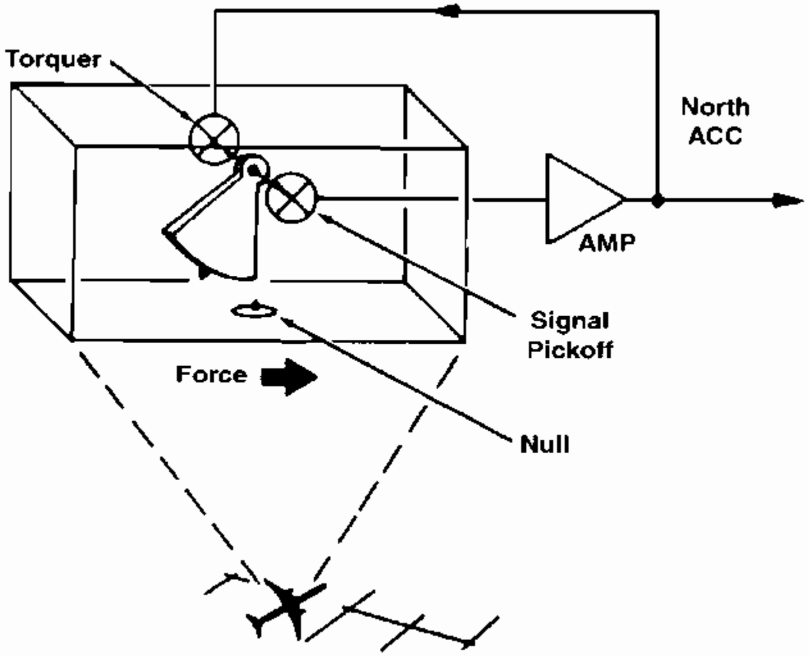
D = acceleration/2 * time^2 = $a/2 * t^2$

Accelerometer

The basic measuring instrument of the inertial navigation system is the accelerometer. Two accelerometers are mounted in the system. One will measure the aircraft's accelerations in the North-South directions, and the other will measure the aircraft's accelerations in the East-West directions. The accelerometer is basically a pendulous device. When the aircraft accelerates, the pendulum, due to inertia, swings off its null position. A signal pickoff device tells how far the pendulum is off the null position. The signal from the pickoff device is sent to an amplifier, and current from the amplifier is sent back into the accelerometer to the torquer motor. The torquer motor will restore the pendulum back to its null position.

Inertial navigation depends on the integration of acceleration to obtain velocity and distance. In any integration process one must know the initial conditions, which in this case are velocity and position. The accuracy to which the navigation problem is solved depends greatly upon the accuracy of the initial conditions. Therefore, system alignment is of paramount importance.

Figure 384: Accelerometer

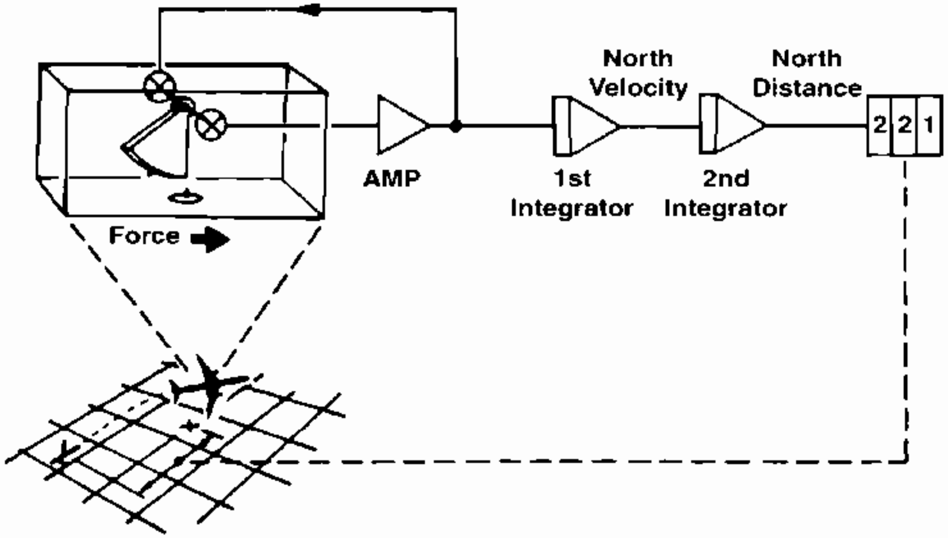


The acceleration signal from the amplifier is also sent to an integrator, which is a time multiplication device. It starts out with acceleration which is in meter per second squared. In the integrator, it is literally multiplied by time and the result is a velocity in meter per second.

It is then sent through a second integrator and again it is a time multiplier. With an input of meter per second, which is multiplied by time, the result is a distance in meter or in miles. It can be computed that the aircraft has traveled 221 miles in a northerly direction from time of takeoff.

The computer associated with the inertial system knows the latitude and the longitude of the takeoff point and calculates that the aircraft has traveled so far in a North-South direction and so far in an East-West direction. It now becomes simple for a digital computer to continuously compute the new present position of the aircraft.

Figure 385: Accelerometer with Integrators



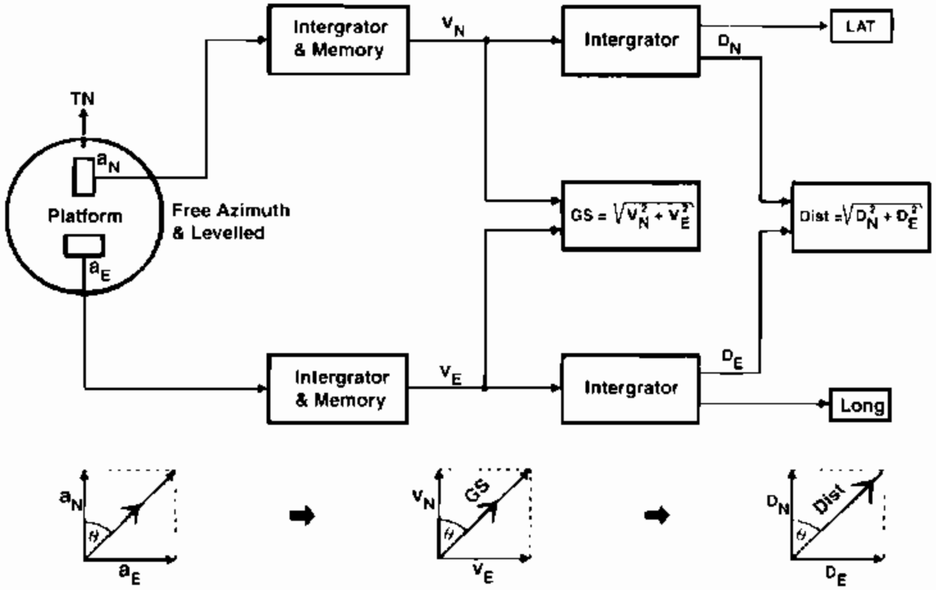
Platform

X, Y and Z Axis

- X Axis North South
- Y Axis East West
- Z Axis Up Down

To navigate in horizontal level 2 perpendicular acceleometers are used. This accelerometers are installed on a platform.

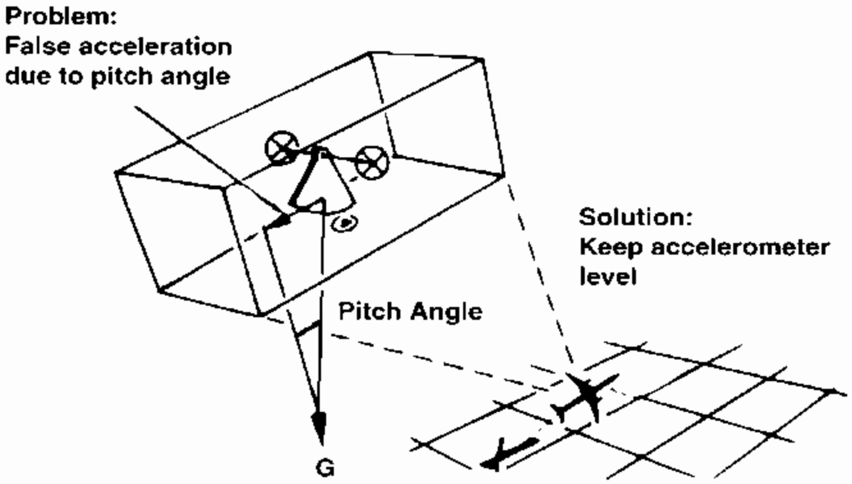
Figure 386: Platform with X and Y Accelerometers



Leveling of Accelerometers

The accelerometer's output is affected by the attitude of the aircraft. In the illustration below, the aircraft is shown in a nose up attitude during takeoff. This pitch angle makes the pendulum swing off the null position due to gravity. The accelerometer would output an erroneous signal, which would result in an erroneous velocity and distance traveled. Therefore, there is a false acceleration problem caused by this pitch angle. The solution to this problem is of course to keep the accelerometer level at all times.

Figure 387: Tilted Accelerometer sensing Earth Gravity


Problem:
False acceleration due to pitch angle

Solution:
Keep accelerometer level

To keep the accelerometer level, it is mounted on a gimbal assembly commonly referred to as the platform. The platform is nothing more than a mechanical device which allows the aircraft to go through any attitude change and at the same time maintain the accelerometers level. The inner element of the platform where the accelerometers are mounted, will also mount the gyroscopes used to stabilize the platform. The gyros provide signals to motors, which control the gimbals of the platform.

Figure 388: Platform Principle

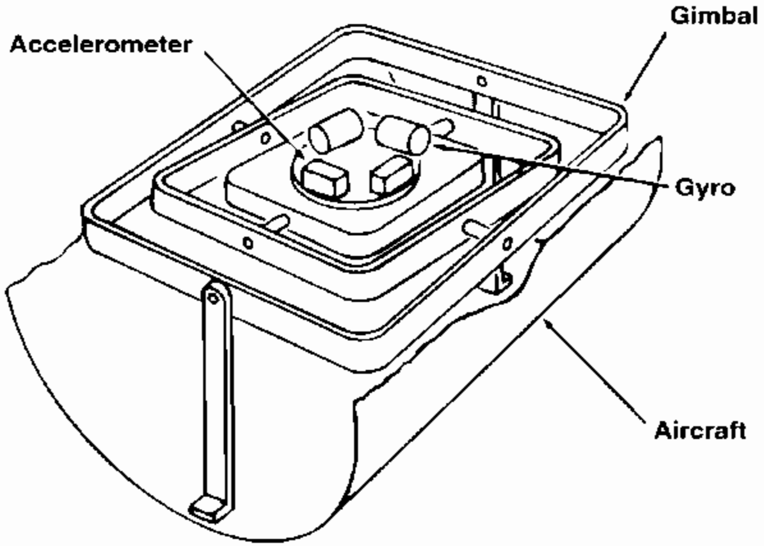
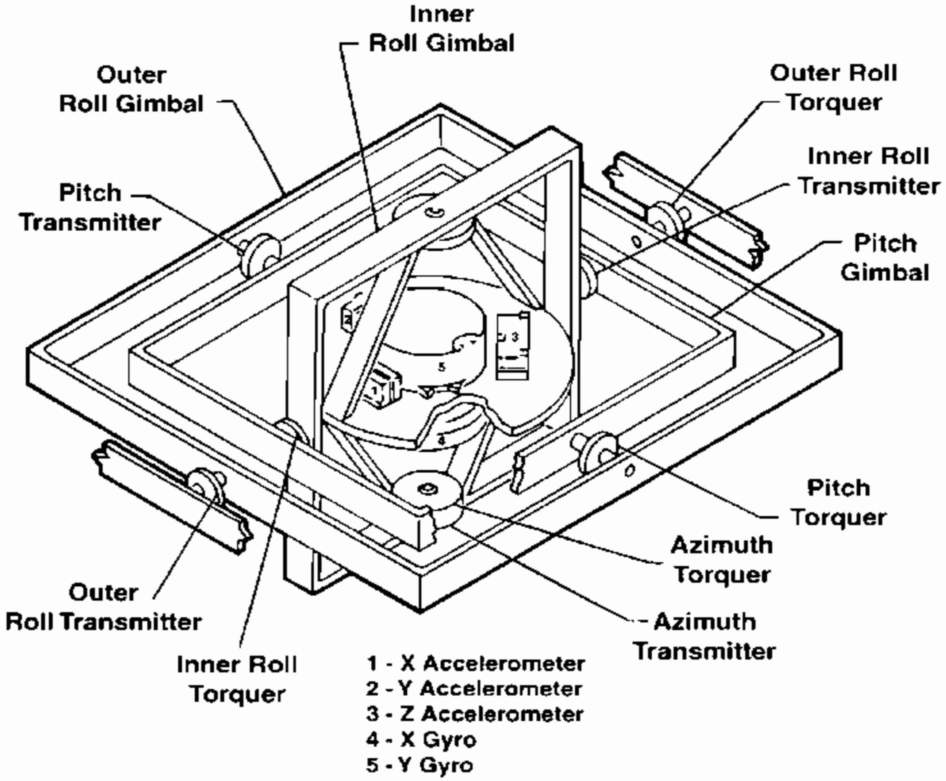


Figure 389: Platform with 2 Gyros and 3 Accelerometers

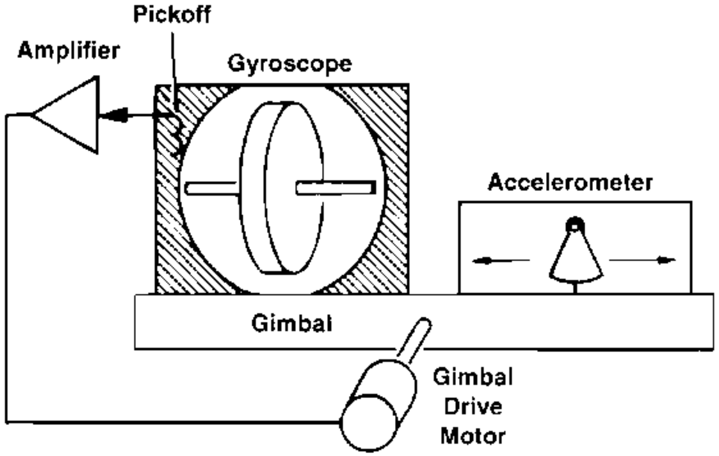


Z-gyro signal is taken from Y-gyro

Gyros

The gyro is used to control the level of the platform. The gyro and accelerometer are mounted on a common gimbal. When this gimbal tips off the level position, the spin axis of the gyro remains fixed. The case of the gyro moves with the gimbal, and the amount of movement is detected by the signal pickoff in the gyro. That signal is then amplified and sent to a gimbal drive motor, which restores the gimbal back to a level position. In this example, the accelerometer is going along for the ride. Since the accelerometer is just being kept level, it does not sense a component of gravity and is able to sense only true horizontal accelerations of the aircraft. Here we have illustrated a single axis platform. In reality, movement can occur in three axes of the platform, pitch, roll, and yaw.

Figure 390: Rate Integrating Gyro



Earth Rate Compensation

The previously described gyro stabilized platform would remain fixed in space, but the aircraft is not operating in space. It is operating on an earth which is round and rotating. In order to keep the accelerometers level with respect to the earth, so that they sense acceleration of the aircraft in a horizontal direction only, some compensation must be made. Take the example of looking down at the earth from a point in space over the South Pole. At noon, the platform is leveled so that the accelerometers sense only horizontal accelerations. Now, as the earth rotates, the platform would maintain the same orientation in space; however, from an earth vantage point, the platform would appear to tip over every 24 hours.

To compensate for this apparent tipping, the platform is forced to tilt in proportion to the earth's rate. From our space vantage point, the platform appears to tip over every 24 hours, while from an earth vantage point, it remains fixed and level as required for proper operation. The required earth rate compensation is a function of latitude, since what is being compensated for is the horizontal component of earth rate that is felt by the gyros. At the equator this value is 15.04 degrees per hour, and with travel north or south of the equator, it reduces until it becomes zero at the poles.

Transport Rate Compensation

The aircraft travels from a place at the equator toward north. At the equator the platform was leveled. Without compensation the platform maintains its position toward the space, but not against the earth surface. The computer compensates this effect depending on aircraft position, heading and speed, to maintain the platform all the time perfectly leveled.

Figure 391: Earth Rate

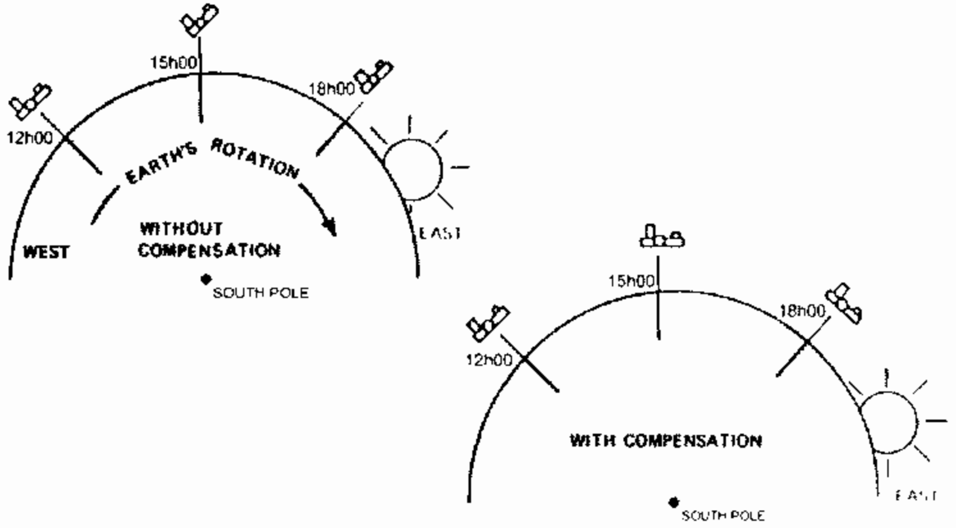
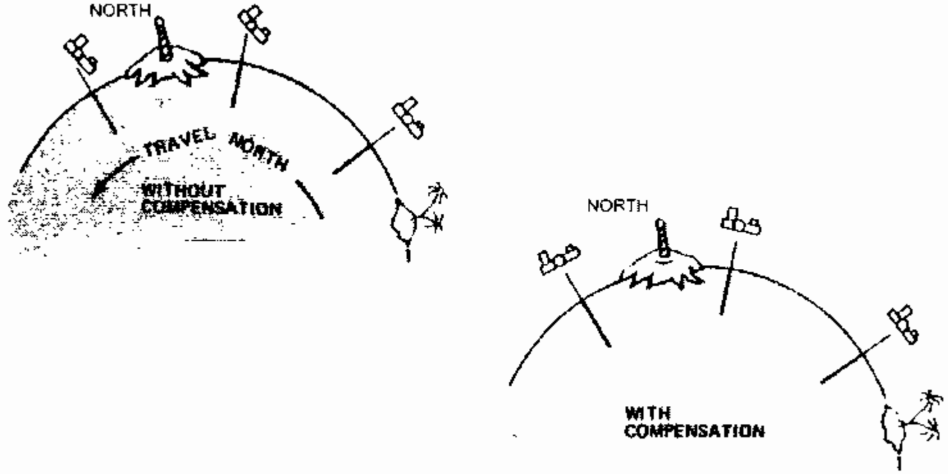


Figure 392: Transport Rate



Navigation

Navigation may be thought of as the means of finding the route from one location on the earth' s surface to another. This is made possible by dividing the surface of the earth with a grid system that allows us to give an address to any location

Longitude

The earth may be thought of as a sphere rotating in space about an imaginary axis that runs through its two geographic poles This sphere is divided from north to south by lines that intersect at the poles and cut through the center of the earth. These lines are called meridians of longitude and are measured from the prime meridian which passes through Greenwich, England. There are 360 meridians, labeled 1 to 179 East and 1 to 179 West The prime meridian is zero degrees longitude. and the international date line is the 180-degree meridian. Meridians of longitude east of the prime meridian are called east longitude, and those to the west are west longitude.

The meridians are not parallel, but each one of them is a part of a great circle, that is, a part of a line on the surface of the earth formed by a plane that passes through the center of the earth.

Latitude

To form an intersecting line with the meridians, the earth is divided by parallel lines formed on the surface by planes that cut the earth into parallel slices, each perpendicular to the axis of rotation The line that cuts the earth at its center is called the equator and it' s latitude is zero. The lines to the north are called parallels of northern latitude, with the north pole located at 90 degrees north latitude. Parallels to the south are called southern latitude, and the south pole is located at 90 degrees south latitude The parallels are, as their name implies, parallel to each other, but the equator is the only parallel that is also a great circle

All of our maps and charts are based on the grid system of latitude and longitude, with the geographic north and south poles being the references for this grid. The flight route from a departure to a destination point is divided into several waypoints This waypoints are defined by latitude LAT and longitude LONG

Figure 393: Latitude and Longitude

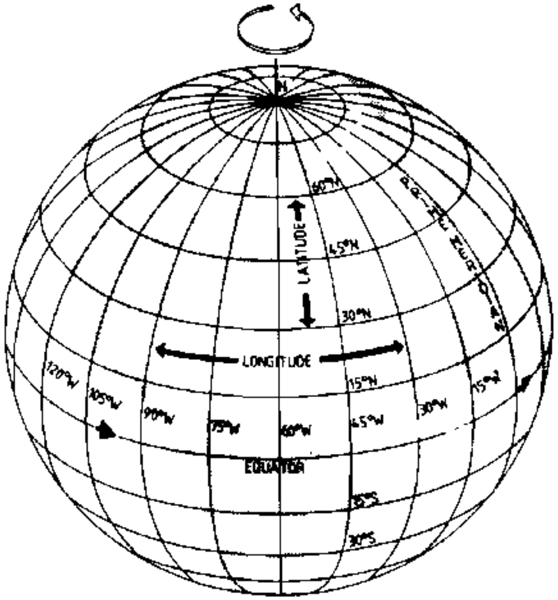
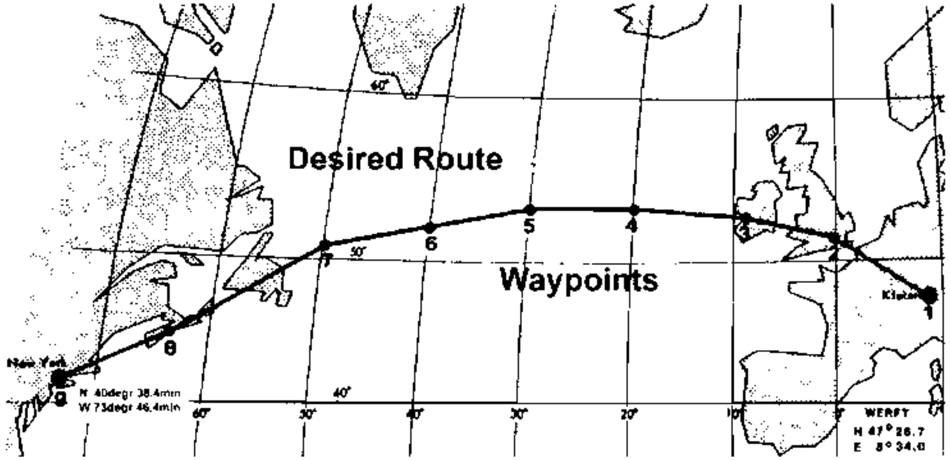


Figure 394: A Flight from Zurich to New York



Parameters and Display

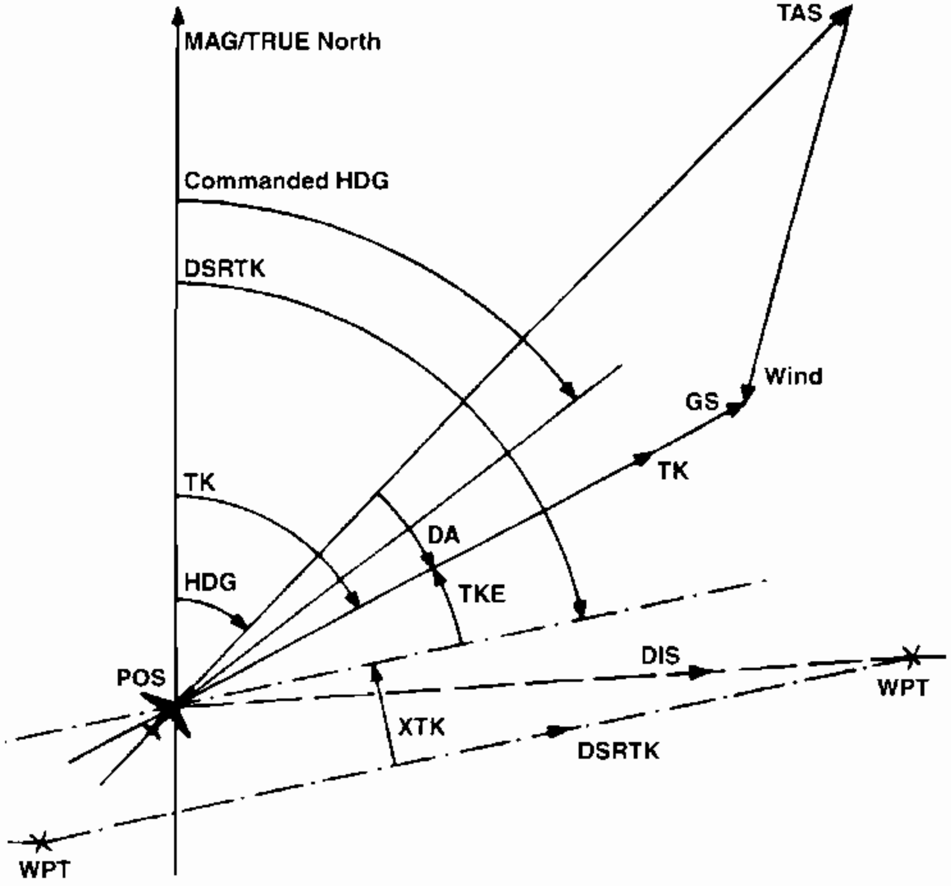
The navigation parameter are presented in digital form at inertial system control display units CDU, or multi function display units MCDU.

Horizontal situation indicator HSI and navigation displays EFIS ND presenting the navigation parameter in analog and digital format.

Table 9: Parameter

WPT	Waypoint	Defined by Pilot
DSRTK	Desired Track	Greatcircle Line between two WPT's
POS	Present Position	Latitude/Longitude
HDG	True or Magnetic Heading	Direction of longitudinal axis
TK	Actual Track Angle	Direction flown above ground
DA	Drift Angle	Vector HDG - Vector TK
TKE	Track Angle Error	Vector DSRTK - Vector TK
TAS	True Air Speed	Signal from Airdata System
GS	Ground Speed	1 kt = 1.852 km/h
XTK	Cross Track Deviation	Lateral Distance from DSRTK
DIS	Distance	Aircraft to next WPT
WS	Wind Speed	Vector GS + Vector TAS
WD	Wind Direction	Angle from where wind comes

Figure 395: Parameter



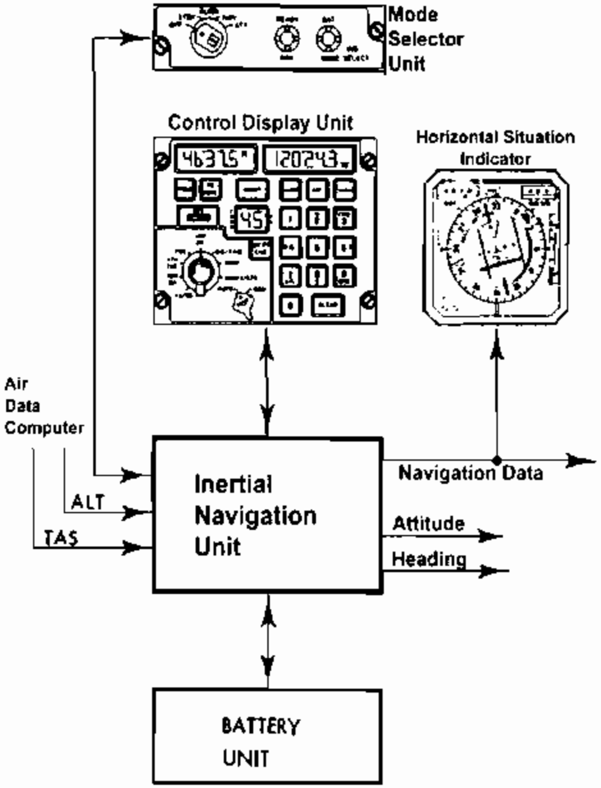
Inertial Navigation System

The position information calculated by the INS equipment is typically displayed to the flight crew through an horizontal situation indicator or EFIS. The flight crew typically controls the INS from a cockpit display called a control-display unit CDU.

If the IRS is switched on, there is a need to insert the present position to align the system. The alignment takes 10 minutes.

When airplane power fails, the IRU switches to battery power. Aircraft batteries or separate batteries provides the power for a maximum of 30 minutes.

Figure 396: Inertial Navigation System INS



All navigation functions are system integrated.

Figure 397: Controls of Inertial Sensor System

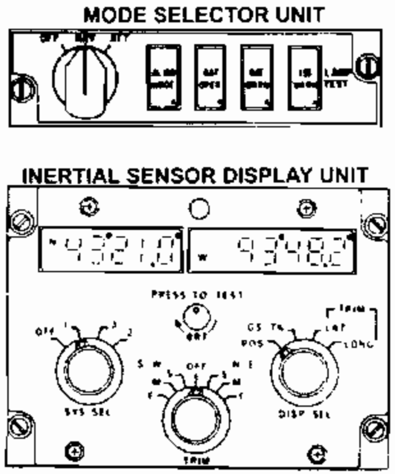
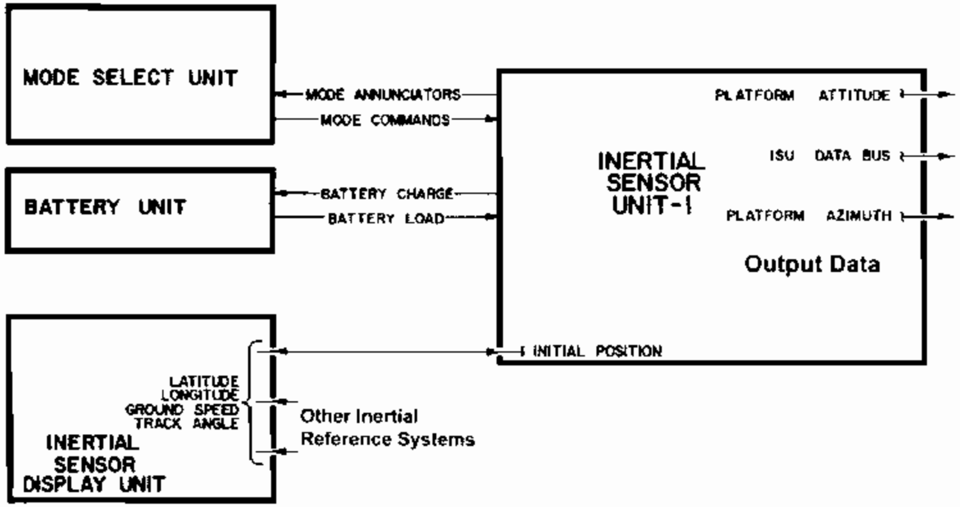


Figure 398: Inertial Sensor System (ISS)



This system provides inertial parameter to other navigation devices (RNAV/FMS)

Strapdown System

In a strapdown inertial reference system, the gyros and accelerometers are mounted solidly to the system chassis which is in turn mounted solidly to the aircraft. There are no gimbals to keep the sensors level with the surface of the earth. The accelerometers are mounted such that the input axis of one accelerometer is always in the longitudinal aircraft axis, one is in the lateral axis, and one is in the vertical axis Likewise, the gyros are mounted such that one gyro senses roll, one senses pitch, and the other senses yaw.

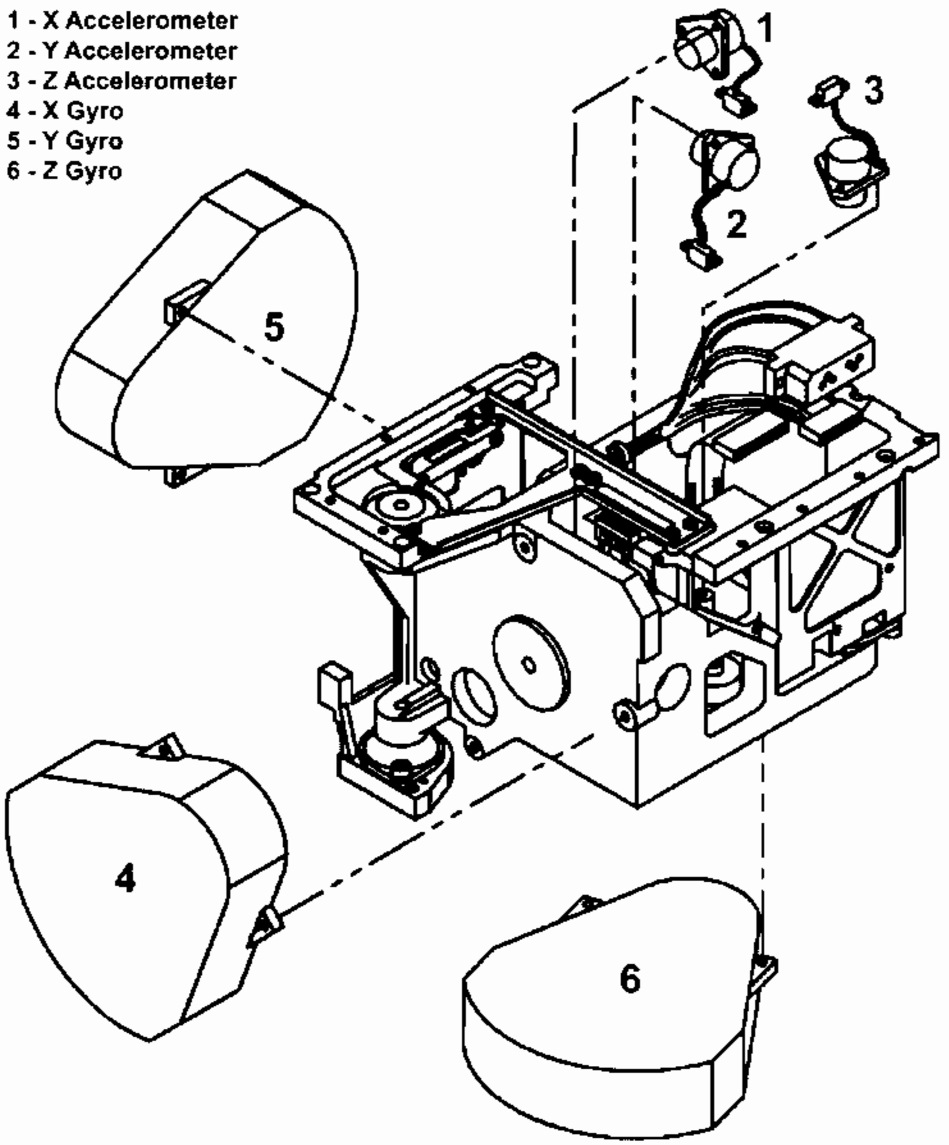
A microprocessor calculates velocity, position, and attitude from the inertial sensors acceleration and angular rate measurements. Three accelerometers and three gyros are needed because, in a three-dimensional world, an aircraft can simultaneously accelerate and rotate in three orthogonal axes - pitch, roll and heading.

In order to navigate over the surface of the earth, the system must know how this aircraft acceleration is related to the earth's surface. Because accelerations are measured by accelerometers that are mounted to the lateral, longitudinal, and vertical axes of the aircraft, the IRS must know the relationship of each of these axes to the surface of the earth. The laser gyros in a strapdown system make the measurements necessary to describe this relationship in terms of pitch, roll, and heading angles. These angles are calculated from the angular rates measured by the gyros through an integration - similar to the manner in which velocity is calculated from measured acceleration. For example, suppose a gyro measures a yaw rate of three degrees per second for 30 seconds. Through integration, the microprocessor calculates that the heading has changed by 90 degrees after 30 seconds.

Given the knowledge of pitch, roll, and heading that the gyros provide, the microprocessor resolves the acceleration signals into earth-related accelerations, and then performs the horizontal and vertical navigation calculations.

To reach the demanded accurancy of a strap down inertial navigation system, the sensitivity of the instrument (gyros and accelerometers) must10 times higher than those of a gimbaled platform. Laser gyros and precision pendulum accelerometers are used.

Figure 399: Accelerometer and Laser Gyros



Laser Principle of Operation

Laser = Light Amplification by Stimulated Emission of Radiation.

The laser gyro is a device that measures rotation by using the properties of two laser beams rotating in opposite directions inside a cavity. The principles of operation of an ordinary single beam laser are described below, and then expanded into a description of the double-beam laser gyro.

In a laser cavity, photons are emitted (or light is radiated) in all directions. However, only the light that radiates in a straight line between two or more mirrors is reinforced by repeated trips through the gain medium. This repeated amplification of the light reflecting between the mirrors soon reaches saturation, and a steady-state oscillation results. This light oscillating between the mirrors is typically called a laser beam. To obtain useful laser light outside the laser cavity, a small percentage of the laser beam is allowed to pass through one of the mirrors.

A laser gyro operates much like an ordinary laser, but rather than just two mirrors it contains at least three so that the laser beams can travel around an enclosed area. Such a configuration allows the generation of two distinct laser beams occupying the same space. One beam travels in a clockwise direction and the other travels in a counter clockwise direction. The operation of a laser gyro is founded on the effects rotational motion has on the two laser beams.

A dc voltage is applied across a laser cavity, establishing an electrical discharge in a mixture of helium and neon gases. The discharge that develops is similar to that in a neon sign. Light amplification occurs when a photon strikes a neon atom that has been pumped into the excited state. This results in a net gain of photons, or an amplification of light also known as "lasing."

The light is a pure frequency. The helium-neon laser gyro, as defined by its wavelength and this is 6'328 Angstroms, 0.6328 µm or 632.8 nm. So the frequency is 474 x 10^{12} Hz.

A laser changes incoherent light, light whose vibrations do not have any consistent phase relationship, into coherent light, whose vibrations are all in phase. The light beam from a laser is highly concentrated, very narrow, and has an extremely small area. Laser technology is opening new doors in all aspects of science.

Figure 400: Spectrum of the Light

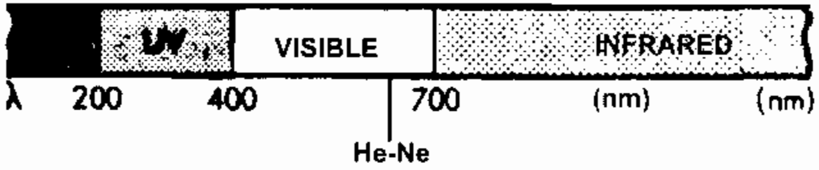
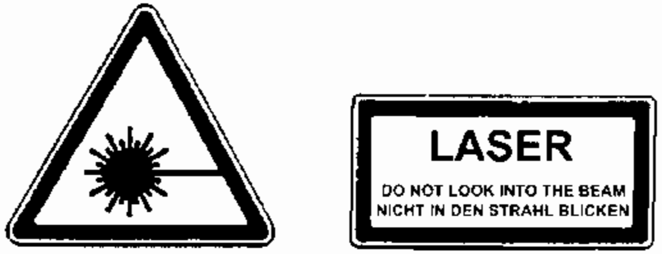


Figure 401: LASER - Beams are dangerous!



Laser Gyro

Laser gyros are sensors of angular rate of rotation about a single axis. As exemplified. They are made of a triangular block of temperature-stable glass. Very small tunnels are precisely drilled parallel to the perimeter of the triangle, and reflecting mirrors are placed in each corner. A small charge of helium-neon gas is inserted and sealed into an aperture in the glass at the base of the triangle. When high voltage is run between the anodes and cathode the gas is ionized, and in the energy exchange process many of the atoms of the gas are transformed into light in the orange-pink part of the visible spectrum.

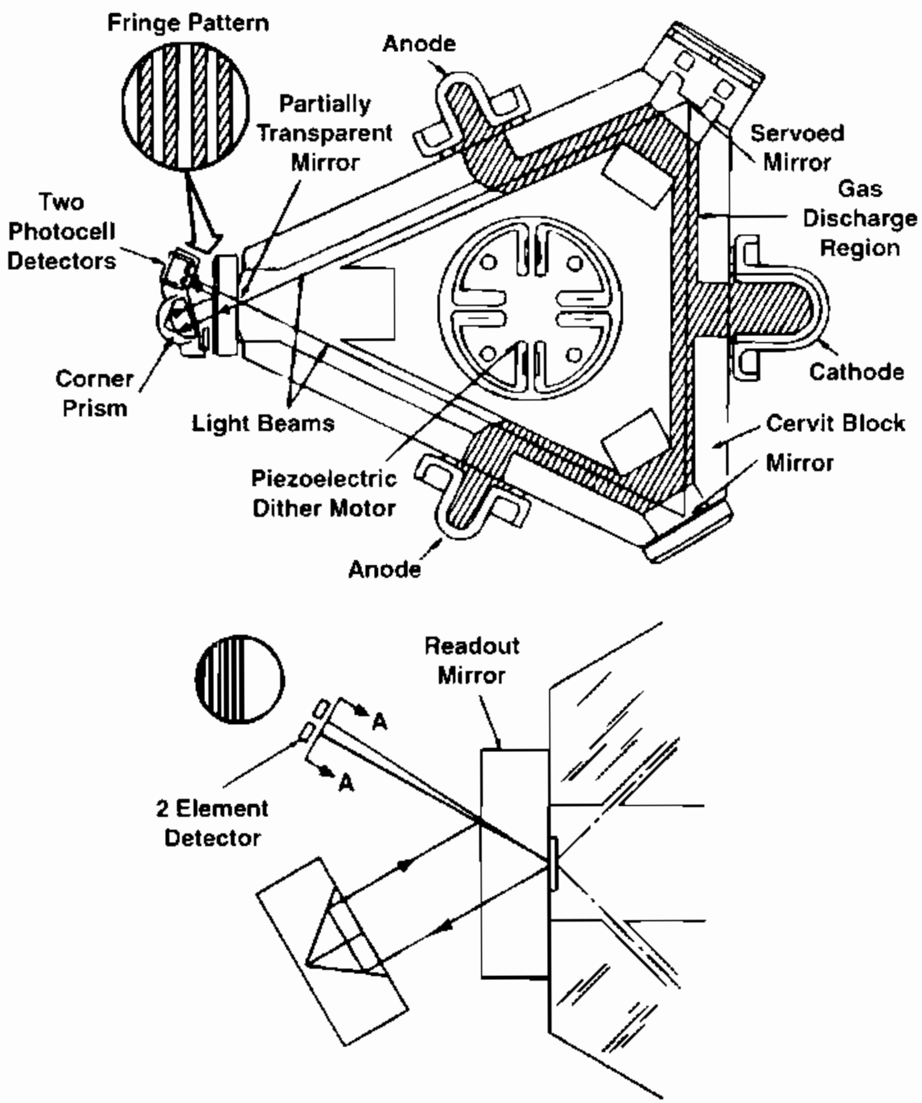
In a laser gyro two beams of light are generated, each travelling around the cavity (in this case a triangle) in opposite directions.

The laser beams have coherent wave-like properties. The light is a pure frequency. The helium-neon laser gyro, as defined by its wavelength (the reciprocal of frequency), it is 6'328 Angstroms.

Although the frequency is determined by the gas that is lasing. It can be varied somewhat by changing the path length over which the waves have to travel. For a given path length there are an integral number of waves. If the path length is altered, the waves will be either compressed or expanded, but there always will be an integral number of cycles that occur over the complete path. If the waves are compressed, more cycles occur per unit time. Hence, the frequency increases If expanded, the opposite is true.

Since both contrarotating beams travel at the same constant speed of light, it takes each the same exact time to complete its circuit. However, if the gyro were rotated on its axis, the path length of one beam would be shortened, while that for the other would be lengthened. Since, as explained, the laser beam adjusts its wave-length for the length of the path, the beam that travelled the shorter distance would rise in frequency (wavelength decreases), while the beam that travelled the longer distance to complete the circuit would encounter a frequency decrease.

Figure 402: RLG



Detecting the Difference

This frequency difference between the two beams is directly proportional to the angular rate of turn about the gyro's axis. Simply stated, that is the principle of the laser gyro. Thus, frequency difference becomes a measure of rotation rate. If the gyro doesn't move about its axis, both frequencies remain equal (since the path lengths of both beams are equal) and the angular rate is zero.

The difference in frequency in the laser gyro is measured by an optical detector that counts the fringes of the fringe pattern generated by the interference of the two light waves. Since the fringes are seen as pulses by the photocell, the detected frequency difference appears at the output of the detector in digital form, ready for immediate processing by the system's associated digital electronics.

Note that there are two photocells. The function of one is to tell the direction in which the fringes are moving, which is an indication of whether the gyro is rotating to the left or right.

Light Path

The three corner mirrors are not identical. One is servoed so that it can make micro-adjustments to keep the physical path always the same. Another permits a small amount of light to pass through so as to impinge on the photocell detectors. The prism, as can be seen, flips one beam around causing it to meet and interfere with the beam aimed directly at the photocells. The interfering beams alternately cancel and reinforce each other, thus generating the fringe pattern.

The block of glass used for the laser gyro is made from Cervit, a special glass, the physical dimensions of which remain constant over a wide temperature range.

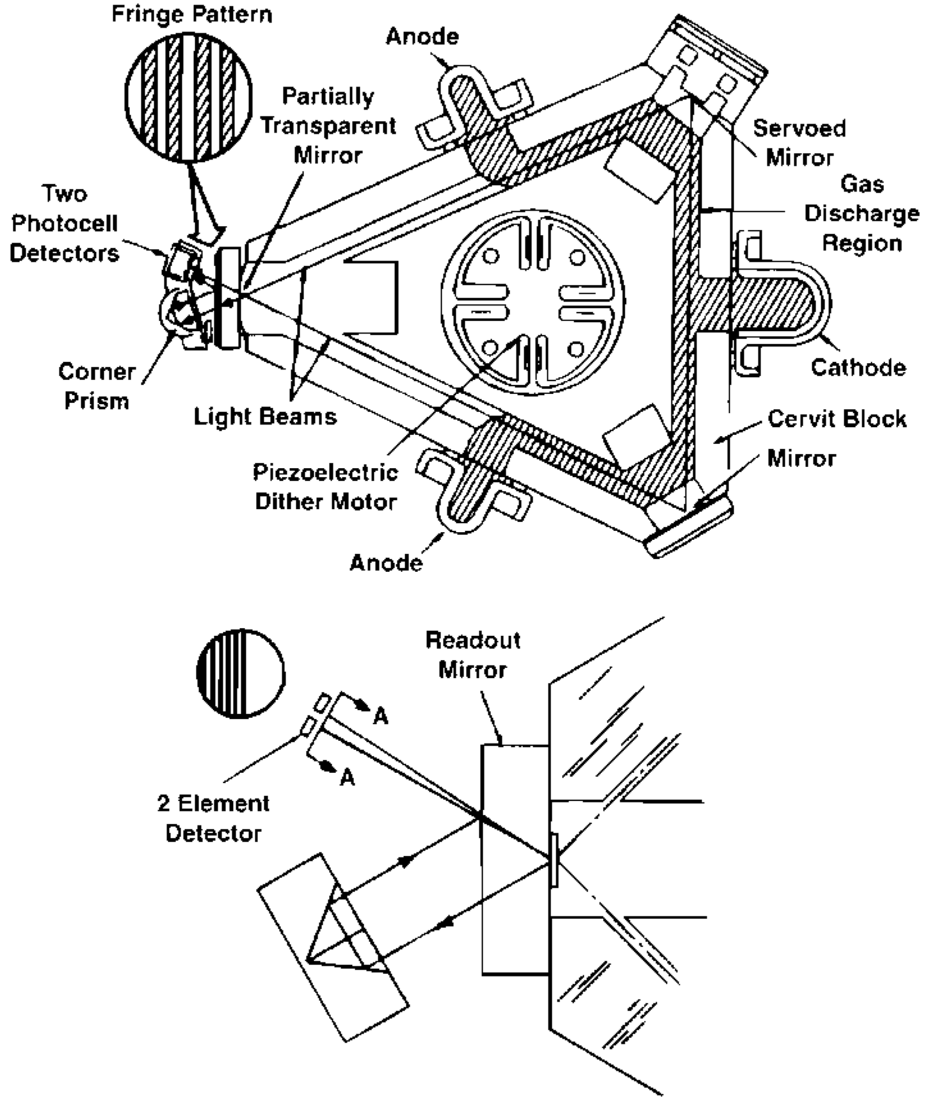
High Voltage

To start the lasing action, 3,000 volts are applied across the anodes to the cathode. Although one can't see the laser beams in the laser gyro, a plasma is formed between the cathode and the two anodes that glows an orange pink that is in the same part of the visible spectrum as the 6,328 Angstrom beams. This plasma can be seen.

Dithering

In the center of the Cervit block is a device called a dither motor. The motor, which vibrates at 319 Hz, eliminates "laser lock," a hangup that sometimes occurs in the deadband around the zero-rate point.

Figure 403: RLG



Accelerometer Principle of Operation

The basic principles of an inertial accelerometer have not changed. Pendulous accelerometers have a very good performance and reliability at an acceptable cost, so new technology has not been applied to accelerometer designs.

Inertial accelerometers contain a pendulum that tends to swing off its null position when it is exposed to an acceleration or deceleration. A photo electric pick-off device is positioned so that it can measure the size of the swing, and generate an electrical signal proportional to the swing. This signal is amplified proportionately into a current which is used to torque the pendulum back to the null position. The net result of this control loop is that the pendulum remains in the null position, and a current has been generated proportional to the acceleration that the accelerometer is experiencing. This current is the output of the accelerometer.

The current output of the accelerometer is an analog signal. The current is converted into a voltage, which is converted into a digital signal by a high-precision analog-to-digital (A/D) converter. This digital signal is supplied to a microprocessor, which uses this acceleration measurement in the navigation computations, integrating that measurement once over time to give velocity. Velocity is then integrated once more over time to give distance travelled.

Figure 404: .Accelerometer

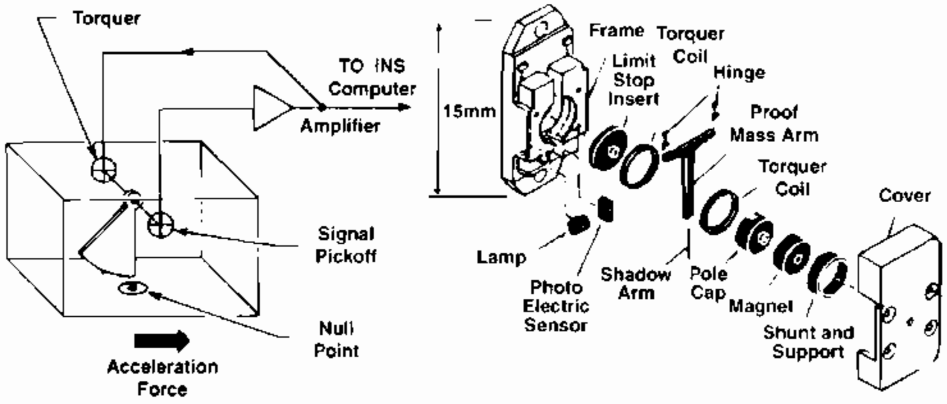
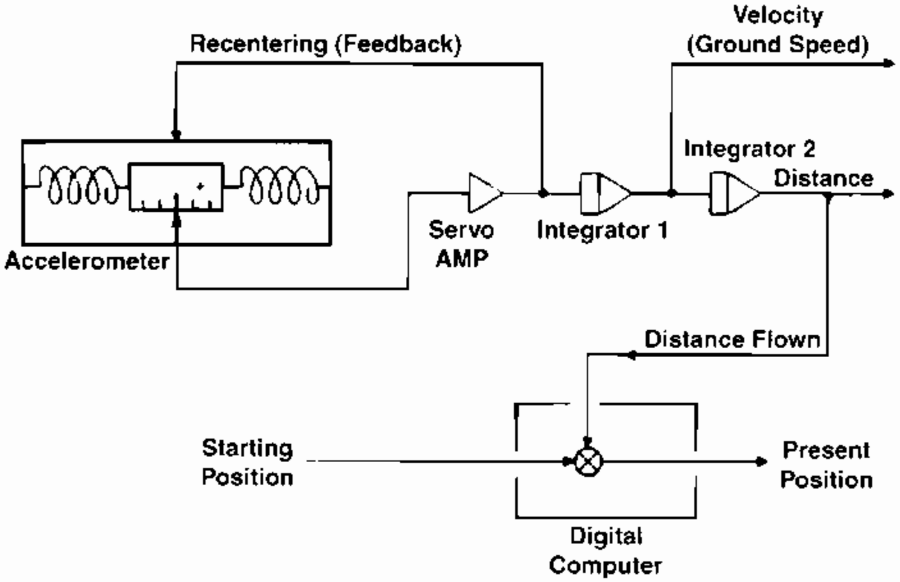


Figure 405: Navigation based on Acceleration



Triple-Axis Navigation Computation

Accelerometers

Three accelerometers are stationary relative to the airplane frame. To determine how much acceleration is causing horizontal movement on the earth, the outputs of the accelerometers have to be compensated by the IRU computer, taking into account the airplane attitude and earth curvature.

The compensated outputs from the accelerometers are vectorially added to determine the actual direction of travel and the amount of travel horizontally. In general, the accelerometers are not oriented north-south and east-west, but their output signals can be related to a north-east coordinate system, and the present position can then be determined in terms of latitude and longitude.

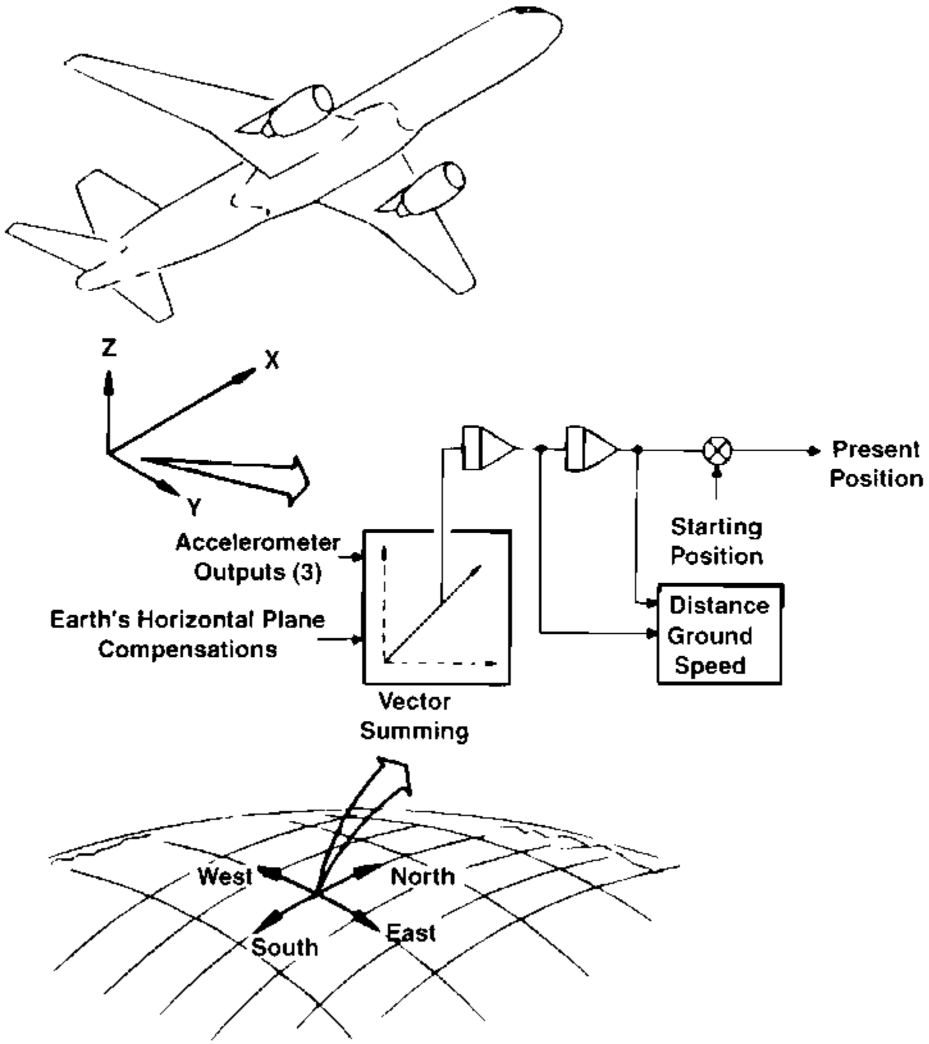
Vertical velocity and altitude are calculated using the acceleration that is measured perpendicular to the earth's surface.

Inertial accelerometer cannot distinguish between gravitational force and actual, aircraft acceleration. Consequently, any accelerometer that is not perfectly parallel to the earth's surface will measure a component of the earth's gravity in addition to the true aircraft acceleration. Therefore, the IRS's microprocessor must subtract the estimated local gravity from the measured vertical acceleration signal. This prevents the system from interpreting gravitational force as upward aircraft acceleration.

Laser Gyros

The purpose of the gyros is to measure rotational motion of the aircraft with respect to the earth. However, the laser gyro in a strapdown configuration inherently measures movement of the aircraft with respect to inertial space. The earth rotates with respect to inertial space at a rate of one rotation per 24 hours as it spins from west to east on its own axis, plus one rotation per year as it revolves around the sun. The sum of these two rates is equivalent to an angular rate of 15.04 degrees per hour. The microprocessor compensates for this rate by subtracting this value, which is stored in memory, from the signal measured by gyros.

Figure 406: 3-D Navigation



Alignment

During alignment the inertial reference system determines the local vertical and the direction of true north. The three gyros sense angular rate of the airplane. Since the plane is stationary during alignment, the angular rate is due to earth rotation. The IRU computer uses this angular rate to determine the direction of true north.

The IRU computer has determined true north by sensing the direction of the earth's rotation. The magnitude of the earth rotation vector allows the IRU computer to estimate latitude of the initial present position. This calculated latitude is compared with the latitude entered by the operator during initialization.

The system software performs a vertical levelling and determines aircraft true heading and latitude. The levelling operation brings the pitch-and-roll attitudes within 1.0 degree accuracy (coarse levelling), followed by fine levelling and heading determination. Initial latitude and longitude data must be entered by manually entering the actual present position via the ISDU or by entering it by the FMS CDU.

Upon ALIGN completion, the IRS will enter NAV mode automatically. Alignment Time. The IRU completes alignment in a maximum of 10 minutes. During alignment, the ALIGN annunciator is lit. Under normal circumstances, alignment should be initiated only within the latitudes of 70° North to 70° South.

To complete alignment, **the pilot must enter the present position** (latitude and longitude) of the aircraft on an FMS or ISDU and transmit the position to the IRU during the alignment time.

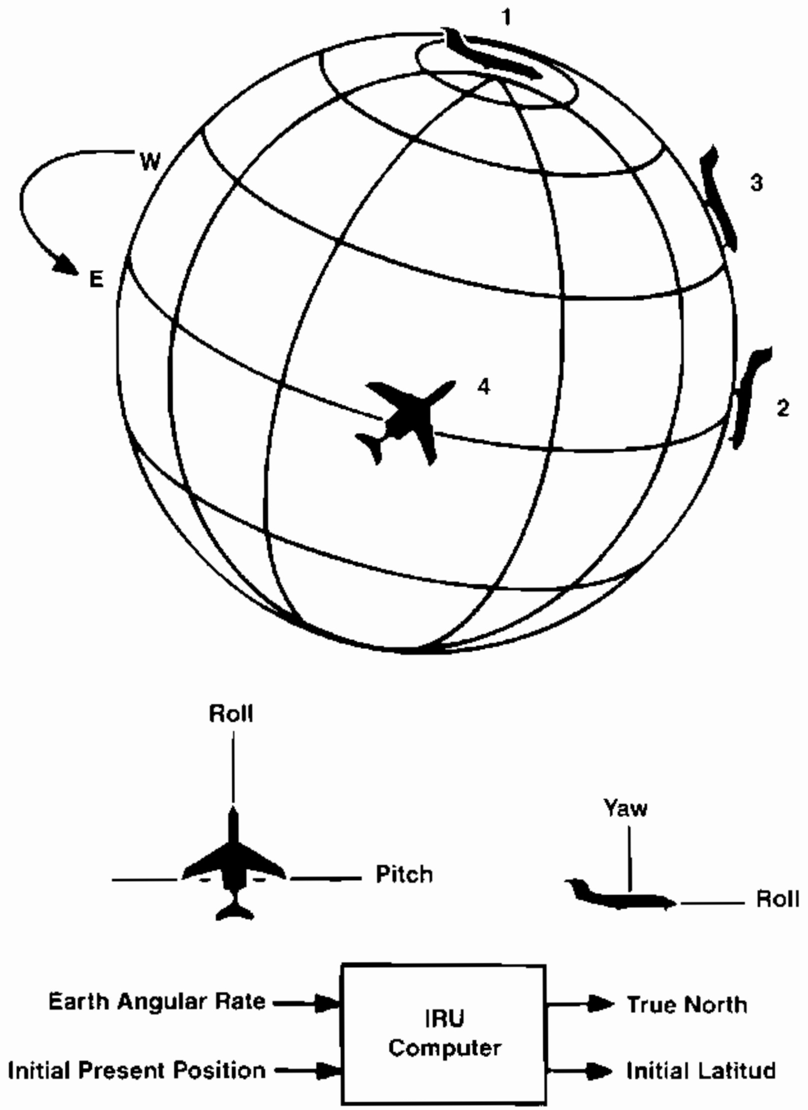
During alignment, the aircraft must remain stationary. If the IRU detects excessive aircraft motion, the ALIGN annunciator flashes and the FAULT annunciator lights. If this occurs, the alignment has to be restarted. Normal passenger-loading activities and wind gusts will not disturb alignment.

If the pilot does not enter present position within the normal alignment time, the MSU ALIGN annunciator flashes, and the IRU will not enter the NAV mode until it receives a valid input of present position.

The pilot may update the current latitude and longitude entry any number of times without delaying alignment as long as the IRU has not entered the NAV mode. Each successive latitude and/or longitude entry writes over the previous entry. Only the latest entry is used for navigation.

The sensed earth rate sensed with the 3 RLG's depends on aircraft position latitude 1 - 4 and the aircraft azimuth.

Figure 407: Alignment, determining Latitude and Heading



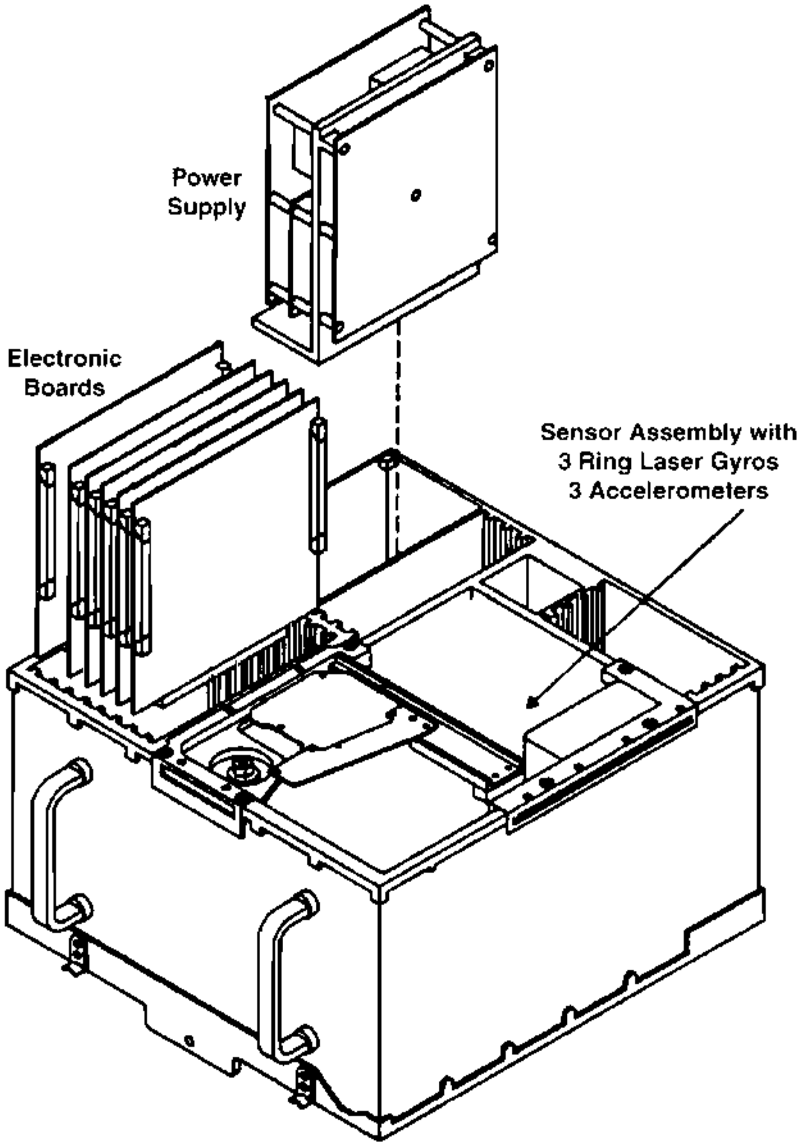
Inertial Reference Unit

Each IRU contains three laser gyros, three accelerometers several electronic boards, power supply and chassis. The instruments are fixed to the chassis, so those sense all the aircraft movements and the earth gravitation. The computer compensates the signals from the "strapped down" sensors. This sensed data and local vertical coordinates, combined with airdata inputs, serve to compute the following.

The IRS provides the following aircraft flight information:

- Primary aircraft attitude in pitch and roll
- Magnetic and true heading
- Body linear acceleration
  Longitudinal
  Lateral
  Normal
- Body angular rates
  Pitch
  Roll
  Yaw
- Inertial velocity
  N-S, E-W
  Ground speed
  Track angle
  Vertical rate
- Navigation position
  Latitude
  Longitude
  Inertial altitude
- Wind data
  Wind speed
  Wind angle
  Drift angle
- Calculated data
  Flight path angle and acceleration
  Along track and cross track acceleration
  Inertial pitch and roll rate
  Vertical acceleration and potential vertical speed

Figure 408: IRU



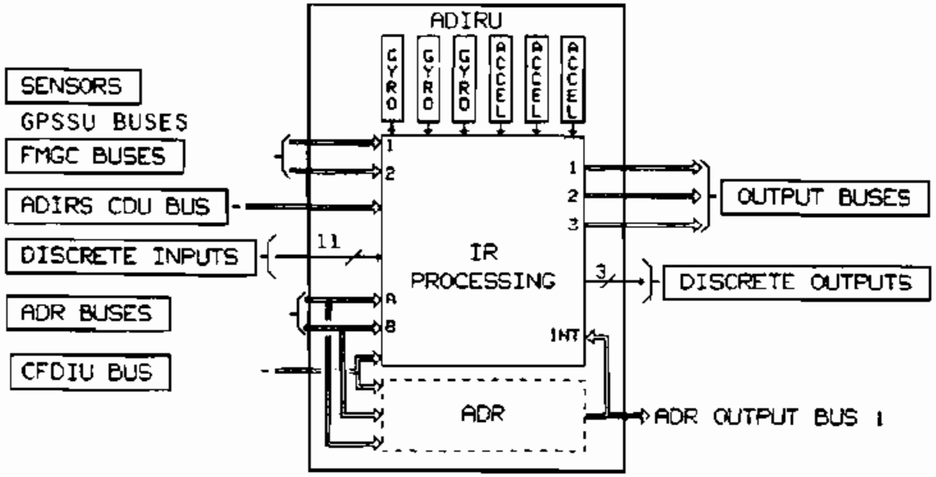
Example A320

The Airdata Inertial Reference Unit ADIRU handles all airdata computations and works as a inertial reference system.

The external inputs are:

- Global Positioning Sensor Unit (GPSSU) provides satellite navigation data for hybridisation to the Flight Management System.
- FMGC (Flight Management Guidance Computer) Buses provides initialisation for IRS for alignment. The data must be inserted via MCDU.
- ADIRS CDU provides initialisation if FMGC input has failed.
- Discrete inputs provides different option programming like installation orientation.
- Airdata Reference buses from other and own system provides airdata informations for wind calculations and corrections.
- CFDIU (Centralized Fault Display Interface Unit) is a maintenance tool for trouble shooting and maintenance.

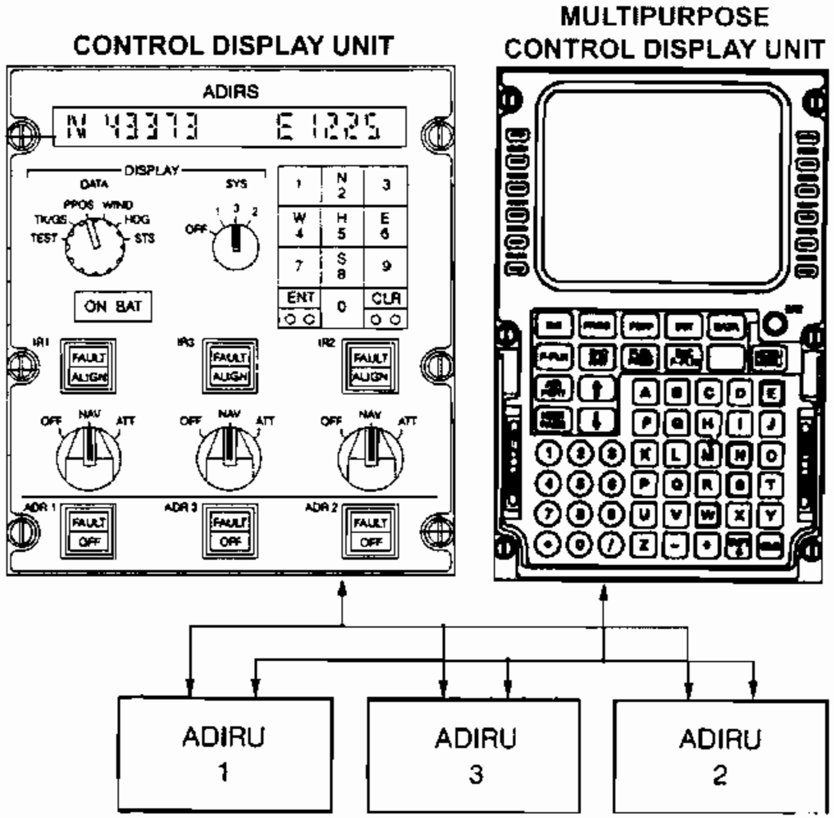
Figure 409: .Inertial Reference Unit



Output is provided to:

- Electronic Flight display System (EFIS)
- Auto flight system
- Discrete outputs turning on IRS FAULT and ALIGN lights.
- Air Data Reference data are provided to all users needing of this informations.

Figure 410: Inertial Reference System



Flight Director

Introduction

In 1950, an entirely new idea in flight instrumentation, the original flight director or Zero Reader, was introduced.

This system took information from the cockpit instruments and gyros, processed it through an electronic computer, and presented it as *How to Fly* information on a single indicator. Thus, instead of having to calculate for himself from five or six different instruments, a pilot could navigate and make landing approaches simply by *zeroing* or centering two cross-pointers on the indicator.

A flight director (FD) system in simple form is designed to provide computed steering commands to the command bars of the ADI and/or to an autopilot system. The system uses various signal inputs such as:

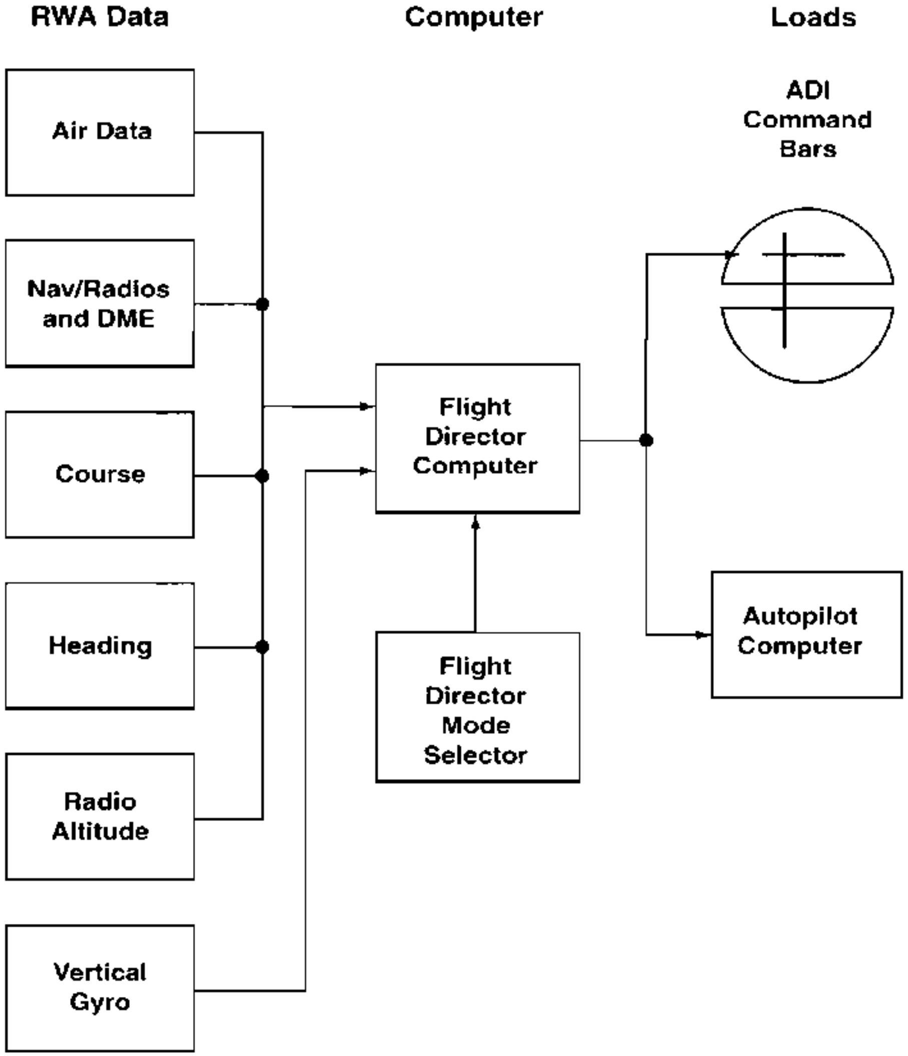
- Air data
- Radio
- Course information
- Heading information
- Vertical gyro

to generate the computed steering commands. A typical flight director system, like an autopilot system, can be divided into four parts:

- Sensors
- Computer
- Controls
- Loads

The sensors provide the raw data to be processed by the computer. The flight director mode selector tells the computer which raw data to use, depending on pilot mode preference. The computer processes the raw data and gain scales the information to be displayed on the ADI command bars and/or to the autopilot computer.

Figure 411: Functional Block Diagram FD

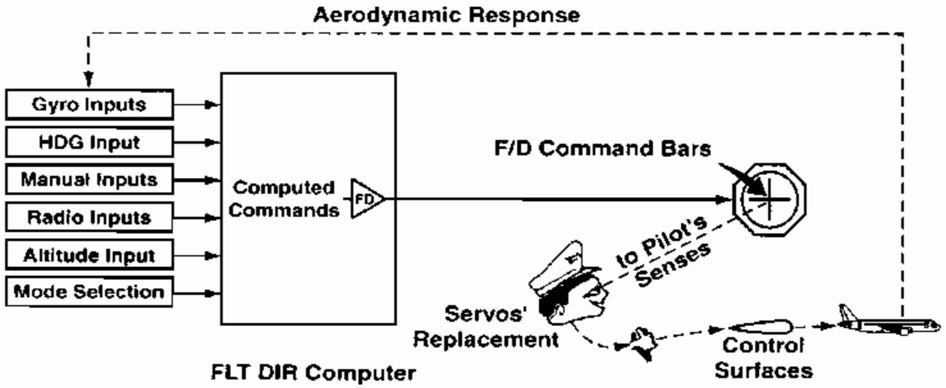


Flight Director

One advance in flight instrumentation is the flight director. This instrument functions like an attitude indicator with the addition of the steering bars. The triangular delta or wings symbol represents the airplane, and the steering bars are controlled by the autopilot command and error-sensing systems.

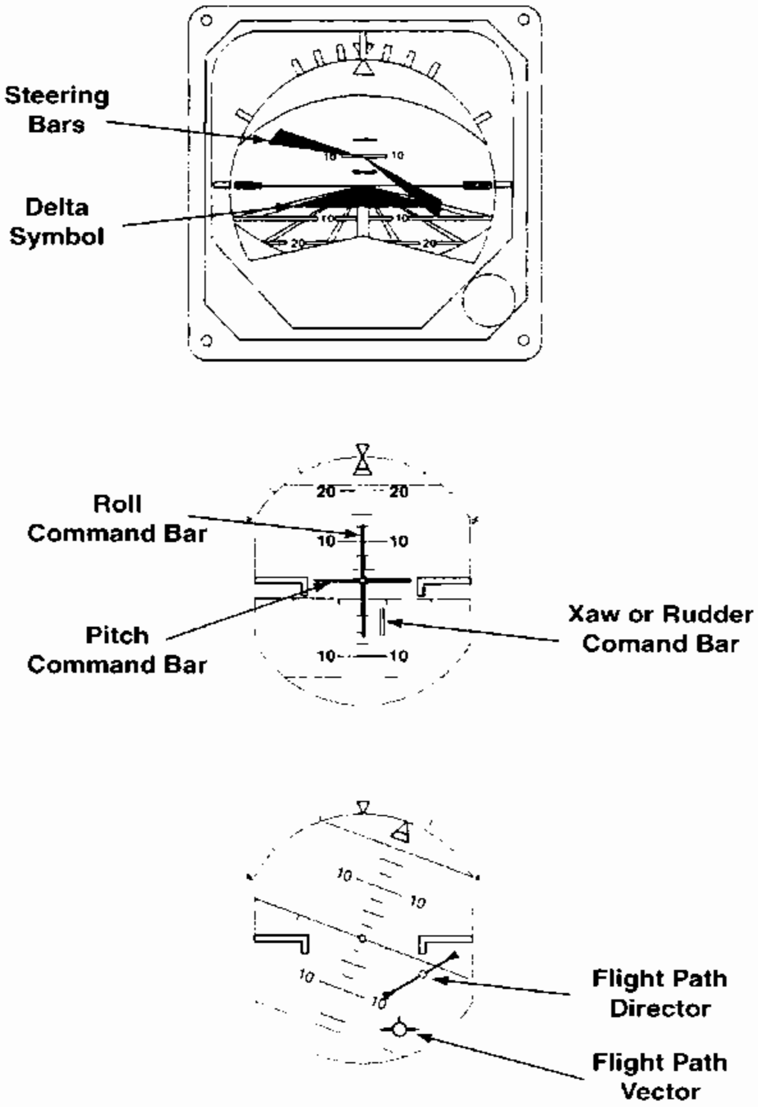
Rather than sending the signals to the appropriate servos to actually control the aircraft, the signals are sent to the steering bars that tell the pilot what to do. For example, the flight director is telling the pilot to pitch the nose up and turn to the right. The flight director shows the pilot the changes to make in pitch and roll in the same way the horizontal situation indicator (HSI) shows the pilot the proper changes to make in directional flight.

Figure 412: Principle



For landing approach or takeoff climb also a Flight Path Director can be used. The director shows the commanded flight path angle and track. The vector shows the actual flight path angle and track.

Figure 413: Various Displays



Closed Loop

Earlier system was a separate system consisting of:

- Flight Director Roll Computer
- Flight Director Pitch Computer
- Flight Director Mode Selector
- Flight Director Mode Annunciator
- Flight Director Indicator with Roll and Pitch Command Bars

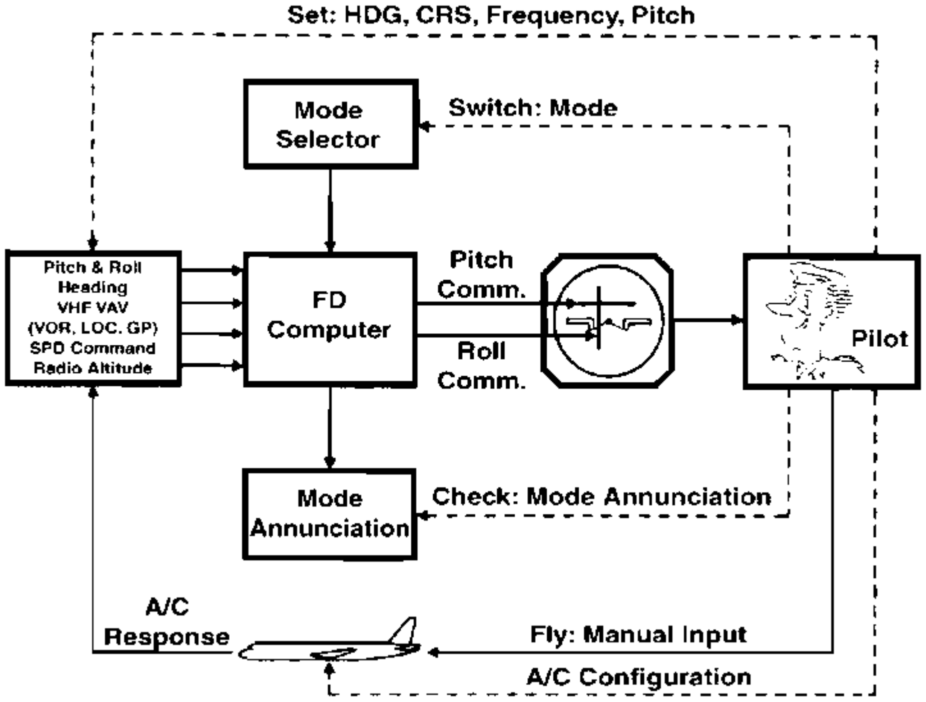
Today the Flight Director Commands are calculated in the Autoflight Computers with the same fundamental laws of the Autopilot. The FD - command display (Flight Director Horizon or Primary Flight Display) gives steering orders to the pilot.

The difference between an autopilot and flight director is:

- The flight director provides steering commands to the human pilot. He or she must follow the steering commands. The command bars must be always centred to satisfy the steering orders. In this way the FD represents with the pilot a closed control loop. The pilot acts like a servo.
- The autopilot provides the steering orders directly to the associated flight controls by electric or hydraulic servos. The pilot is primarily not involved to steer the airplane. Monitoring, mode selection, communication and intervention at abnormalities is its duty.

Both systems using same input signals and operational modes.

Figure 414: FD operational Loop



Principle of FD Indication

Heading select manoeuvre with flight director

Example

1 Aircraft flies heading 090° Preselected heading is 150°

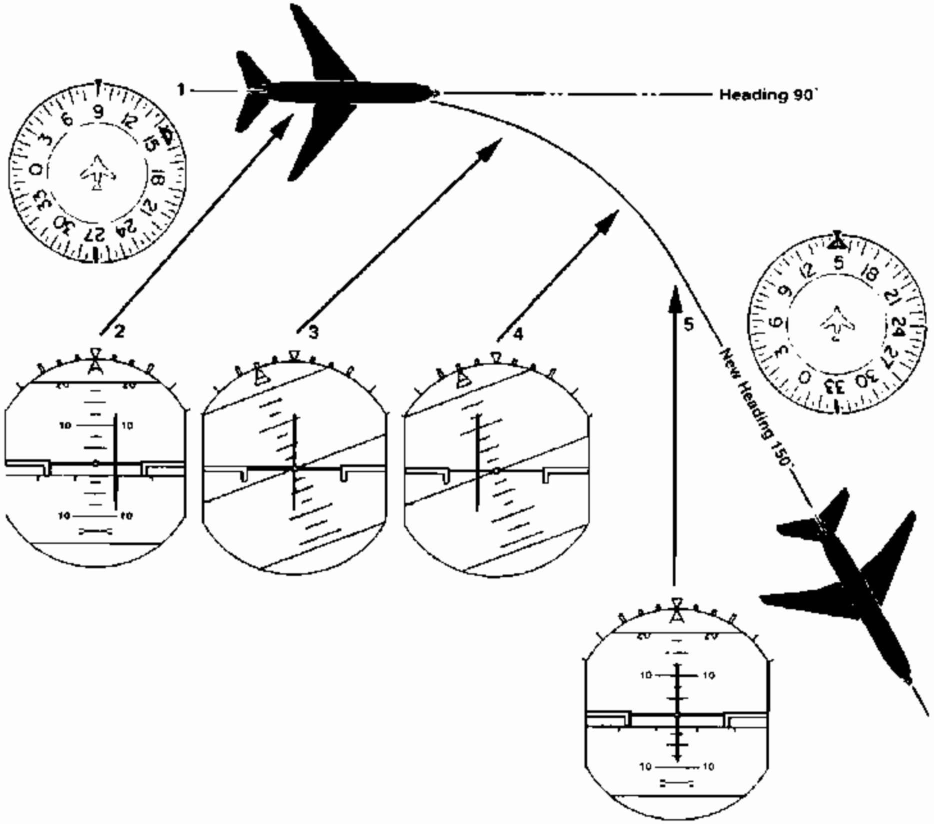
2. Roll command bar orders right bank.

3. Aircraft has correct right bank. FD-bar is centred.

4. Aircraft is reaching the selected heading.
Roll-bar orders left control-wheel deflection for establishing wings level to terminate the manoeuvre.

5. Aircraft heading is 150° FD-bars are centred.

Figure 415: Heading Change Maneuvre with FD



ILS approach with Flight Director

Example:

1. The aircraft is left of runway centerline and below glide path.
   Glide path and Localizer deviation are not zero
   Glide path and Localizer pointers are not centred.

   Roll command bar orders right turn
   Pitch command bar order is fly up

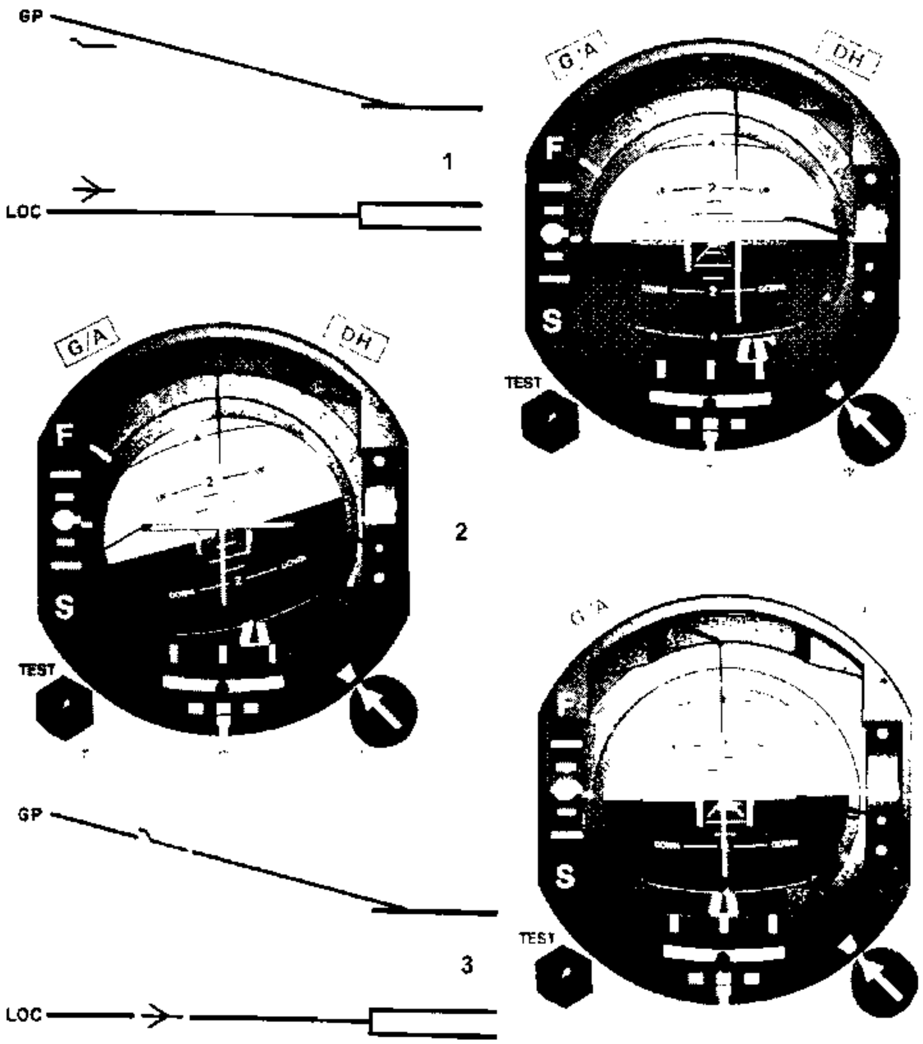
2. The pilot has initiated the correct manoeuvres
   The aircraft is still not on the ILS track, so the
   Glidepath and Localizer deviation are not zero
   Glidepath and Localizer pointers are not centred.

   Both FD-bars are centred

3. The aircraft is centred on localizer and glide path.
   Glide path and Localizer deviation is zero
   Localizer and glidepath pointers are centered

   FD bars are centered

Figure 416: ILS Approach Command and Deviation



13.5 Electrical Power (ATA 24)

DC Generators

There are two types of electricity: static and current. Static electricity produces electrical fields caused by an accumulation of electrons that are not moving. Current electricity, a more useful type, is caused by the movement of electrons. In DC (direct current) electricity, the electrons move through the circuit in one direction. In AC (alternating current), the electrons periodically reverse their direction of flow. There are five ways current electricity can be generated: The conversion of chemical energy, heat, light, pressure and magnetism.

All electrical energy used in an aircraft comes from two sources: the conversion of chemical energy and magnetism. Storage batteries convert chemical energy into electricity for starting the engine and for use in emergencies, but the electricity for normal operation is produced by magnetism in a generator or alternator.

Generator Principles

AC Generator Principles

AC is easier to produce than DC. A loop of wire rotates in the magnetic field, which is caused by lines of magnetic flux between the two pole pieces. The two ends of the loop terminate in slip rings connected to the external circuit through carbon brushes.

DC Generators and Alternators

All electricity produced by magnetic generators is AC, the output is rectified, or changed into DC. There are two types of rectifiers: mechanical and semiconductor. The pole pieces and rotating coil are similar to those in the description of the AC generator, but the ends of the coil are terminated in the two segments of a split-ring commutator. Carbon brushes ride on the commutator to connect the coil to the external circuit.

The output waveform is low frequency pulsating DC. By adding a second coil at right angles to the first, the frequency of the pulsations, called the ripple frequency, is doubled, and the terminal voltage is much smoother than that produced by a single coil. By adding even more coils, the ripple frequency is further increased and the output voltage becomes smoother

Figure 1: Rotating coil in a magnetic field

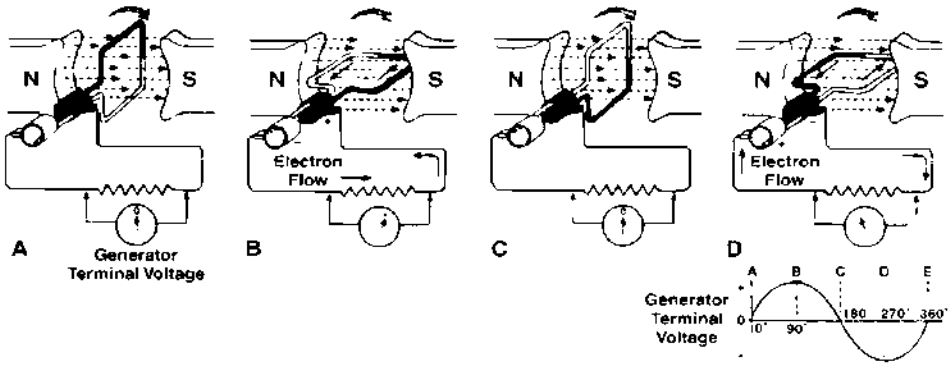


Figure 2: Rectifying the current by commutator

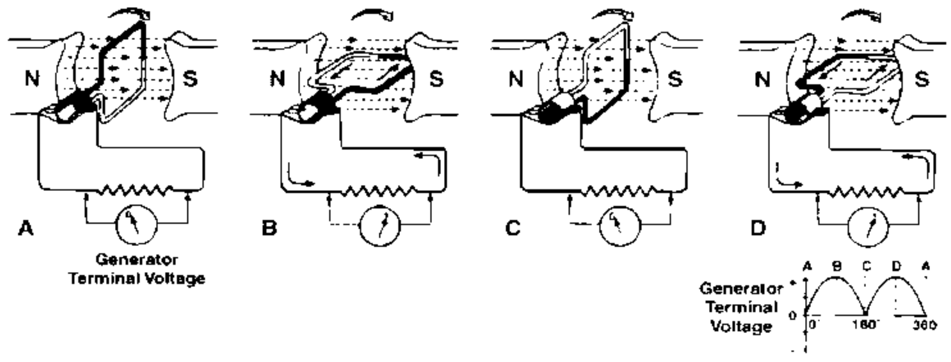
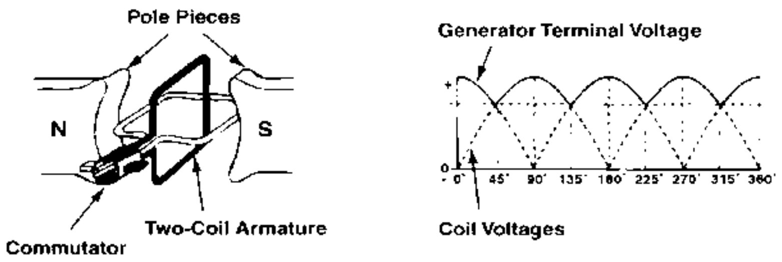


Figure 3: Smoothening output ripple by aditional rotor coils



DC Generators and Alternators

DC Generator

Field Magnets

In practical generators, the magnetic field is produced by electromagnets. The frame of a typical aircraft DC generator has four electromagnetic poles. The strength of the magnetic field, and thus the voltage produced by the generator, are determined by the voltage regulator which controls the amount of current flowing in the field coils.

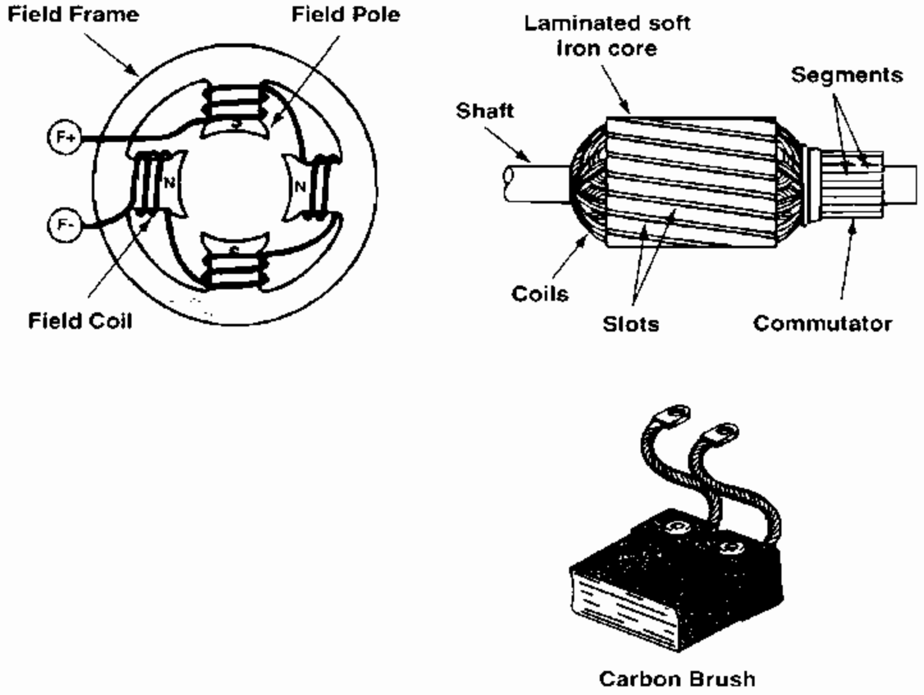
Armature

Practical generators have a number of coils wound in slots around a drum-like core of laminated soft iron on the armature shaft. The ends of the coils are soldered into copper commutator segments, which are insulated from each other and from the armature shaft.

Carbon Brushes

A pair of carbon brushes picks off the output current from the rotating armature.

Figure 4: Stator, Rotor and Carbon Brush



Generator Circuit

Generator output current is produced in the rotating armature. Most light aircraft use a basic electrical system that has been adapted from automobile systems. The generators and regulators are similar in appearance to those used in automobiles, but there are internal differences, differences in materials, and especially differences in the inspections used to certificate the components for use in aircraft. It is not permissible to use an automobile component in a certificated aircraft even though the parts do look alike.

Generator fields are self-excited. This means that the field current comes from the armature. As the voltage produced in the armature rises, the field current rises and causes the armature voltage, and consequently the load current, to increase even more. All generators must use some type of current limiter as well as a voltage-regulator.

The A-circuit's field coils are connected to the insulated brush inside the generator, the voltage regulator acts as a variable resistor between the generator field and ground.

The B-circuit's field coils are connected to the grounded brush, the voltage regulator acts as a variable resistor between the generator field and the armature.

Figure 5: Generator Excitation Field A-Circuit

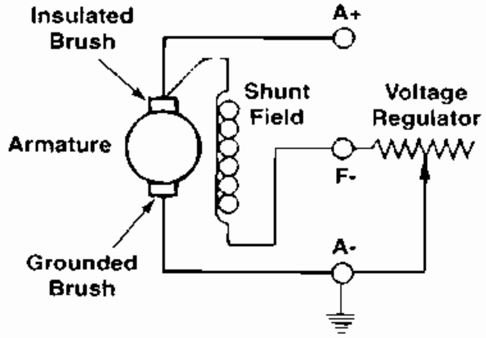
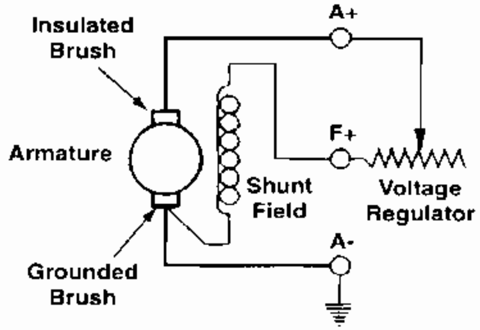


Figure 6: Generator Excitation Field B-Circuit



Electromagnetic Voltage Regulator

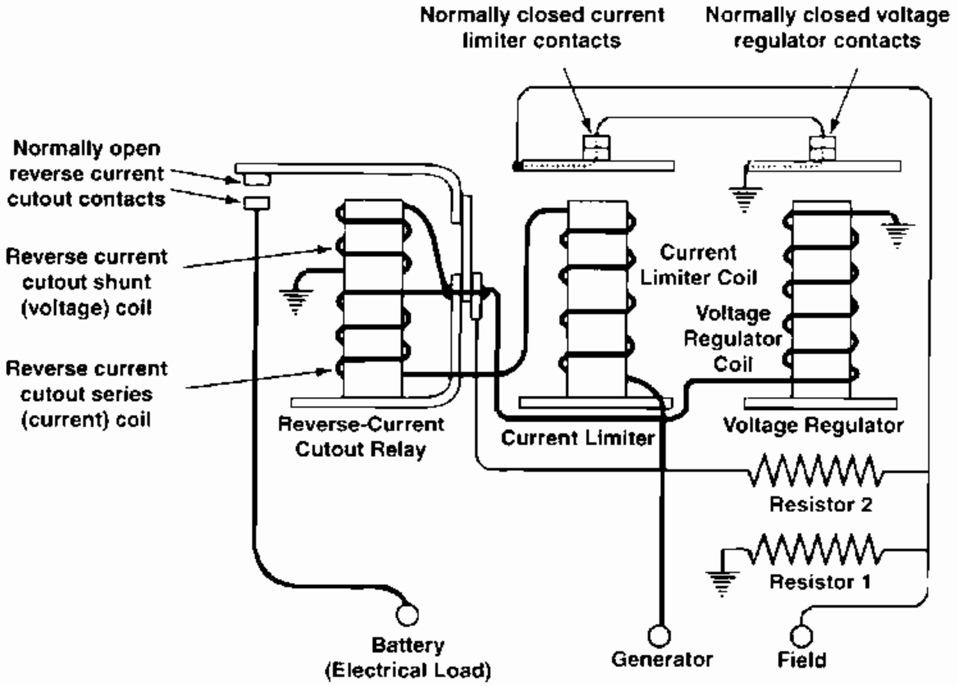
The generator control contains three units: a voltage-regulator, a current-limiter, and a reverse-current cutout relay.

The voltage regulator senses the generator output voltage, and its normally closed contacts vibrate open and closed many times a second, limiting the amount of current that can flow through the field.

The current limiter is actuated by a coil in series with the armature output. When the generator puts out more than its rated current, the current limiter's normally closed contacts open and put a resistance in the field circuit to lower the generator output voltage to a level that will not produce excessive current.

The reverse-current cutout disconnect the generator from the aircraft bus when the generator voltage drops below that of the battery, and they automatically connect the generator to the bus when the generator voltage rises above that of the battery.

Figure 7: Electromagnetic Generator Control

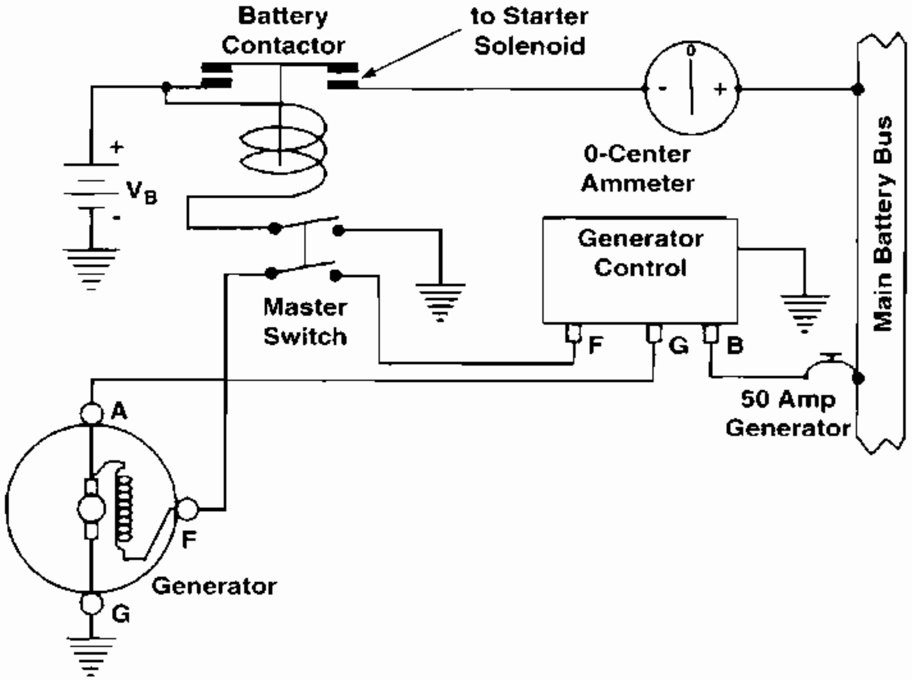


Generator System

The A-circuit type generator system is typical for most single engine light airplanes.The armature terminal of the generator connects to the G terminal of the generator control unit. The contacts of the reverse-current cutout are between the G and the B terminals. When the generator output reaches a specified voltage, the reverse-current cutout contacts close and connect the generator to the main bus.

Field current produced in the generator flows from the field terminal of the generator, through the generator side of the master switch, into the F terminal of the control unit, and through the voltage regulator and current-limiter contacts to ground. If either the voltage or the current are too high, one set of normally closed contacts opens and this field current must flow through the resistor to ground. The zero-centre ammeter shows the amount of current flowing either from the battery to the main bus (-) or from the generator through the main bus into the battery (+) to charge it.

Figure 8: DC Generator Circuit



DC Alternators

As semiconductor diodes able to withstand the temperature and vibration were developed, the far more practical alternator replaced the generator for producing almost all automotive and aircraft electricity. DC alternators have three primary advantages over generators:

They have many more sets of field poles so they can produce current at a lower speed.

The high current is produced in the stationary component and is rectified by semiconductor diodes.

An alternator system is lighter in weight than a generator system.

The rotor is made of two end pieces of iron that form the magnetic poles. Some rotors have four pairs of poles and others have as many as seven pairs. The voltage regulator supplies current through brushes and slip rings to a coil of insulated copper wire between the two end pieces to control the strength of the magnets.

The stator windings in which the output current is produced consist of a series of coils wound in slots in a laminated soft iron frame. The coils are arranged in a three-phase Y-connected circuit. The AC output of the stator is converted into DC by a six-diode, three-phase rectifier.

Current flowing from the main bus through the voltage regulator magnetizes the rotor. As the rotor turns, the multiple pairs of poles induce a voltage in the three phases of the stator winding. The three-phase AC converted into DC by the 6 diodes and sent to the main bus through a high-current circuit breaker

Figure 9: Rotor and Stator

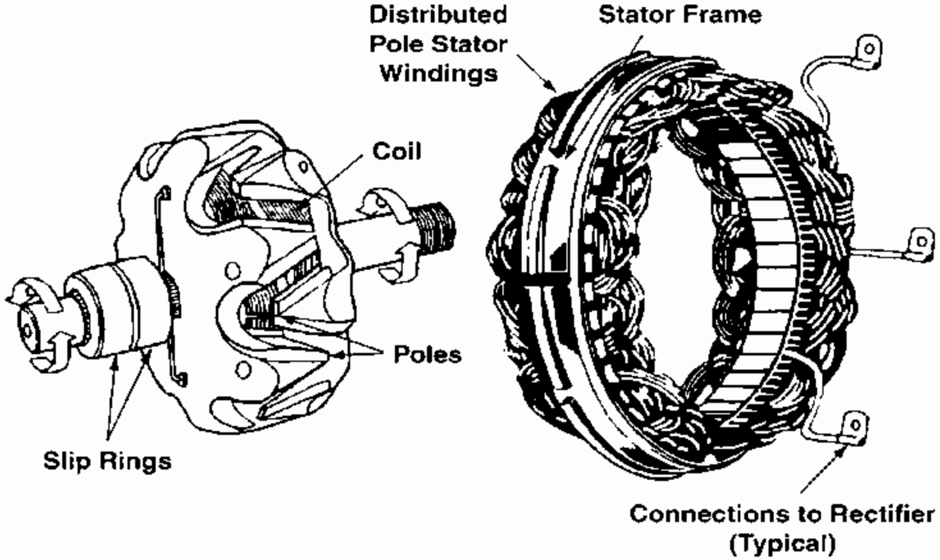
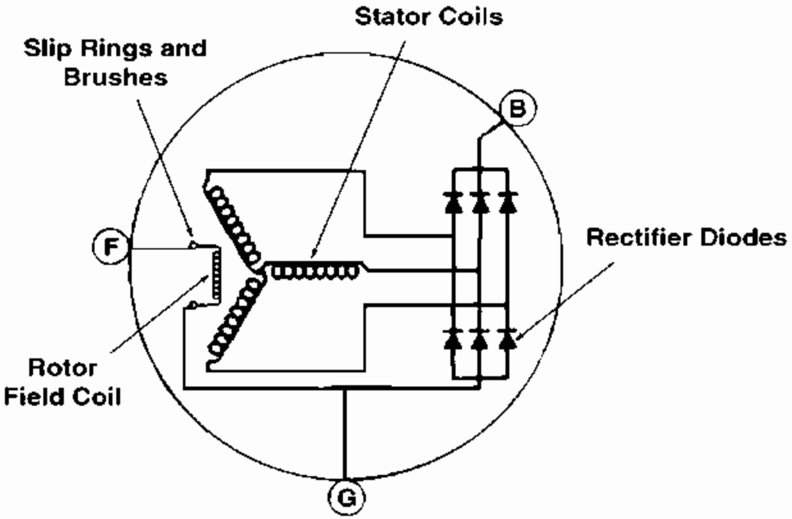


Figure 10: DC - Alternator Schematic



Solid-State voltage Regulator

Most of the modern systems use a solid-state voltage regulator.
When the alternator switch is turned on, the field relay closes and current flows through transistor T1 and the rotor field coil.

As soon as the engine starts, the alternator begins to output voltage, and when the voltage rises to the regulating value, the zener diode ZD, begins to conduct. Then, through the action of transistor T2, T1 shuts off the field current and the output voltage drops. As soon as the voltage across ZD drops below its zener voltage and stops conducting, T1 turns back on, allowing field current to flow again.

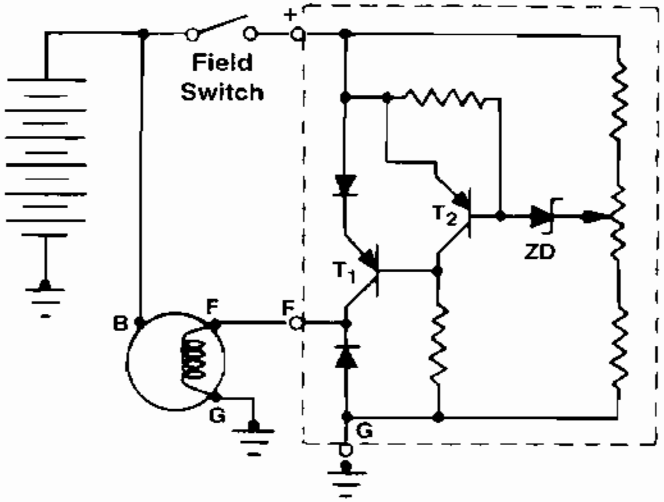
This solid-state device provides smooth and consistent control of the system voltage with no moving parts.

The solid-state rectifier used in the alternator prevents the flow of any current from the load bus back to the alternator stator winding, so there is no need for reverse-current relay with an alternator.

The field current is taken from the regulated bus voltage rather than directly from the alternator output, and this makes the alternator self-limiting with regard to current output, so there is no need for a current limiter.

There is a need, however, for a relay or switch in the alternator field to prevent current flowing through the field winding when the engine is not running. This field relay or switching transistor is typically contained in the voltage regulator or alternator control unit.

Figure 11: Voltage Regulator solid state



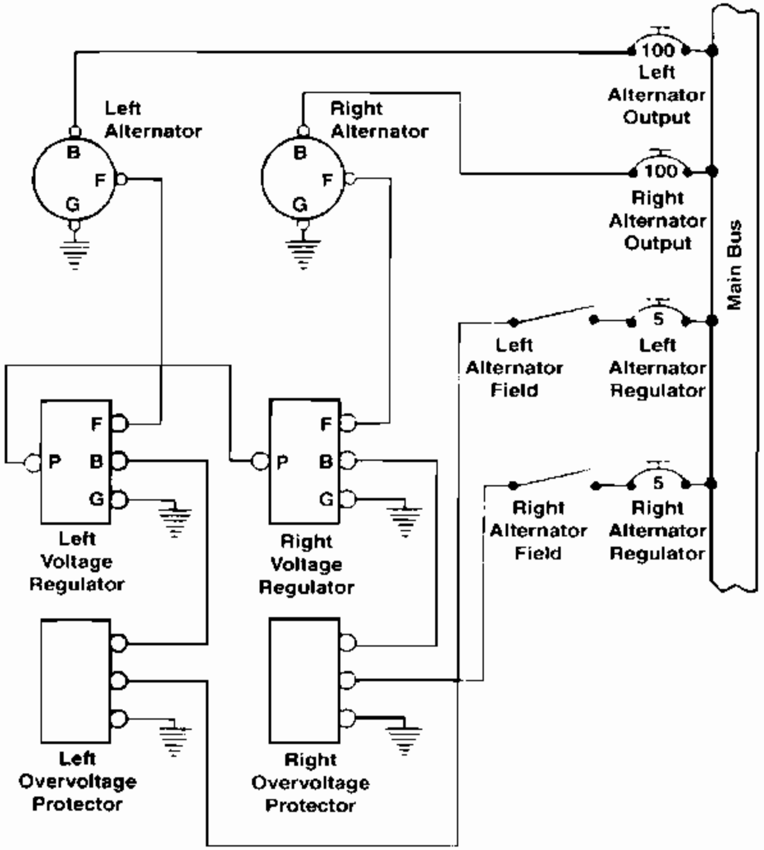
Twin Engine Aircraft DC Alternator System

The output of each alternator goes to the main bus through a 100 A circuit breaker. Field current is supplied to each alternator through a 5 A circuit breaker, alternator field switch, solid-state over voltage protector, and solid-state voltage regulator.

Both regulators are connected through their P, or paralleling terminals. So circuits inside the regulators compare the field voltages. If one alternator produces more current than the other, its field voltage is higher. This difference is electronically sensed, and the voltage regulator decreases the field current flowing to the high-output alternator and increases the field current to the other. This adjusts the output voltages so the alternators share the load equally.

The over voltage protector senses the output-voltage of the alternator. If this gets too high, the over voltage protector opens the field circuit, stopping further output from the alternator. In some installations, a red light on the instrument panel illuminates to show the pilot that the alternator has stopped producing current.

Figure 12: .



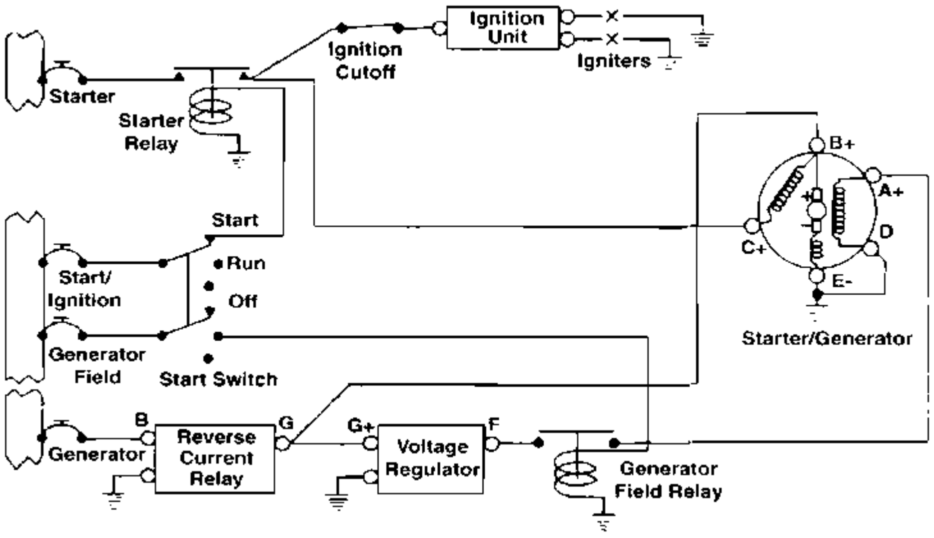
Turbine-Engine Starter-Generator System

Smaller turbine engines installed in business jet airplanes have a combination starter-generator rather than a separate starter and generator. They have an extra set of series windings. The series motor windings are switched into the circuit when the engine is started, but as soon as it is running, they are switched out.

When the start switch is placed in the START position, the starter relay closes and allows current to flow to the starter-generator through its C+ terminal, the series motor windings, the armature, and the starter-generator series windings, to ground. At the same time, current flows through the ignition-cutoff switch into the igniter unit to ignite the fuel.

When ignition is achieved, the start switch is moved to RUN position. The generator field relay, closes the field relay to connect the generator field to the voltage regulator. When generator field current flows, the generator produces current. As soon as the voltage builds up to the specified value, the contacts inside the reverse-current cutout relay close and the current produced in the generator flows from the B+ terminal through the reverse-current relay to the bus. When the start switch is placed in the OFF position, the generator-field relay opens, disconnecting the generator field from the voltage regulator, and the generator stops producing load current.

Figure 13: ..Starter - Generator



AC Generation

Alternator

A typical AC alternator for a jet aircraft has a rating of between 40 to 120 kVA and has a three-phase output, with the phases normally connected in a Y-arrangement producing a 400 Hz current. There are two basic types of alternators in use, brushless and the brushtype. Today's aircraft typically use the brushless alternator system employing an integrated oil cooler to help eliminate the heat generated during operation.

A brushless alternator consists of three separate fields, a permanent magnetic field, an exciter field, and a main output field. The permanent magnets furnish the magnetic flux to start the generator producing an output before field current flows. The magnetism produced by these magnets induces voltage into an armature that carries the current to a generator control unit, or GCU. Here, the AC is rectified and sent to the exciter field winding. The exciter field then induces voltage into the exciter output winding. The output from the exciter is rectified by six diodes, and the resulting DC flows through the output field winding. From here, voltage is induced into the main output coils. The permanent magnet, exciter output winding, six diodes, and output field winding are all mounted on the generator shaft and rotate as a unit. The three-phase output stator windings are wound in slots the alternator housing.

The three-phase output of AC alternators typically have a voltage of 120 volts across each of the phase windings, and with the windings connected in a Y, the output between each of the terminals is 208 volts. The common end of the 3 windings is connected to the aircraft's structure. The neutral current flows via structure.

AC Voltage Regulator

The complex nature of AC power systems in an aircraft requires more considerations for voltage regulation than are required for DC systems. The voltage control circuit must sense the voltage output of all three phases in the alternator, and if they are not equal and within limits, adjust them accordingly. There must be provisions in the regulator to reduce the alternator voltage if the frequency drops below a specified level, and the control system must have provisions for equalizing both the real and the reactive loads among the generators. Many aircraft use a Generator Control Unit (GCU) to perform these functions as well as performing system testing and fault isolation.

Figure 14: Brushless Generator

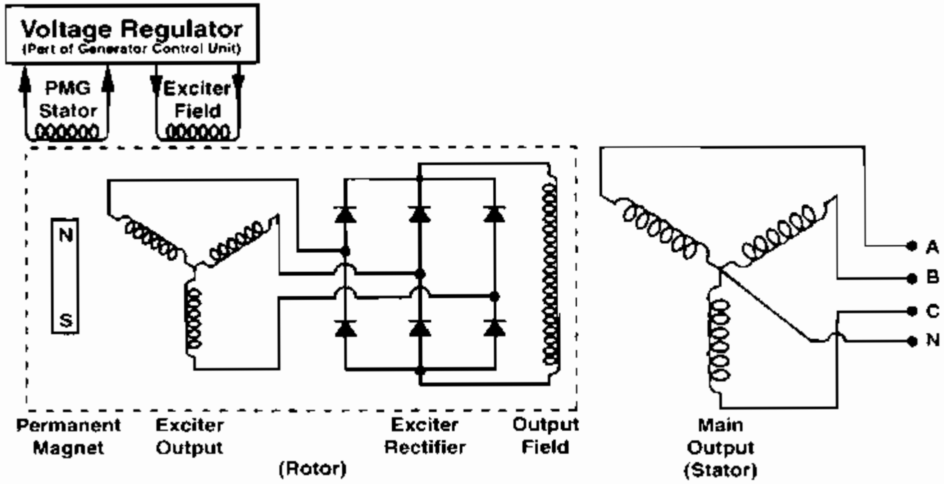
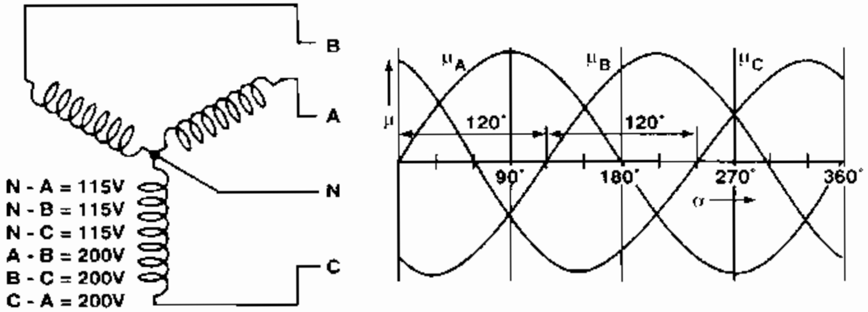


Figure 15: 3 Phase Alternating Current Voltages

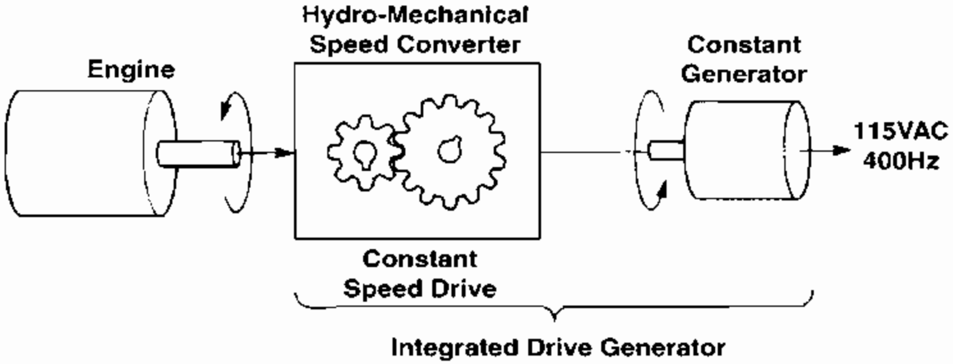


Constant Speed Drive (CSD)

It is essential that the alternator output have a nominal frequency of 400 hertz with a tolerance usually from 380 to 420 hertz. This is accomplished throughout the engine operating speed range by using a hydraulically operated constant-speed drive unit between the engine and the alternator.

A CSD consists of a variable hydraulic pump and motor, connected together so that regardless of the engine speed, the CSD output will be constant. This constant speed is required for the alternator to have an output of 400 hertz. Many modern aircraft employ an Integrated Drive Generator (IDG) which contains both the alternator and CSD in one compact unit. If there is an generator or CSD failure, the pilot may disconnect the inputshaft from the drive to prevent any damage.

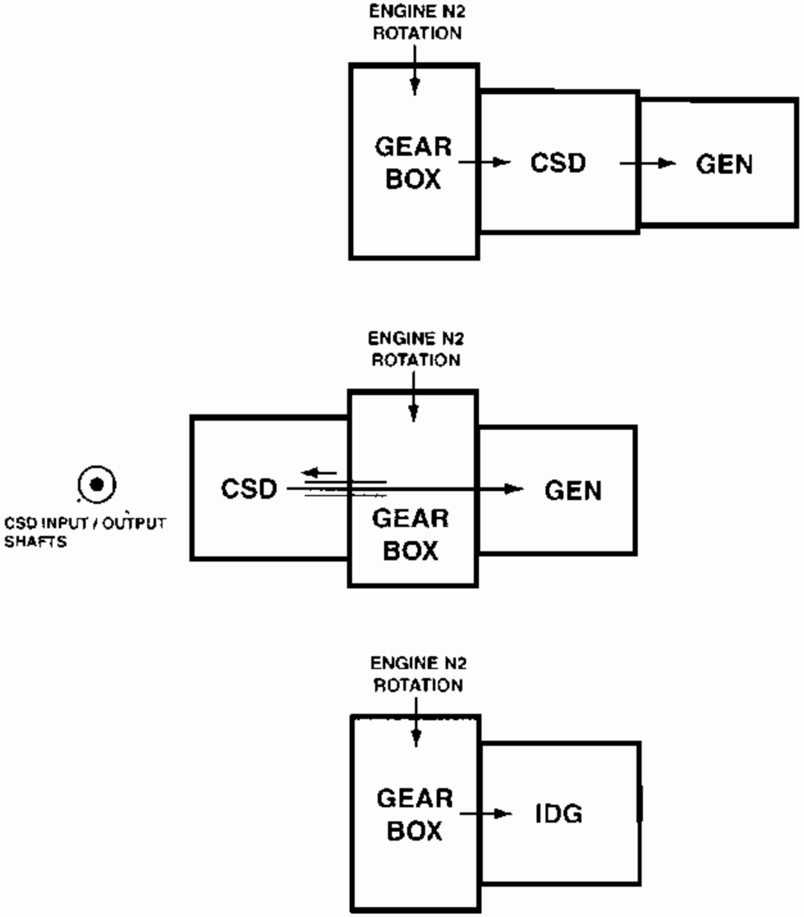
Figure 16: CSD controlling the Generator Speed



CSD and Generator Configuration

- First, the CSD ist located between the engine driven gearbox and the generator. The generator has to be removed for replacing the CSD.
- Second, The CSD is located on opposite side of the gearbox. CSD input/output occurs via coaxial arrangement shafts. Each components can be replaced separatly.
- Last, the IDG (Integrated Drive Generator) is reduced to a single component.

Figure 17: Evolution of Generator Drive



CSD Principle

The constant speed drive converts variable engine input speed to a constant output speed which enables the generator to produce electrical power at a constant frequency of 400 hertz.

The constant speed drive adds to or subtracts from the variable engine input speed through controlled differential action to produce a constant output speed.

Governoring System

The governor assembly senses the output speed and regulates the supply pressure to achieve the required control pressure at the control cylinder of the variable pump. Maintaining the correct pressure level in the control cylinder provides a constant output speed.

Normal Governing

The flyweights are connected to the rotating shaft. As output speed changes, a change in centrifugal force causes the flyweights to pivot on their axies. The flyweight toes act against a bearing on the governor stem which compresses the spring and moves the stem.

When the proper output speed is achieved, a balance exists between the spring and fly-weight force. This balance positions the stem to meter the supply pressure to achieve the required control pressure.

Figure 18: CSD Principle

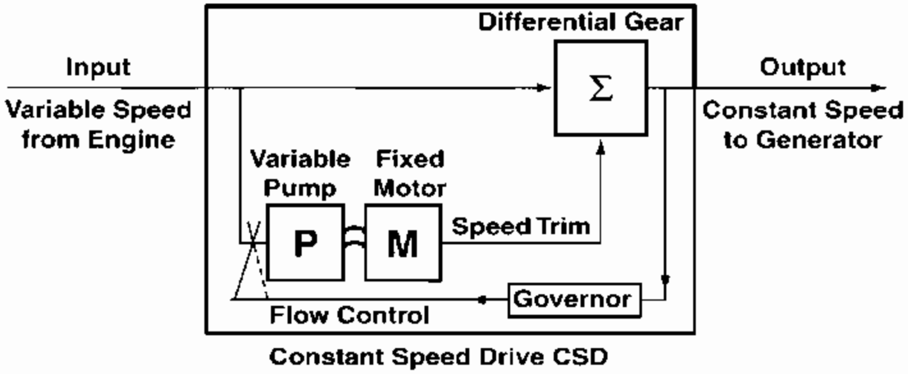
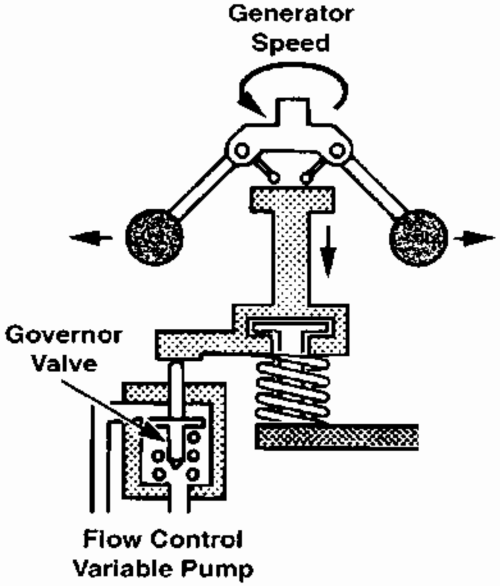


Figure 19: Governor Principle



Integrated Drive Generator

The IDG converts the varying engine accessory gearbox speeds of 4,500 to 9,120 revolutions per minute to a constant generator speed of 12,000 ± 120 revolutions per minute. The generator operates at a constant output frequency of 400 ± 4 hertz.

Variable speed shaft power is provided to the IDG input shaft, which is directly coupled to the carrier shaft of the differential. The variable displacement hydraulic unit is driven by the carrier shaft at a direct ratio of the input speed. The variable displacement hydraulic unit is hydraulically coupled to a fixed hydraulic unit which is mechanically connected to the input ring gear of the differential. The speed and direction of the input ring gear is controlled by an output speed sensing governor which controls the displacement of the variable hydraulic unit.

Speed summing is accomplished in the differential by adding or subtracting trim speed. Planet gears are used to transmit this speed to the output ring gear which rotates at a constant speed as a result of the speed summing. The output ring gear is engaged with the generator drive gear so the generator also rotates at a constant speed.

Generator Control

The generator is controlled by the corresponding generator pushbutton. When pressed in, if the generator speed is high enough, the generator is energized. If the delivered parameters are correct, the Generator Line Contactor (GLC) closes to supply its network.

The Generator Fault light comes on when any generator parameter is not correct or when the Generator Line Contactor is open.

IDG Disconnection

In case of oil overheat or drop of oil pressure, the amber IDG FAULT light comes on and the ECAM system is triggered. To disconnect the IDG from the accessory gearbox, the IDG pushbutton must be pressed.

IDG Reconnection

In flight, IDG disconnection is irreversible. The system can only be reconnected on the ground with engines shut down to avoid damage to the drive shaft clutch device. A mechanical reset handle (ring) fitted to the IDG enables the drive to be reconnected while the engine is stationary on the ground.

NOTE: Do not reconnect the IDG when the engine is in windmilling as it will damage the IDG disconnection mechanism.

Figure 20: IDG Blockdiagram

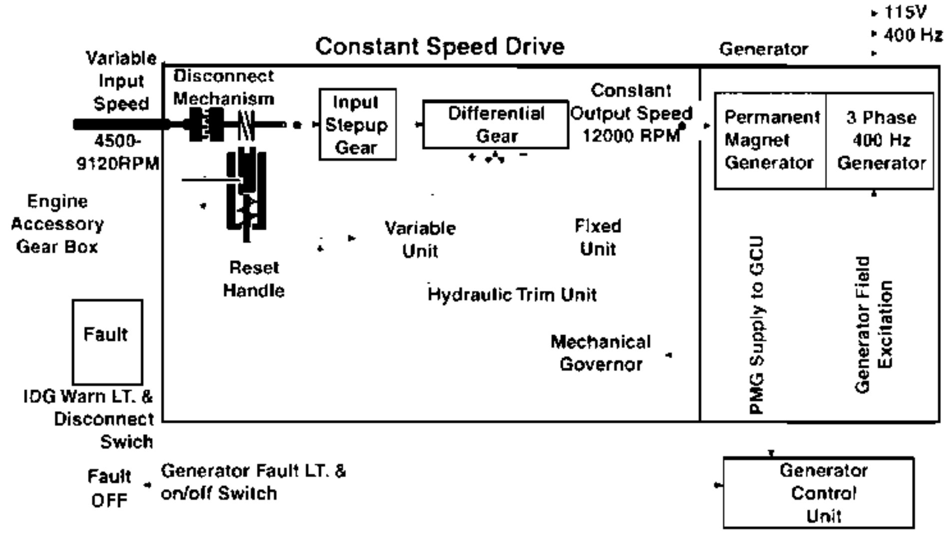
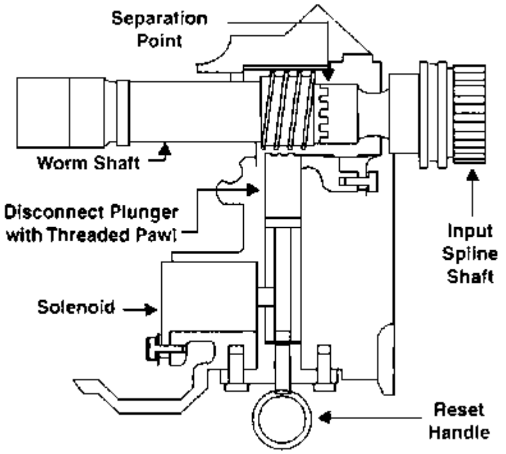


Figure 21: Disconnect Mechanism



IDG Hydraulic System

General

The constant speed drive hydraulic system consists of two pump and motor assemblies, a mechanical governor, a scavenge pump, a charge and scavenge pump, a vacuum break valve, a scavenge relief valve and a filter, pressure differential indicator, an external circuit bypass valve, a charge relief valve, a charge pressure switch, a scavenge pressure switch, and a rotating deaerator

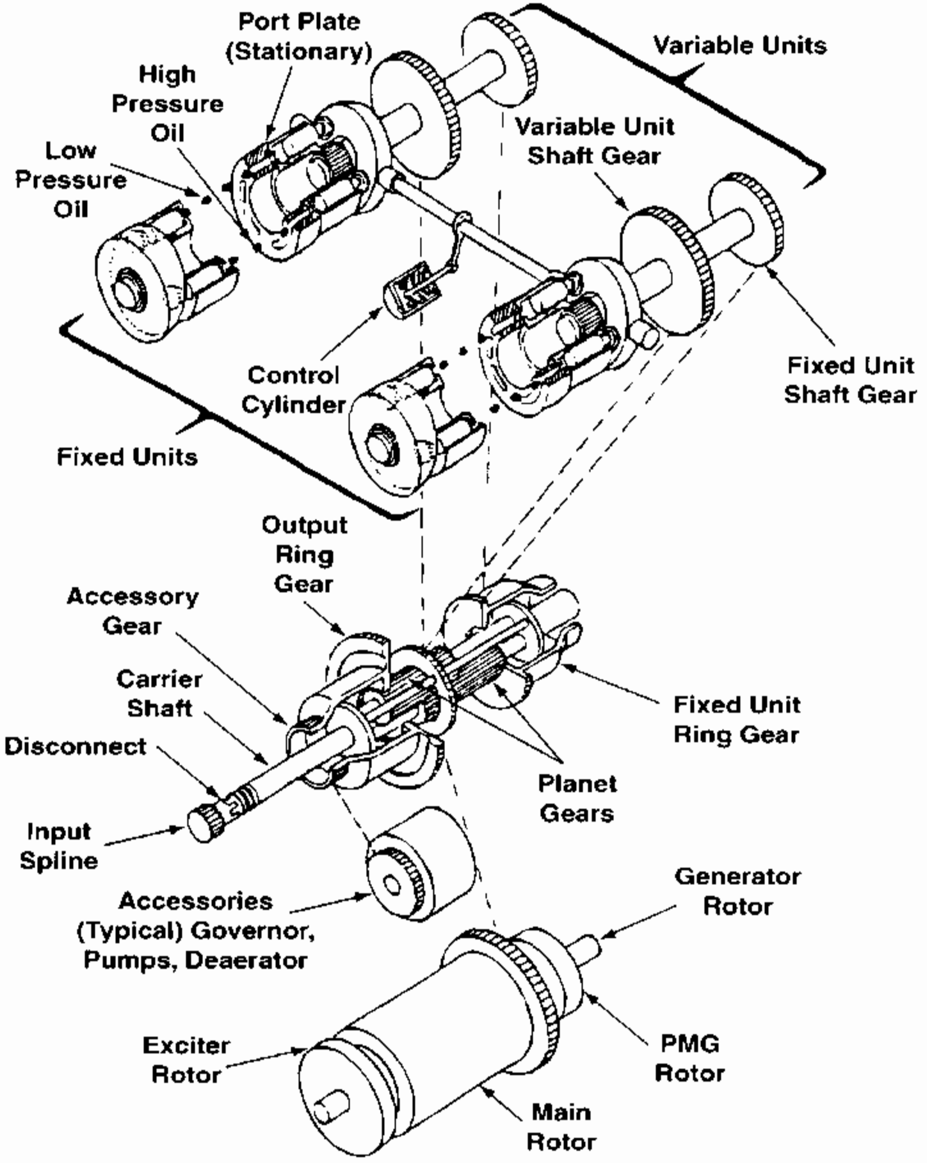
Governor and Support

The governor is a spring-loaded, flyweight-operated, hydraulic control valve whose driving gear is in mesh with the differential output ring gear through the scavenge pump gear. The governor senses CSD output speed and controls the oil pressure to the control cylinder, maintaining a constant output speed of 12,000 revolutions per minute.

Pump and Motor Assemblies

The left-hand and right-hand pump and motor assemblies both consist of a fixed unit and a variable unit. The fixed unit includes a fixed wobbler plate and a steel cylinder block with nine piston-slipper assemblies. The variable unit consists of a variable wobbler and a cylinder block containing piston-slipper assemblies. Each pump and motor assembly also contains a port plate.

Figure 22: Hydromechanical Gear Train



IDG Example (A320)

Table 1: IDG Characteristics

Voltage	115/200 VAC
Power	90 kVA
Frequency	400 Hz +/- 5 Hz
Input Speed	4'500 - 9'120 RPM
Generator Speed	12'000 RPM
Oil Temperature	< 127°C
Oil Pressure	220 - 280 PSI
Weight	56 kg

Figure 23: Integrated Drive Generator

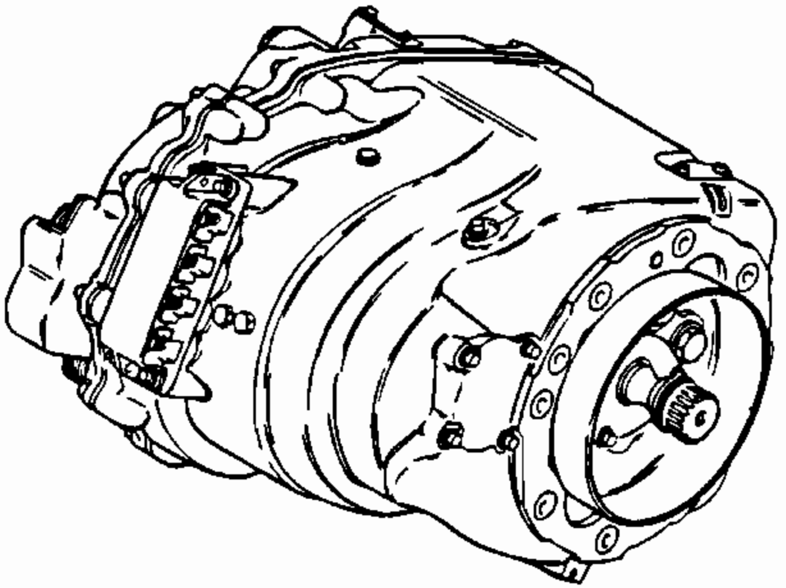


Figure 24: Constant Speed Drive mayor Subassemblies

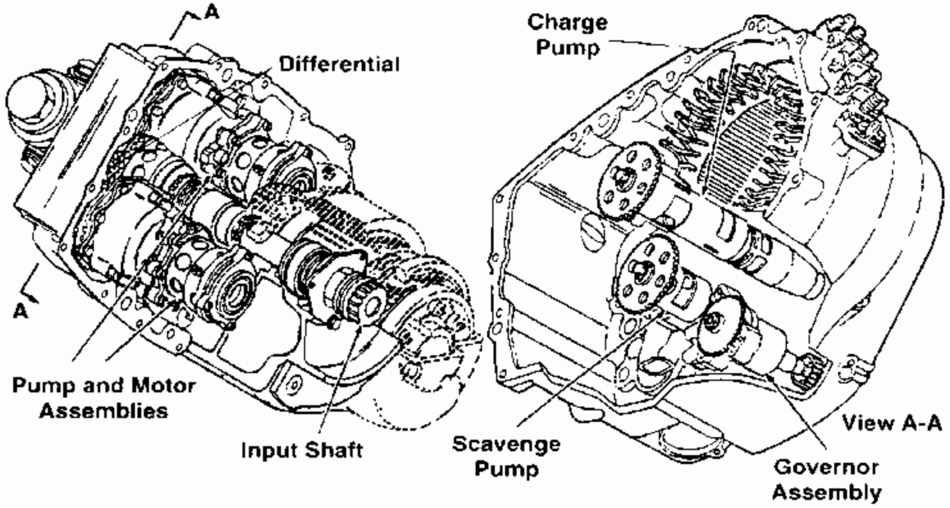
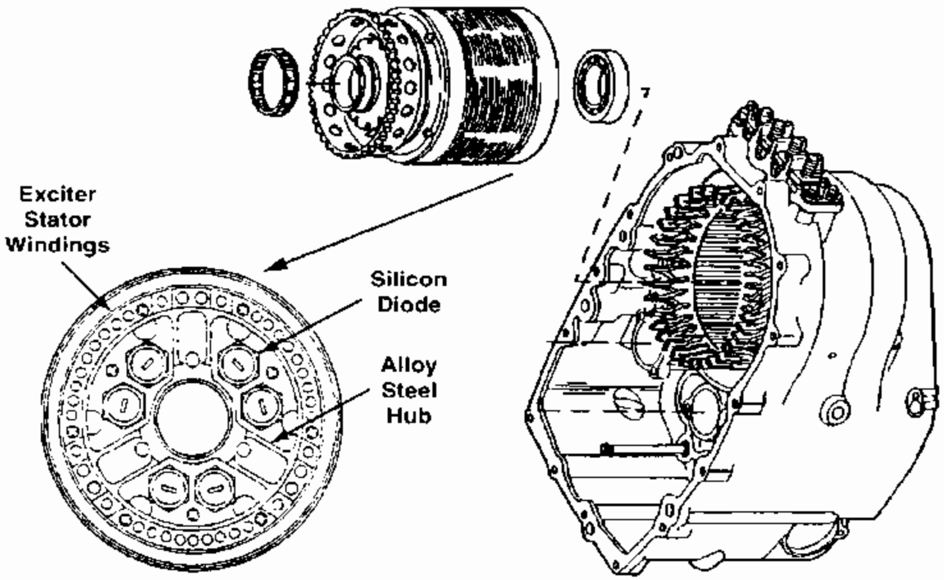


Figure 25: Rotor, rotating Diodes and Stator Subassemblies



Brushless Generator

The generator is a conventional 3 co- axial component brushless generator which consists of:

- a Permanent Magnet Generator (PMG),
- a rotating diode pilot exciter,
- the generator itself.

The generator is driven at a constant speed and is cooled by air or oil spraying.

Rotation of the permanent magnet generator rotor induces an alternating current (ac) voltage in the 3-phase windings of the permanent magnet generator stator. This ac voltage is supplied through a connector on the IDG housing and aircraft wiring to the GCU where it is rectified into direct current (dc) voltage. This rectified dc voltage is used by the GCU voltage regulator to control the dc voltage applied to the windings of the generator's exciter field and GCU power supply.

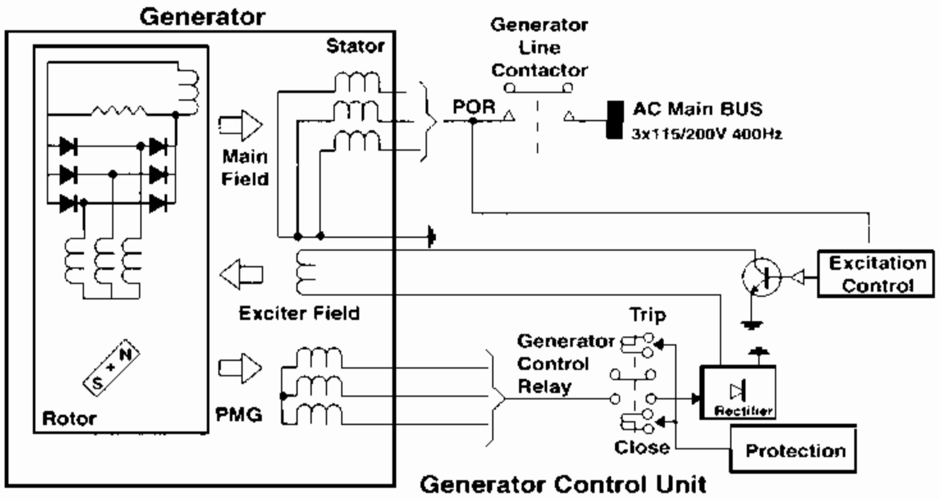
The Permanent Magnet Generator (PMG) supplies the exciter field through the Generator Control Relay (GCR) and the Generator Control Unit through a Rectifier Unit.

The stationary magnetic field produced by the direct current in the windings of the exciter field induces a 3-phase ac voltage in the rotating windings of the exciter armature (rotor). This ac voltage is converted to dc voltage by the rotating rectifier assembly on the armature. By applying this dc voltage to the main generator field, current flows in the field winding producing a magnetic field rotating with the generator shaft.

This rotating magnetic field induces an ac voltage in the windings of the main generator stator. The generator output is fed through the generator current transformers inside the IDG and through the terminal block on the IDG housing.

The excitation control and regulation module keeps the voltage at the nominal value at the Point Of Regulation (POR).

Figure 26: Generator and Excitation Control

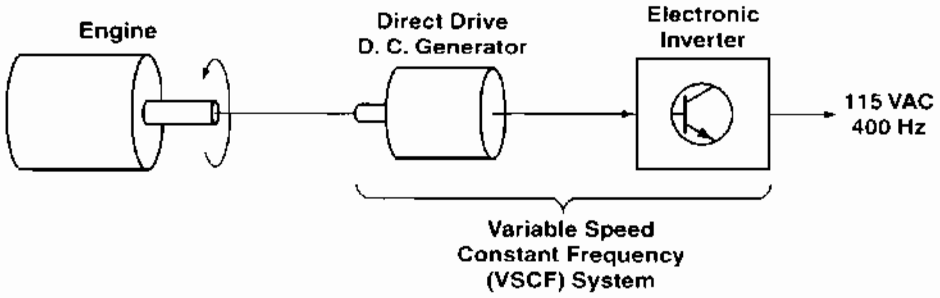


Variable Speed Constant Frequency (VSCF) Alternators

The VSCF systems are the latest attempt to eliminate moving parts from the various electrical components on the aircraft. This system utilizes a large DC alternator which is not reliant on a constant input speed. The mechanically complex constant speed drive unit is therefore not required. The DC output voltage from the alternator is sent to a solid-state device which converts the DC to an AC voltage of a constant 400 hertz.

This unit is typically referred to as an inverter. The electronic control circuitry for VSCF system is quite complex; however, the reliability of the electrical system should outperform the CSD needed for the typical AC alternator. It is very likely that future AC power systems will rely on the VSCF system due to their enhanced reliability.

Figure 27: VSCF Principle



Batteries

One of the more important devices used to produce electricity is the battery or the electro-chemical cell. When atoms of some of the chemical elements react with atoms of other elements, electrons are released from one element and are attracted to the other. The force of attraction for these electrons is an electrical pressure we call voltage.

Primary Cells

The primary cells in most common use today are carbon-zinc cells, alkaline-manganese cells, mercury cells, silver oxide cells, and lithium cells. All of these cells release electrons when one of the active elements, the anode, is oxidized.

Carbon-Zinc Cells

Carbon-zinc cells have been used for years in flashlights and as a low-cost, low-voltage source of electrical power for portable radios. All this cells have an open-circuit voltage of 1.5 volts. The amount of current a cell can produce is determined by the amount of active ingredients that make up the cell. Cells range all of the way from the small AAA cells used in some small flashlights to the No. 6 dry cell that is used to power some door bells and to provide power for some emergency lighting systems.

Alkaline-Manganese Cells

Today we use thousands of small battery-operated, motor driven devices such as clocks, tape recorders, VCR cameras and toys. These devices, as well as radios and portable audio systems, have brought about a demand for a battery that is inexpensive, yet more powerful and more durable than the carbon-zinc battery. The active elements in the cell are zinc and manganese dioxide. The open circuit voltage is also 1.5 volts. The physical construction gives the alkaline-manganese cell a much lower internal resistance and a much higher voltage during their discharge. Cells are available in the same sizes as the older carbon-zinc cells, as well as in several sizes of button cells for small devices. These cells are more expensive than the carbon-zinc cells, but since they have a longer operating life, their overall operating costs are lower.

Mercury Cells

Mercury cells have a large capacity and a long life for their small size, and they are manufactured in button, or disk, cases. These batteries are used in such devices as watches, calculators, hearing aids, and cameras. The cell open-circuit voltage is 1.4 volts. One of the most important characteristics of this type of cell is that its voltage remains almost constant until the cell is practically used up. Some mercury cells are designed for a much lower discharge rate.

Silver Oxide Cells

Mercury cells have been replaced for use in calculators and watches by silver oxide cells that cost somewhat more, but last longer. Therefore their overall cost is lower. Silver oxide cells have an open-circuit voltage of 1.55 volts and this voltage drops very little until the cell is almost completely discharged. The extremely long operating life and the wide range of temperatures in which the cell can operate has made silver oxide cells the most efficient type of power supply for hearing aids, calculators, and electronic watches.

Lithium Cells

Lithium is one of the alkaline-metal chemical elements and is the lightest metal known. Lithium cells have an open-circuit voltage of between 2.8 and 3.6 volts depending upon the type of cathode material used. Lithium cells have the longest shelf life of any primary cell, and even though there have been problems involving lithium cells installed in aircraft to power the emergency locator transmitters, these cells have the potential of becoming one of the most important types of primary cell.

Secondary Cells

The electro-chemical action in a primary cell is non-reversible, but in a secondary cell, the action is reversible. The cell is discharged by taking electrons from its negative plates. When these electrons leave, the active materials on the plates change, but they are not destroyed as they are in a primary cell. By putting electrons back into the cell in the direction opposite that which they left, the active material on the plates is changed back into its original condition and the cell is recharged. The two most commonly used secondary cells are the lead-acid cell and the sintered-plate nickel-cadmium cell.

Lead-Acid Cells

Almost all automobiles and many aircraft use lead-acid batteries to store electrical energy for starting the engines. The cells are made of positive and negative plates covered by an acid electrolyte. The electrolyte used in lead-acid batteries is a mixture of sulfuric acid and water, and it changes its chemical composition as the state of charge of the battery changes. As its composition changes, its specific gravity also changes. This allows the specific gravity of the electrolyte to serve as an indicator of the state of charge of the battery. When the cell is fully charged the specific gravity of the electrolyte is around 1.285, and when it is completely discharged, the specific gravity drops to approximately 1.150.

Aircraft Batteries Lead-Acid Batteries

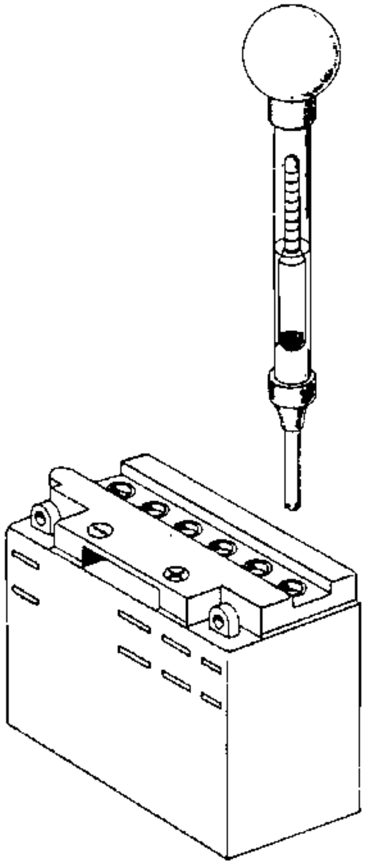
Lead-acid batteries are the most commonly used type of battery in light general aviation aircraft. They are made up of a number of cells which have an open-circuit voltage of about 2.1 volts.

Battery Charging

Batteries may be charged by the constant-current or constant-voltage method. In either method, the positive (+) lead of the charger is connected to the positive terminal of the battery and the negative (-) lead to the negative terminal.

The sulfuric acid electrolyte from a battery will burn skin, eat holes in clothes, and cause severe corrosion in aircraft structure. Spilled electrolyte must be neutralized by a solution of baking soda (sodium bicarbonate) and water, and the battery box area of an aircraft should be protected by some type of chemical-resistant paint.

Figure 28: Lead-Acid Battery with Density-Meter



Battery Installation

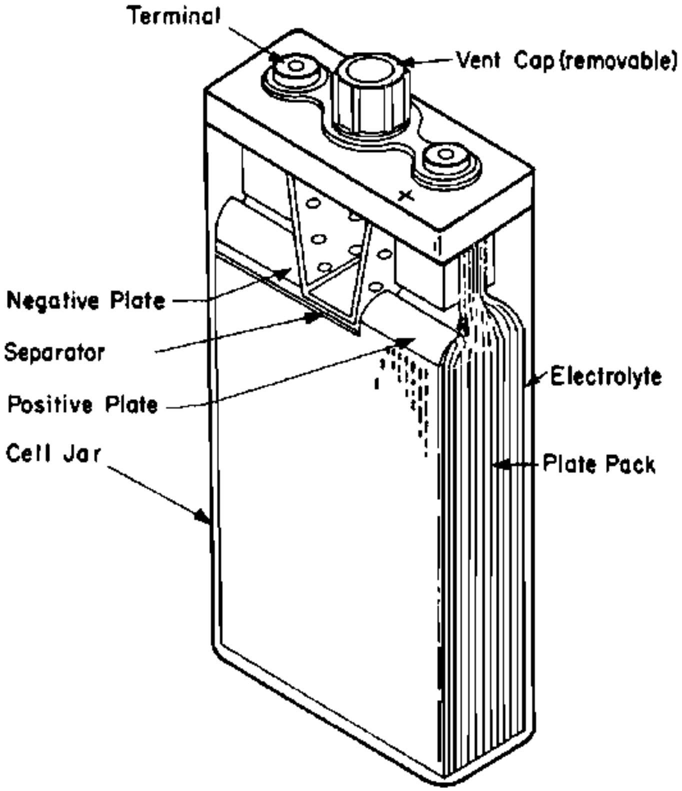
When a battery is installed in an aircraft, it should be firmly secured in a clean, corrosion-free battery compartment. Connect the positive, or "hot," lead first so there will be no sparks if your wrench should contact the aircraft structure, then connect the ground lead. Be sure that the battery box is adequately ventilated in the manner recommended by the aircraft manufacturer. If a sump jar is installed in the battery vent line, make sure its pad is saturated with a baking soda and water solution.

Nickel-Cadmium Cells

Nickel-cadmium cells have the advantage that they can furnish high rates of current flow without the voltage drop. They operate over an extremely wide range of temperatures. Nickel-cadmium cells are made in many sizes and shapes.

The active material in the positive plate of the cell is nickel hydroxide, and the active material in the negative plate is cadmium hydroxide. The positive and negative plates are separated with a thin strip of a special plastic material that allows the electrolyte to reach all parts of the plates. The electrolyte used in these batteries is a solution of potassium hydroxide and water The voltage of a nickel-cadmium cell is about 1.25 volts. The cell keeps this voltage until it is almost completely discharged.

Figure 29:



Thermal Runaway

If a nickel-cadmium cell is subjected to an excessively high charging rate, even though its internal resistance is low, it can become overheated. When this occurs, its internal resistance drops. The lower internal resistance allows the cell to take more current from the charger and more heat is generated. This condition is known as thermal runaway and it can destroy a cell. Sealed nickel-cadmium cells are vented to relieve the pressure that could build up to a dangerous level under thermal runway conditions. The problem of thermal runaway is minimized by using a constant-current charger that limits the amount of current that can be put into the cell.

Cell Memory

Nickel-cadmium cells have a characteristic that causes them to lose capacity if they are repeatedly discharged and charged to only a small percentage of their capacity. For example, if 20% of a cell's capacity is taken out of it and the cell is recharged repeatedly, the cell will lose some of its capacity and it will never accept a full charge. A cell that has had its capacity decreased by repeated shallow charges can be restored to its full capacity by completely discharging it and overcharging it to approximately 140% of its rated ampere-hour capacity. **(Deep cycling)**

Cell Voltage Changes During Discharge

The characteristic of a nickel-cadmium cell to keep its full voltage until it is almost totally discharged is both good and bad. This characteristic allows electrical loads to have the full voltage until the cell is discharged, but the cell voltage gives no indication of the amount of charge still left in it. The specific gravity does not change as the state of charge of the battery changes. When the battery discharges, the plates absorb some of the electrolyte. The level of the electrolyte in the cell is the lowest when the cell is fully discharged. The only way to know the amount of charge in a nickel-cadmium cell is to completely discharge it and then measure the amount of charge put back into it.

Aircraft Nickel Cadmium Batteries

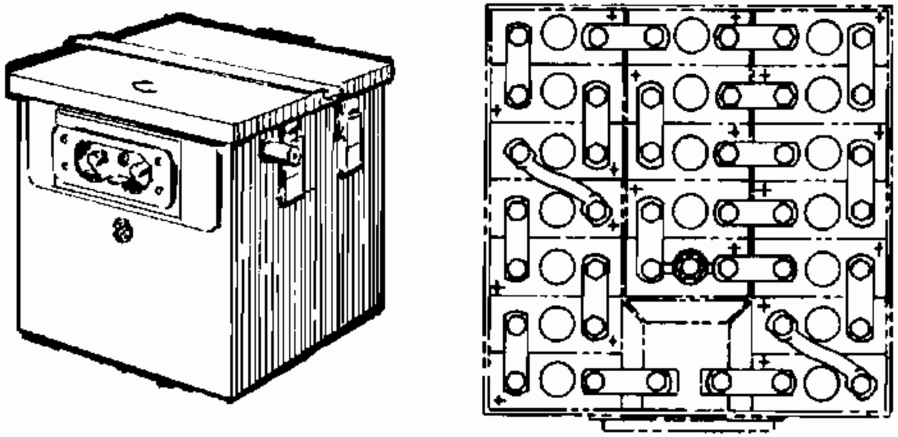
Nickel-cadmium batteries are used in many aircraft because of their ability to produce large amounts of current for starting turbine engines. They are installed and serviced in ways similar to that of lead-acid batteries, but special precautions must be observed.

Nickel-cadmium batteries must not be serviced in the same area used for servicing lead-acid batteries. They can easily contaminate each other. Tools used for servicing lead-acid batteries should not be used for servicing nickel-cadmium batteries.

Nickel-cadmium batteries are made up of individual cells connected together with cell links and installed in an insulated steel case. Corrosion or loose links can cause overheating, resulting in burn marks on the hardware.

Nickel-cadmium batteries can be charged by either a constant-voltage or a constant-current charge. In the aircraft they get a constant-voltage charge, and in the shop, they are usually given a constant-current charge.

Figure 30: NiCd Bettery

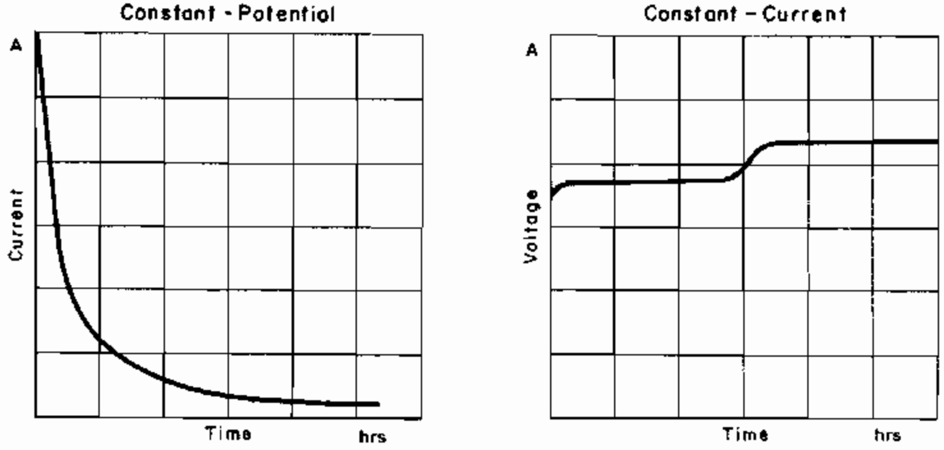


The two basic methods of charging nickel-cadmium batteries are the constant-potential and constant-current methods. Variations of the two methods are often incorporated in automatic charging equipment.

Nickel-cadmium batteries can be charged quickly by the constant-potential method, but the charging time will depend on the current delivery capability of the charging equipment.

The constant-current method is slower, but it is the preferred method of charging nickel-cadmium batteries when time permits and equipment is available. The constant-current method is much more effective in maintaining cell balance and capacity. This method permits easy computation of the charge input in ampere-hours.

Figure 31: Ni-Cd Battery Charging Method



Battery Handling and Charging

Caution: Do not add water to adjust the electrolyte level of discharged cells. Spewing will occur during subsequent charging.

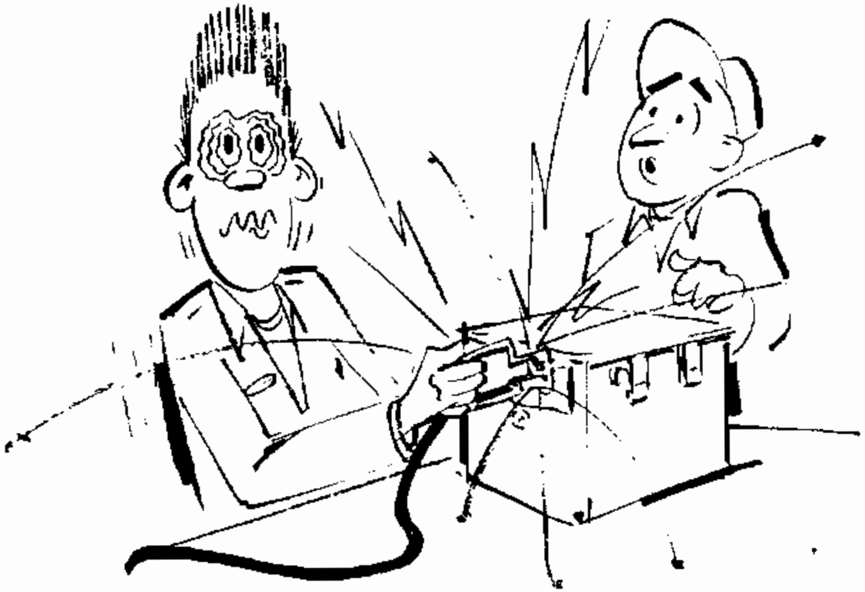
Warning: The electolyte used in nickel-cadmium batteries is a caustic solution of potassium hydroxide. Serious burns will result if it comes in contact with any part of the body. Use rubber gloves, rubber apron and protective goggles when handling this solution. If electrolyte gets on the skin, wash the affected areas with large quantities of water, neutralize with 3% acetic acid, vinegar or lemon juice. If electrolyte gets into the eyes, flush with water and get immediate medical attention.

Caution: Rings, metal watch bands and identification bracelets should be removed. Metal articles will, if allowed to contact intercell connectors of opposite polarity, fuse themselves to the connectors and severe burning will result.

Caution. For battery connection to bus or charger, double check the connections:

Connect the minus pole of the charger to the minus pole of the battery
Connect the plus pole of the charger to the plus pole of the battery

Figure 32: Uups !



Transformer – Rectifiers

The primary electrical power source of larger aircrafts are AC Generators producing 115/200 Volts 400 Hertz. Many systems in the airplane uses 28 Volt DC.

- To convert the high voltage alternating current into lower voltage, transformers are used.
- Rectifiers changes the alternating current AC into direct current DC. Both devices are build in the same unit.

Diodes as Rectifier

Figure 33: Diode and a Check-Valve

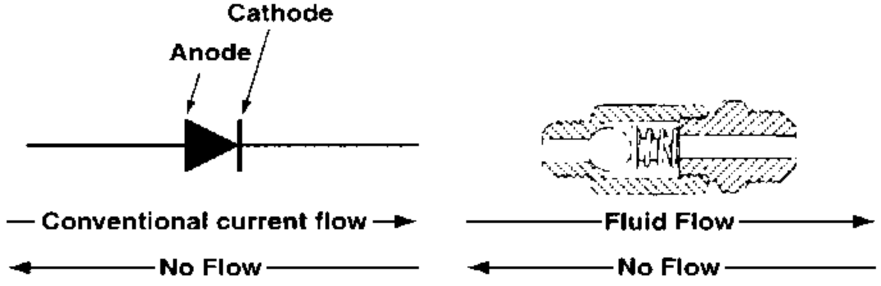


Figure 34: Conducting and blocking diode in an electric circuit.

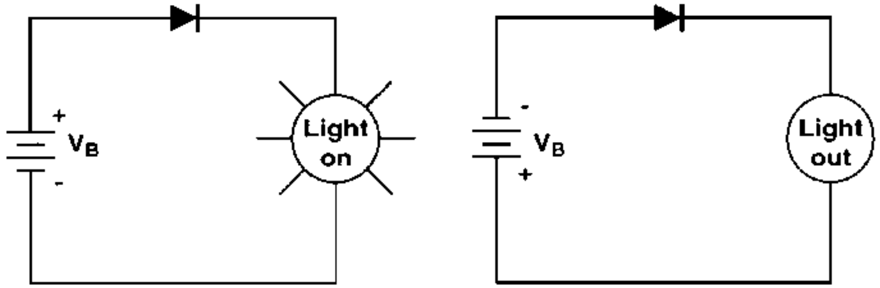
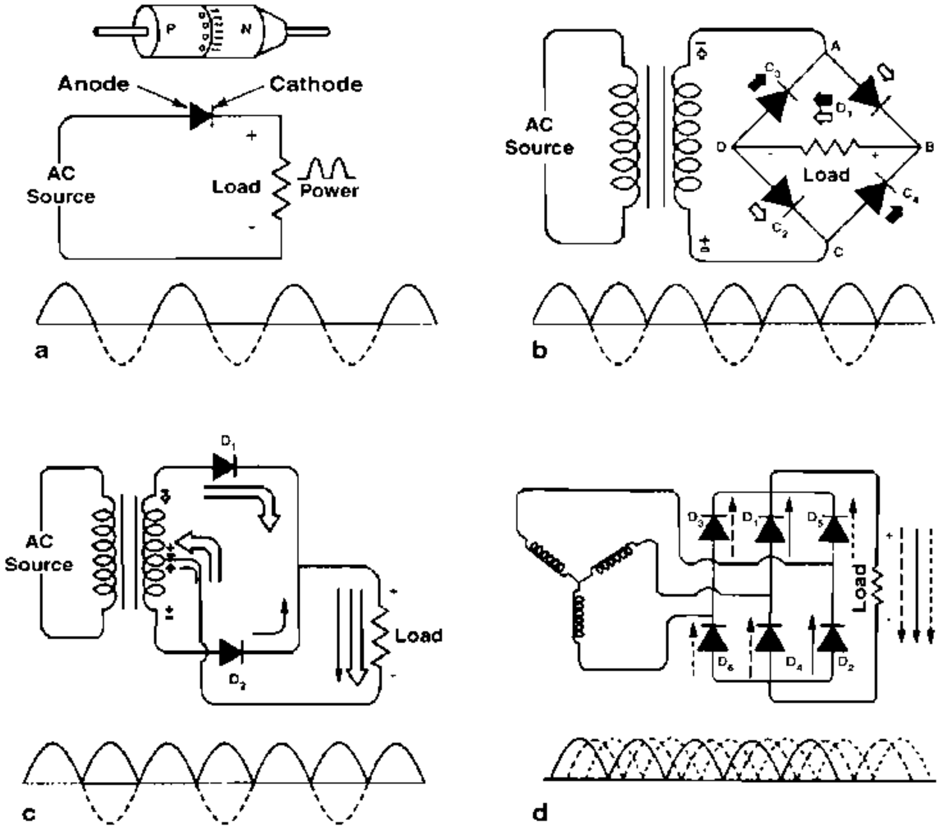


Figure 35: Various rectifier circuits



a) Half-wave rectifier with one diode
b) Full-wave rectification with bridge type rectifier
c) Full-wave rectification needing a transformer with 2 secondary coils
d) 3-Phase rectification needing 6 diodes gives more steady output current

Transformer Rectifier Unit

The 3 phase alternate current is routed to the primary side of the transformer. The 3 coils are connected in star order.

Two secondary sides are at the transformer. SEC 1 is in star order. SEC 2 is in delta order. The output of the secondary side is rectified by full wave rectifier circuits.

The purpose of the two different secondary side with separate rectification is less power ripple of the rectified 28VDC power output.

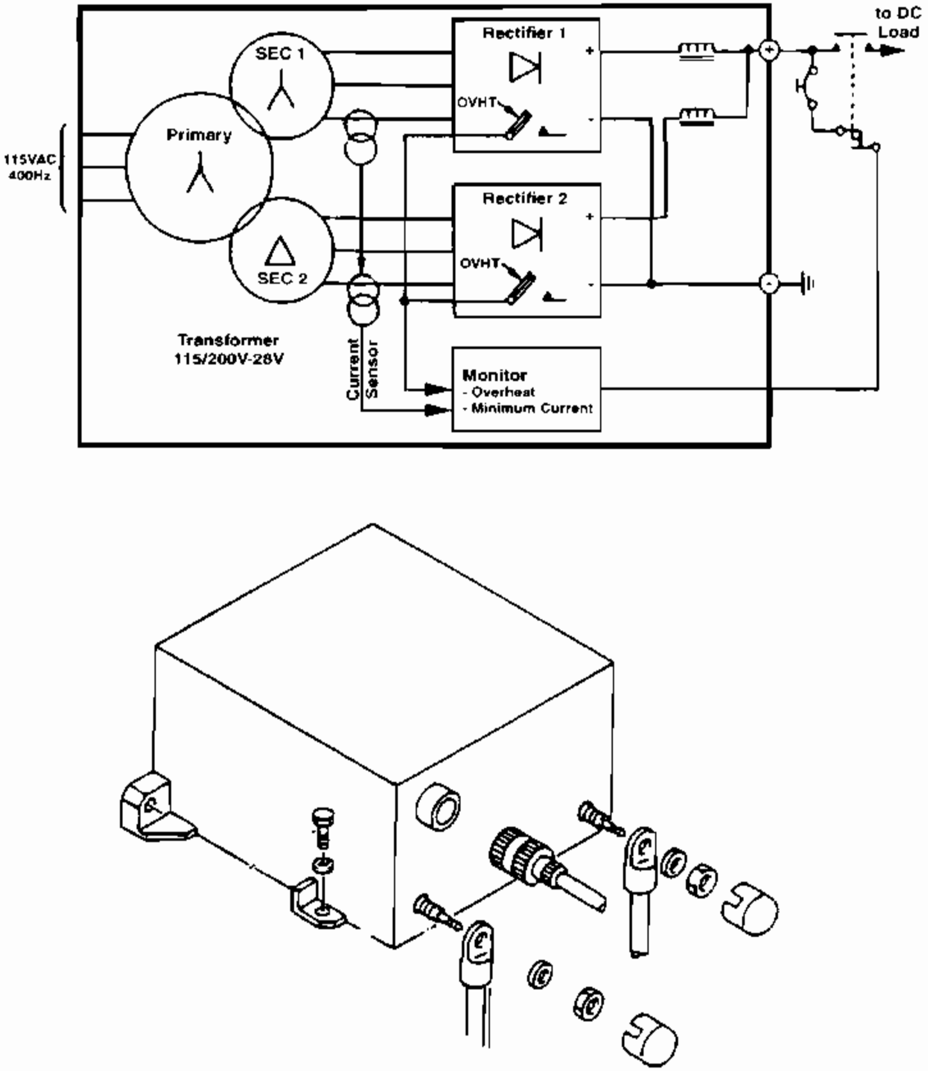
If the temperature of the rectifiers is over a certain limit, overheat switches providing signals to the monitor circuit inside theTRU. This causes an opening of the TRU contactor at the DC power output.

The rectifier current is monitored. Overcurrent or below a certain minimum-current also causes the opening of TRU contactor.

Table 2: Typical current ratings

Time Limitation	Output Current
Continious	100 - 200 A
1 - 5 Minutes	300 A
30 Seconds	500 A
3 Seconds	1000 - 1200 A

Figure 36:



Inverters

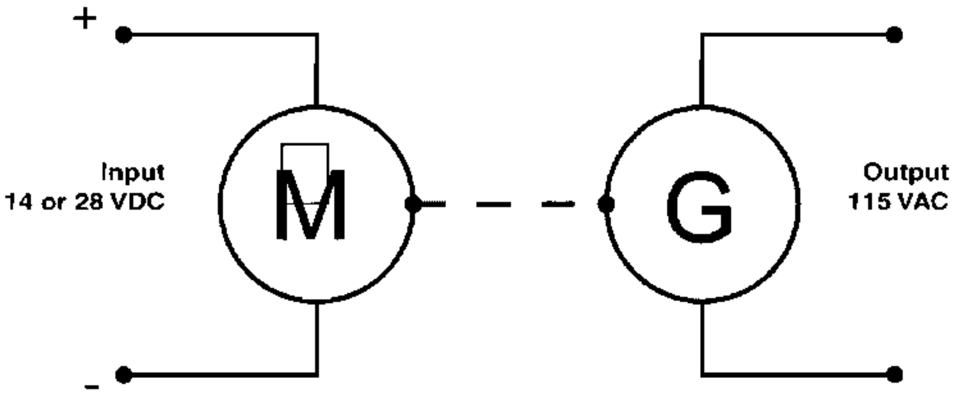
Small aircrafts have DC systems for their primary electrical power, but require AC for certain instrument and electronic systems. These aircraft use inverters to provide the needed AC.

Emergency power system of larger aircrafts are using inverters to convert the battery DC power into 115 Volt 400 Hertz to supply the most important systems in case of a complete power failure.

Rotary Inverter

Old aircrafts was using rotary inverters, which are primarily motor-generator units. Rotary inverters consists of a DC motor with the armature for an AC generator mounted on its shaft. A typical inverter has a 14 or 28-volt DC input and a 115 volt single- or three-phase, 400-hertz output.

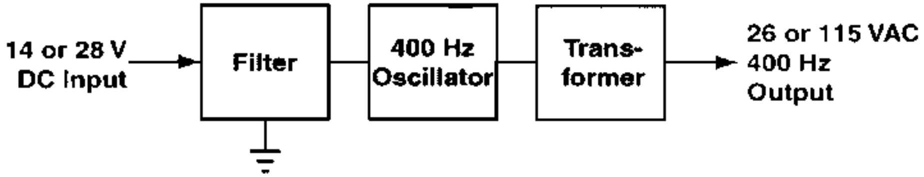
Figure 37: Rotary Inverter



Static Inverter

The newer trend for inverters is to use solid-state, or static, inverters. Static inverters consist of an oscillator that converts DC into 400-hertz AC with the proper waveform. This AC is then passed through a transformer to get the proper voltage. The filter at the input side eliminates interferences back to the DC power distribution system.

Figure 38: Static Inverter



Switching Power Supply

A regular transformer will not work with direct current DC. To change a voltage into an other voltage, the DC input must be choppered i.e. with 1kHz. So the transformer is working. For getting DC, the output voltage can be rectified.

Due of the high frequency from the chopper-oscillator, the transformer uses less iron for the necessary magnetic field. The unit can be build much smaller. This kind of power supplies are lightweight and efficient. (Used for computers, television and other electronic equipment)

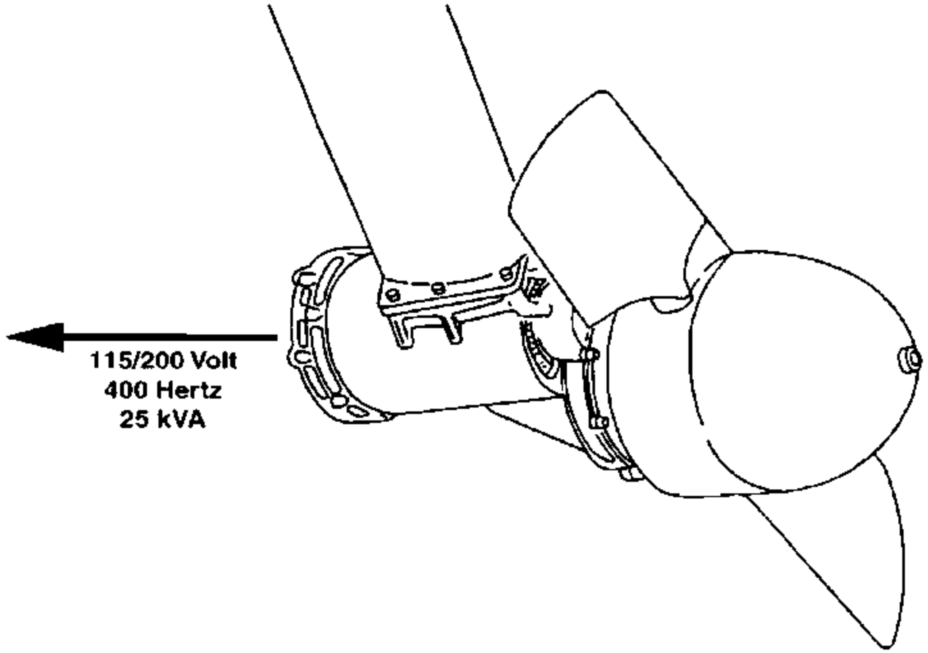
Emergency Power Generation

If the normal electrical power generation fails, there are other possibilities to supply the most essential systems for emergency use.

Air Driven Generator

In case of need, the pilot extends the ADG into the airstream. The turbine begins to rotate and drives on its shaft directly the generator. To keep the speed of the generator constant, there is a build in governor in the propeller, adjusting its bladeangle.

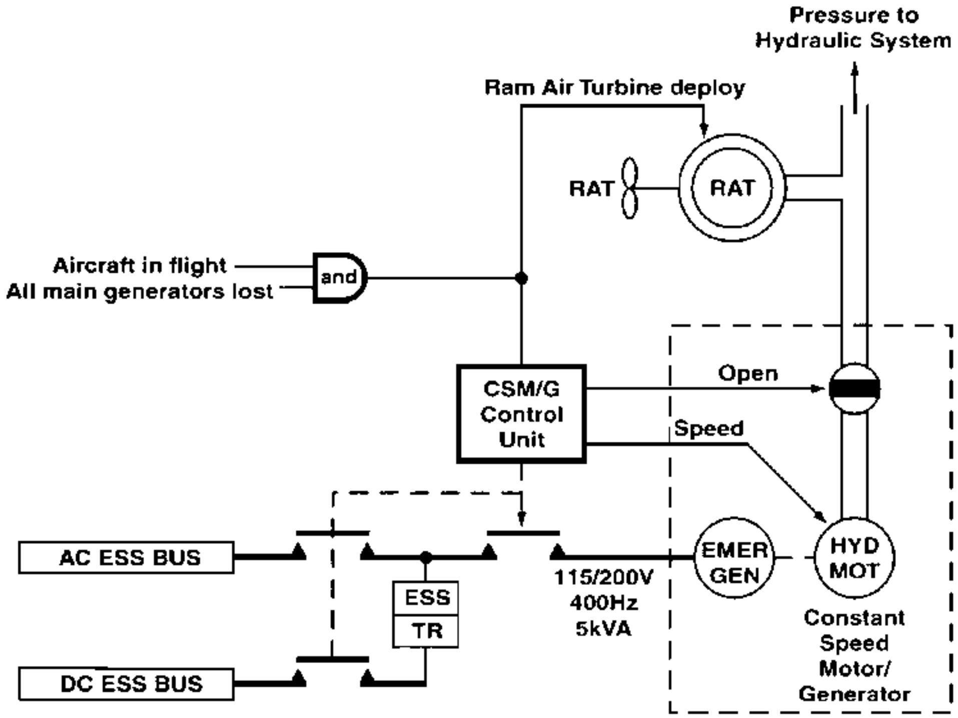
Figure 39:



Constant Speed Motor/Generator

A other solution is the ram air turbine who drives at its shaft a hydraulic pump. If the normal power sources failed, the ram air turbine deploys automatically its propeller into the airstream. The pump provides hydraulic pressure for the most essential aircraft systems. There is a hydraulic motor driving a generator inside the same unit. The generator provides sufficient electrical power for a safe flight in emergency configuration.

Figure 40: Hydraulic pressure and electrical power generation



External Power

If the airplane is on ground with no engines running, there is only the aircraft battery who provides electric energy. This is not sufficient for longer time or all the systems. Outside the fuselage there is a electrical connector to feed electric energy into the aircraft network. The electricity is generated with rotary- or static inverters on ground installations or mobile generator systems driven by a combustion engine. Small aircraft uses a cart carrying batteries or a transformer-rectifier

Power switching from and to aircraft power source to external source or APU source produces short power transients of 100 ms.

No Break Power Transfer

This function avoids busbar power interruption during supply source transfer on ground in normal configuration.

The system controls simultaneous connection of the two sources for a short time.

- External power with APU
- External power with engine driven generator
- APU generator with engine driven generator

To achieve this, both sources are synchronized on a frequency reference signal. Synchronization may take up to 15 seconds for APU GEN with GPU, and some milliseconds in all other cases.

For this paralleling, the frequency difference should be less than 0.5 Hz the phaseangle less than 15°

If synchronization is not achieved within allowed time transfer is performed anyway (without simultaneous connection of two sources).

Figure 41: EXT. PWR Receptacle

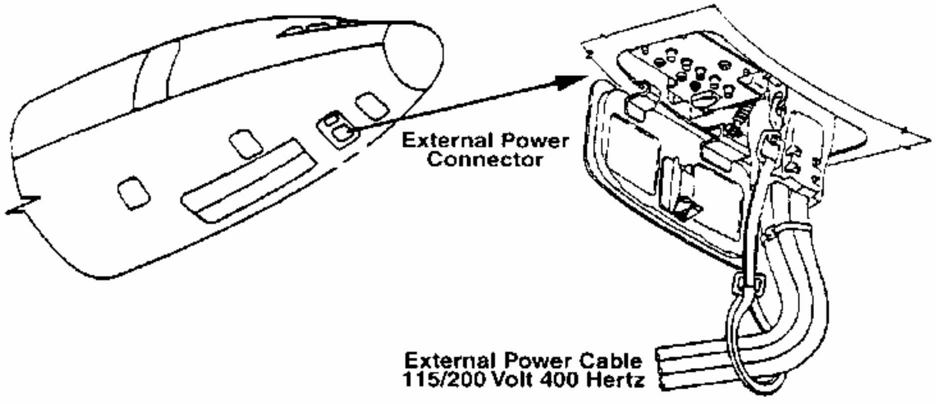
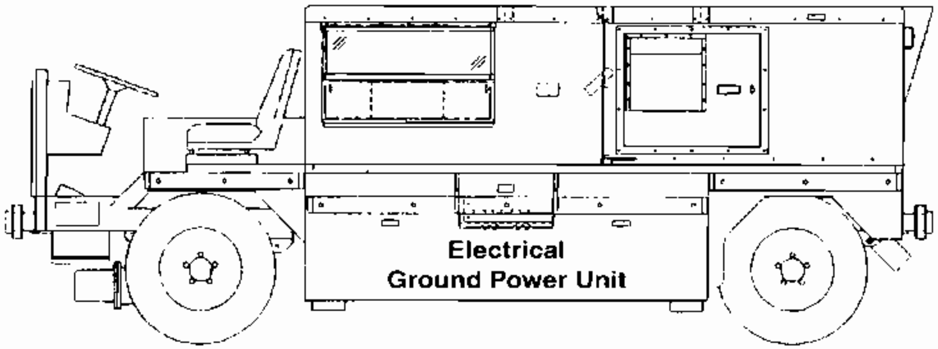


Figure 42: Self propellant GPU



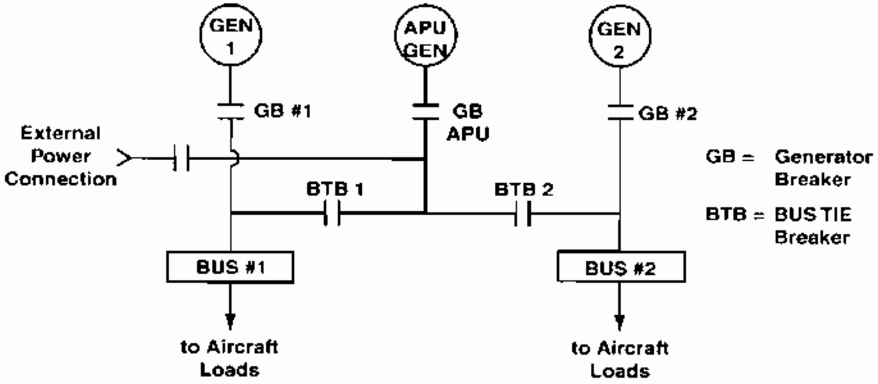
Power Distribution

There are two basic types of large aircraft power distribution systems-the split-Bus and the parallel system. The split-bus system is typically found on twin engine aircraft such as the Boeing 757 and 767, the McDonnell Douglas MD-80 and the Airbus A320. The parallel system is typically used on aircraft containing three or four engines such as the MD-11 and Boeing 747.

Split-Bus Power System

This schematic shows that the AC generator power from the right engine is connected to the right distribution-bus and isolated from the left bus by the bus tie breakers (BTB). The left AC generator supplies power only to the left bus. In the event of a generator -failure, the failed generator is isolated by the generator breaker (GB) and BTB 1 and 2 close to connect the isolated bus. On some aircraft the Auxiliary Power Unit (APU) generator could be started during flight and used to carry the load of the failed generator. In that case the left and right busses would once again be isolated.

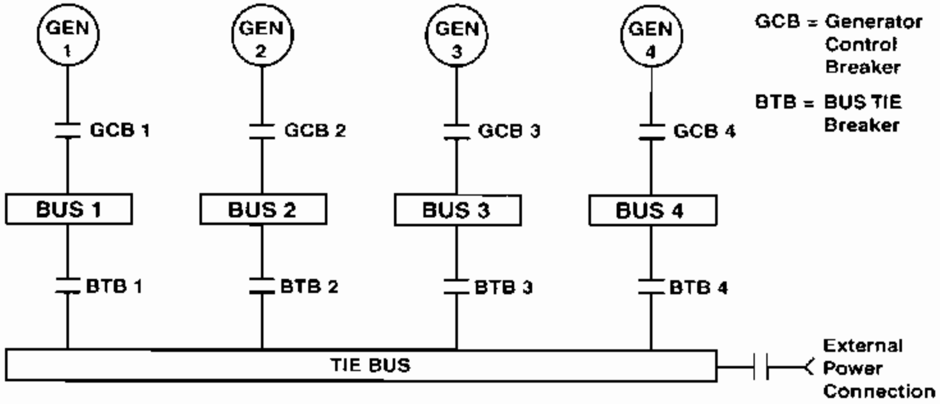
Figure 43: Two Engine Aircraft



Parallel Power System

With this system all generators are connected to a common bus and share the electrical loads equally. In the event of a generator failure, the failed unit would be isolated from the bus by its generator breaker and the flight would continue with remaining generators supplying the electrical power. The electrical loads are supplied from the individual buses, not from the tie bus.

Figure 44: Four Engine Aircraft



Power Sources

Main Generator

Nominal Power: 90 - 120 kVA
Frequency: 400 Hz.
Nominal Current: 260 - 350 A

External Power

Voltage: 115/200 VAC 3 Phases
Nominal Power: 90 - 120 kVA
Nominal Current: 260 - 350 A

Transformer-Rectifier

Output Voltage: 28 VDC
Nominal Current: 100 - 200 A

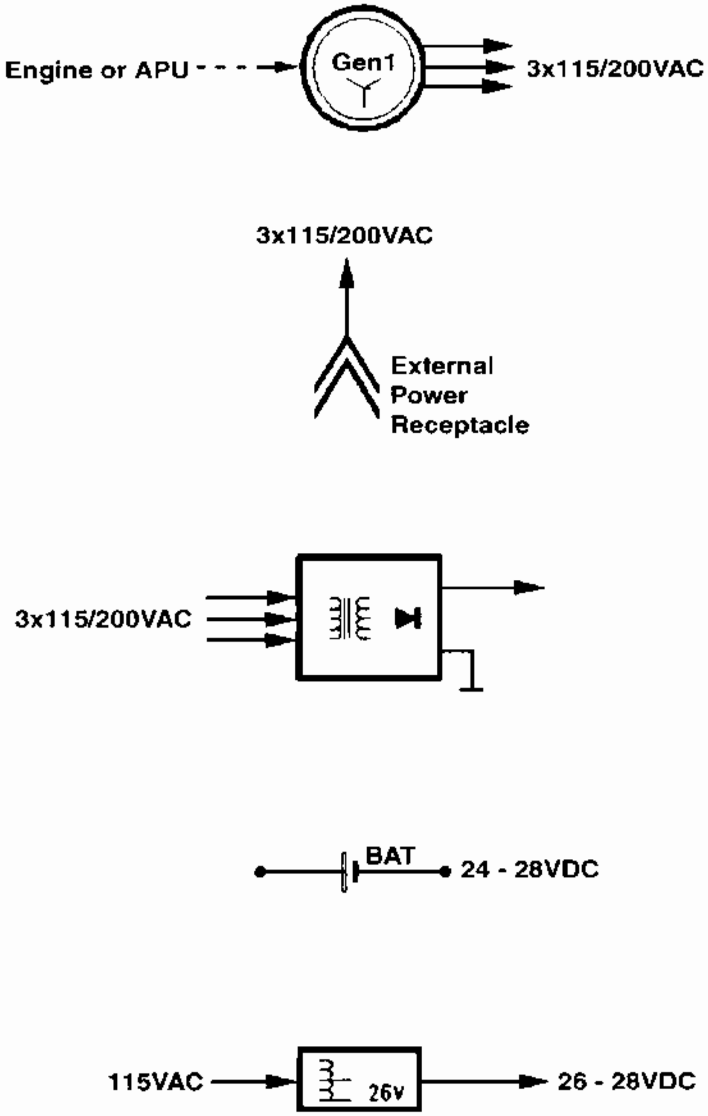
Aircraft Battery

Output Voltage: 24 - 28 VDC
Capacity: 20 - 50 Ah
Fused Current: 400 A

Instrument Transformer

Provides instrument excitation 26 - 28 VAC for synchros and differential transformers.
Nominal current: 2 A

Figure 45: Various Power Sources

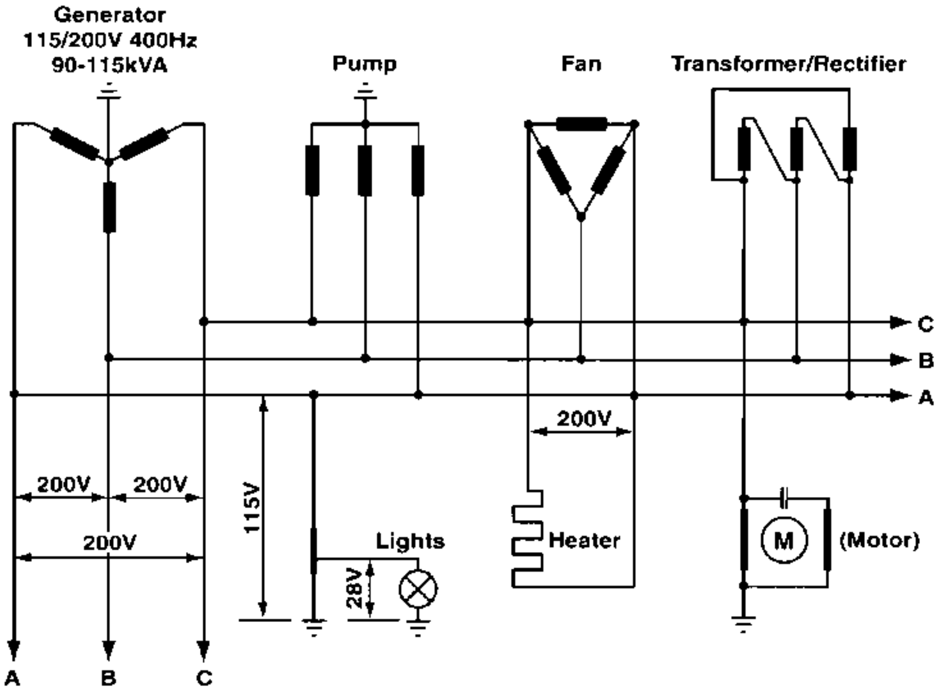


AC Distribution

The three phase current network of commercial aircrafts is feeding symmetrical loads (3 phase heaters and motors) and assymetrical loads (single phase 115V and 200V consumer).

Due of assymetrical load, a neutral current flowing through the aircraft structure. That means the metallic structure of the aircraft is conducting high currents. Therefore low resistance connections to the structure must be granted. (Electrical Bonding)

Figure 46:

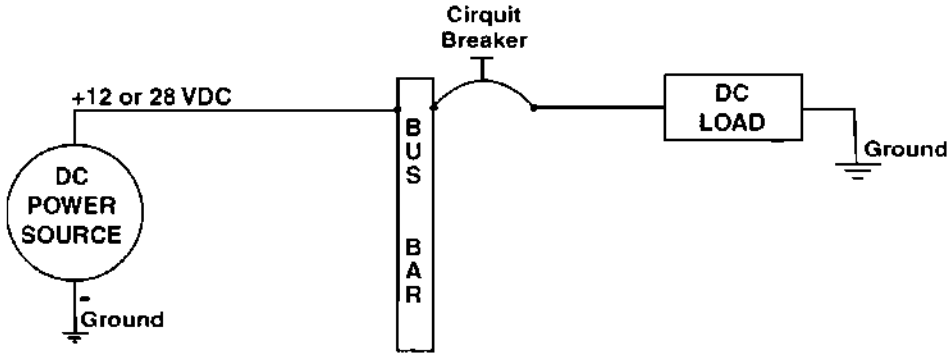


DC Distribution

The positive pole of DC power sources like Tranformer/Rectifiers and aircraft batteries is routed via wiring to to the DC-loads. The aircraft structure is used as the return conductor the negative pole of the power source.

This kind of installation is the same as in cars.

Figure 47:



Example

A320

Aircraft electrical power is provided by two three phase AC engine generators driven by an integrated drive (GEN 1 GEN 2) with an output rated at 90 kVA - 115/200 V - 400 Hz. A third equal generator (APU GEN) driven directly by the APU can replace either or both engine generators at any time. One engine generator, the APU generator or the external power may supply the complete AC and DC system.

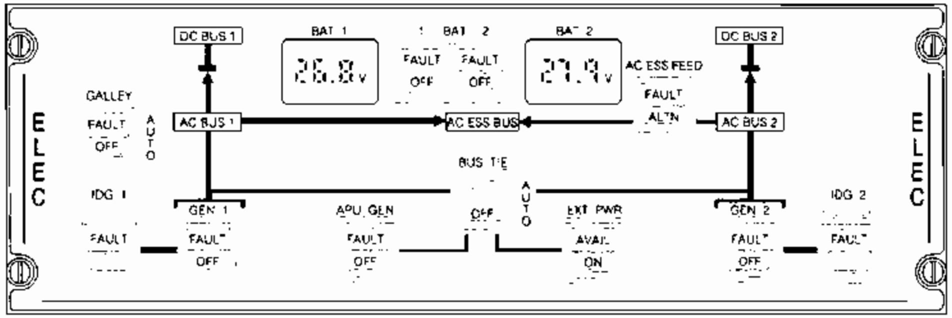
An emergency generator, AC three phase, 5 kVA - 115/200 V 400 Hz driven by the hydraulic system, automatically provides emergency power in case of failure of all generators.

A static inverter 1 kVA transforms the DC voltage from battery 1 into single phase 115V -400 Hz AC supplies the AC ESS Bus. When the aircraft speed is more than 50 kts, the static inverter is automatically activated if only batteries are supplying the aircraft.

Two main Transformer Rectifiers TR1 and TR2 permanently provide the DC power. A third identical transformer rectifier, the ESS (essential) TR is used to supply the DC ESS BUS from the emergency generator in case of total loss of ENG and APU generators or if TR1 or TR2 fails.

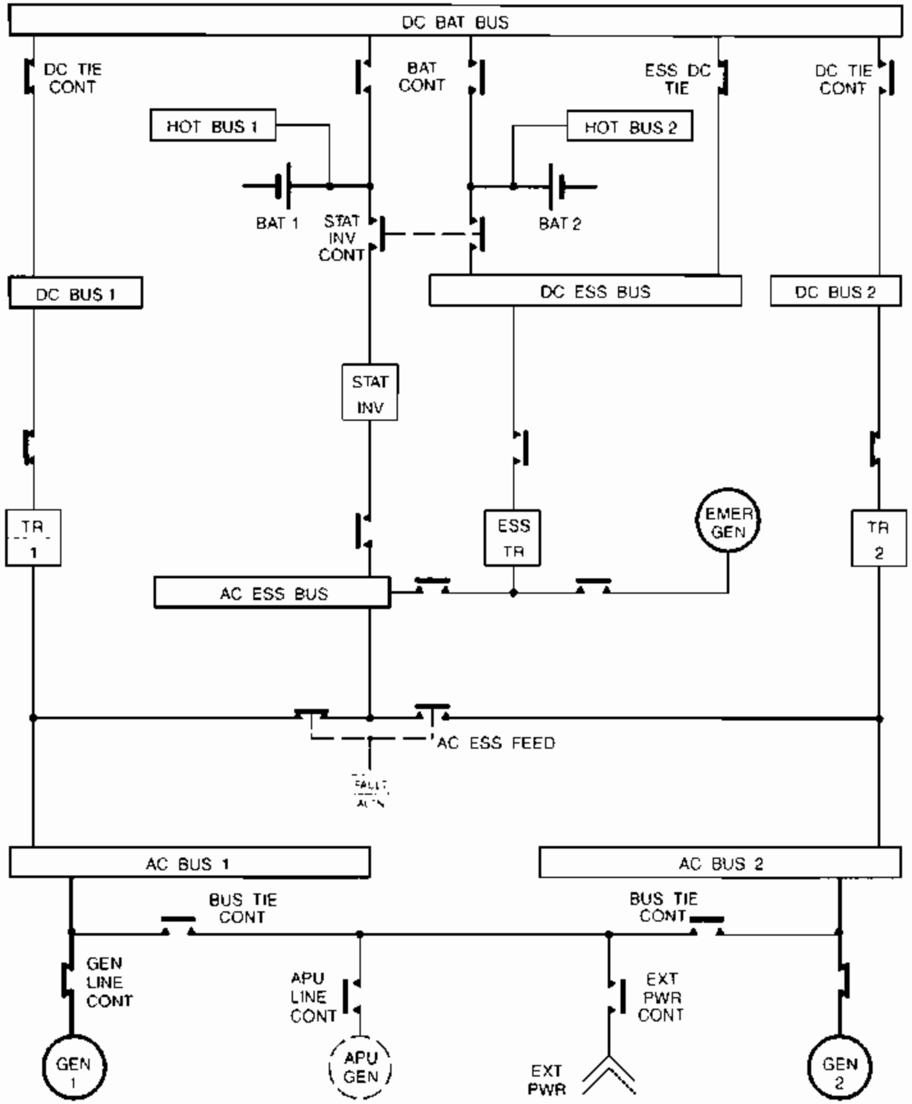
Two main batteries of normal capacity of 23 Ah each are permanently connected to the two hot busses. Each battery has an associated Battery Charge Limiter (BCL). The BCL monitors battery charging and controls its battery contactor.

Figure 48:



Electrical Control Panel A320

Figure 49: Power Distribution System



Electrical Protection

Aviation Regulations requires that all circuits other than the main circuit for the starter must be protected by a device that will open the circuit in the event of an excessive flow of current. This can be done with a current limiter, a fuse, or a circuit breaker. The primary function of a circuit protection device is to protect the wiring in the circuit. It should open the circuit before enough current flows to cause the insulation on the wire to smoke.

Fuses

There are two types of fuses used in aircraft circuits-the regular glass tubular fuse and the slow-blow fuse.

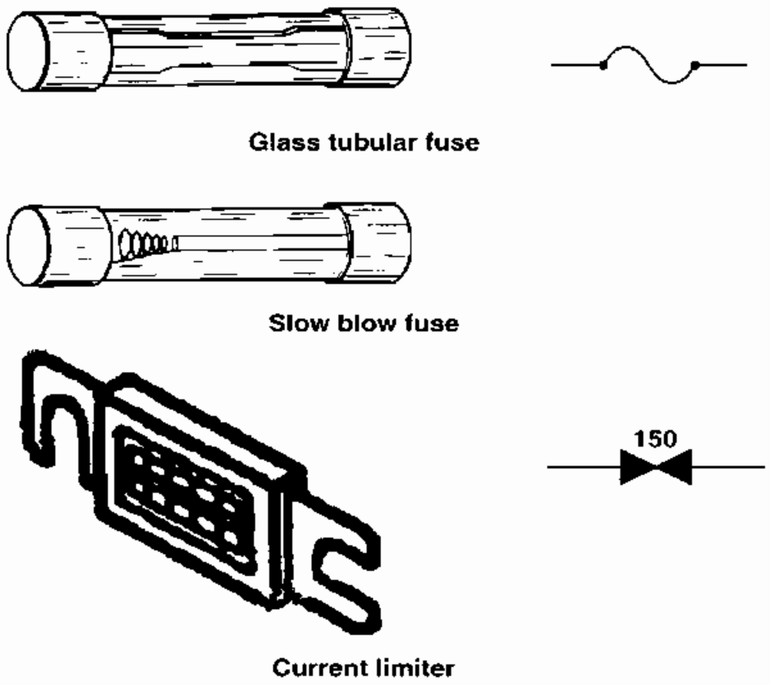
The regular fuse has a simple narrow strip of low-melting-point material that will melt as soon as an excess of current flows through it.

The slow-blow fuse has a larger fusible element that is held under tension by a small coil spring inside the glass tube. This fuse will pass a momentary surge of high current such as you have when the switch in a lighting circuit is closed, but it will soften under a sustained current flow in excess of its rating, and the spring will pull the link in two, opening the circuit.

According to the flight regulations aircraft that are equipped with fuses are required to carry at least 50% of any one type of fuse installed on the aircraft. If one fuse of a particular type is installed, one spare of the same rating must be carried on the aircraft at all times.

Fuses which are accessible by maintenance personnel only are found on some aircraft. These fuses, commonly called current Limiter, are often used to isolate a complete distribution bus in the event of a short to that bus. The pilot would simply continue the flight without use of the isolated bus and the have problem corrected upon landing.

Figure 50: Various Melting-Fuses



Glass tubular fuse

Slow blow fuse

Current limiter

Circuit Breakers

There are two basic types of circuit breakers. Those that operate on heat and those that are opened by the pull of a magnetic field. Most breakers work on the principle of heat. When more current flows than the circuit breaker is rated for, a bimetallic strip inside the housing warps out of shape and snaps the contacts open.

There are three basic configurations of circuit breakers used in aircraft electrical systems: the push-to-reset, the push-pull type and the toggle type.

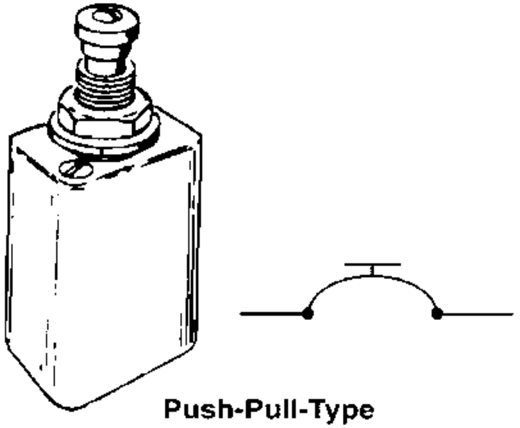
The push-pull-type circuit breaker has a small lip that can allow the breaker to be pulled to open the circuit. Normally these circuit breaker buttons are in, but if a breaker is overloaded, the button pops out and is easily identified. To aid in this identification, many of these circuit breakers have a white band around the button that is visible when the breaker has popped. This type of circuit breaker should be used to switch the circuit only for maintenance purposes.

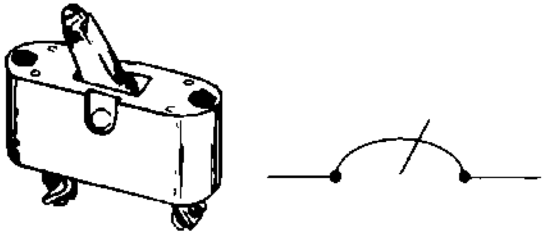
The toggle-type circuit breaker is normally used as a control switch as well as a circuit breaker. When the toggle is up, the circuit is closed, but if the circuit is overloaded, the breaker will pop partially down. To restore the circuit, move the toggle all of the way down and then back up.

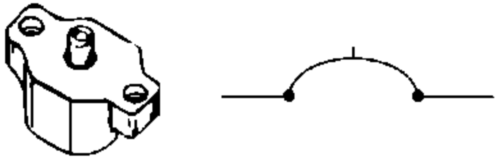
The button of the push-to-reset type of circuit breaker is normally in, and it pops out only when the circuit has been overloaded. This type of circuit protection device cannot be used as a switch, as there is no way to grip the button to pull it out.

Figure 51: Principle of CB

Figure 52: Various CB's


Push-Pull-Type Circuit Breaker

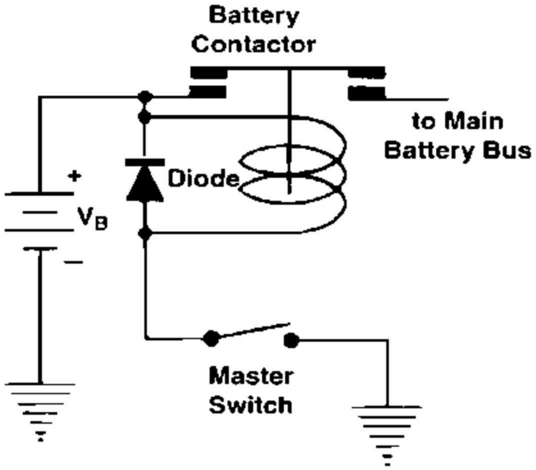

Toggle-Type Circuit Breaker


Push-to-Reset Circuit Breaker

Induced Current Protection

When current begins to flow through the contactor coil, a strong magnetic field builds up around the coil. But as soon as the switch between the coil and ground is opened, current stops flowing in the coil, and as it stops, the magnetic field collapses across all of the turns of wire in the coil. The collapsing magnetic field produces in the coil a short pulse, or spike, of very high voltage whose polarity is opposite to that of the battery. The amount of induced voltage is determined by the rate at which the magnetic field cuts across the conductor. The faster the current changes, the greater the induced voltage. This voltage spike can damage any electronic equipment connected to the system when the master switch is opened. It can also damage the master switch by causing an arc to jump across the contacts as they are opening.

Figure 53: Voltage spike protection by a freewheel diode

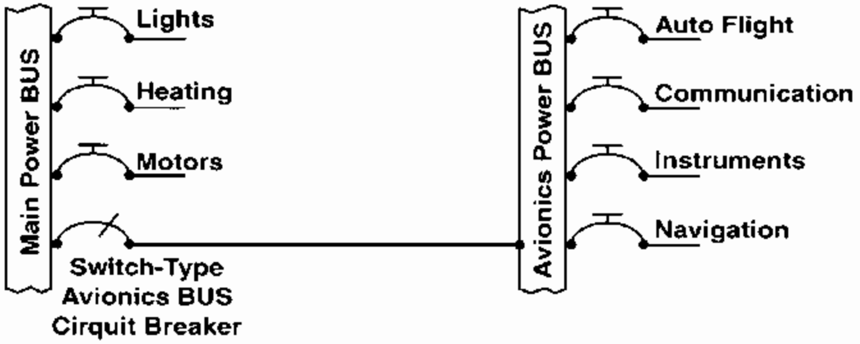


To prevent this kind of damage, a reverse-biased diode or freewheel-diode is connected across the contactor coil. During normal operation, no current can flow through it, but the high-voltage spike that is produced when the master switch is opened forward-biases the diode, and the induced current flows back through the contactor coil and is dissipated. The induced current will flow in the same direction as the flow of current that produced the magnetic field.

Split-Bus Circuits for Avionics Protection

To prevent damage to radio equipment, all radio equipment should be turned off before the engine is shut down, and a careful check made to be sure all of it is turned off before the engine is started. Most modern aircraft carry so much electronic equipment that it is possible to fail to turn off some system when the engine is started or shut down, or when the external power source is connected to the aircraft. To prevent this kind of damage, modern practice is to connect all of the voltage-sensitive electronic and avionics equipment to a separate bus and connect this bus to the main bus with either a switch-type circuit breaker or a relay.

Figure 54: Switchable Avionics Power Bus



The figure shows a popular system that uses a switch-type circuit breaker to connect the avionics bus to the main bus. Before starting or shutting down the engine, the pilot opens the circuit breaker and all of the avionics equipment is isolated from the main bus. Any spikes of high voltage are absorbed by the battery, and there is no danger of damage to this equipment.

Differential Current Protection

There is a danger of short circuit between two generator lines or one generator line and ground. Also an insulation failure of the generator feeders is dangerous.

The differential protection prevents the damages of the electrical wiring and the generator windings between the two detection current transformers. One 3-phase current-transformer is located inside the generator and reads the current.

If the difference between the current at the generator and the current to the power consumers differs a certain amount, the Generator Line Contactor will open and the generator excitation field is turned off.

The three-hole current transformer contains 3 toroidal transformers, one for the each of the power feeder cables. The current transformer sends its signal who is proportional to the current in its feeder cables to the Generator control unit.

If the current from the generator is not equal to the current who flows to the power consumers, that means there must be a failure inside the generator windings or the generator feeder cables who brings the power from the generator to the power distribution center inside the aircraft.

Other Protections

In commercial aircrafts there are additional electrical protection devices in the generator and power supply system such as:

Over and under frequency

Over and under voltage

Incorrect phase sequence

Open phase

Generator overload

Figure 55: Principle

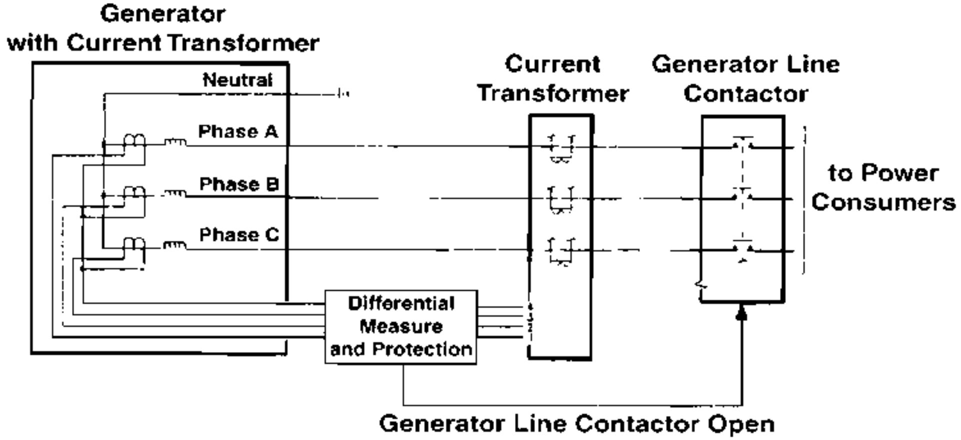
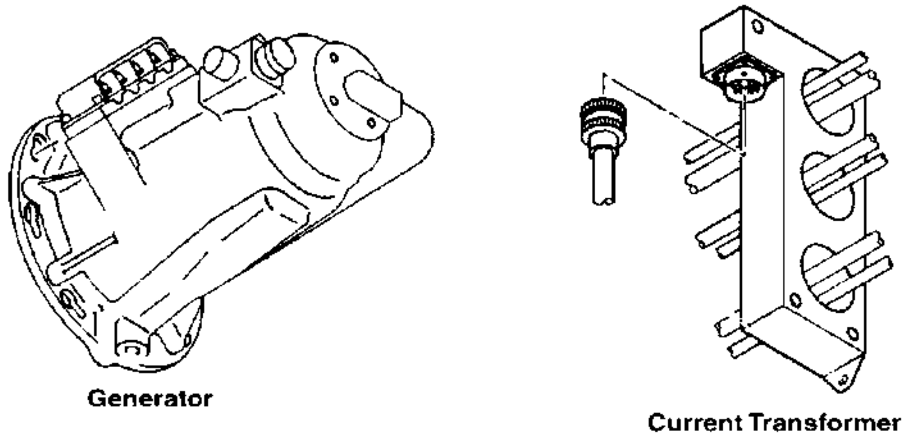


Figure 56: Current Transformer inside Generator and as a separate unit.



Avionics Equipment Ventilation

A big amount of heat produced in all avioncs system has to be taken away from the temperature sensitive electronics. The system ensures the ventilation of the avionics equipment in order to guarantee a high reliability level. The main items of equipment which are ventilated are

In the cockpit:

- Display Units
- Overhead Panel
- Pedestal

In the avionics compartment:

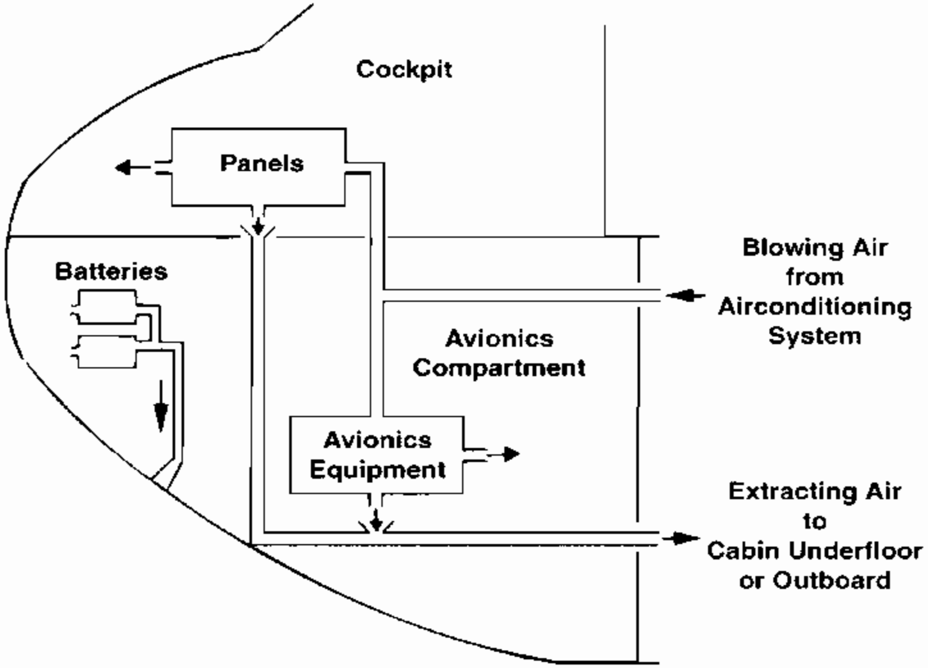
- Electronics Racks
- Forward shelf,
- ADIRUs
- Weather radar shelf,
- Batteries
- AC/ DC power center

The avionics equipment ventilation includes two sub- systems:

- Blowing Sub - System
  The required blowing airflow is bled from the cabin air conditioning system or recirculation fans.
- Extract Sub - System
  The air used for the avionics equipment ventilation is extracted by means of the extract fan. The air is ducted either through the underfloor extract valve or the overboard extract valve.

Ensure that the avionics equipment ventilating system is operating, as long the aircraft is powered!
Damage of expensive components or a fire may occur.

Figure 57: Avionics equipment ventilation System (A330 simplified)



13.6 Equipment and Furnishings (ATA 25)

Passenger Address

Overview

Passengers are informed about a variety of matters on board via the PA System. In addition, the PA System supplies the boarding music. The system consists of an amplifier, a loudspeaker system and a number of microphones. The PA System is used by cockpit and cabin crew.

The passenger address system enables announcements to the passengers via cabin loudspeakers. Announcements can be made from the cockpit or cabin attendant's stations.

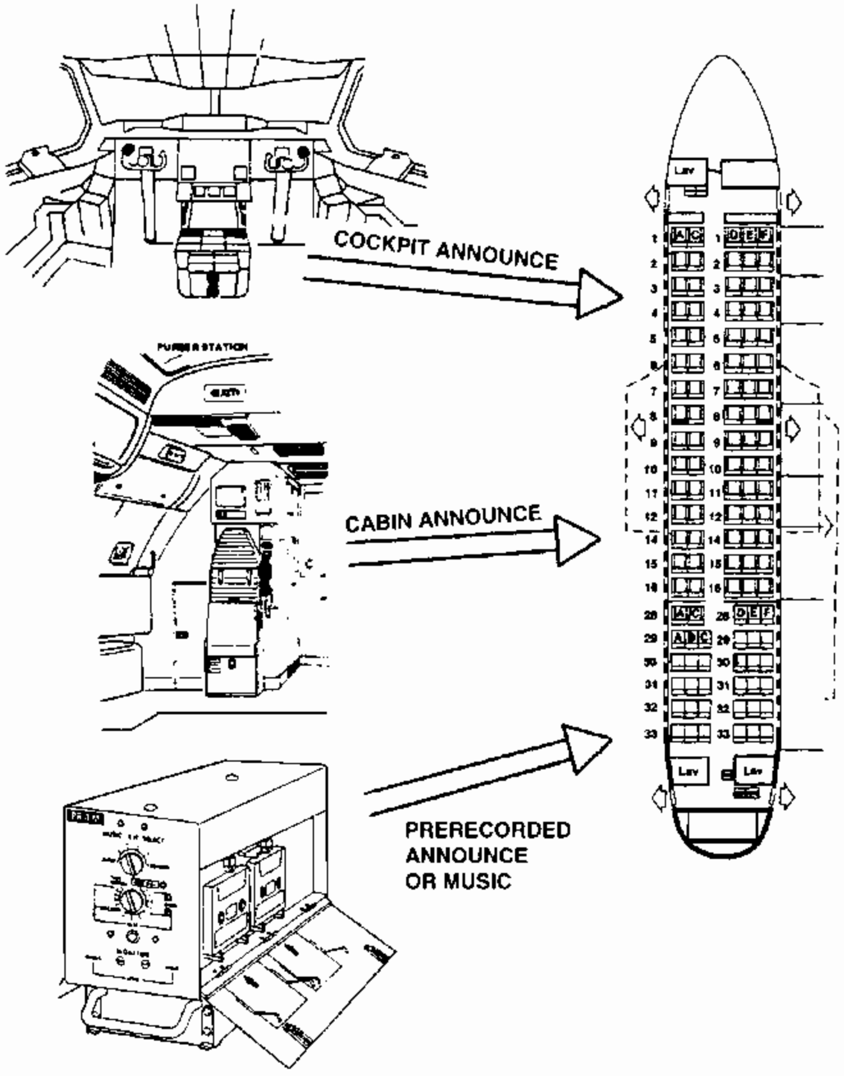
A tape reproducer enables recorded announcements and boarding music to be broadcast through the PA system.

Loudspeakers are distributed in the cabin overhead of the passenger seats, toilets and for the flight attendants at their working stations.

There are several levels of priority assigned to the passenger address system.

1. Cockpit
2. Cabin attendants
3. Prerecorded announcements
4. Boarding music

Figure 1: Announcements to Passengers



System

The main is the amplifier Depending of the type of aircraft up to 3 units are necessary to drive all the speakers. According the priority there are different inputs from the signal sources.

Cockpit and cabin microphones

From cockpit, handsets, hand-, boom- or mask microphones are used. (1st priority)

From cabin, handsets or hand microphones are used. (2nd priority)

Tape reproducer

Prerecorded announcements usually consist of a spoken text. This text can be heard in various language. The cabin attendant selects and start the desired announce. The tape reproducer starts automatically if the cabin pressure is lost.

Boarding music is the music that plays while passengers are embarking or disembarking. Research shows that the music creates a relaxed atmosphere.

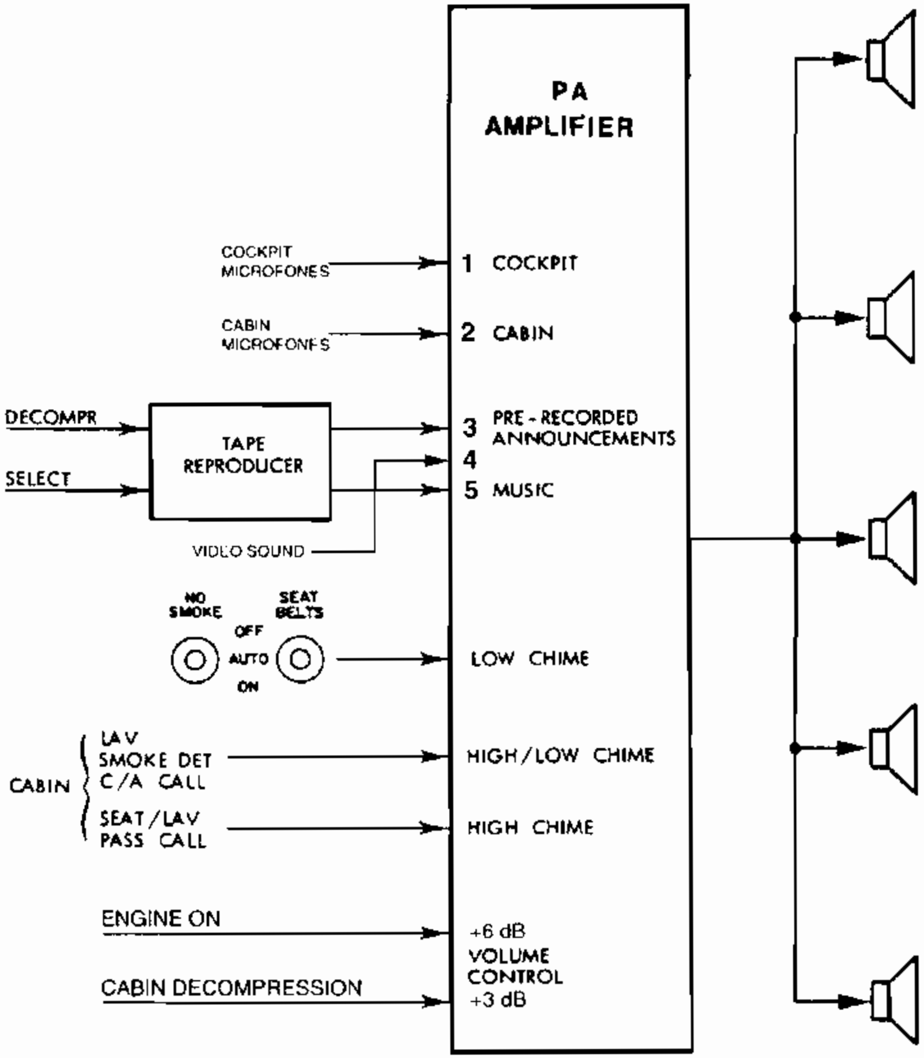
Electronic chimes

The sound of an electronic chime is produced by the PA amplifier. It has three possibilities: the "high chime" (passenger call to the cabin crew), "low chime" ("no smoking", "fasten seat-belt") and "high/low" chime (call on the "cabin interphone" or lavatory smoke warning).

Volume control

To compensate the noise of a running engine the volume is increased when engines are on. To get a better understandably of the emergency announcement, at cabin decompression, the volume is also automatically increased.

Figure 2: PA System

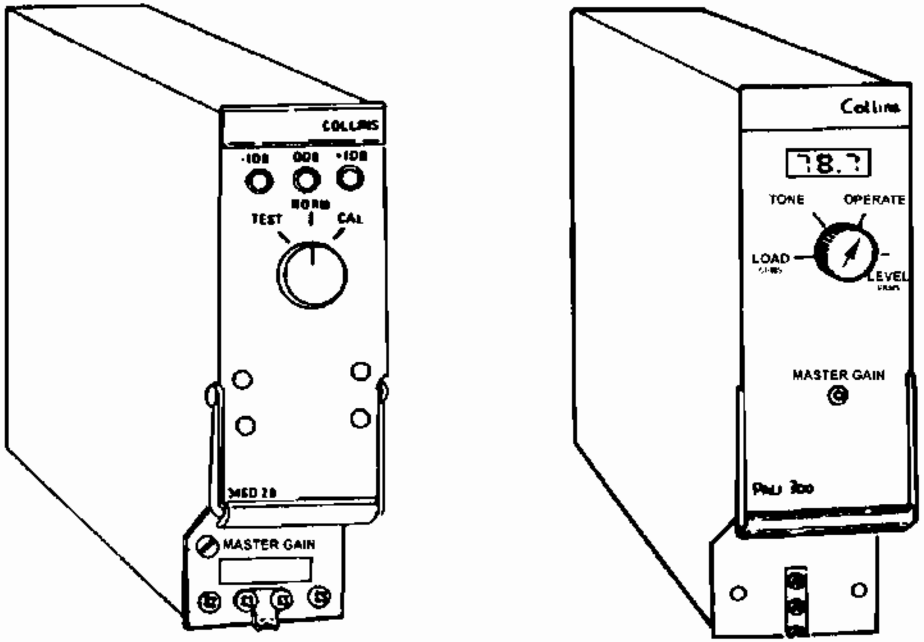


Amplifier

The microphone and audio signals go to an input circuit. A priority circuit gets the PTT signals and permits only the signal with the highest priority to go through the input circuit to the amplifier, in the PA amplifier.

The microphone signals go to an amplifier/compressor circuit. This circuit makes, from a variable input signal, a signal with an almost constant amplitude. This signal goes to a main preamplifier. The engine and decompression discretes adjust the gain of this amplifier. The signal from the preamplifier goes to the main power amplifier. The master gain potentiometer adjusts the input of the power amplifier. The PA GAIN input makes an adjustment in the power amplifier. The output of the main power amplifier is 30 W continuous or 120 W peak. The main amplifier audio goes to the speakers. The sidetone is attenuated main audio is routed to the handsets and flight interphone, to give control during announcements.

Figure 3: Amplifier Unit

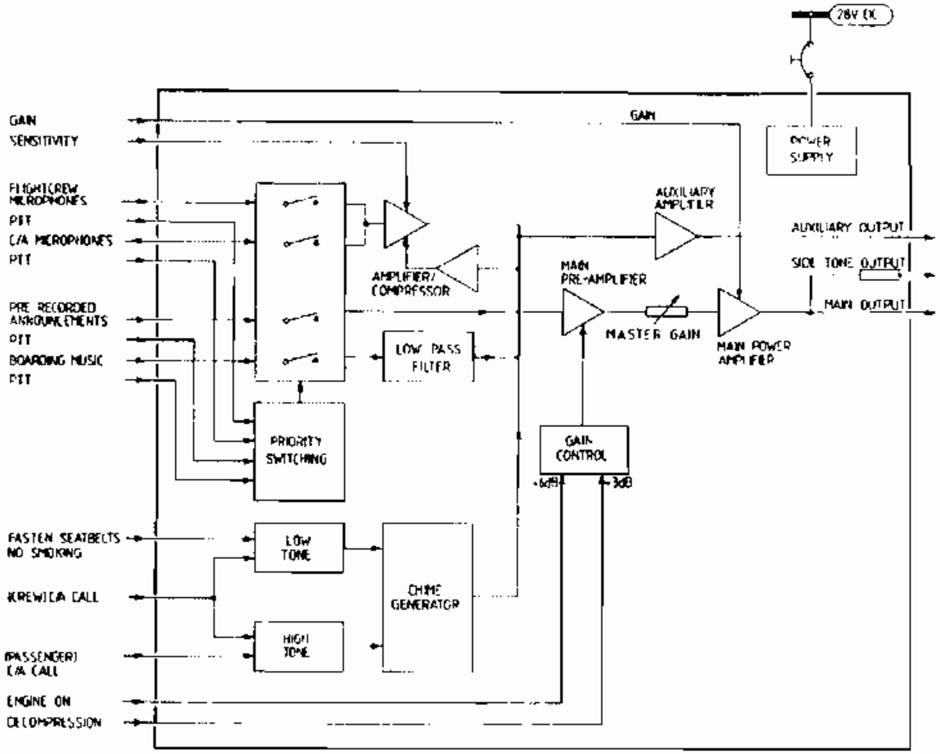


The prerecorded announcements go straight to the main preamplifier, but the boarding music goes through a low pass filter before it goes to the main preamplifier

The audio attention signals and the call signals are the chimes. A chime generator makes from a high or low tone a chime sound. The low tone is 491 Hz, the high tone 586 Hz.

The auxiliary amplifier has no external adjustments. This amplifier gives 5 W continuous power or 20 W peak. The amplifier gets all the chime signals, but only the audio input from cockpit microphones.

Figure 4: Amplifier Schematic



Prerecorded Announcement and Music Reproducer

The main functions of the recorder are to play:

- music
- pre-recorded announcements (on request of a cabin attendant)
- a pre-recorded emergency announcement (automatically)

The recorder has 4 cassette decks, 2 for music cassettes and 2 for cassettes with pre-recorded announcements. The recorder uses standard audio cassettes, which it plays in mono, in one direction only. There are 4 channels on each tape, which are played with a 4 track play-back head.

The cassette with boarding music contain music on each channel, each cassette contains half of the music program. When one deck plays, the other one rewinds and is then standby to play again.

The two cassettes can contain up to 126 announcements on channel 1 and 2. Channel 3 contains at several intervals the emergency announcement. Channel 4 contains signals, which make it possible to determine the start position of each announcement. When one deck plays an announcement, the other one searches for the next announcement.

Newer models of reproducers, the emergency announcement is stored in EPROMS (Solid state stored voice) to provide a faster access to the important instructions for the passengers in emergency situations.

The control panel gives control signals to the recorder to play music or to play one or more pre-recorded announcements. The recorder gives ready signals to the control unit when an announcement is ready to play and when an announcement playback is finished. The audio signals go to the PA amplifier together with PTT signals. An oxygen-in-use signal starts the emergency announcement.

Figure 5: Prerecorded Announcement and Music Reproducer PRAM

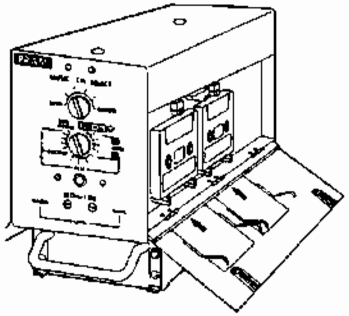
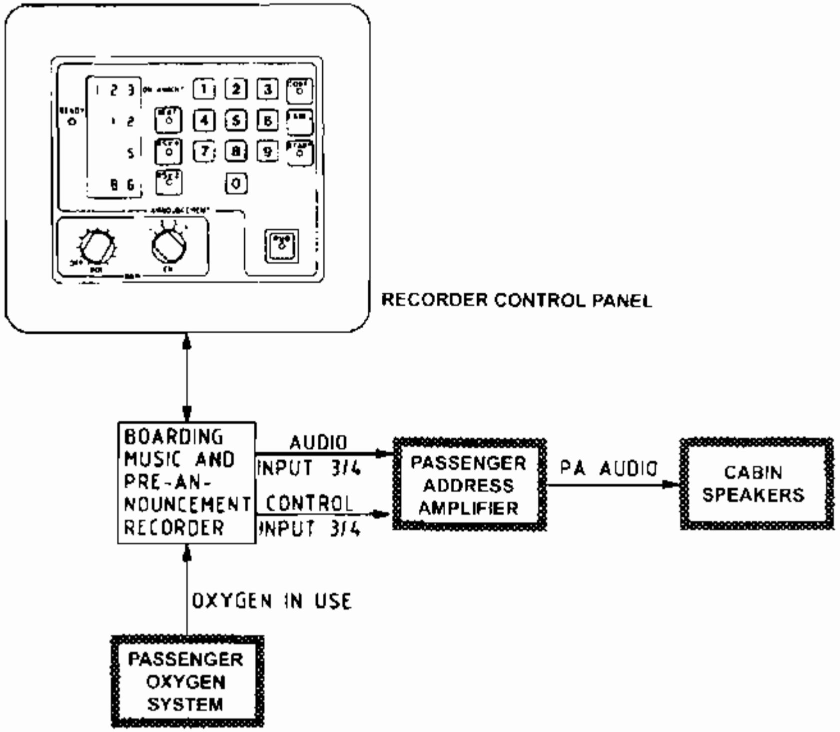


Figure 6: PRAM Schematic



Speaker

In some type of aircraft, there are more than 100 loudspeakers which can be divided into groups. An announcement can be made to a certain group or groups of passengers. Some loudspeakers are muted to prevent acoustic feedbacks.

To match the speaker impedance (8 Ohm) to the output of the amplifier(125 Ohm) each speaker has its own impedance matching transformer. To adapt the output level of each speaker the transformer secondary coil has different taps.

For weight saving, the speaker impedance is higher (2500 Ohm) so there is no need for a matching transformer.

Main speakers

Speakers installed in the passenger compartment of the cabin and toilets are connected to the main output of the amplifier. All announcements of the cockpit- and cabin-crew also prerecorded announcements and boarding music will be heard.

To get the attention of the passengers, by turning on or off the lighted cabin-signs FASTEN SEATBELTS and NO SMOKING a low chime sound is generated.

Auxiliary speakers

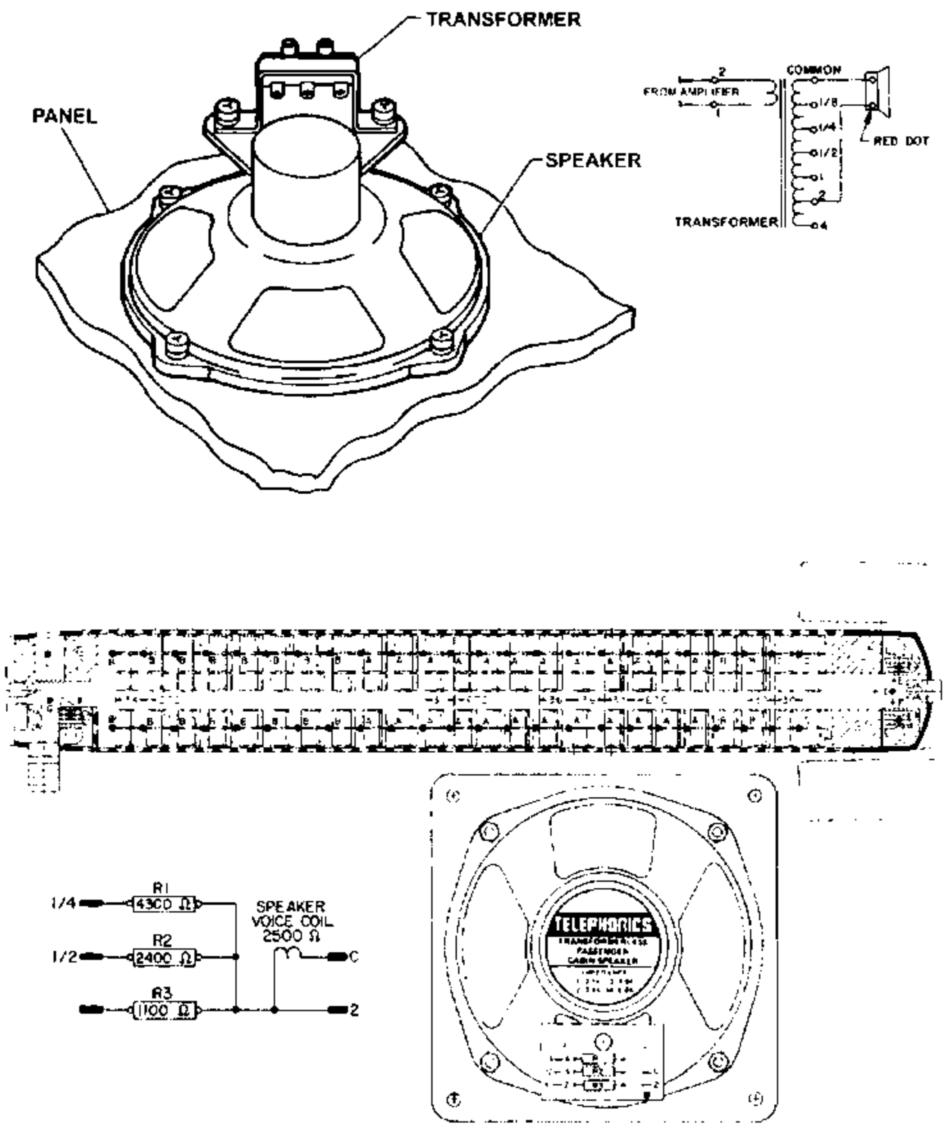
Speakers installed at the attendants stations in the cabin door area and galleys reproduces only the announcements from cockpit and all chime sounds.

High chime: Passenger to Attendant call

Low chime: Fasten Seat belts or No Smoking signs on or off

High Low chime: Lavatory Smoke Warning or Crew call

Figure 7: Speakers



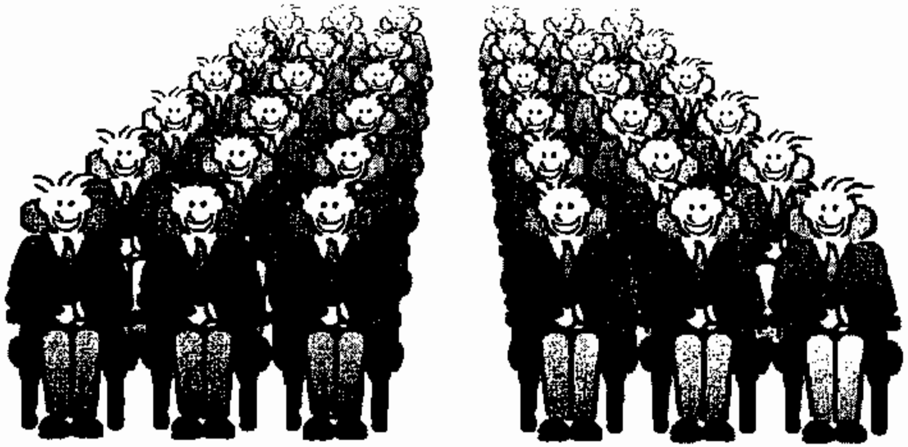
Passenger Entertainment and Service System

Passengers like to be entertained during the whole flight. Following entertainment and services are available:

Table 1:

Kind of entertainment	Performed by:
Food and Beverages Special Attention	Flight Attendants
Music	PES Audiotapes or CD's
Video Films and Games	PES Video Tape Reproducers or DVD's
Video Games interactive	PES Processors
Maps and Infos	Passenger Visual Information System
Telephone	Handset via SATCOM
Reading Light Control Attendand Call	PSS Passenger Service System

Figure 8: Passengers to be entertained



PES Passenger Entertainment System

Video, Music, Interactive Video Games and Inseat Telephone System

PSS Passenger Service System

Attendant Call, Individual Reading Light Control and No Smoking Light on/off

Video Entertainment System

Installed in short and medium range airplanes, the purpose is:

- Passenger visual emergency instruction (Oxygen Mask, Live-vest)
- Advertising for tax free shopping
- Flight information Maps (Passenger Visual Information System)
- Information about arrival at destination
- Short movies

The Passenger Entertainment Video System provides prerecorded video programs through the LCD-monitors which are installed in the cabin as headrack mounted display units. The video sound can be heard from the cabin loudspeakers.

Video Tape Reproducer VTR

The video tape reproducer plays video cassettes. Beside regular controls of the reproducer there are controls for advanced presentation options like repeat and random access mode.

Video System Control Unit

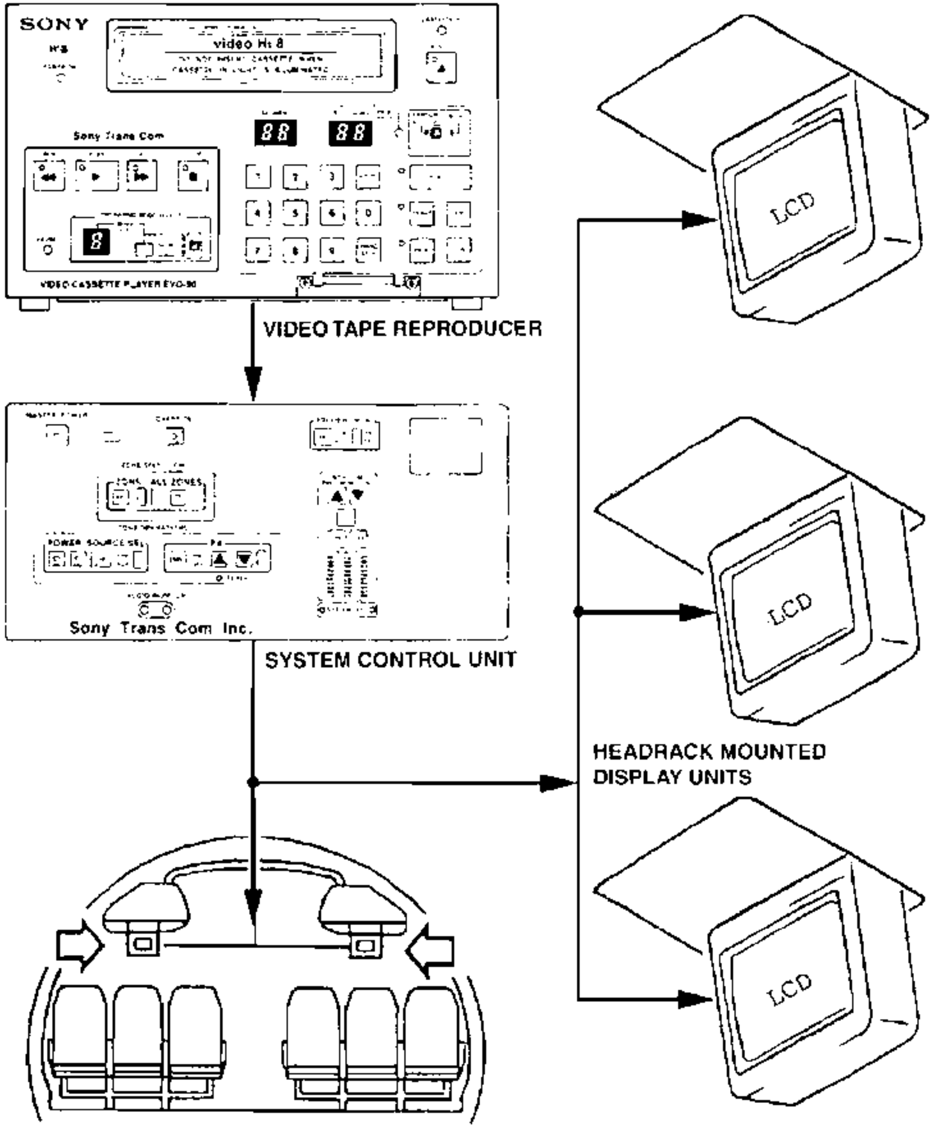
Different controls allowing the management and distribution of video and sound to the cabin. Following controls are possible:

- Power switching
- Signal source selection VTR or Information System
- Monitor selection (Display Units) in various cabin areas
- Previewing of a video

Headrack Mounted Display Units

Retractable TFT screen (about 20pcs.) are located in the headrack overhead the passenger. They are stowed if the system is not in use, or an unexpected force is applied i.e. passengers head touches the screen.

Figure 9: Video Entertainment and Information System



Passenger Visual Information System

The Passenger Visual Information System supplies the Passengers with information on ambient aircraft flight data, times and aircraft position in the flight plan. The information is displayed on the monitors of the Passenger Entertainment System.

The system receives data from various Navigation Systems and the Aircraft Communication Addressing and Reporting System (ACARS).

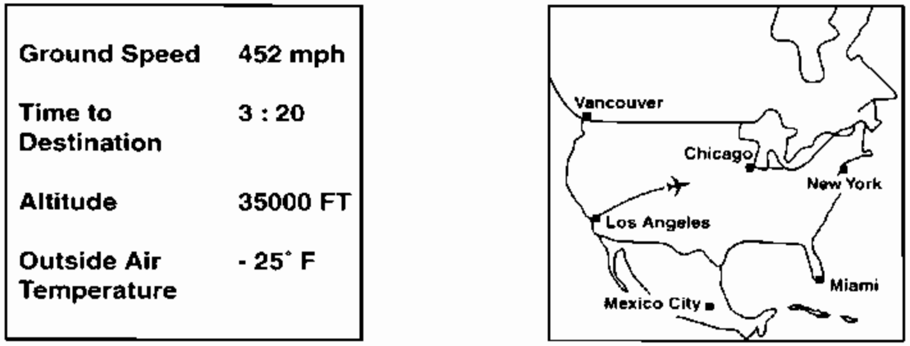
The RCU is the input unit on which the shown information is selected by the use of menus. Its front plate has four switches in line under an LCD for control.

The DIU computer processes data for use with the stored menus, transforms the digital data into video signals and sends them to the monitors. The available information menus and the data used from the different input buses (e.g. altitude, static air temperature, heading & drift angle, ground speed & present position).

The subsequent information can be selected and shown to the passengers:

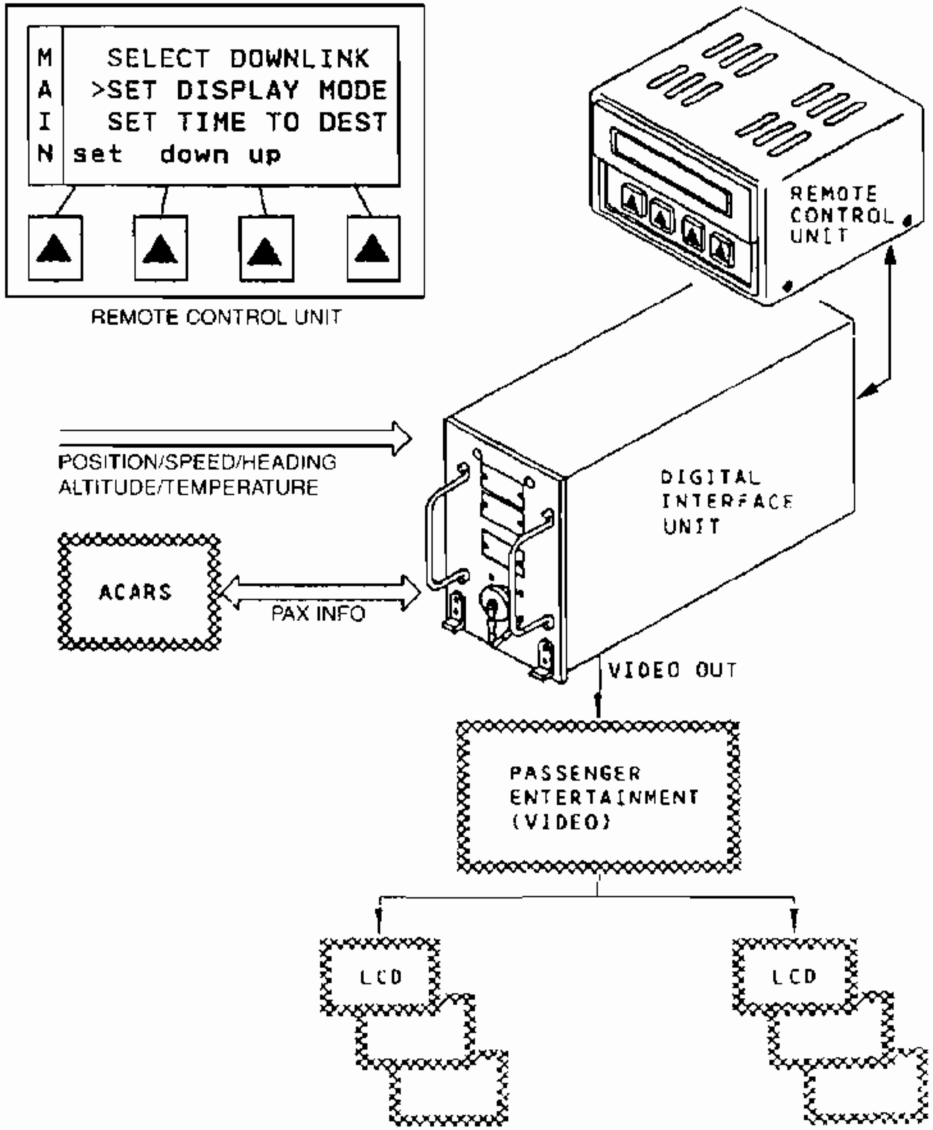
- Airline logo or other symbols
- Present aircraft ground speed
- Time required to reach the destination
- Present flight altitude
- Outside air temperature
- Local time at the destination airport
- Flight route already completed on differently scaled maps
- Present aircraft position on differently scaled maps
- Special points of interest along the flight path on a map.

Figure 10: Info and Map Display



Ground Speed	**452 mph**
Time to Destination	**3 : 20**
Altitude	**35000 FT**
Outside Air Temperature	**- 25° F**

Figure 11: PVIS



Passenger Entertainment System PES

Longhaul aircrafts will be equipped with more complex systems. This systems may comprises total entertainment features.

Video on individual screens

Music and film track sound

Interactive Games

Inseat Telephone

Passenger Control Units and/or Passenger Handsets is used to control the PES/PSS. For the satellite telephone system the reverse side of the handset is used.

A very important function, the Passenger Address system must interrupt all other inputs to the loudspeakers and to the displays and earphones in the seat in order to get all the passengers attention.

Figure 12: PES Audio and Interface to PSS simplified

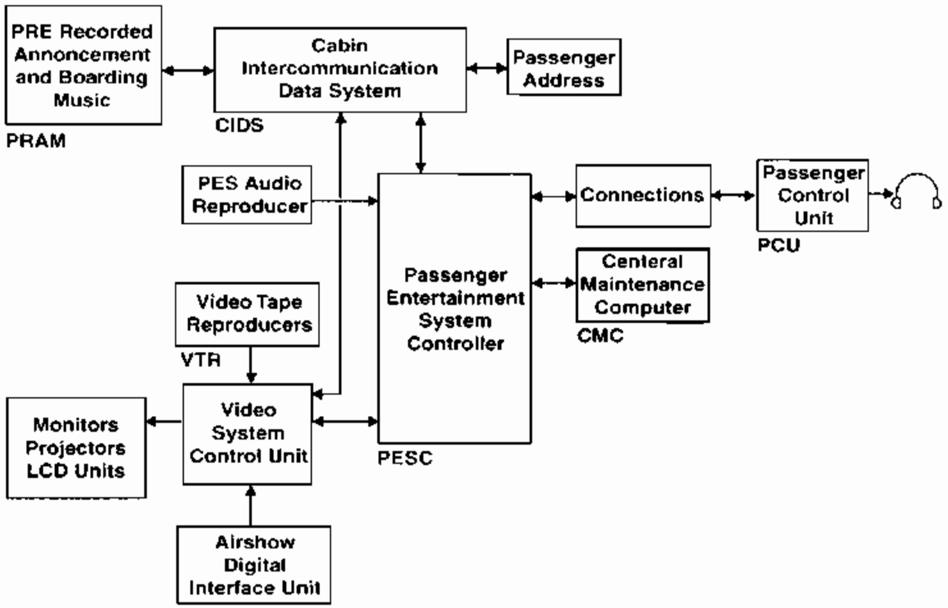


Figure 13: Passenger Control Unit (PES Controls)

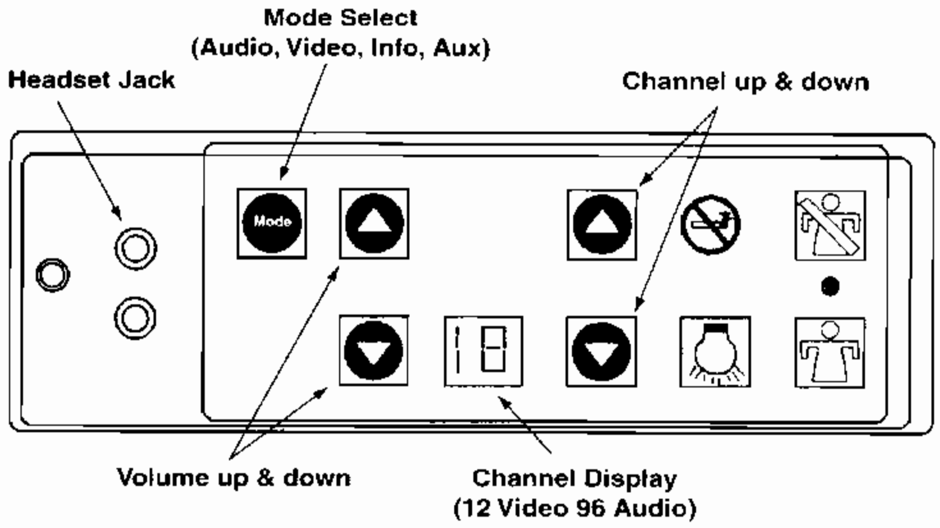
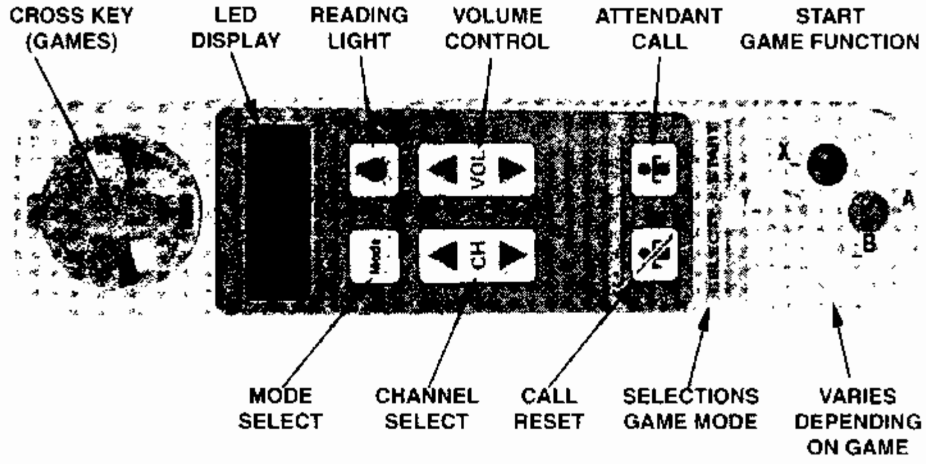


Figure 14: Passenger Handset (PES and PSS Controls)



Passenger Service System

Reading light control and attendant call is controlled via this subsystem. In compare with conventional wiring, a reduction of wiring will result.

A passenger reading light command for example, coming from the handset in the seat passenger control unit, takes its way through the passenger entertainment system controller and further on to the CIDS system where the correct passenger service unit above a seat must be adressed and the correct reading light must be illuminated.

Both systems, the CIDS and the Passenger Entertainment System must work correctly together to make sure that all functions are available.

Figure 15: Passenger Service Unit

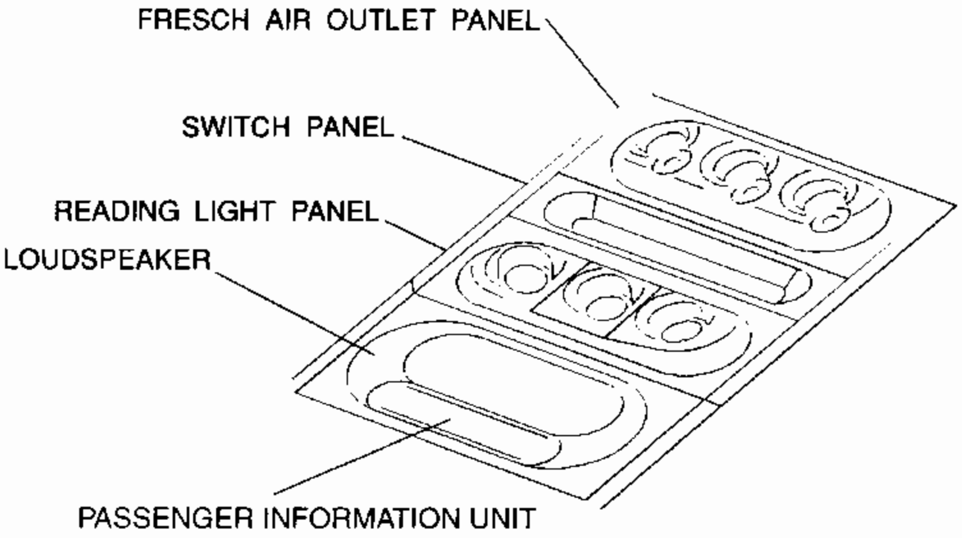


Figure 16: Passenger Control Unit (PSS Controls)

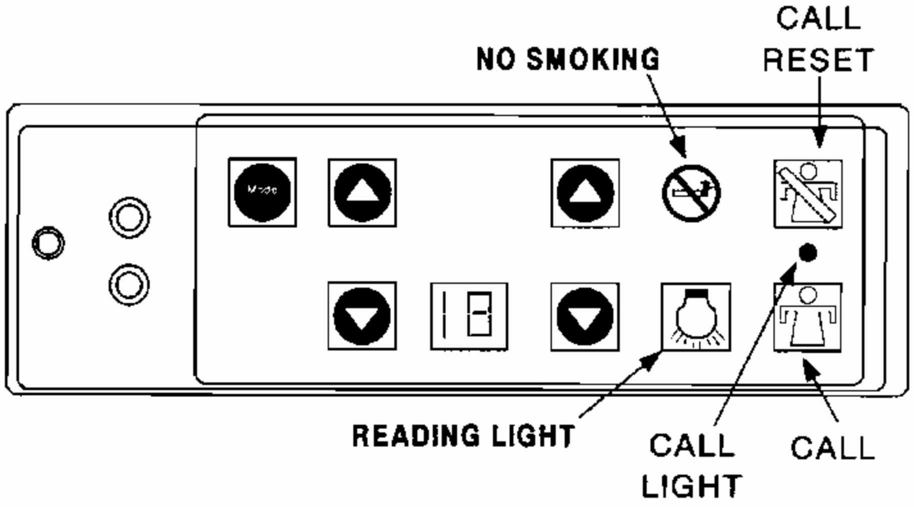
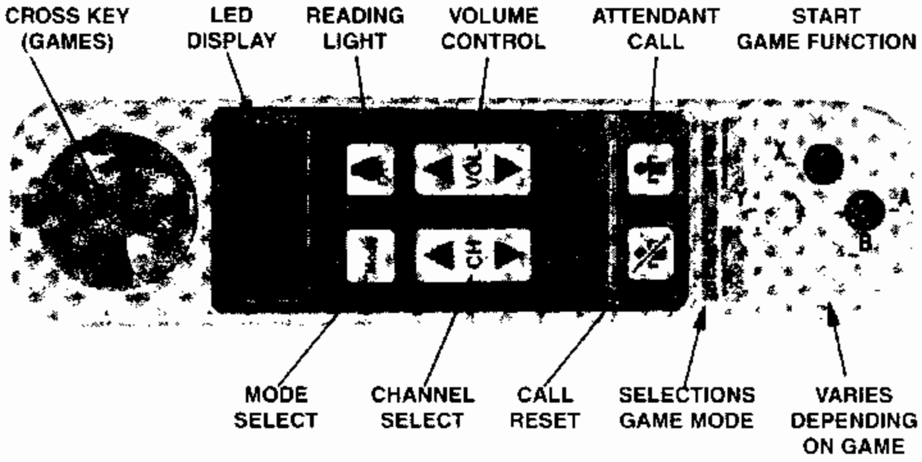


Figure 17: Passenger Handset



Matsushita System 2000E

The design of passenger entertainment and service systems is continiously developing. On following pages the MAS2000 is shortly explained.

System 2000E is an interactive, fully integrated passenger entertainment system. The system is designed with a modular approach to support both Overhead and In-seat Video, Audio, Telephone, and Interactive Services.

Audio Up to 96 Channels of Hi-Fi Audio

- Up to 48 Digital Audio Inputs
- Up to 72 Analog Audio Inputs
- Up to 6 Passenger Address (PA) Inputs

Video Up to 24 Video Channels. Supporting a wide variety of inputs:

- Video Cassette Players
- TV Tuners
- Passenger Video Information Systems
- Video Cameras
- Video On Demand (VOD)

Telephone Telephone services can be made available at each seat:

- Air-to-Ground calls
- Seat to seat calling
- Fax and Data transmission

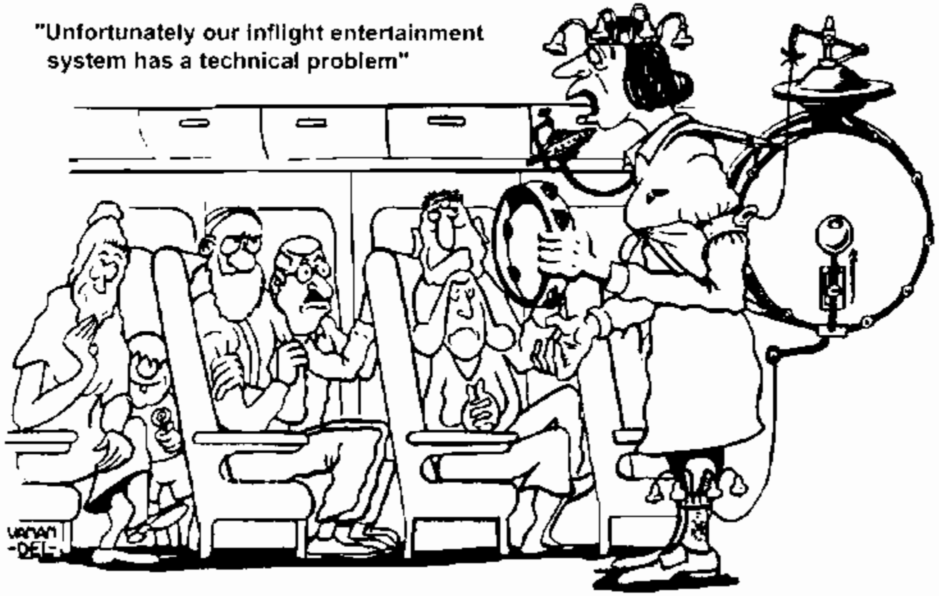
Interactive A variety of interactive options to customize the cabin environment and passenger experience:

- Video Games
  - Nintendo
  - Windows-based
- Shopping Services
- Business Services
- Passenger Information Services
- Program Information
- Audio/Video

Passenger Service System provides the passenger with an interface to:

- Reading Lights
- Attendant Call Lights

Figure 18:



INSEAT AUDIO

System 2000E audio is digitized using Adaptive Pulse Code Modulation (ADPCM) techniques for data compression. Adaptive PCM techniques have proven better audio quality, especially in regard to low frequency dynamic range. This provides the quality of CD audio without excessive bit rates. Audio system flexibility is achieved by using a combination of digital audio and analog audio inputs.

Audio Quality Specifications

Frequency response (Hi-Fi)	40 Hz -15 kHz
Dynamic range	> 70 dB
Signal-to-noise ratio	> 60 dB
Crosstalk	> 60 dB
Total harmonic distortion	< 1 % at 1 kHz

EVSCU Audio Signal Flow

Analog audio inputs from Compact Disk Reproducers (CDRs) and Audio Reproducers (ARs) are converted to digital, compressed and multiplexed, the digitized audio data stream.

The audio is then combined with the RF Video inputs. The EVSCU then outputs a combined RF video/ADPCM audio signal to the EPESC over a coaxial line. It must be noted that the RF Video will only be input to the EVSCU in some Airbus configurations, to be combined with ADPCM audio and be sent on the EPESC. In most cases, the RF video does not input to the EVSCU inputs are compressed, multiplexed and inserted into the EPESC.

ADPCM stands for Adaptive Differential Pulse Code Modulation. This is a 16 bit digital audio signal that has been compressed to 4 bits. This allows a large signal to be transmitted much faster than it was not compressed.

EPESC Audio Signal Flow

Analog audio from Compact Disk Reproducers (CDRs), Audio Reproducers (ARs) and analog PA audio from the aircraft PA system, is sent to the EPESC and digitized. The digitized audio is inserted (either inside/or outside of the EPESC) into the RF video/audio data stream and sent to the EADBs, and IVASEBs where it is demultiplexed into analog audio and sent to the headphones.

INSEAT VIDEO

The Inseat Video is the portion of the system that provides passengers with video at their own LCD mounted in the seat. Passengers can select from a number of RF video channels, including Airshow at the seat, depending on the system software configuration.

Video games and interactive programs are transmitted by the CMEU over the Token Ring LAN and do not use an RF video channel.

Inseat Video Signal Flow

The signal used by the Inseat Video System starts in the same manner as the overhead video system. The Flight Crew manually controls the VCPs from the CMT.

The VCP sends a baseband composite video output to the VMU, which amplitude modulates the signal on an RF carrier.

The RF video (on some Airbus configurations) is then sent to the EVSCU. In most cases however, the RF video will go to a Combiner(s)/Splitter(s) for distribution to the EADBs.

For some Airbus configurations, the EVSCU adds the audio portion of the video program it receives from the VCPs (after digitizing and compressing it from 16 to 4 data bits) to the RF signal.

The RF signal is then sent to the EPESC. The EPESC routes the RF signal to the to the EADBs. The EADBs output the RF signal to the IVASEBs in up to 5 columns.

Each IVASEB then demodulates the RF video signal, de-multiplexes the audio signal, converts it from digital to analog, and supplies the video output to the LCDs for display while the audio is sent to the Remote Jack Module or Headset.

The Handset controls the IVASEB, providing volume control and selection of which video channel to display.

EVSCU	Enhanced Video System Control Unit
EPESC	Enhanced Passenger Entertainment System Controller
EADB	Enhanced Area Distribution Box
IVASEB	Integrated Video Audio Seat Electronics Box
CMEU	Cabin Passenger Management System Memory Expansion Unit
VMU	Video Modulation Unit

Figure 19: PES Inseat Audio

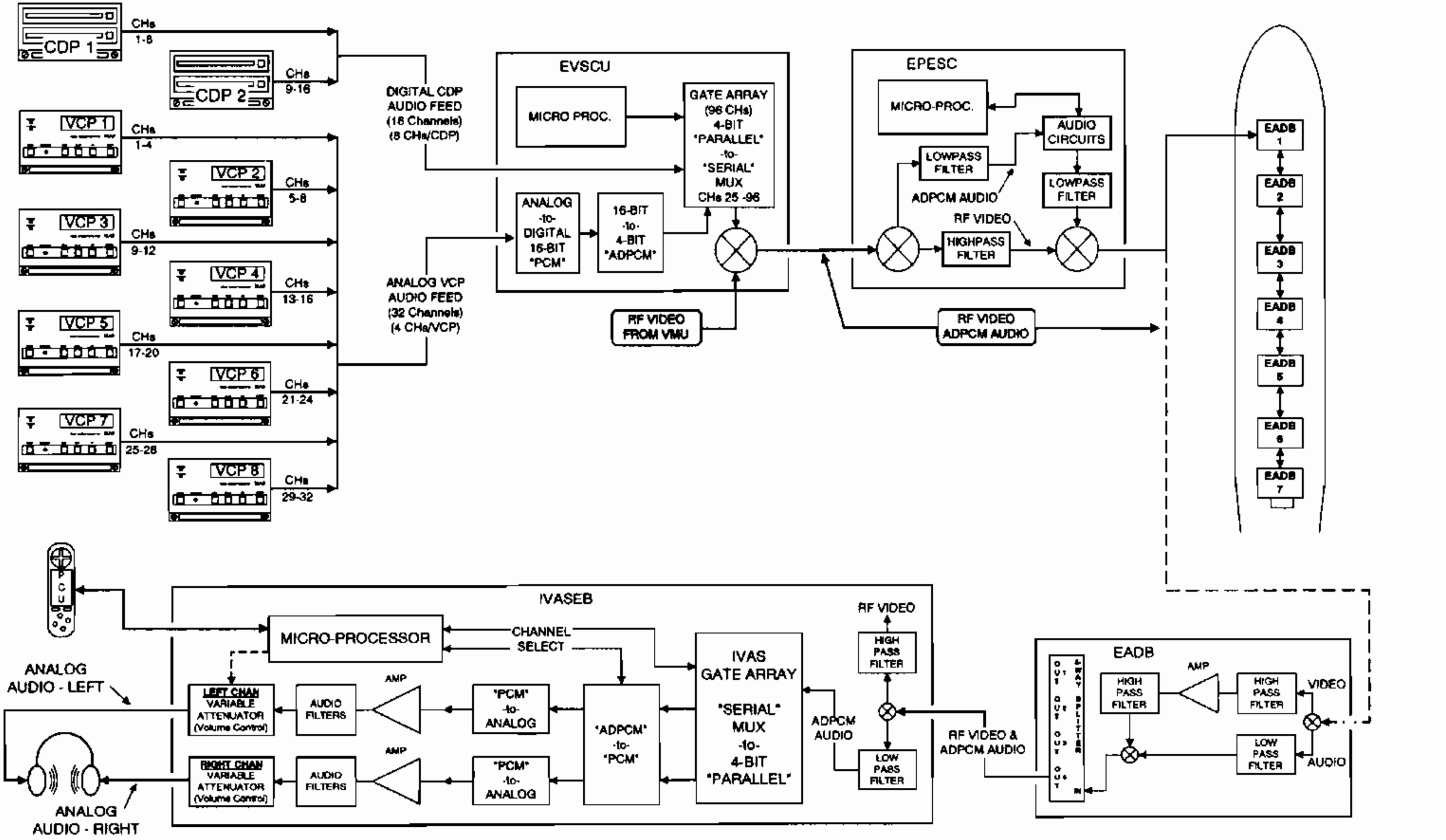
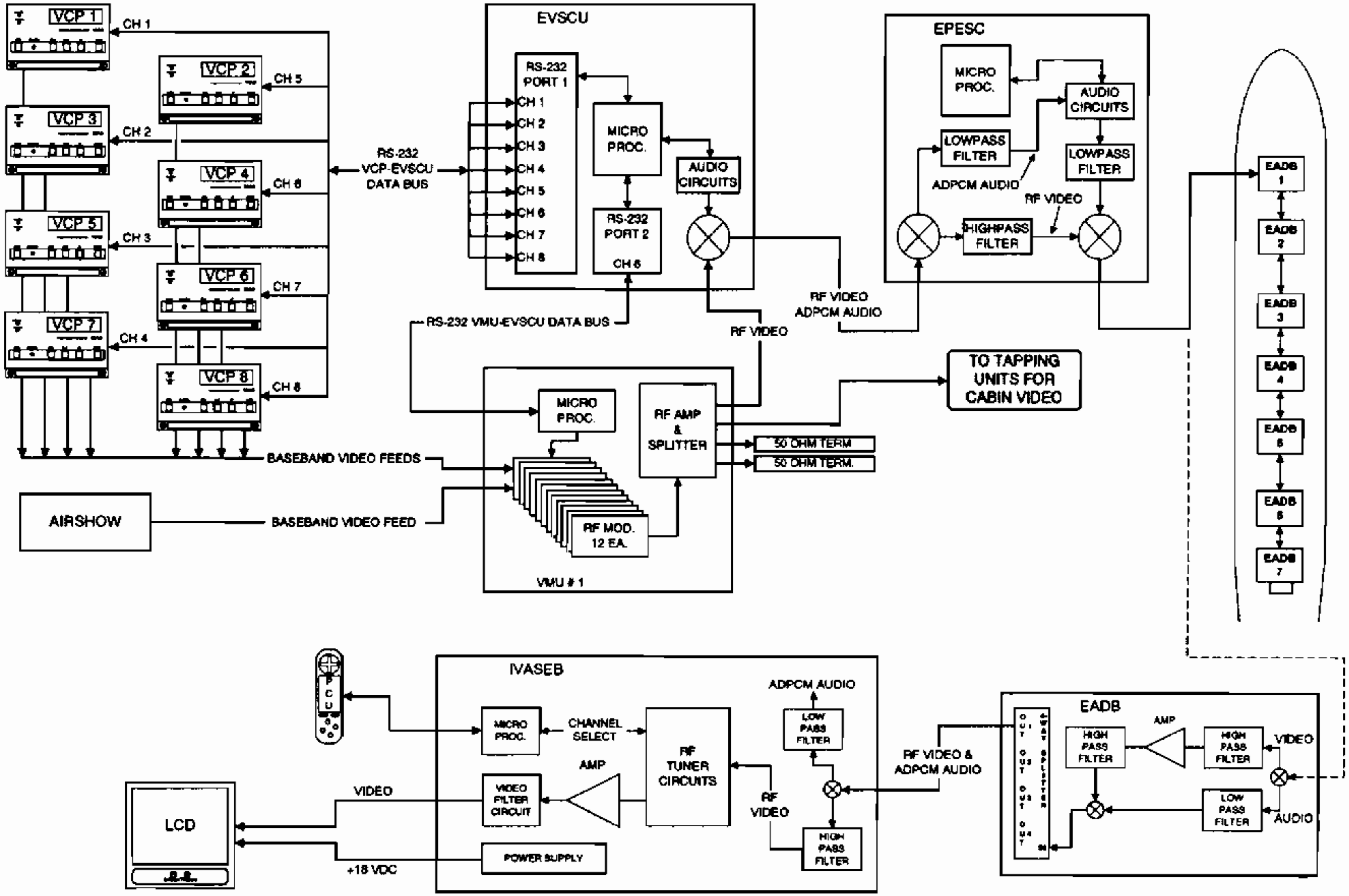


Figure 20: PES Inseat Video



RF Distribution

RF (Cable Television System) - The system supports up to 27 input-to-output channels of modulated video. This is similar in fashion to the Cable TV found in the home. It is also includes audio on the same coaxial cable(s).

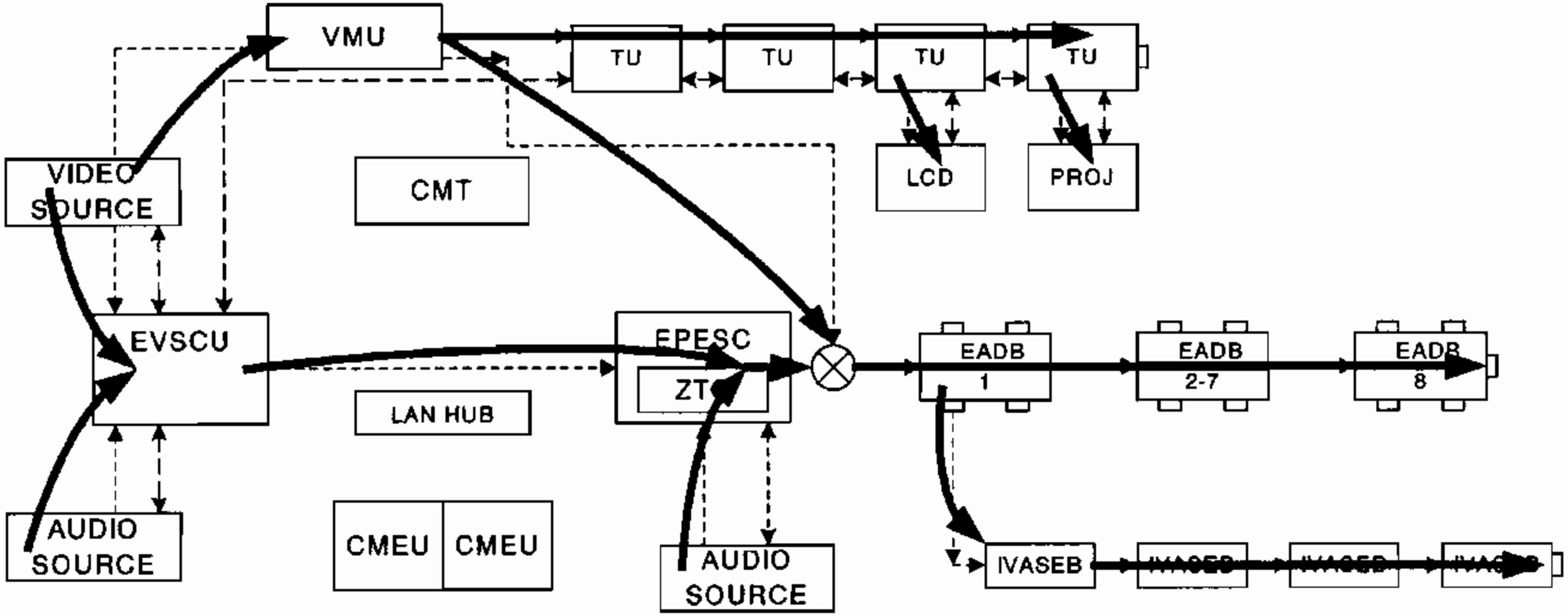
The Source of the Video sends video to the VMU. The VMU sends the video to the Overhead Display Units through the TUs. The VMU also sends the video to a combiner to add audio.

The Audio Source(s) send audio to the EVSCU or the EPESC. The EVSCU sends audio to the EPESC. The EPESC sends the audio to the combiner to add with the video from the VMU.

The combiner adds the video and audio together. The combined video and audio is sent to the EADB's. The EADB's split the video and audio for four columns of IVASEB's. This is one-way communications from the Sources and Controllers through distribution units to the seats.

Video Source	Video Cass. Players, Camera PVIS,
Audio Source	CD players, Video, Passenger Address
EVSCU	Enhanced Video System Control Unit
VMU	Video Modulator Unit
CMT	Cabin Management Terminal
EPESC	Enhanced Passenger Entertainment System Controller
TU	Tapping Unit
LCD	Liquid Cristal Display (Video)
PROJ	Cabin Video Projector
EADB	Enhanced Aera Distribution Box
IVASEB	Integrated Video Audio Seat Electronics Box

Figure 21: RF Distribution



NETWORK (LAN) Distribution

The Token Ring Network (LAN) - most System 2000E LRUs communicate on a 16Mbps Token Ring Network. This Local Area Network (LAN) is similar to that found in office buildings.

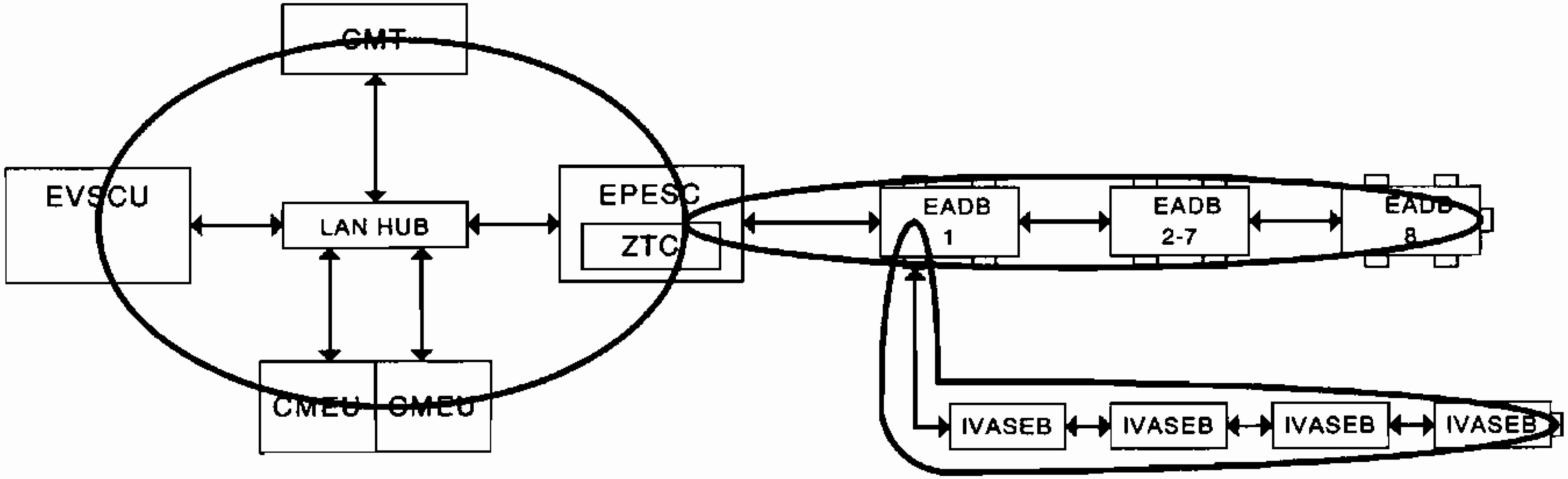
A Token Ring Network operates in one direction throughout a continuous circle. This LAN carries out command and Control data, as well as requests for data, files, or BITE. It must remain as a closed loop (a circle) in order to have correct operations.

The Token Ring LAN Hub connects all the System Controllers. The EPESC connects from the controllers to the EADBs. Each EADB can connect the Token Ring Network through a maximum of four columns of IVASEBs.

The VEADB may also connect to the ZIUs for Token Ring communications.

CMEU	Cabin Passenger Management System Memory Expansion Unit (System file server for operating system software and games)
EVSCU	Enhanced Video System Control Unit
CMT	Cabin Management Terminal
EPESC	Enhanced Passenger Entertainment System Controller
ZTC	Zone Telephone Controller
LAN HUB	Data distribution point 12 Ports
EADB	Enhanced Area Distribution Box (8 pcs)
IVASEB	Integrated Video Audio Seat Electronics Box

Figure 22: Network Distribution



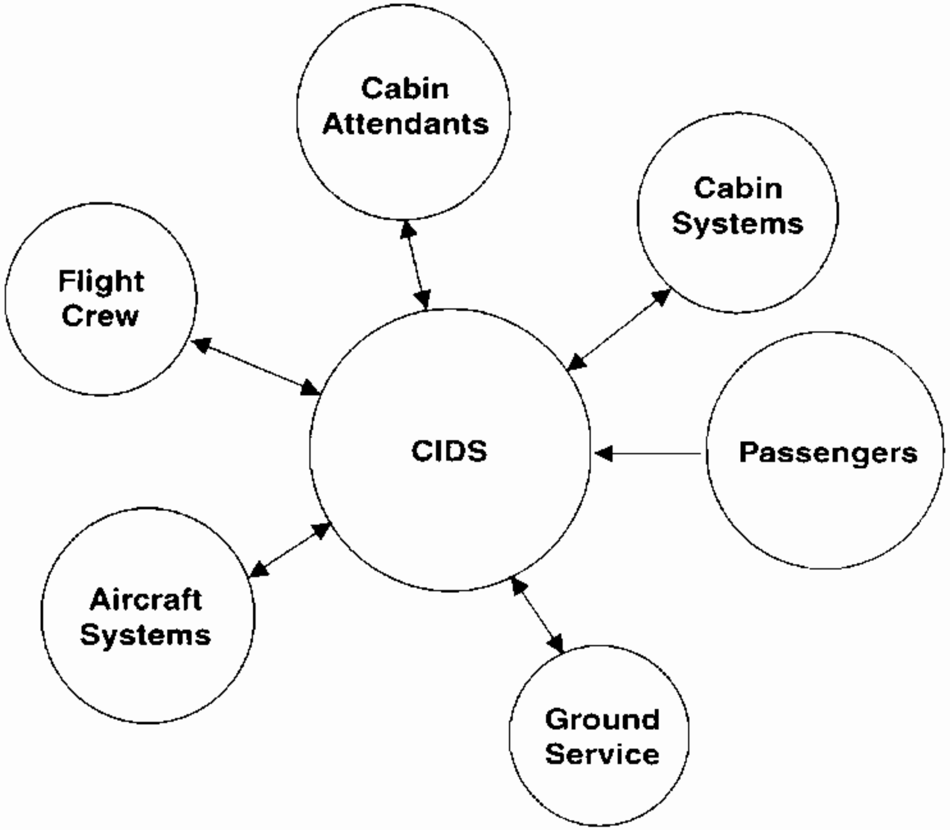
Cabin Intercommunication Data System

Intoduction

The CIDS integrates most of the Cabin systems for communications, indications and calls. The systems integrated/controlled by the CIDS are:

- passenger adress
- cabin and flight crew interphone
- cabin illumination
- evacuation signalling
- lavatory smoke indication
- passenger lighted signs
- passenger call
- service interphone
- emergency lightning test
- passenger reading lights/attendent work light test
- prerecorded announcement and boarding music control
- passenger entertainment system
- air conditioning system controls

Figure 23: CIDS Functions



CIDS Architecture

Functions

The CIDS provides control, monitoring and data processing of various cabin systems through DATA BUS lines.

Director

The DIRECTORS are the major components of the CIDS.They act as an interface between the aircraft and cabin systems and the cockpit controls and indicating in order to process the controls of the cabin systems.

Forward Attendant Panel

The Forward Attendant Panel (FAP) is installed at the Forward Attendant Station. From the FAP, the various cabin systems can be controlled and monitored.

The Cabin Assignment Module (CAM) is part of the Forward Attendant Panel (FAP). The CAM is plugged into the FAP. It stores all the cabin layout and programmable information used by the DIRECTORS.

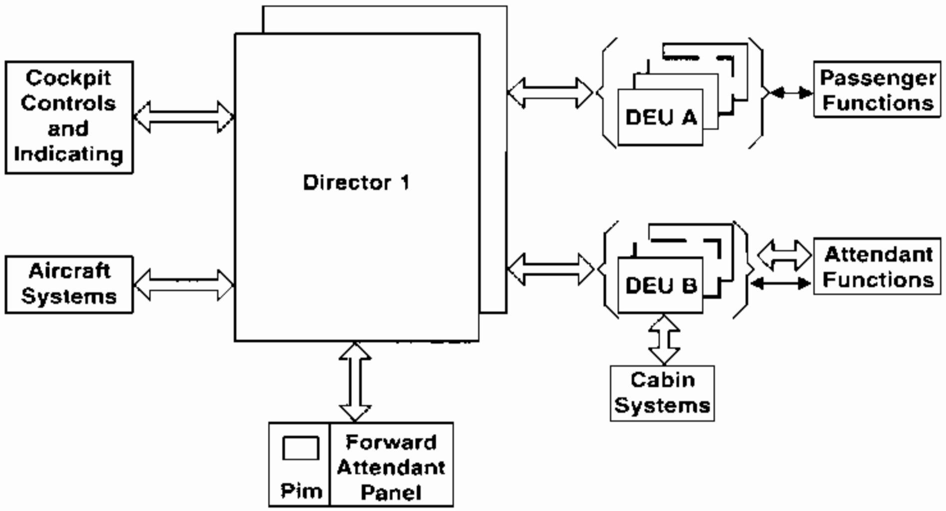
Decoder Encoder Unit A (DEU A)

Decoder Encoder Unit A (DEU A) is a component of the CIDS. It provides an interface between the DIRECTORS and the cabin systems dedicated to passenger use. The DEUs A are connected to the DIRECTORS through DATA BUS lines.

Decoder Encoder Unit B (DEU B)

Decoder Encoder Unit B (DEU B) is a component of the CIDS. It provides an interface between the DIRECTORS and the cabin systems dedicated to Cabin Attendant use. The DEUs B are connected to the DIRECTORS through DATA BUS lines.

Figure 24: Architecture



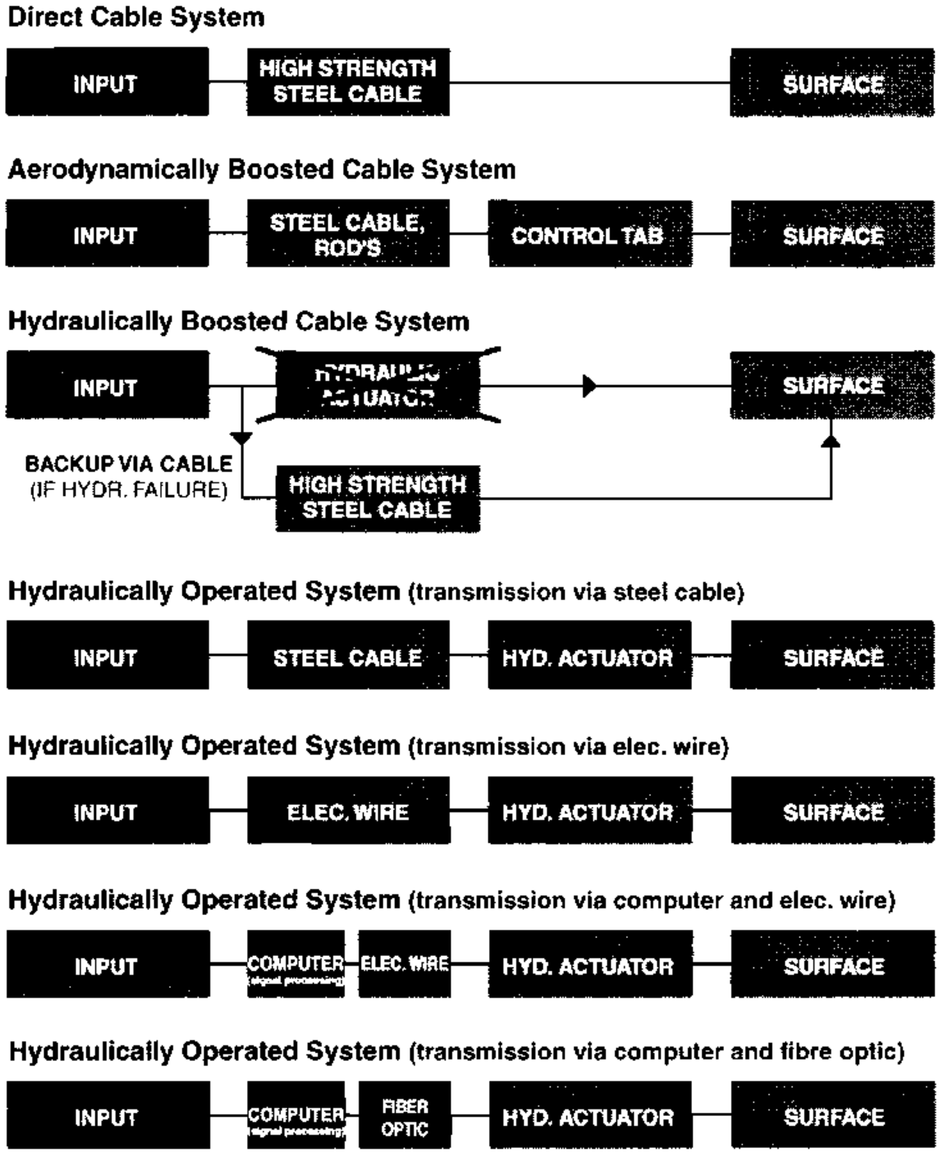
13.7 Flight Controls (ATA 27)

Primary Control System Operating Methods

Different aircraft manufacturers call units of the primary flight control system by a variety of names. The types and complexity of control mechanisms used depend on the size, speed, and mission of the aircraft. A small or low-speed aircraft may have cockpit controls connected directly to the control surface by cables or pushrods. Some aircraft have both cable and a pushrod system. The force exerted by the pilot is transferred through them to the control surfaces. On large or high-performance aircraft, the control surfaces have high pressure exerted on them by the airflow. It is difficult for the pilot to move the controls manually. As a result, hydraulic actuators are used within the linkage to assist the pilot in moving the control surface. Because these systems reduce pilot fatigue and improve system performance, they are now commonly used. Such systems include automatic pilot, automatic landing systems, and stability augmentation systems.

See Figure 1 on page 2 for the different operation, transmission and actuation methods.

Figure 1: Operation Methods



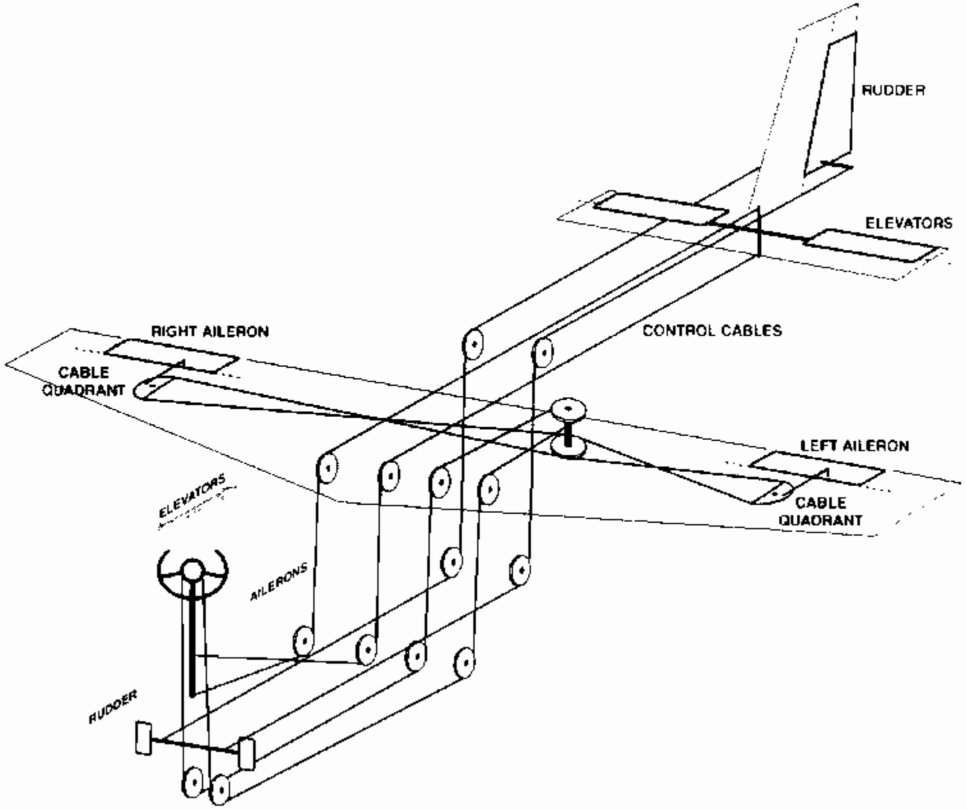
Direct Cable Control Systems

In the direct cable control system, the cockpit controls are connected to the control surfaces with high-strength steel cable. Operation of the control column places tension on the cable. As the cable passes through the fuselage, it is supported by the pulleys. The pulleys also enable the direction of the control cable to be changed. Tension of the control cable system is critical. This kind of control is only usable in low speed general aviation aeroplanes. See Figure 2 on page 3. The force the pilot feels on the steering column while steering the plane, is in direct relation to the airspeed.

Therefore:

The higher the airspeed, the greather the force on the steering column.

Figure 2: Direct Cable Flight Control System using Steel Cables



Aerodynamically Controlled Control System

The control tabs are controlled by the control wheels in the flightdeck so that as one tab moves up, the opposite tab moves down. The ailerons, in this case, are operated aerodynamically. When the control tabs are deflected, aerodynamic forces on the tabs move the ailerons in the opposite direction.

Figure 3: Aerodynamically Controlled Control System

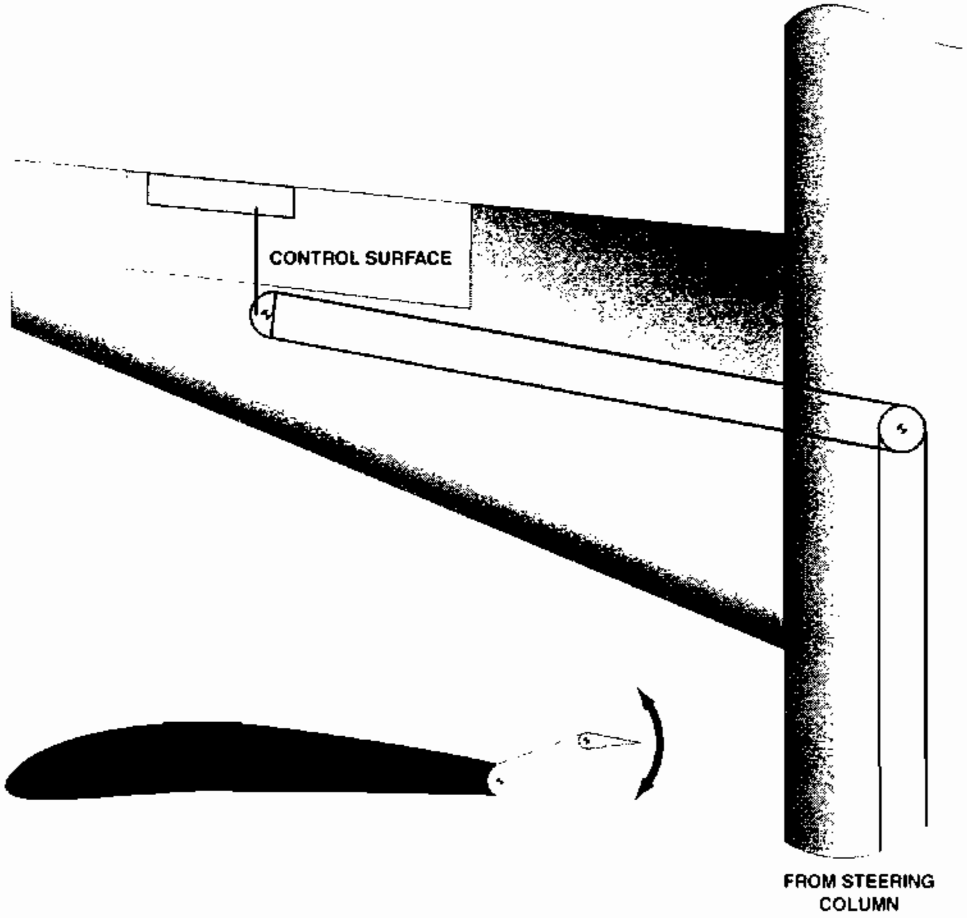
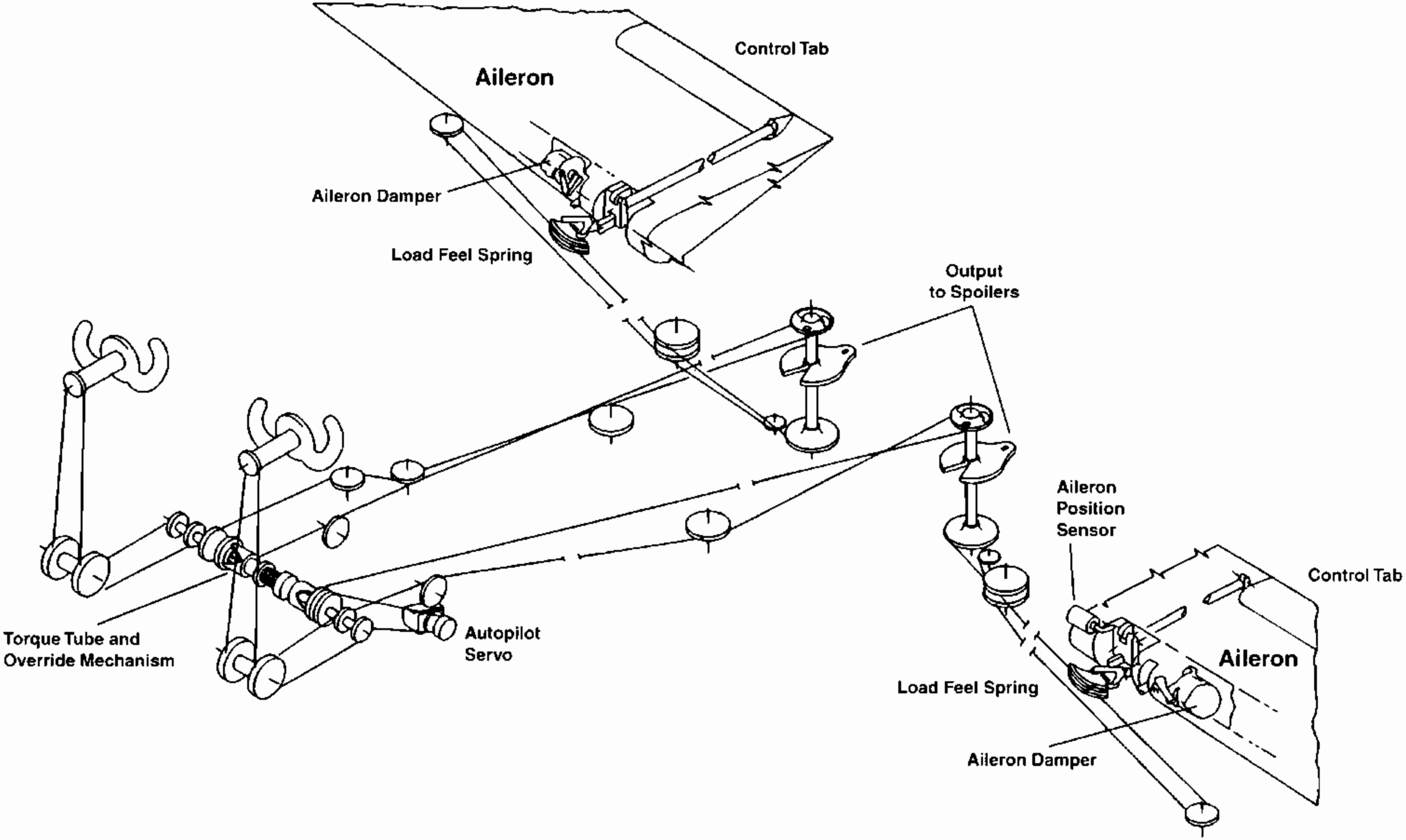


Figure 4: Aerodynamically Controlled Aileron Control System



Hydraulically Assisted Control System

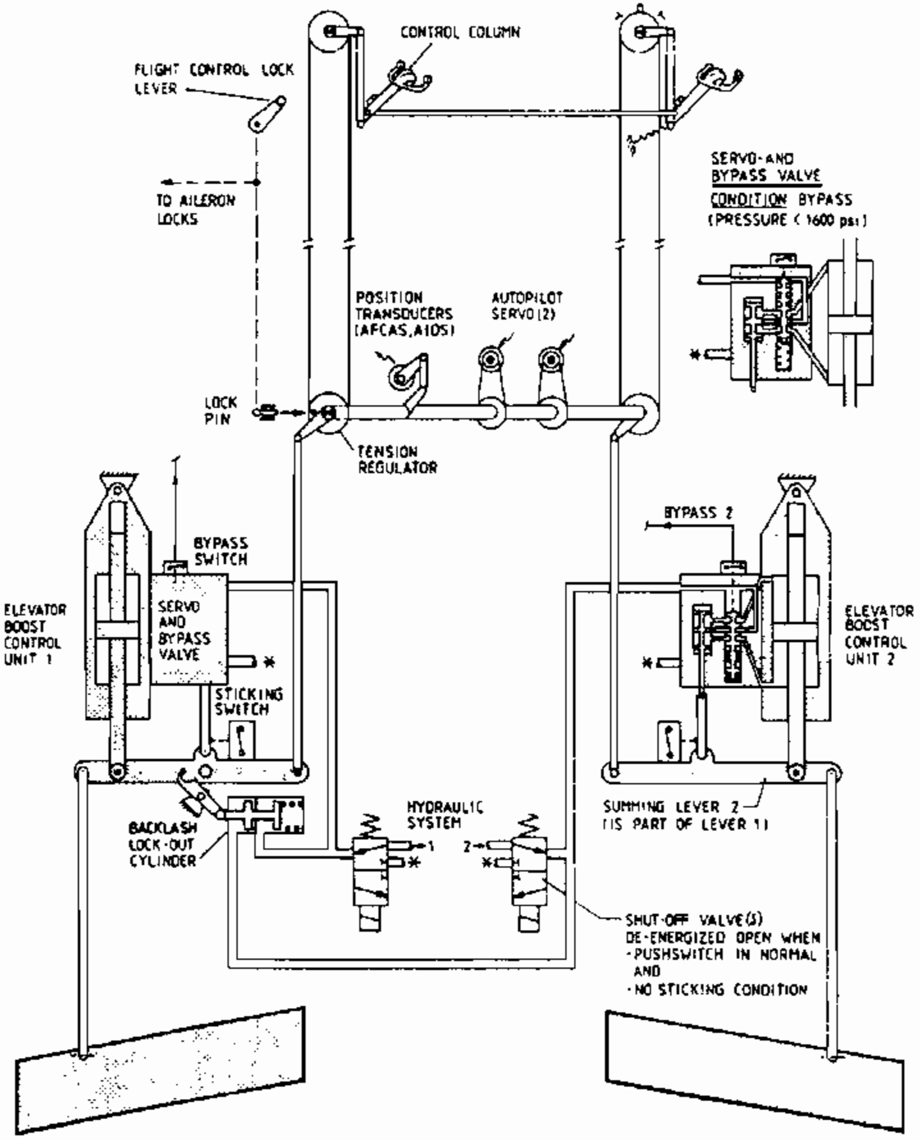
As aircraft increase in size and weight, their controls become more difficult to operate and systems must be used to aid the pilot. The power boosted control system is similar in principle to power steering in an automobile. A hydraulic actuator is in **parallel** with the mechanical operation of the controls, and in addition to moving the control surface, the normal control movement by the pilot also moves a control valve that directs hydraulic fluid to the actuator that moves the surface.

Hydraulically Actuated System with Direct Cable Backup

It is to say, that these days the described system is replaced with a more advanced architecture. In normal operation, the direct connection between the steering column and the control surface is in a disconnected mode, and the input coming from the flightdeck is only directed to the actuators control valve. In case of a hydraulic power failure, the hydraulic actuator is bypassed and the input force coming from the steering column is directed directly to the control surface.

It is obvious, that the necessary force to move the control surface is much higher in this mode.

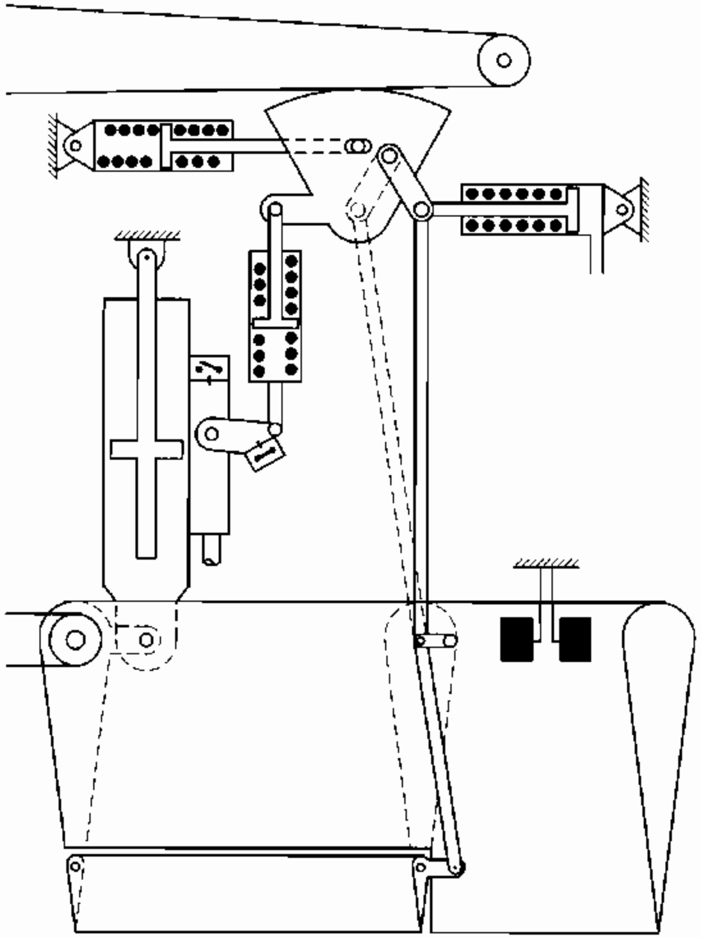
Figure 5: Hydraulically Actuated System with Direct Cable Backup



Hydraulic Actuating System with Control Tab Backup

In the event of a hydraulic system failure, the control forces are too great for the pilot to manually move the surfaces, so, they are controlled with servo tabs. In the manual mode of operation, the flight control column moves the tab on the control surface, and the aerodynamic forces caused by the deflected tab move the main control surface.

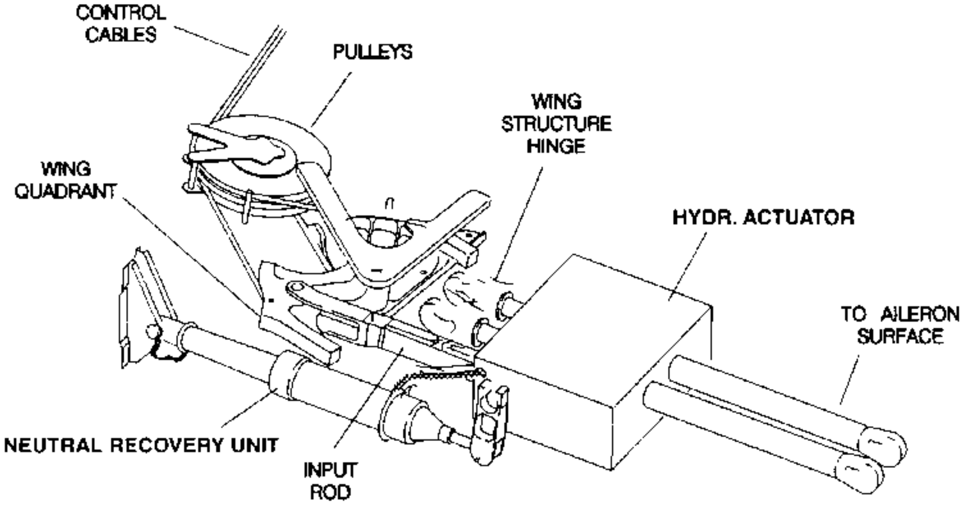
Figure 6: Tab Backup



Hydraulic Power Operated Systems

Boosted flight control systems are found in aeroplanes lighter than approximately 60 tons, in heavier aeroplanes the servo tabs would be to big and need too much force for manual operation of the system. Another problem with a power-boosted control system is that during transonic flight shock waves form on the control surfaces and cause control surface buffeting, and this force is fed back into the control system. To prevent these forces reaching the pilot, many aeroplanes that fly in this region of airspeed use a power-operated irreversible control system. The flight controls in the cockpit actuate control valves which direct hydraulic fluid to control surface actuators.

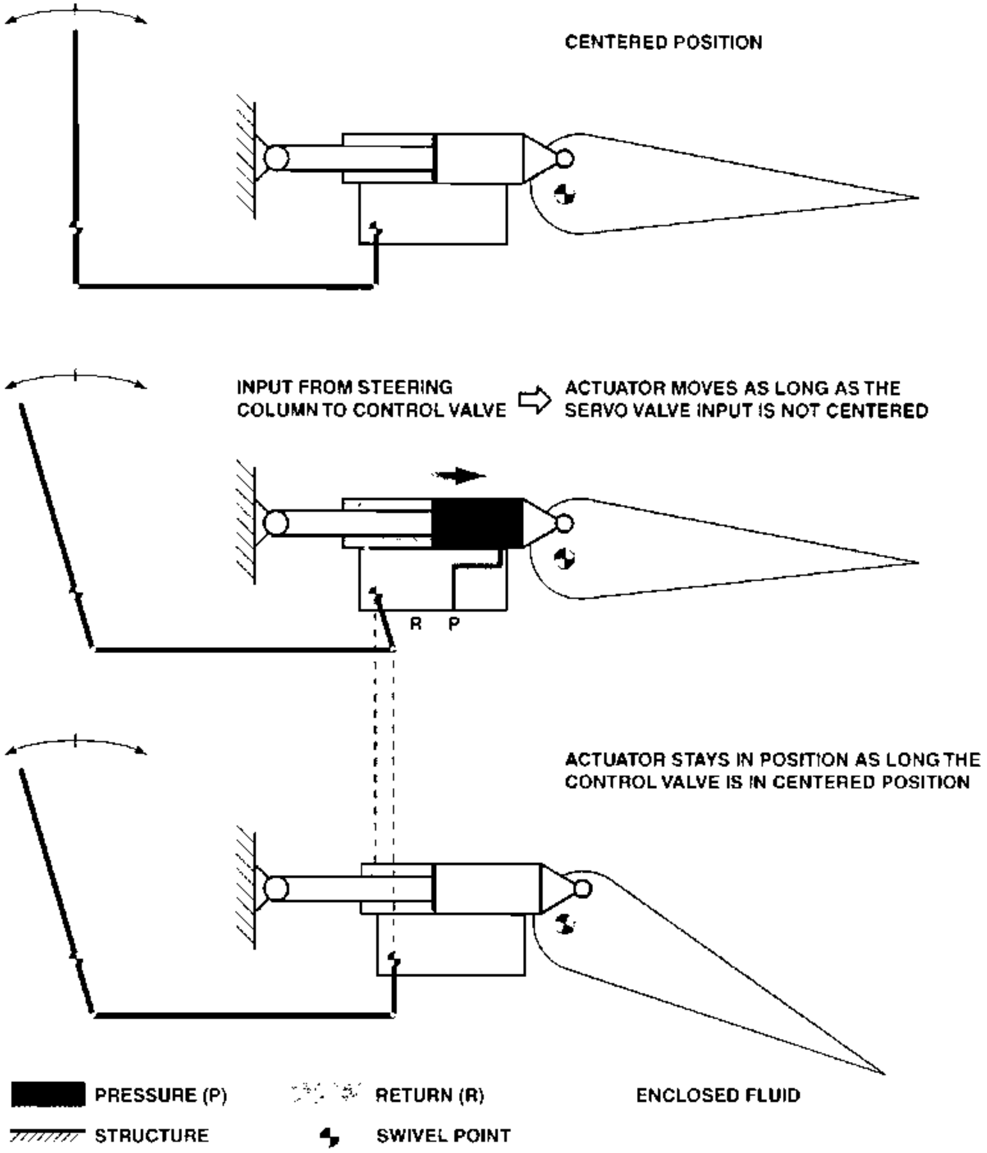
Figure 7: Hydr. Actuator with Control Cables



Follow-up Control

Some kind of follow-up system is used to close the control valve of a servo control unit when it has reached the desired position. Figure 8 on page 8 shows a typical mechanical follow-up system.

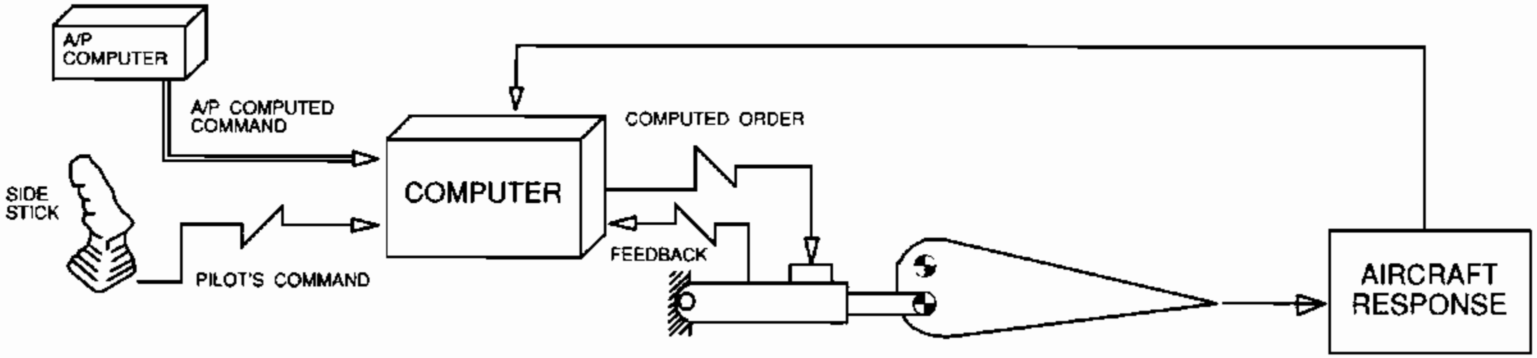
Figure 8: Mechanical Follow-up Control



Fly-By-Wire Systems

Modern aeroplane designs like the airbus A320 or the Boeing 777 use fly-by-wire systems to connect the flight control surfaces to the cockpit controls with electrical wires, rather than with steel cables, push-pull tubes, torque tubes, or other mechanical methods. The cockpit controls are devices that convert the movements or pressures exerted by the pilot into electrical signals which are sent into a computer programmed with all of the flight characteristics of the aeroplane. The computer output is directed through more wires to electro-hydraulic valves that convert the electrical signal into hydraulic fluid flow. This flow changes the position of a main control valve, which directs hydraulic fluid to the appropriate control actuators. Within the actuators, linear variable displacement transducers complete the loop and send feedback signals to the computer, informing it of the amount of actuator movement. Rather than using a control wheel or stick that actually moves, some fly by-wire-equipped aeroplanes have sidestick controllers to fly the aeroplane. Pressures exerted on the controller mounted on the cockpit side console are converted into electrical signals, just as are movements of conventional controls. The Airbus fly-by-wire aeroplanes use a sidestick controller.

Figure 9: Fly by Wire Block Diagram



Advantages of Fly By Wire Systems (Flight Laws)

In normal configuration (no system failures and aircraft airborne) the aircraft is called in NORMAL LAW. In this law, the computer supports the pilot controlling elevators in a turn, lateral attitude hold, automatic pitch trim, turn coordination, dutch roll damping and engine failure compensation.

It also prevents unsafe manoeuvres. Even if a side stick is pulled fully backwards, which would normally lead to a stall, the maximum angle of attack and the pitch attitude are limited by the computer.

Information of many other computers such as airdata, inertial reference (A/C response), slat / flap positions, flight or ground etc. are sent to the flight control computers to calculate and prevent dangerous situations like extrem attitudes (pitch and roll), overspeed, exessive loads factors and stall.

Redundancy / Fail Safe

Hydraulic operated primary flight control system are often designed redundant, this mean two or three actuators (servo control unit) perform the same function, fed from independent hydraulic systems. As discribed before, modern systems are controled through flight control computers. For safety reasons, more than one computer can perform exactly the same function. Usually, one computer is in active mode and performs the real control action, the others are in hot standby mode and monitor the active computer. In case of a failure of the active system, an automatic changeover will take place what brings the faulty computer in an isolated state. See Figure 11 on page 11.

Another form of fail safe operation of the powered flight control is to use split controls, in this case each control surface has its own PFCU supplied by a separate hydraulic system. A loss of a PFCU or a hydraulic system would allow partial control to be maintained. The figure indicates the split control surfaces on a typical jet transport aircraft.

Figure 10: Redundant Hydraulic Power Operated System

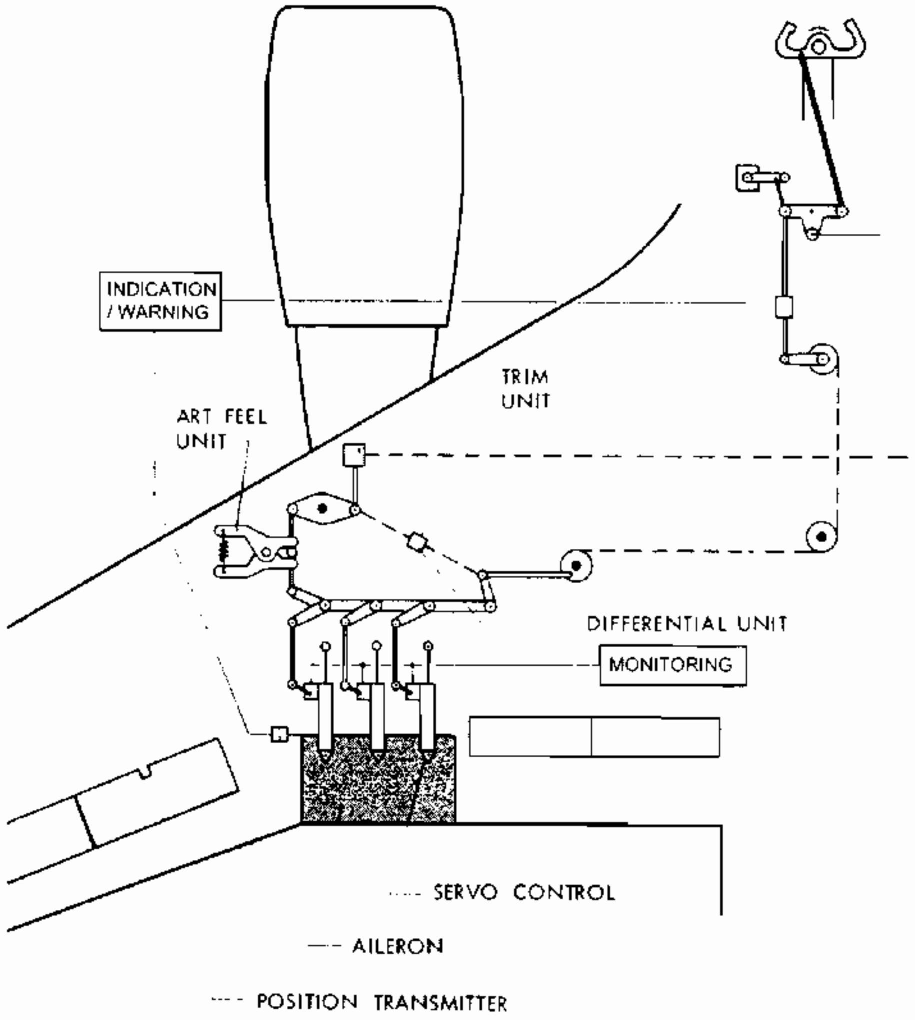
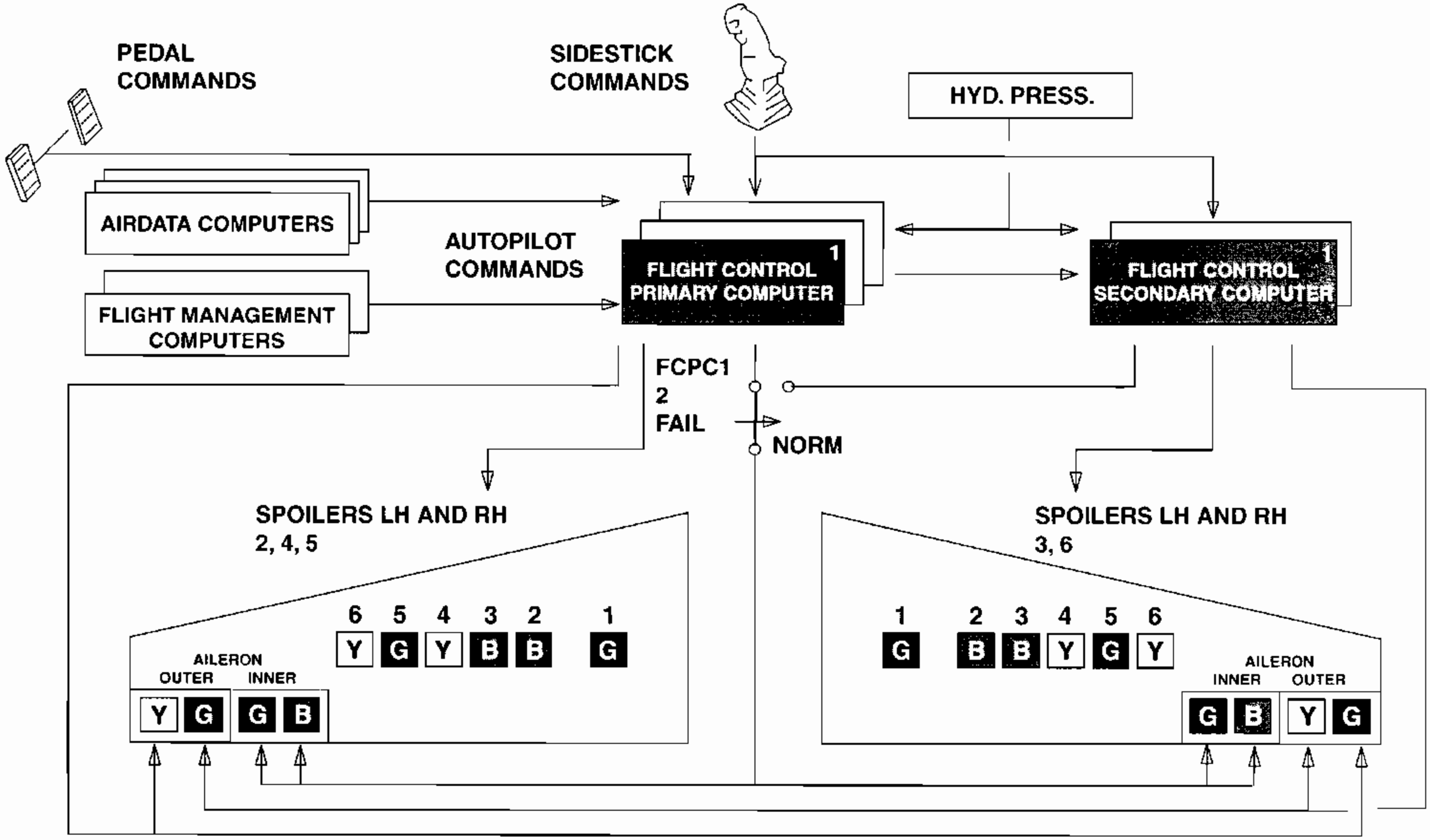


Figure 11: Redundancy of Computers and Hydraulic Systems



Artificial Feel System

Since the pilot has no actual feel of the flight loads in hydraulically actuated systems, some form of artificial feel must be built into the system that will make the control stick force proportional to the flight loads on the control surfaces.

A spring force is usually adequate. However, with elevators and rudders, it is common to have not only a static spring force but also a variable hydraulic force or a spring force more or less compressed by an electric actuator.

Figure 12 on page 12 is a typical artificial feel system using both spring and hydraulic feel. The elevator system is shown, although this artificial feel could be used in rudder or aileron systems. Artificial feel is essentially varied as a function of airspeed.

Figure 12: Artificial Feel Unit Lay-Out

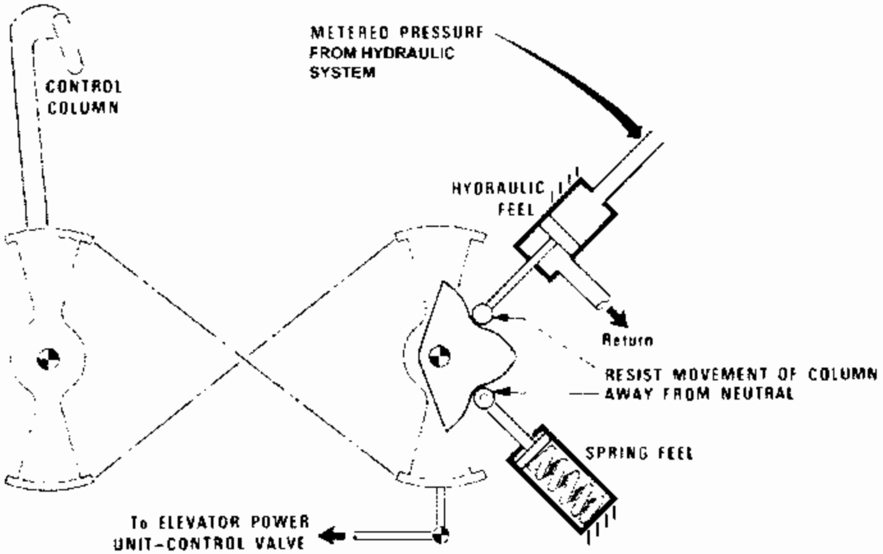
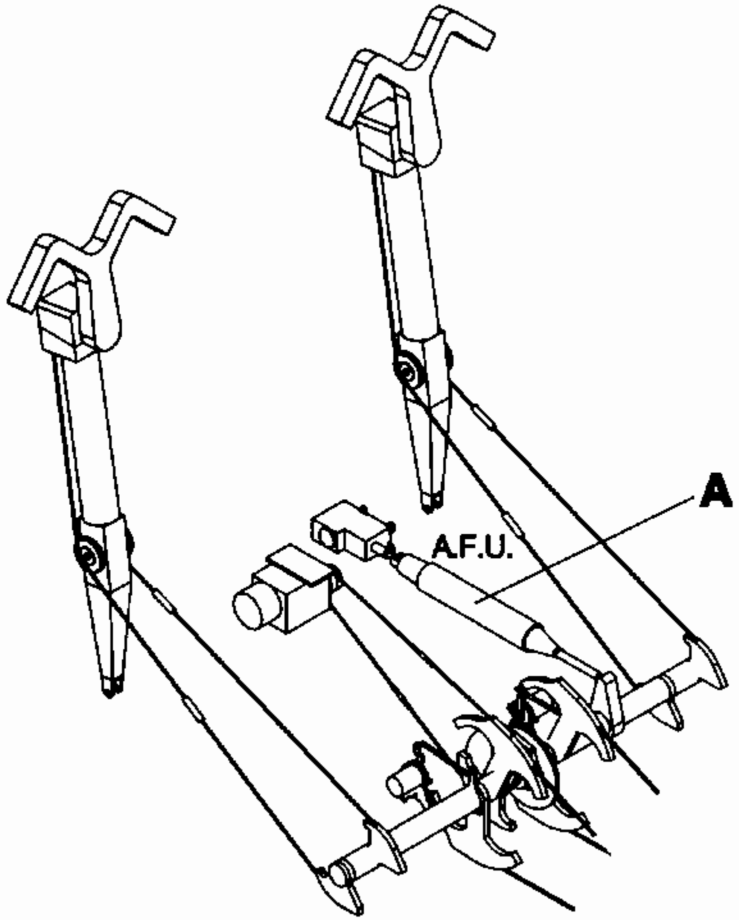


Figure 13: Arificial Feel Unit



Operation of a Fly By Wire Actuator

"Figure 14: Airbus Aileron Actuator" on page 14

Operation with the Servo Control Pressurized

The pressurization of the servo control causes the opening of the inlet (HP) blocking valve (13) and of the return (LP) blocking valve (15).

This causes the supply of the servovalve (11) by the system HP and the connection of the servo control return line to the system LP.

Servo control in the active mode

In this case, the solenoid valve (10) is energized. This lets in the HP which puts the mode selector valve (5) in the active mode. The two chambers of the actuator are thus connected to the users ports of the servovalve. The servo control then operates in the active mode. The mode selector-valve position transducer (3) supplies an electrical signal which identifies this state. The feedback transducer (8) gives the servoloop feedback.

Servo control in the damping mode

In this configuration, the solenoid valve (10) is de-energized. The mode selector valve (5) moves under the action of its spring.This causes the two chambers of the actuator to be interconnected through the damping restriction (6) and the anticavitation valves (7). The mode selector-valve transducer (3) identifies this state. The feedback transducer (8) gives the position of the piston rod to display the aileron position on the SD.

Operation after a Hydraulic Failure

The inlet blocking valve (13) and return blocking valve (15) close. The servo control is then isolated from the aircraft hydraulic system. The accumulator (1) is permanently connected to the return line of the servovalve (11). The return relief valve (16) keeps the pressure in the LP line higher than the pressure in the aircraft return system and permits to fill the accumulator (1). If there is a rupture in the aircraft system return, the return relief valve (16) holds the volume of fluid in the accumulator (1). The mode selector valve (5) moves under the action of its spring. The servo control then operates in the damping mode. The accumulator holds also a volume of fluid to compensate for variation of temperature and some external leakage.

Operation After an Electrical Failure

In this case, the solenoid valve (10) is de-energized. The mode selector valve (5) moves under the action of its spring. The servo control operates in the damping mode.

Maintenance and Rigging Facilities

The maintenance is "on condition". The rod end roller bearing shall be relubricated. The components below are Line Replaceable Units (LRUs): filter, servovalve, solenoid valve, mode selector valve transducer, differential pressure transducer After replacement of the servo control, it is necessary to adjust the feedback transducer (8) . It is necessary to get an equal voltage in the secondary windings (electrical zero) when the aileron is in the neutral position. This is done through an action on the feedback transducer adjustment device (9).

Safety Test

The servo control design permits to perform the tests below:

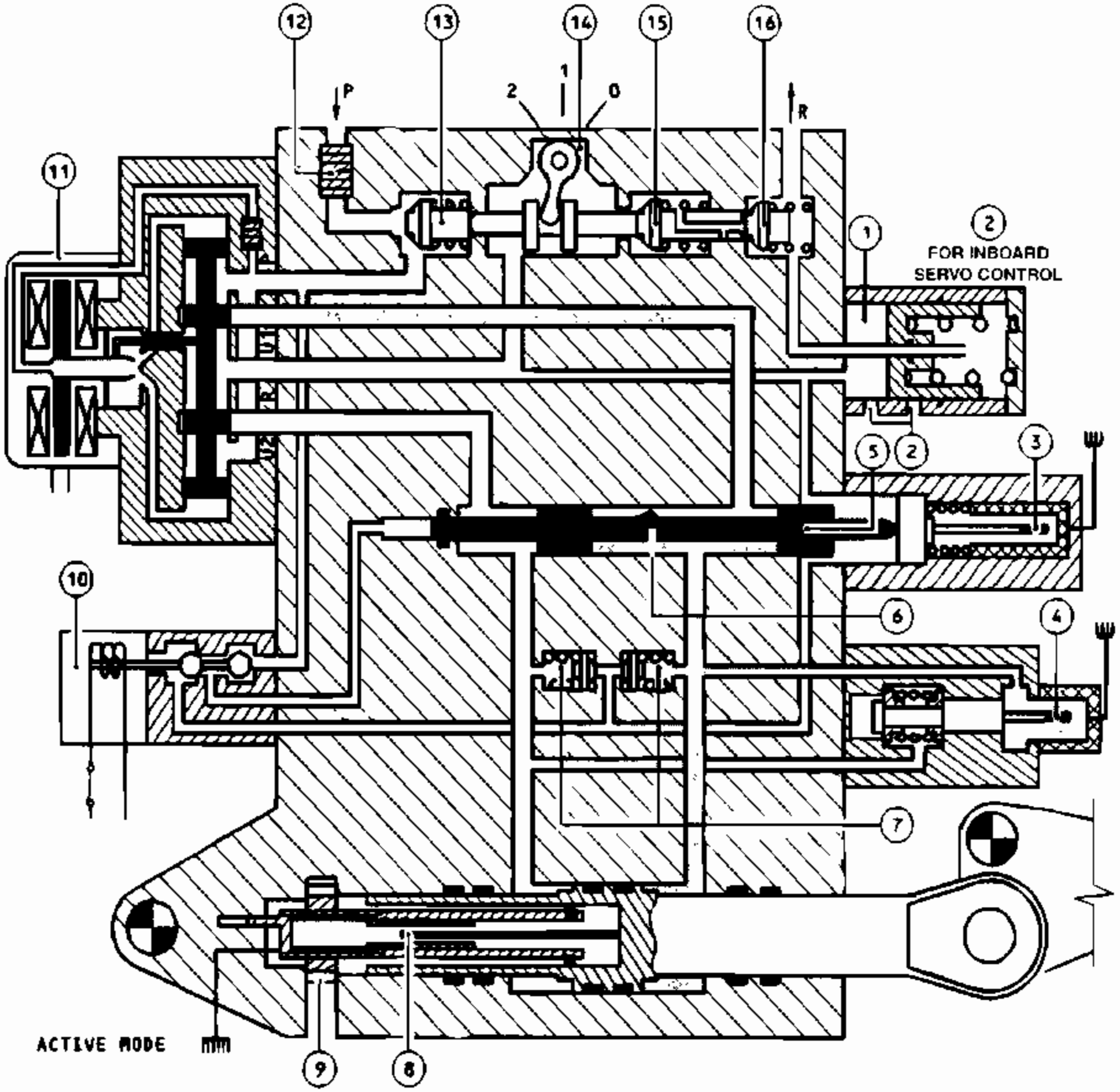
- mode change test using the mode selector valve transducer (3).
- check of the damping coefficient using the differential pressure transducer (4) which measures the pressure differential between the two chambers.
- test of the accumulator (1), blocking valves (13) (15) and return relief valve (16)
- using the accumulator sight indicator (2) and test finger (14) (manually operated).
- Different test finger (14) positions:

0: ZERO Check sealing of: inlet blocking valve (13), return blocking valve (15), return relief valve (16).

1: LEAK CHECK Check sealing of inlet blocking valve (13), return relief valve (16).

2: DISCHARGE Check stroke of accumulator piston (1).

Figure 14: Airbus Aileron Actuator



① - ACCUMULATOR
② - ACCUMULATOR SIGHT INDICATOR
③ - MODE SELECTOR VALVE POSITION TRANSDUCER
④ - DIFFERENTIAL PRESSURE TRANSDUCER
⑤ - MODE SELECTOR VALVE
⑥ - DAMPING RESTRICTION
⑦ - ANTICAVITATION VALVES
⑧ - FEEDBACK TRANSDUCER
⑨ - FEEDBACK TRANSDUCER ADJUSTMENT DEVICE
⑩ - SOLENOID VALVE
⑪ - SERVOVALVE
⑫ - FILTER
⑬ - INLET BLOCKING VALVE
⑭ - TEST FINGER
  0 : ZERO
  1 : LEAK CHECK
  2 : DISCHARGE
⑮ - RETURN BLOCKING VALVE
⑯ - RETURN RELIEF VALVE

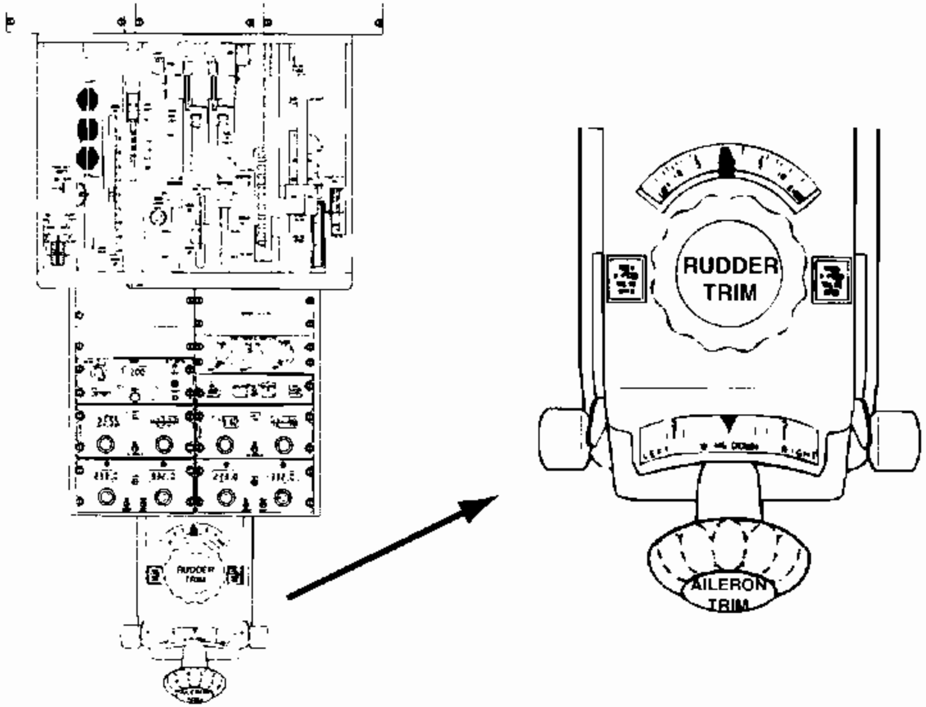
Trim Control Systems

Transport aeroplanes are usually trimmable in its three axes. For further information see Sub Module 8.3 "Theory of Flight".

Roll and Yaw Trimming

Cable Controlled Flight Controls

Trim tabs are normally used for roll and yaw trimming on cable controlled aeroplanes what means, you will find them on the rudder and ailerons. They are controllable from the cockpit and allow the pilot to deflect the control surface in a small amount. This allows the aeroplane to be adjusted to fly straight and level with hands and feet off of the controls. Once a trim tab is adjusted, it maintains a fixed relationship with the control surface as it is moved as shown in Figure 15 on page 15.



Boosted or hydraulic operated aileron and rudder systems are usually trimmed by means of moving the artificial feel and centering unit out of its center position. This is done by a manually or electrical motor operated jack-screw. Fly-by-wire operated systems do not need special provision for trimming the ailerons. If an imbalance occurs during flight, the roll control computers send a re-positioning signal to the aileron servo control units to achieve levelled flight again.

Figure 15: Trim Tab Control

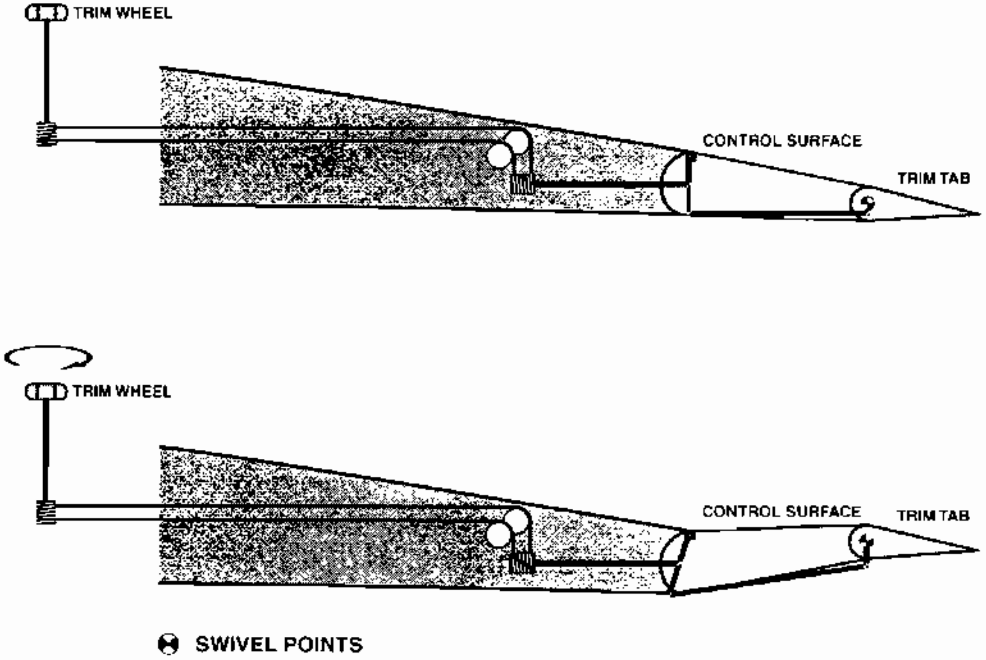
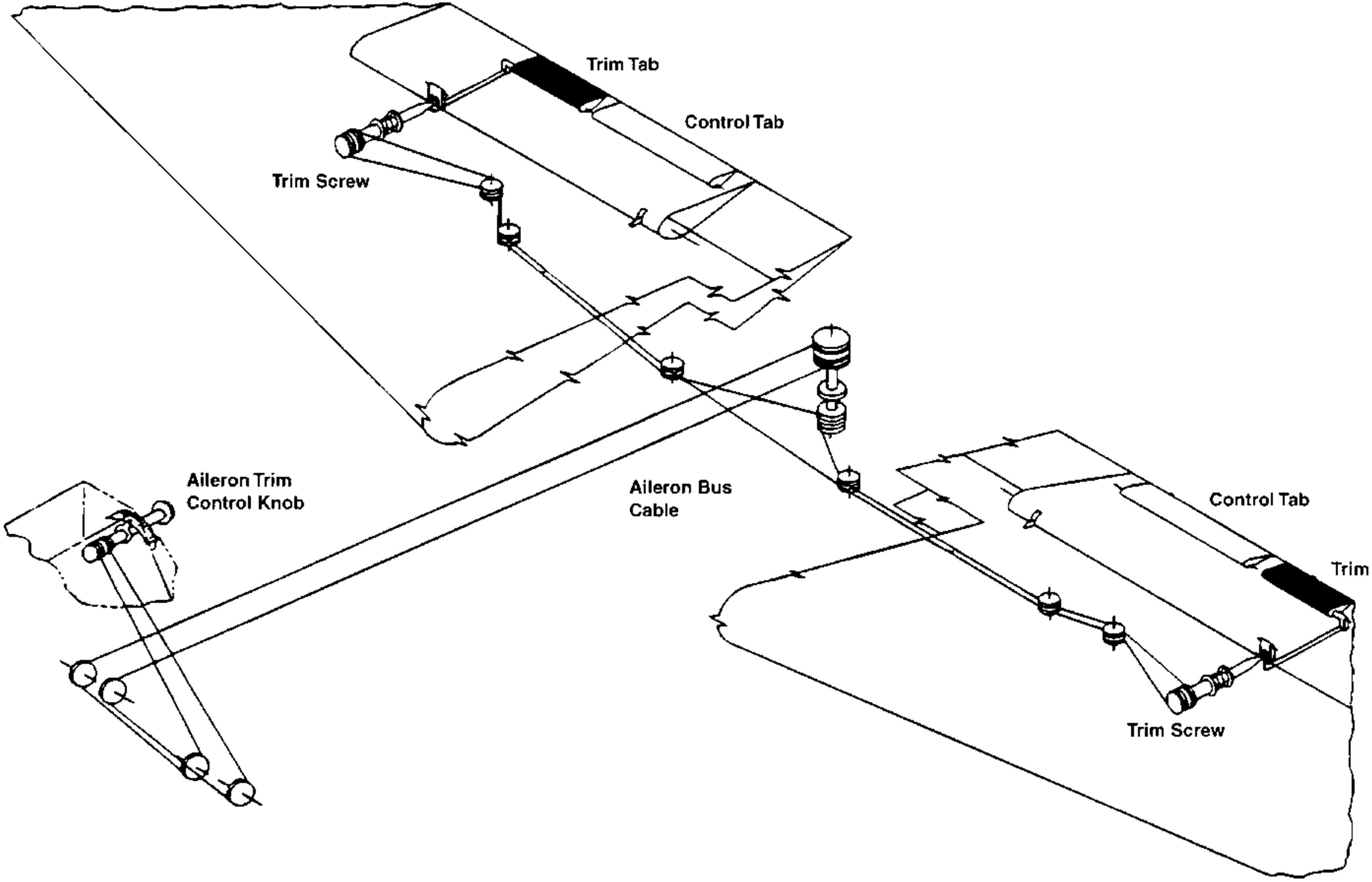


Figure 16: Aileron Trim System on MD- 80



Pitch Trimming

Larger transport aeroplanes are trimmed longitudinal by adjusting the position of the leading edge of the horizontal stabilizer. These stabilisers pivot about the rear spar, and a jack-screw controlled from the cockpit raises or lowers the leading edge. Raising the leading edge gives the aeroplane nose-down trim, and lowering the leading edge trims the aeroplane in a nose-up direction. The system layout is basically the same on most transport aeroplanes. Figure 18 on page 18 show the most used system lay-out. The motors can be electrically or hydraulically driven. Please note, that the example shown in Figure 18 on page 18 shows a system where the surface can only be moved with hydraulic power available. For redundancy, different hydraulic systems supply the THS actuator

Some other systems provide electrical actuators for backup operation.

The trimmable horizontal stabiliser (THS) can be moved either manually or automatically. Manual control is achieved from the cockpit by the different manual control wheels, switches or suit-case handles. Automatic control is achieved with signals from the autopilot or Flight Management systems which send signals direct to the THS-actuator.

During manual movement of the THS an audible signal sounds in the cockpit, so, the pilots can perceive motion of the system. This audible signal is also used to warn the pilots in case of dangerous THS runaway.

Automatic Pitch Trim

In the autoflight mode the command signals from the autopilot are sent to the flight control computers where autotrim signals are calculated and sent to the THS actuator. On large aircrafts, other systems are installed for pitch- and center of gravity control. These aircrafts are equipped with an horizontal stabilizer designed as a fuel tank. This feature makes it possible to transfer a calculated amount of fuel into this tank to keep the center of gravity in a safe and economic range during the flight. Therefore, extensive THS pitch angles can be avoided. See Sub Module 7.16 "Aircraft Weight and Balance" and Sub Module 11.10 "Fuel Systems (ATA 28)" for further information about CG control.

Figure 17: Different Manual Trim Control Inputs

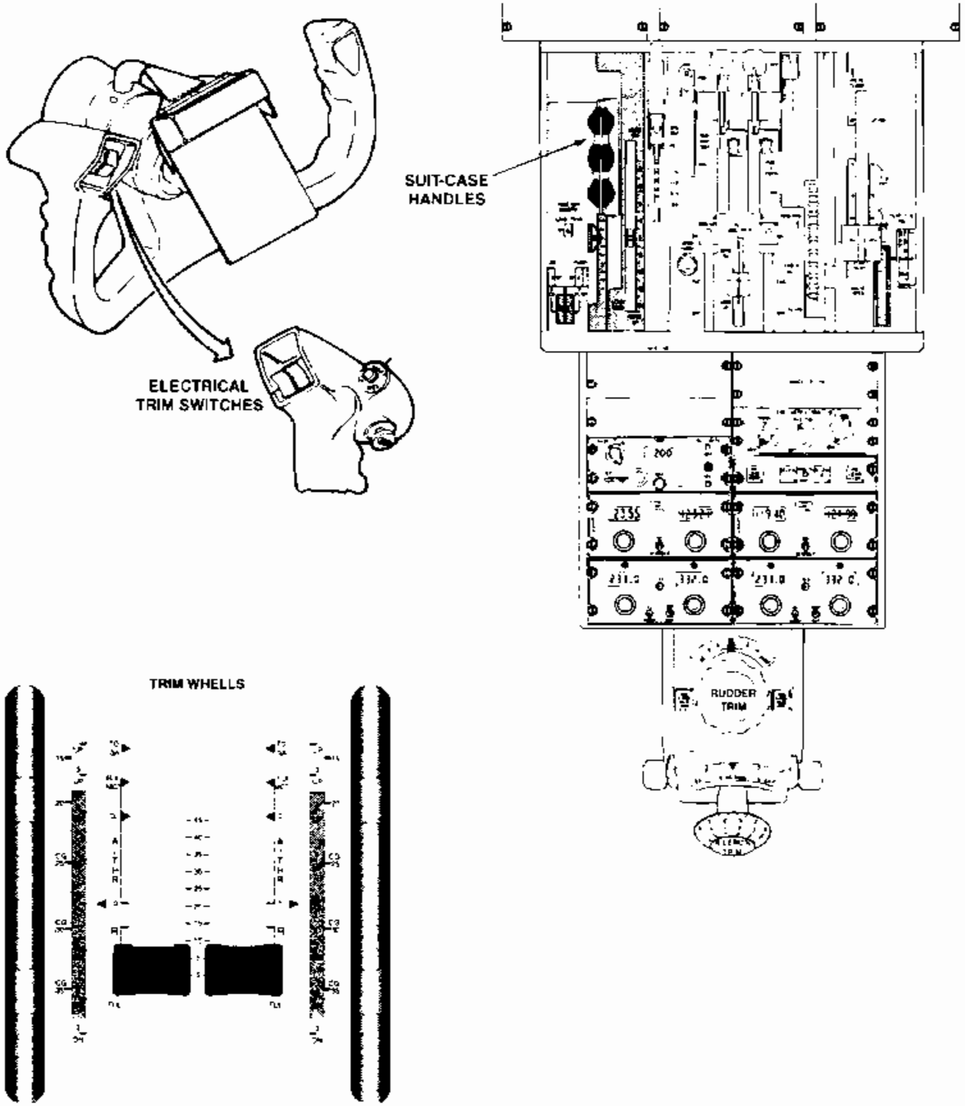


Figure 18: Pitch Trim System Layout

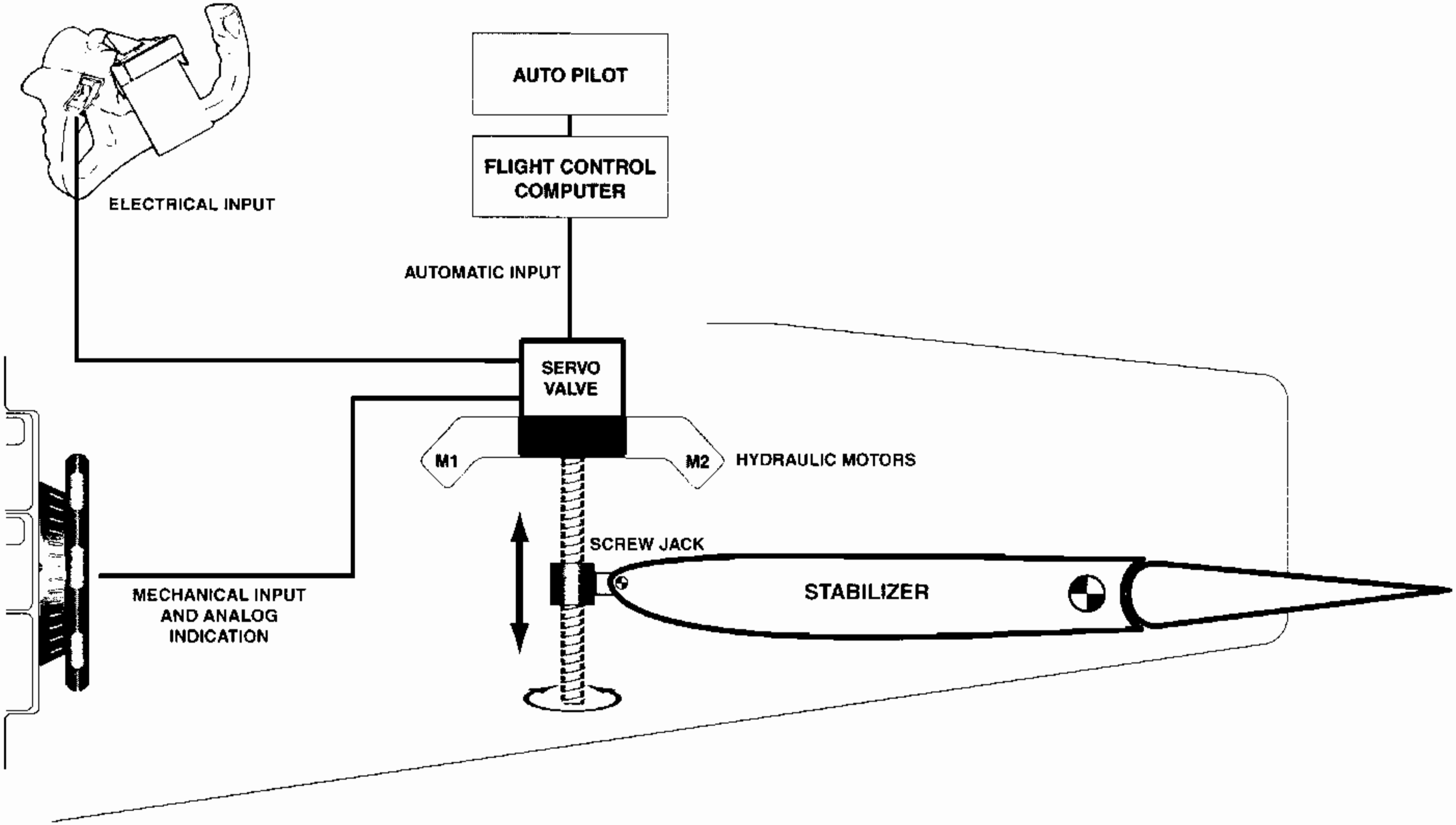


Figure 19: Electrical Trim Actuator with elec. Backup Actuator

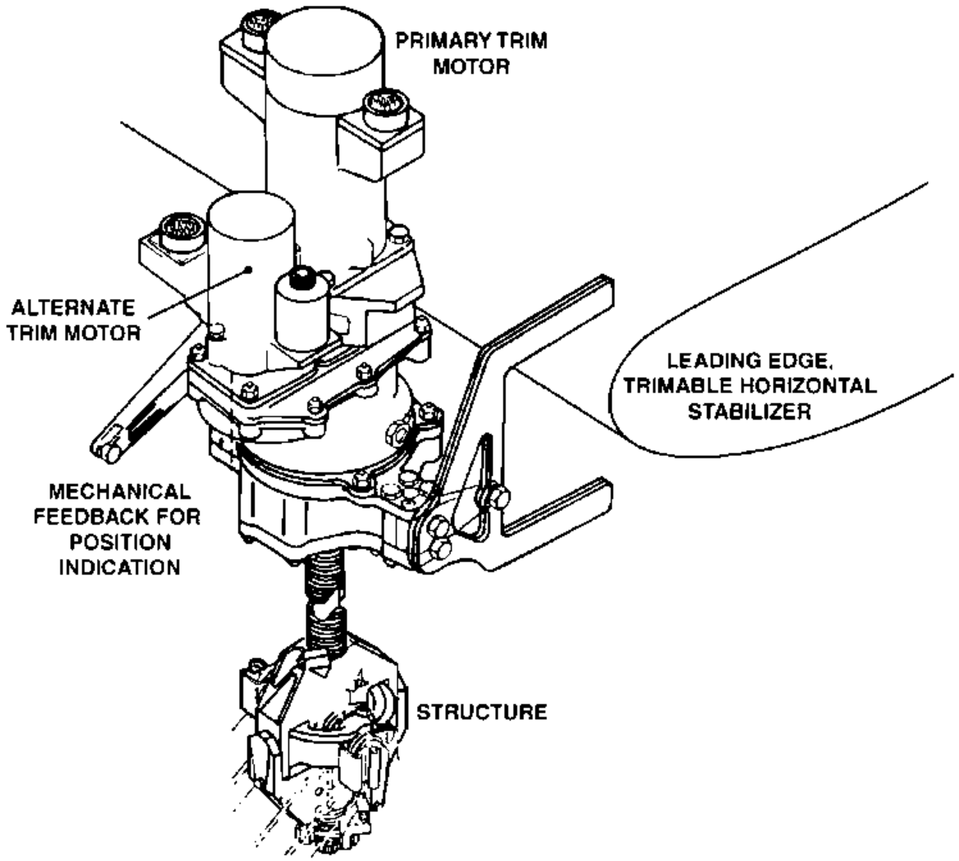


Figure 20: Hydraulically driven Trim Actuator

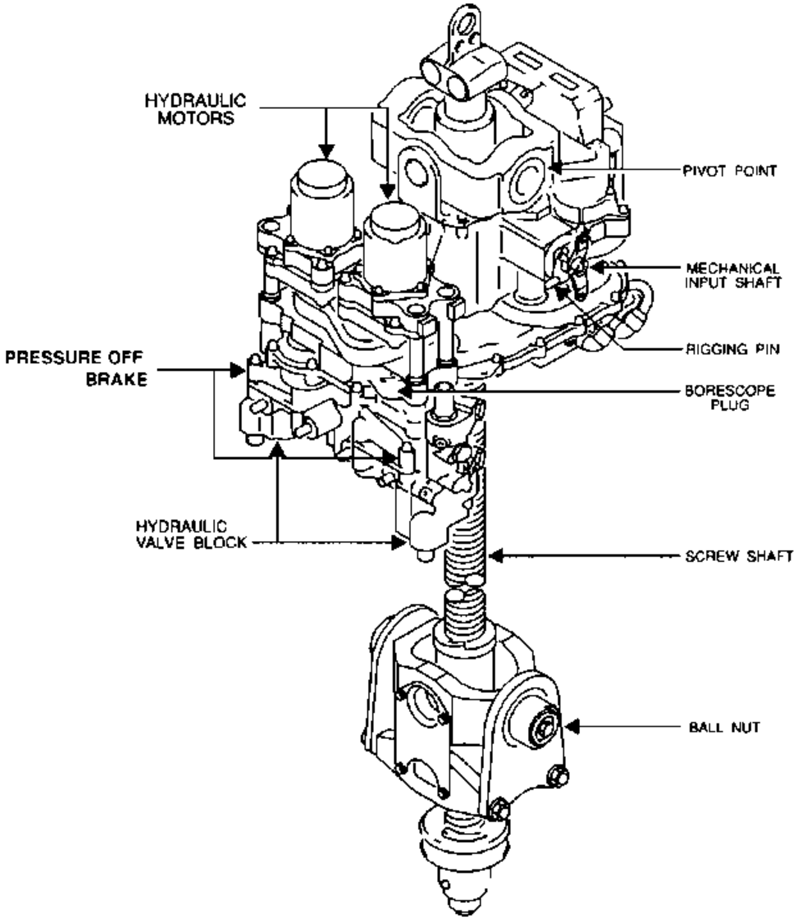
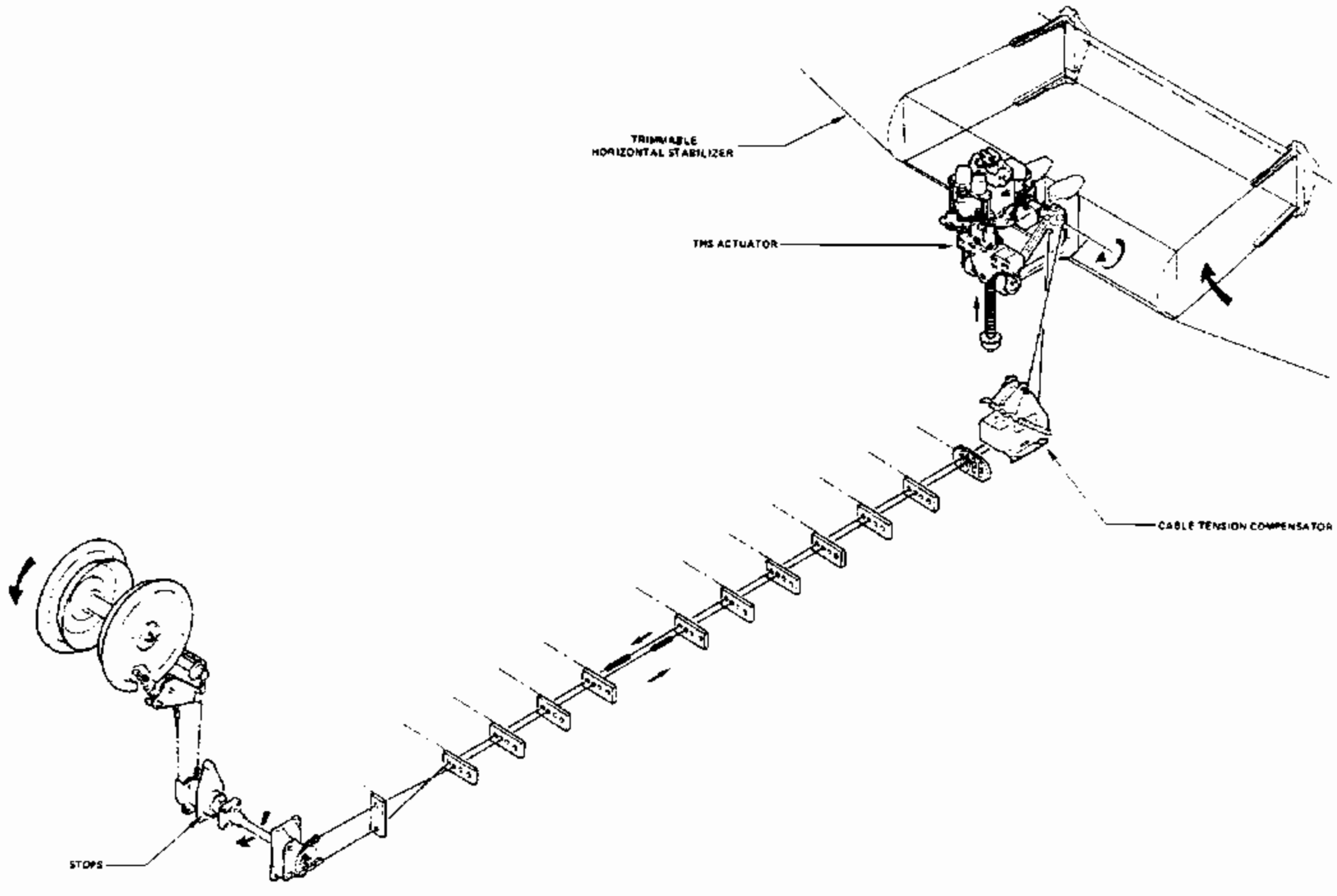


Figure 21: Cable run of a mechanical controlled Hydr. Actuator

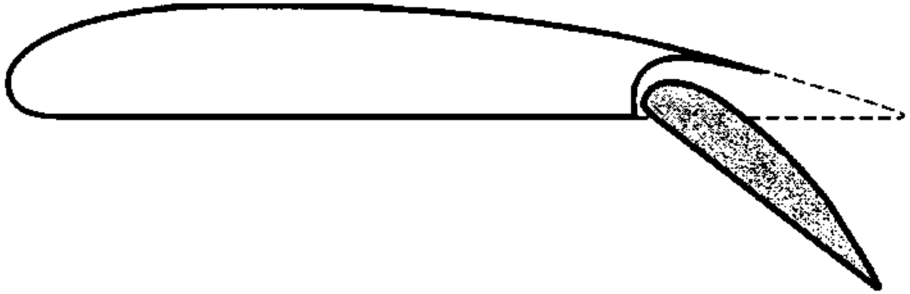


High Lift Devices

ⓘ Please remember the discussion about high lift devices in Submodule 8.3 and 11.1

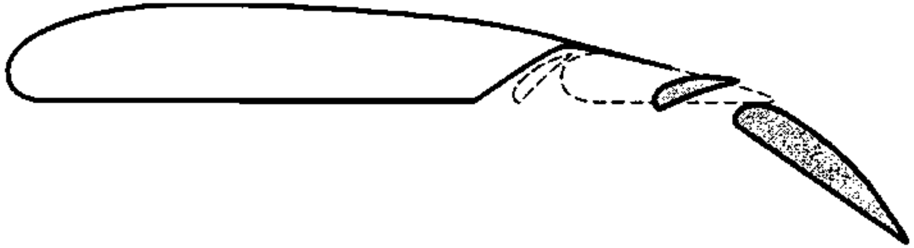
Trailing Edge Flaps

Flaps which only increase the camber have a fixed hinge point and are generally moved by hydraulic actuators. The trailing edge of this type of flap will move downwards immediately if a "flaps extend" selection is made on the flight deck.



Flaps which increase both the surface and the camber have rollers and are installed in specially formed tracks.

After a "flaps extend" selection the flaps will first move backwards via the rollers and the tracks (increase of the wing area) followed by a trailing edge that moves down (camber increase).



To perform this combined movement, a system of driving axles and screw spindles or rotary actuators is used. This system is usually driven by a hydraulic motor or by an electric motor depending on the type and size of aircraft. A screwtype system is often used to prevent flap loads feeding back to the controlsystem. Such flap system lay-out are similar to slat system lay-out. For some aircraft, both types of actuation are used. The flaps are operated with the flap handle on the flight deck. The flap handle can be set to different positions depending on the flight phase. This enables the pilot to select the most efficient flap position. See the typical system layout as shown in Figure 22 on page 22.

Figure 22: Flap System Layout

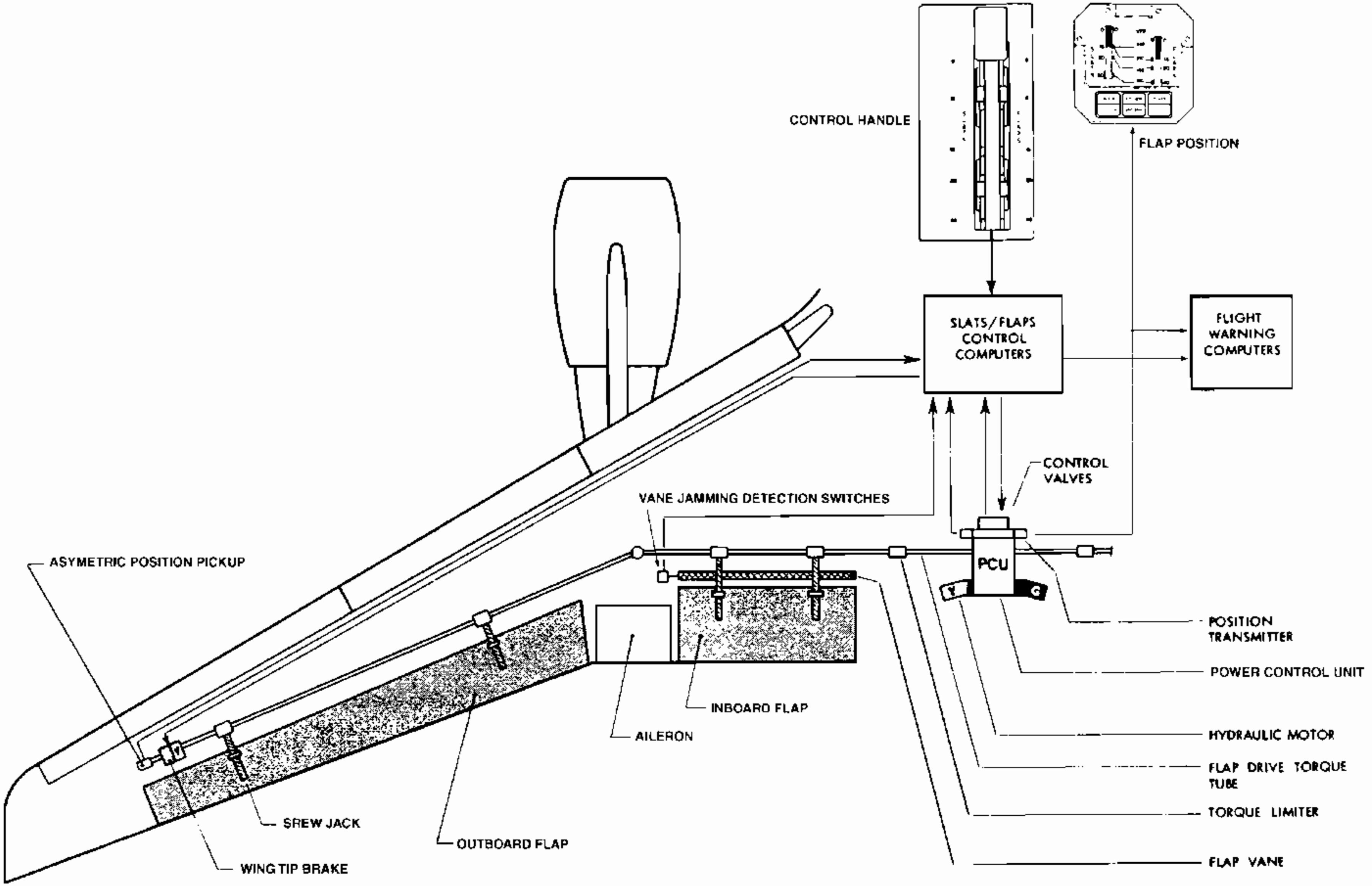


Figure 23: Flaps Configurations

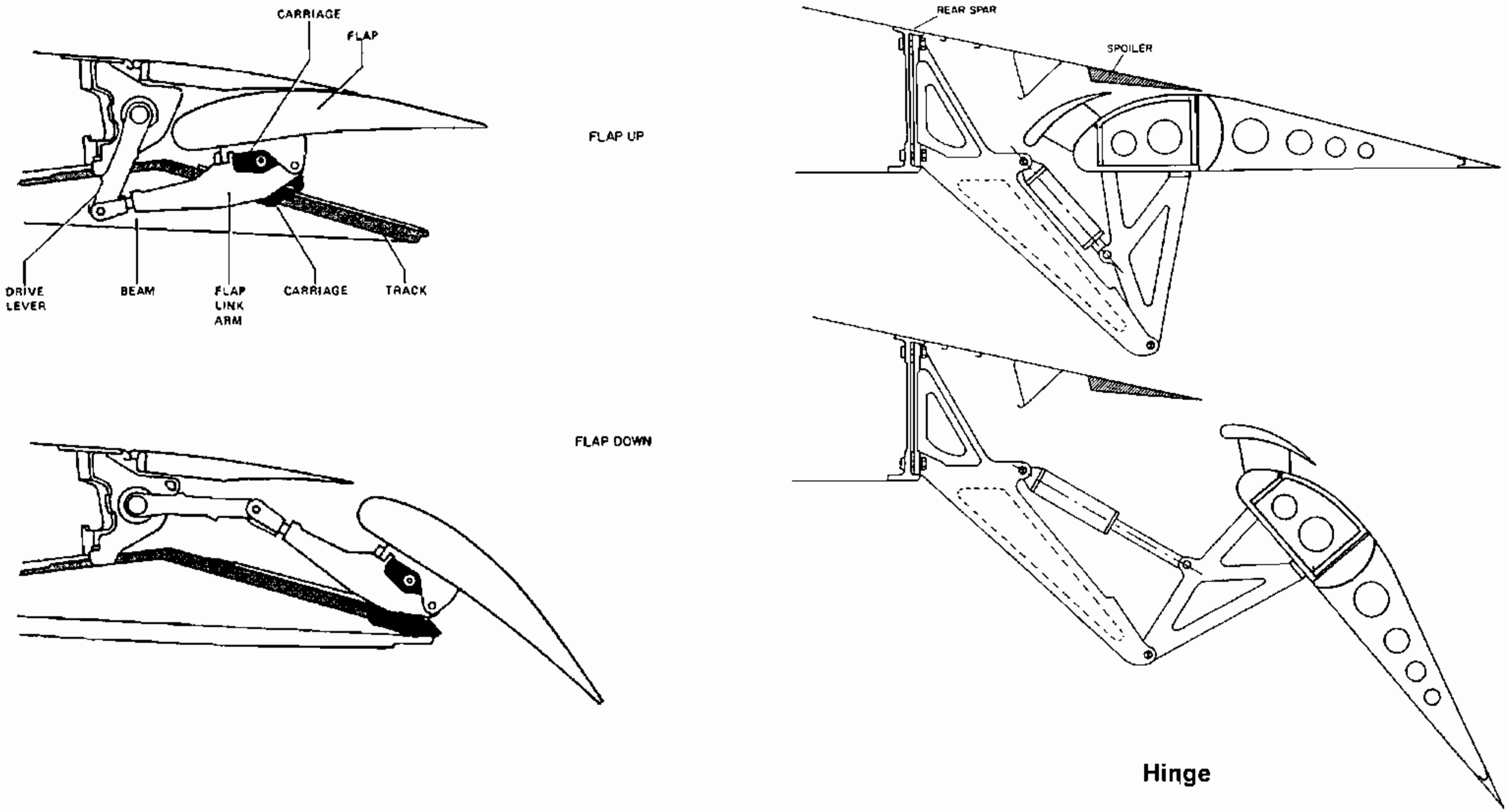
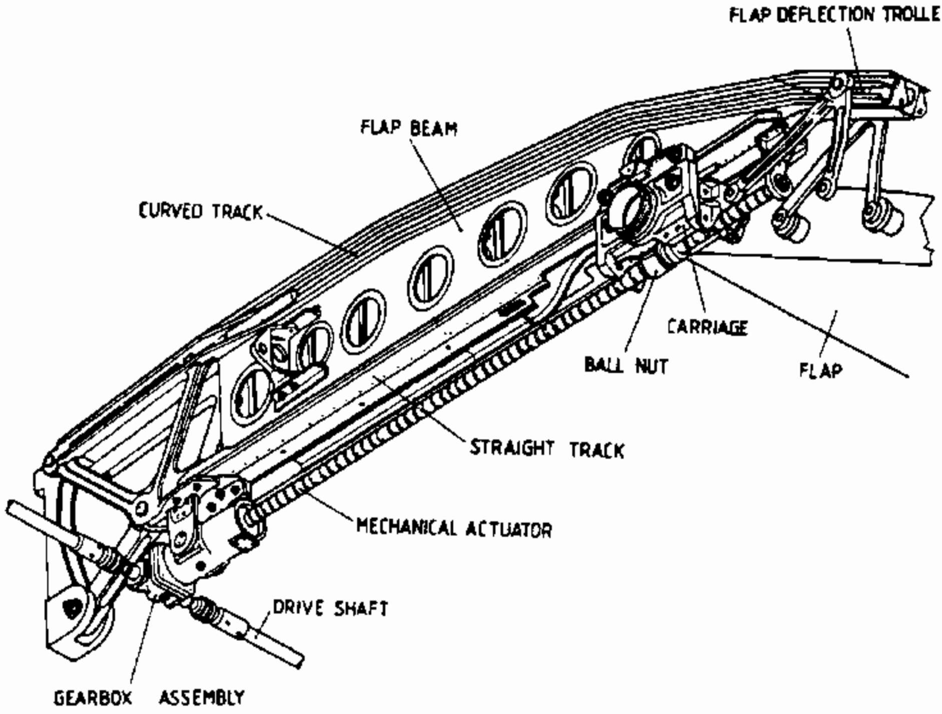


Figure 24: Flap Track, Screw Jack Operated

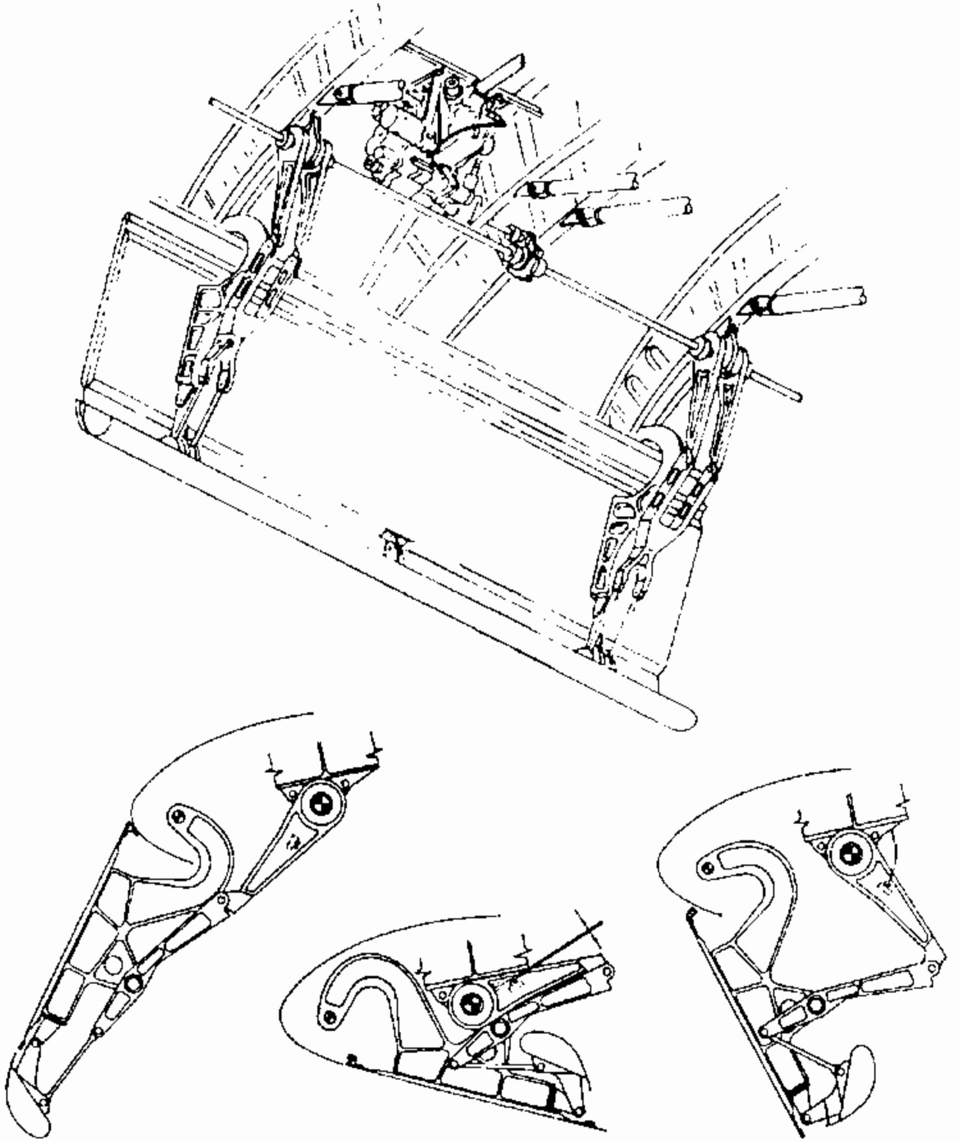


Leading Edge Flaps

Leading edge flaps, also named as "Krüger Flaps", are installed below the forward wing edge as shown in Figure 25 on page 24.

The flaps can have two positions, extended or retracted. The command for these positions comes from the flap handle or via the flap computer. Such leading edge flaps are driven hydraulically, pneumatically or electrically.

Figure 25: Leading Edge Flaps



Slats

Together with the flaps, the slats are used for lift augmentation. The slats are installed on tracks which are attached to the leading edge of each wing. The operation of the slats is usually mechanically by cables, hydro-mechanical or pneumatically. A hydraulic or pneumatic power control unit (PCU) moves the mechanical transmission system which operates the slats on each wing.

Figure 26: Slats

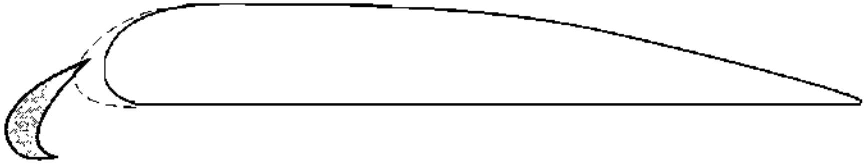


Figure 27 on page 25 shows the mechanism of a typical slat track. Generally the extension of the slats and the flaps must be done at the same time. Therefore, there is only one control handle in the cockpit to operate the flaps and slats. An indication system on the cockpit indicates the position of the slats, similar as the flap system. See the following figures for different track and system layouts.

Figure 27: Pinion Driven Slat

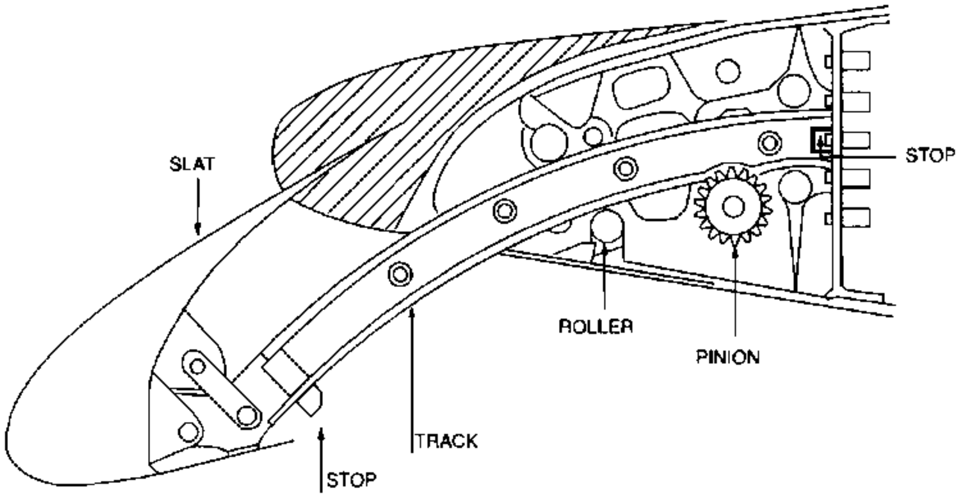


Figure 28: Screw Jack Driven Slat

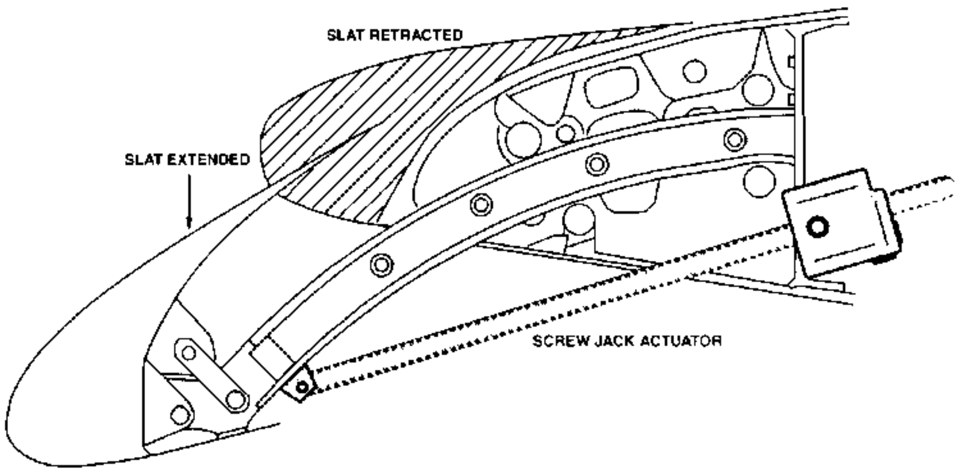


Figure 29: Hydraulic Actuator Driven Slat

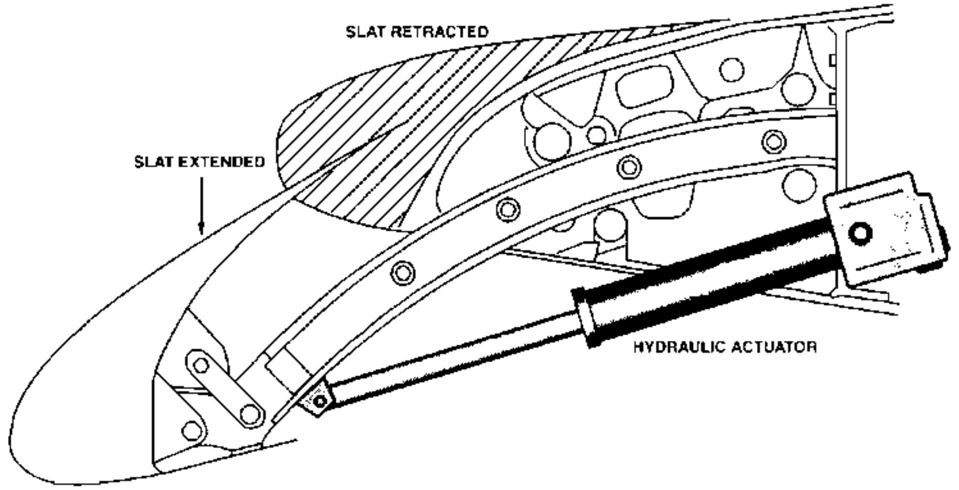


Figure 30: Hydraulically Operated Slat Cable System

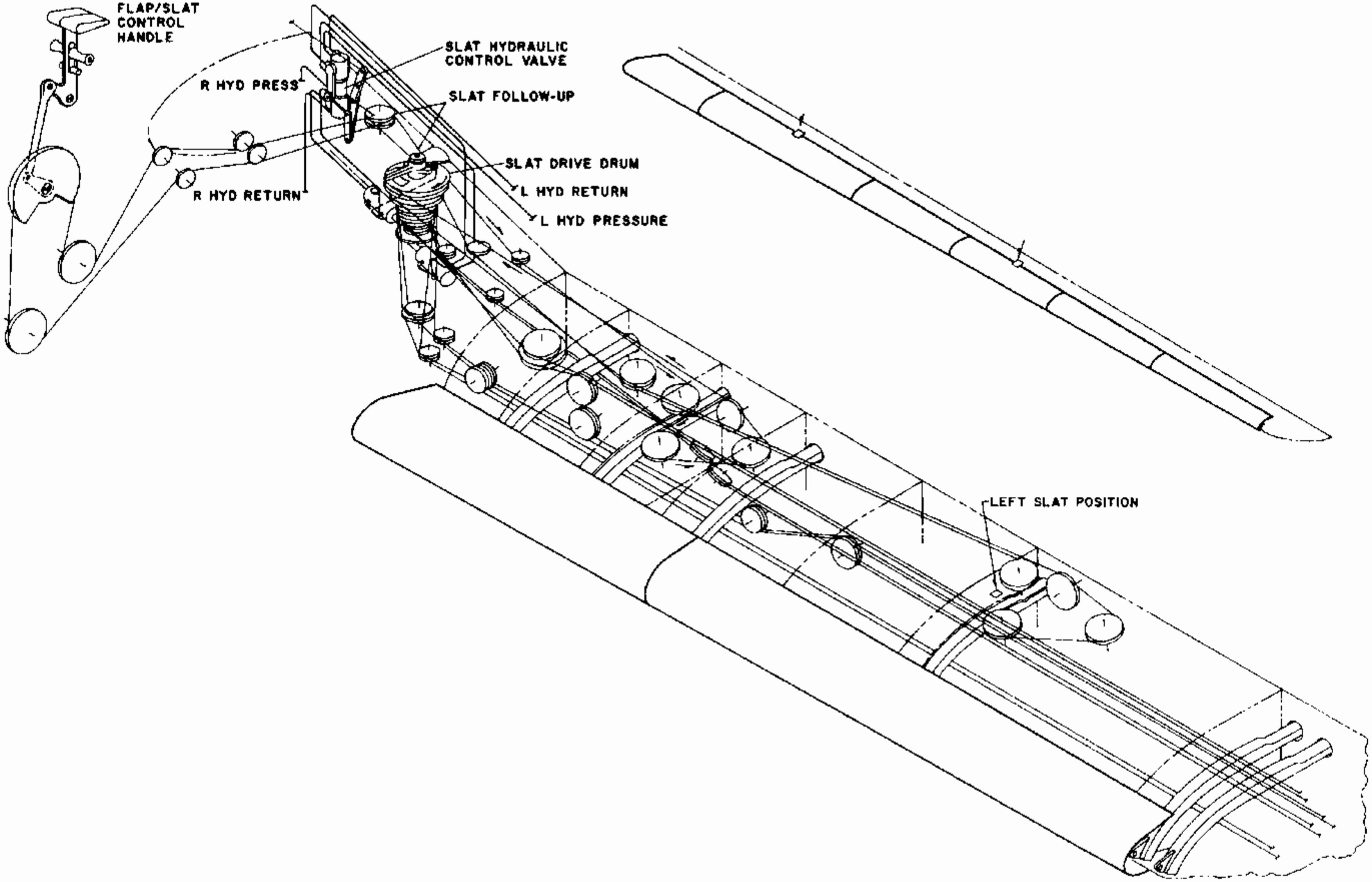
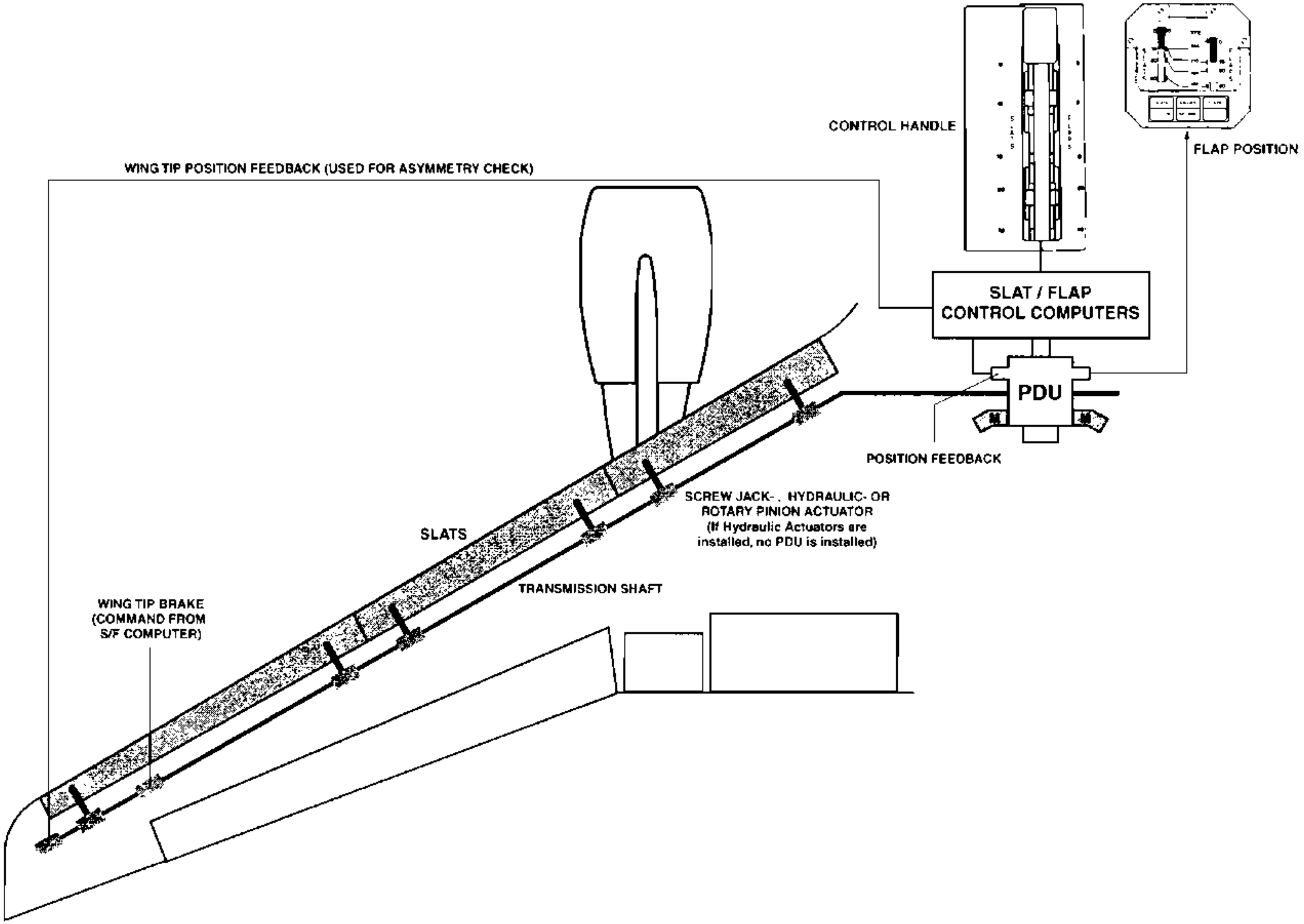


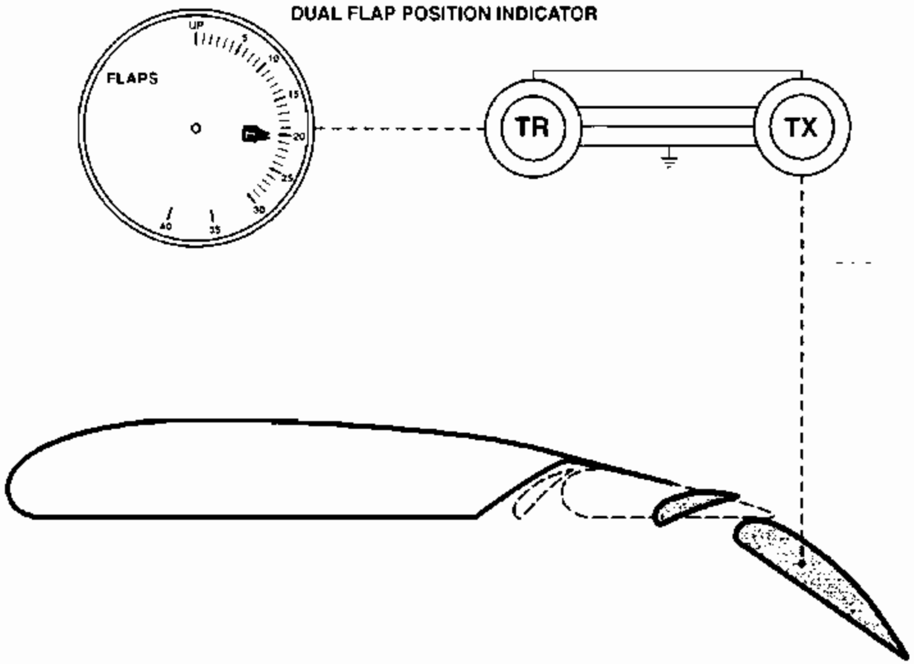
Figure 31: Hydraulically Operated Slat Screw Jack System



Position Indication

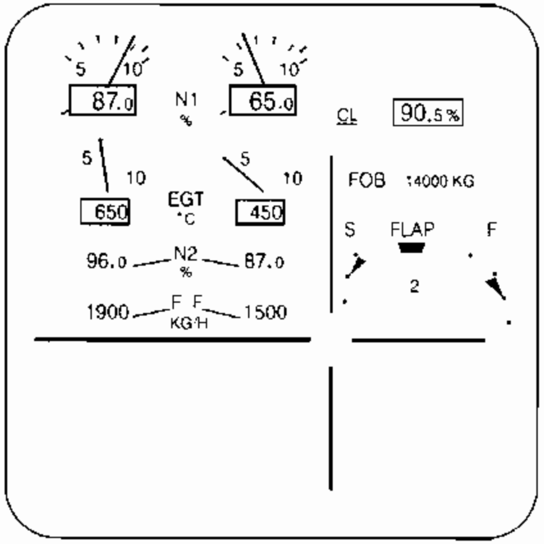
Different methods and types of indicators are in use to shows the actual position of the flaps to the flight crew. The signal transmission can be done either mechanically by steel cables or electrically by using a position pickup unit and an electrical indicator. Please note, that the principle of slat/flap position transmission is usually similar.

Figure 32: Electrical Position Transmission



As you know, modern aircrafts are equipped with displays instead of analog indicators as shown above. Figure 33 on page 28 shows a possibility of slat/flap indication.

Figure 33: Modern Indication Display



Lift Dump, Speed Brakes

Wings of transport aeroplanes are equipped with spoiler surfaces (also named lift dumpers). The different surfaces are used for different applications depending on the actual flight phase. The spoilers are usually grouped in relation to the different functions. This could look as follows:

- Flight spoilers
  - Roll spoilers (lateral control augmentation)
  - Speed brakes (in flight)
- Ground spoilers (landing roll-out or take-off abort)

See Figure 36 on page 31 for a typical spoiler layout.

Read more in Sub Module 11.1.1 "Aerodynamics and Flight Controls"

Roll Spoiler System Operation

Part of the spoiler surfaces on each wing assist the ailerons for lateral control. Movement of the down moving wing spoilers occurs as the control wheel (or stick) actuates the ailerons. The aileron system is connected to the spoiler system in a mechanical or electrical way depending on the aeroplane.

Speed Brake System Operation

During flight, manually moving the pedestal-mounted lever aft will extend the flight spoilers on both wings to serve as speed brakes. Different than the roll spoilers, speed brake surfaces are symmetrically extended according to the handle position to a maximum of approximately 35° depending on the aeroplane. Use of aileron control during speed brake operation results in asymmetrical extension of the spoilers to assist in lateral control.

Ground Spoiler System Operation

The system may be armed for automatic operation by selecting it on the speed brake lever. When the system is armed, all spoilers (flight and ground) will fully extend after a combination of signals from different systems which determines an unequivocal ground configuration of land-roll or take-off abort. The following list shows the most used signals from other systems used for automatic ground spoiler extension:

- Ground / flight signal
- Wheel spinning signal
- Throttle lever angle signal
- Aeroplane speed signal

Figure 34: Typical Speed Brake Handle

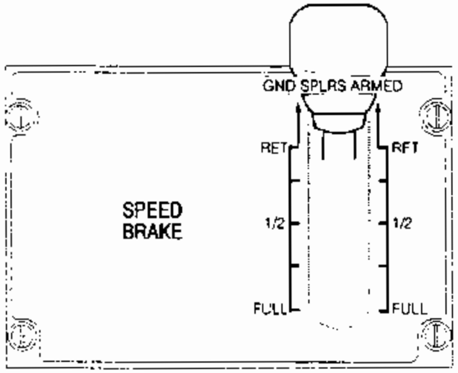


Figure 35: Spoiler Indication

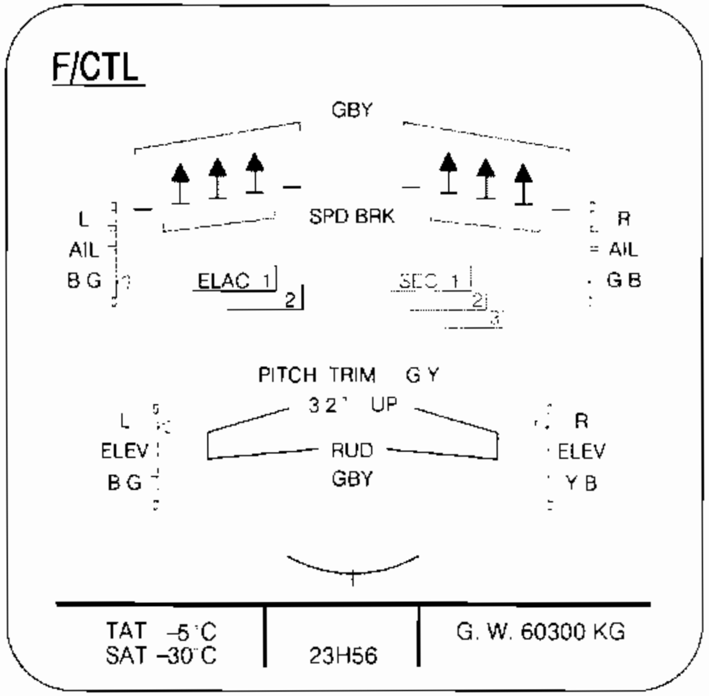


Figure 36: Spoiler Layout

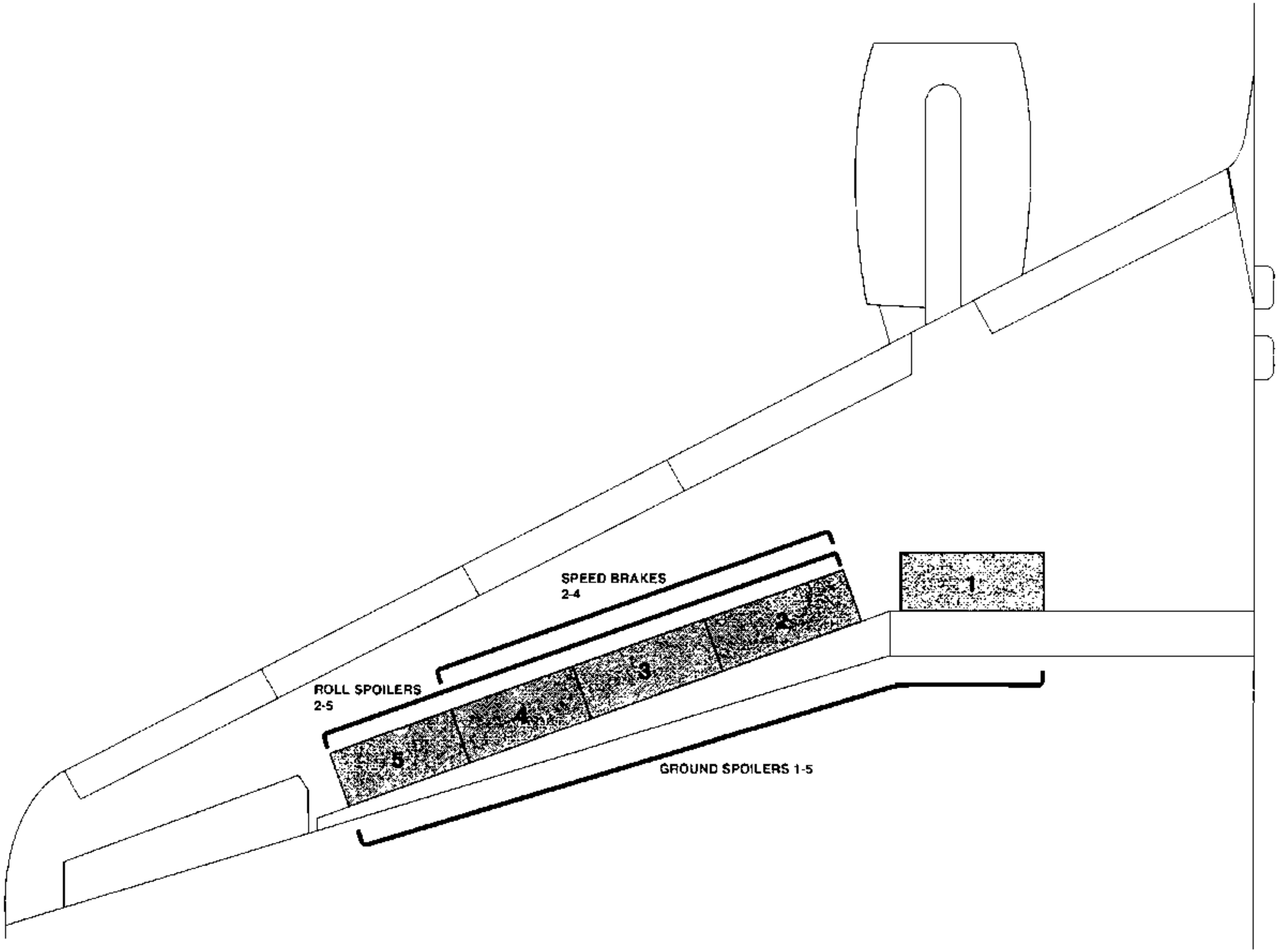


Figure 37: Surface Configurations

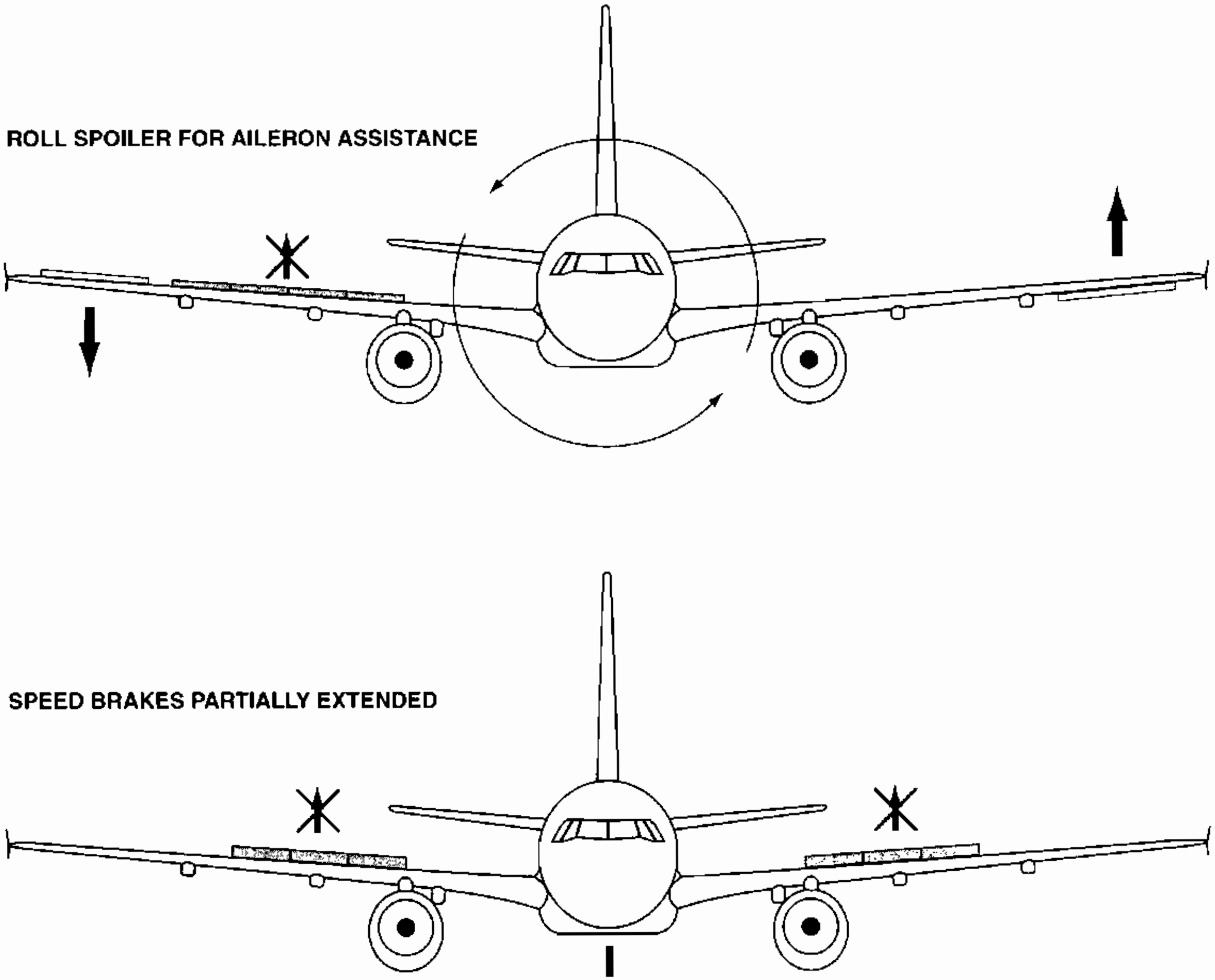


Figure 38: Surface Configurations

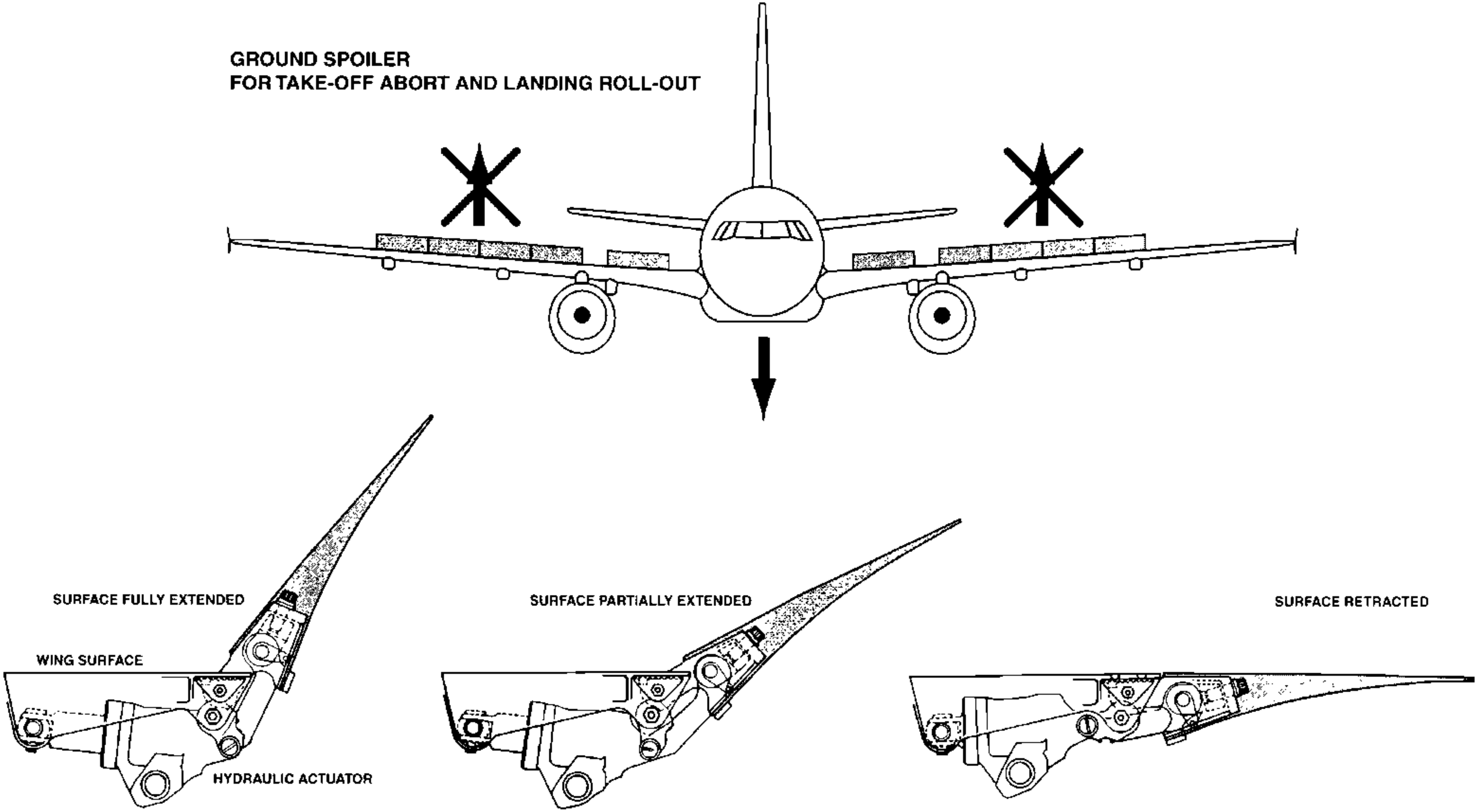
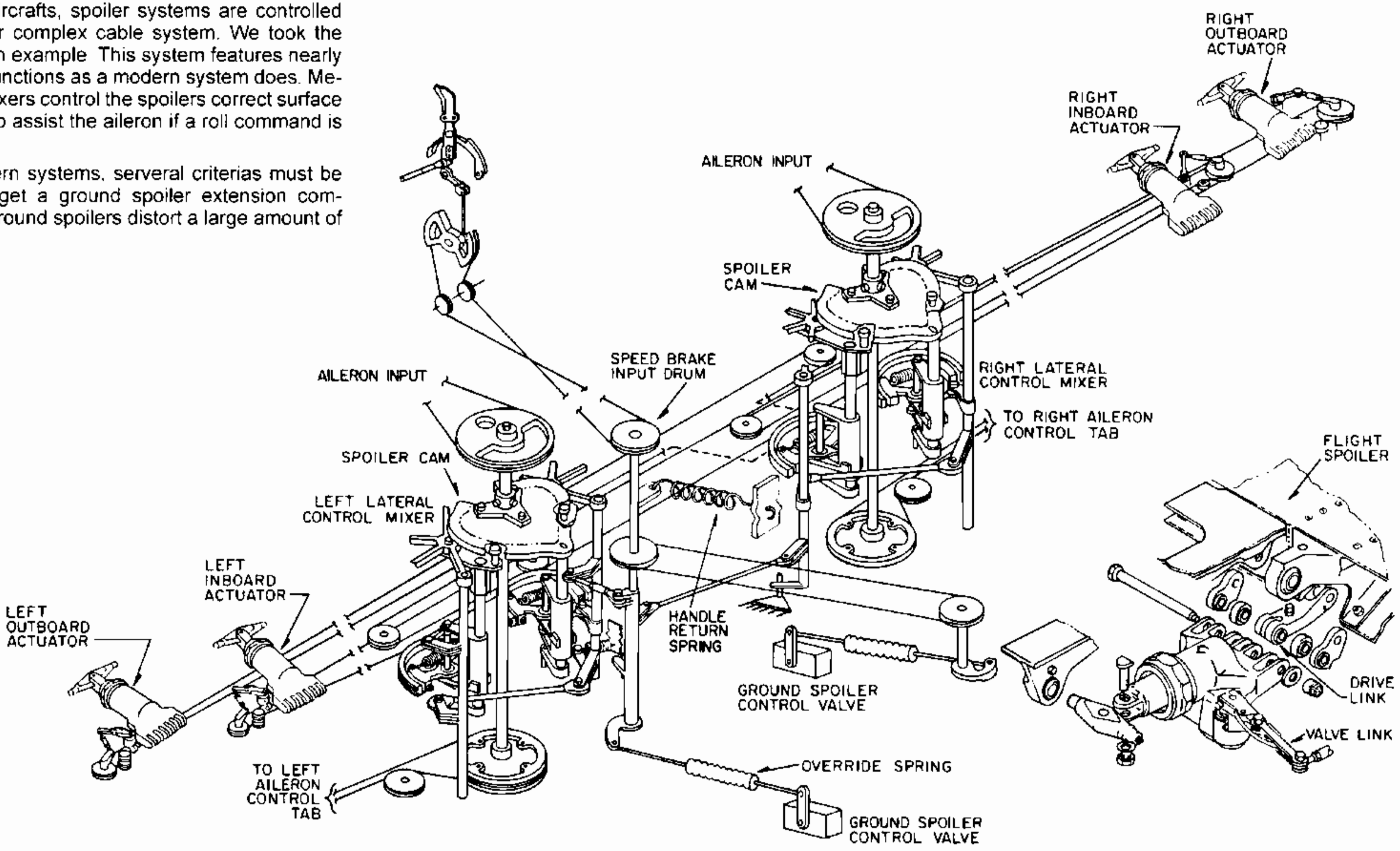


Figure 39: Cable Controlled Spoiler System (MD80)

On older aircrafts, spoiler systems are controlled via a rather complex cable system. We took the MD80 as an example This system features nearly the same functions as a modern system does. Mechanical mixers control the spoilers correct surface deflection to assist the aileron if a roll command is given.

As in modern systems, serveral criterias must be fulfilled to get a ground spoiler extension command, as ground spoilers distort a large amount of lift.



Rudder Travel Limiter

Large aeroplanes are provided with a rudder travel limiter to protect the empennage from overload in case of inadvertent application of excessive rudder control at high speed. In older aeroplanes, the limiter operates by ram air pressure from an own pitot tube installed usually in the leading edge of the vertical stabiliser. The higher the airspeed, the more ram pressure, resulting in proportional restriction of rudder movement.

Modern Aeroplanes rather are provided with a computer controlled rudder travel limiter which receives air speed electrical signals from the air data system for travel limiting computation (Figure 40 on page 35).

Figure 40: Rudder Travel Limiter

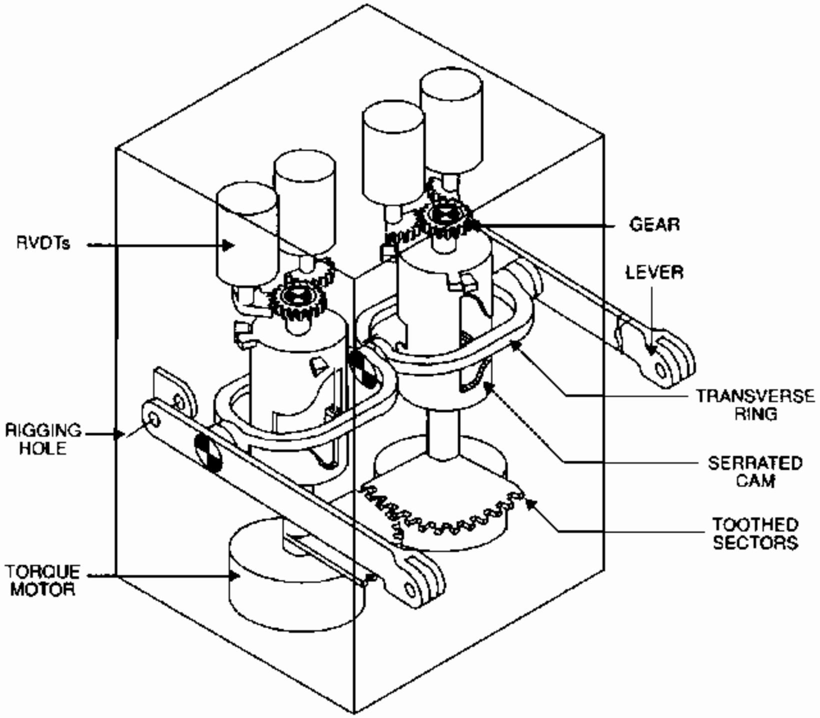


Figure 41: Typical Location of a Rudder Travel Limitation Unit

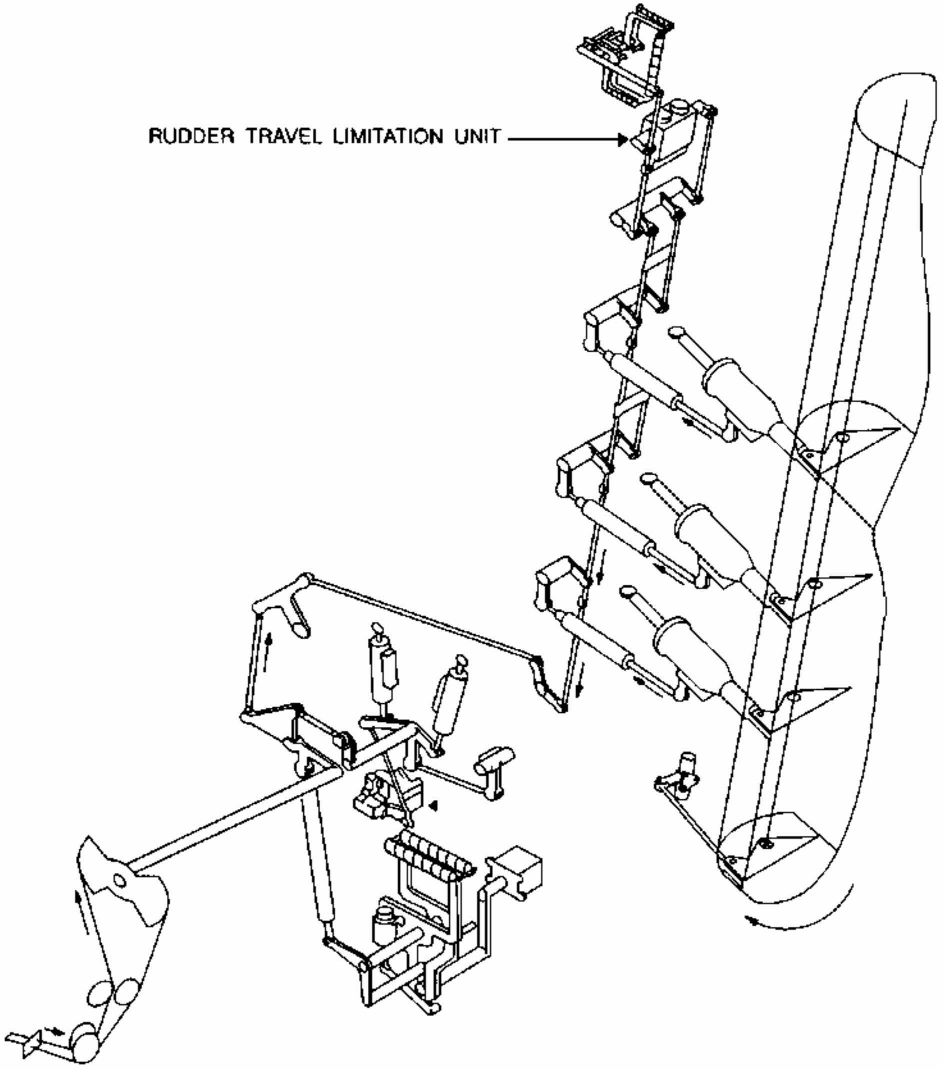
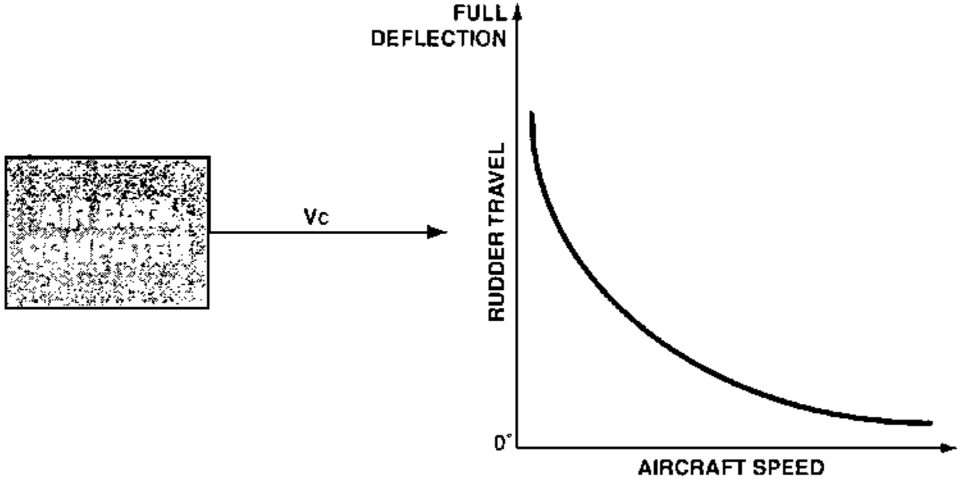


Figure 42: Rudder Travel in relation to Air Speed



13.8 Instrument Systems (ATA 31)

Position Transmitting

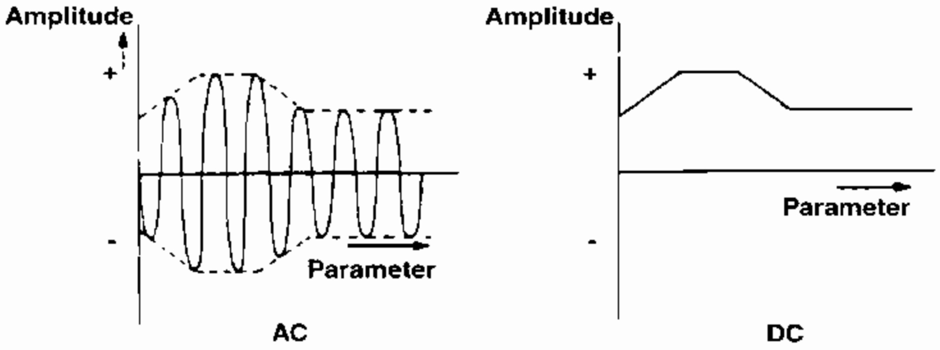
AC and DC Ratio Signals

Introduction

An AC or DC ratio signal has a variable amplitude or level. A certain parameter controls the amplitude or level of such a signal. A device with a variable output level makes such a signal. The amplitude or level, changes under control of the parameter, between a high and a low level. These levels are different from device to device and depend on the design of the device.

Potentiometers, synchros, RVDTs/LVDTs and rate generators are examples of devices that make AC or DC ratio signals. Parameters which control the output of these devices are for example speed, angular displacement, etc.

Figure 1: Amplitude depending of Parameter



Ratio System

Moving coil meter, servo systems, AC converters etc. are all devices that use ratio signals. A simple way to show the level or amplitude of a ratio signal is with a moving coil meter. This type of indicator has a low torque available to drive other systems. When other systems need more torque, a servo system is a better choice.

Figure 2:

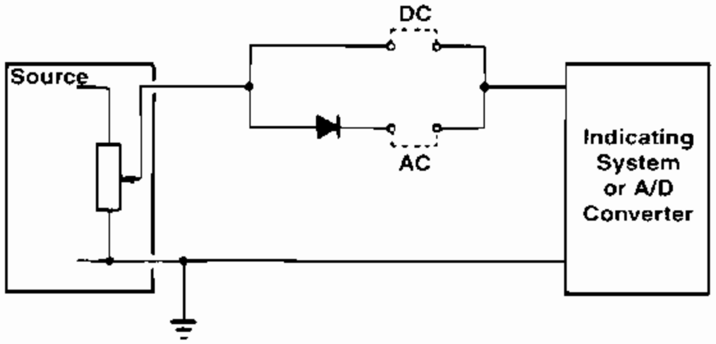
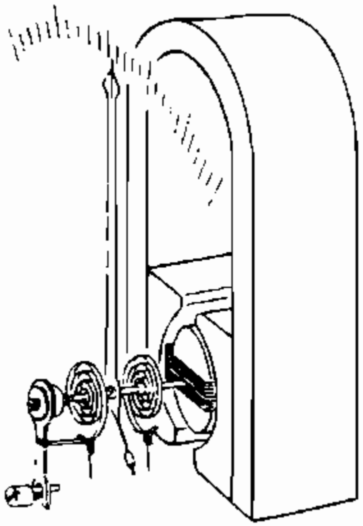


Figure 3: Analog Meter



Variable Resistance Signals

A variable resistance signal is made by a device of which a certain parameter controls the resistance. The resistance varies between a high and a low value. These limits depend on the type and range of the resistor.

Parameters which control the resistance are, for example, temperature, rotation or pressure.

Figure 4: Linear and non linear

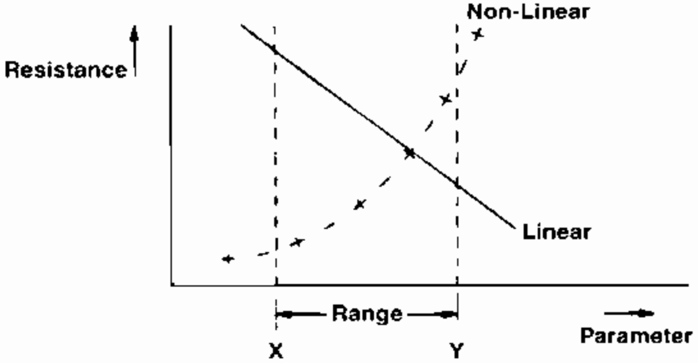


Figure 5: Resistance Temperature Sensor in a Circuit

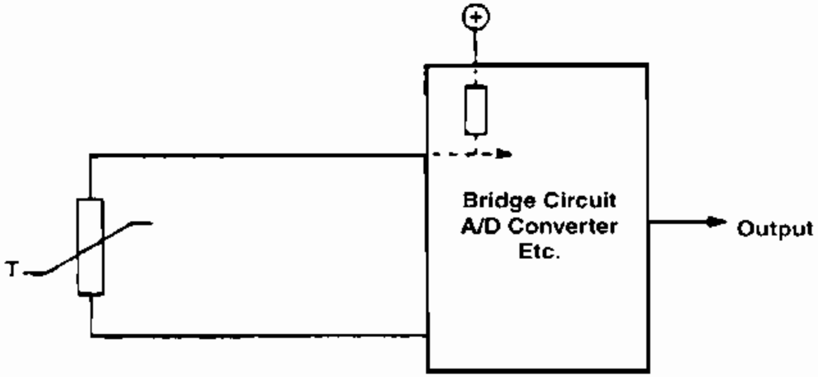


Figure 6: Potentiometer

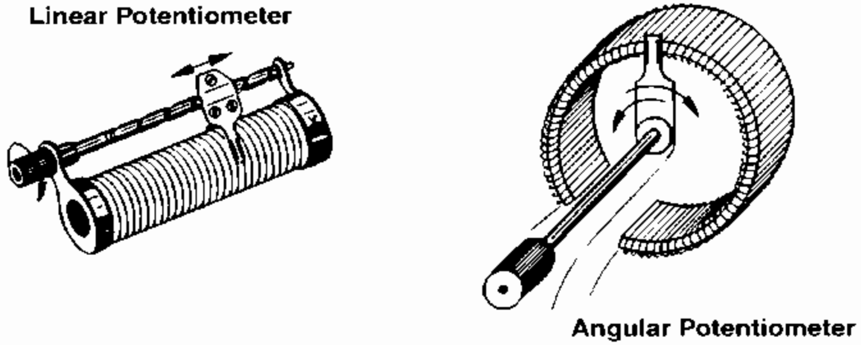
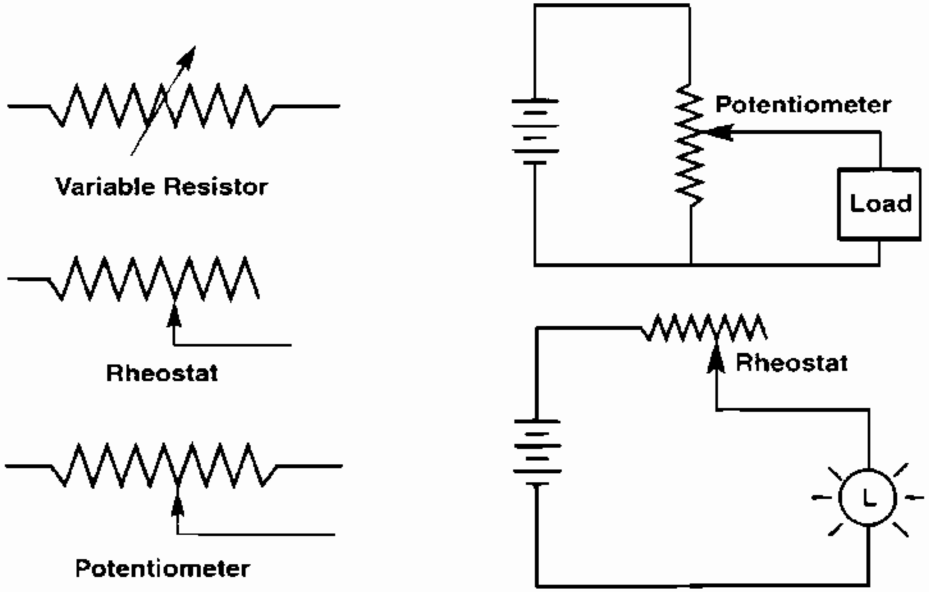
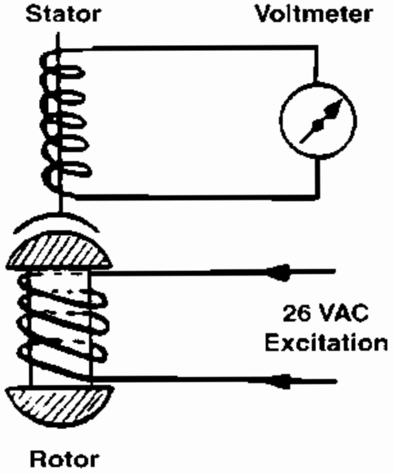


Figure 7: Resistor, Rheostat and Potentiometer



Control Transformer

Figure 8:



A transformer consists of a primary and a secondary coil. The primary coil produces a continuously changing magnetic flux in the iron core. In the secondary coil the changing flux induces a alternating voltage.

a) The primary coil excited by U_1 is aligned with the secondary coil.
Output U_2 has the same phase angle as the input voltage.

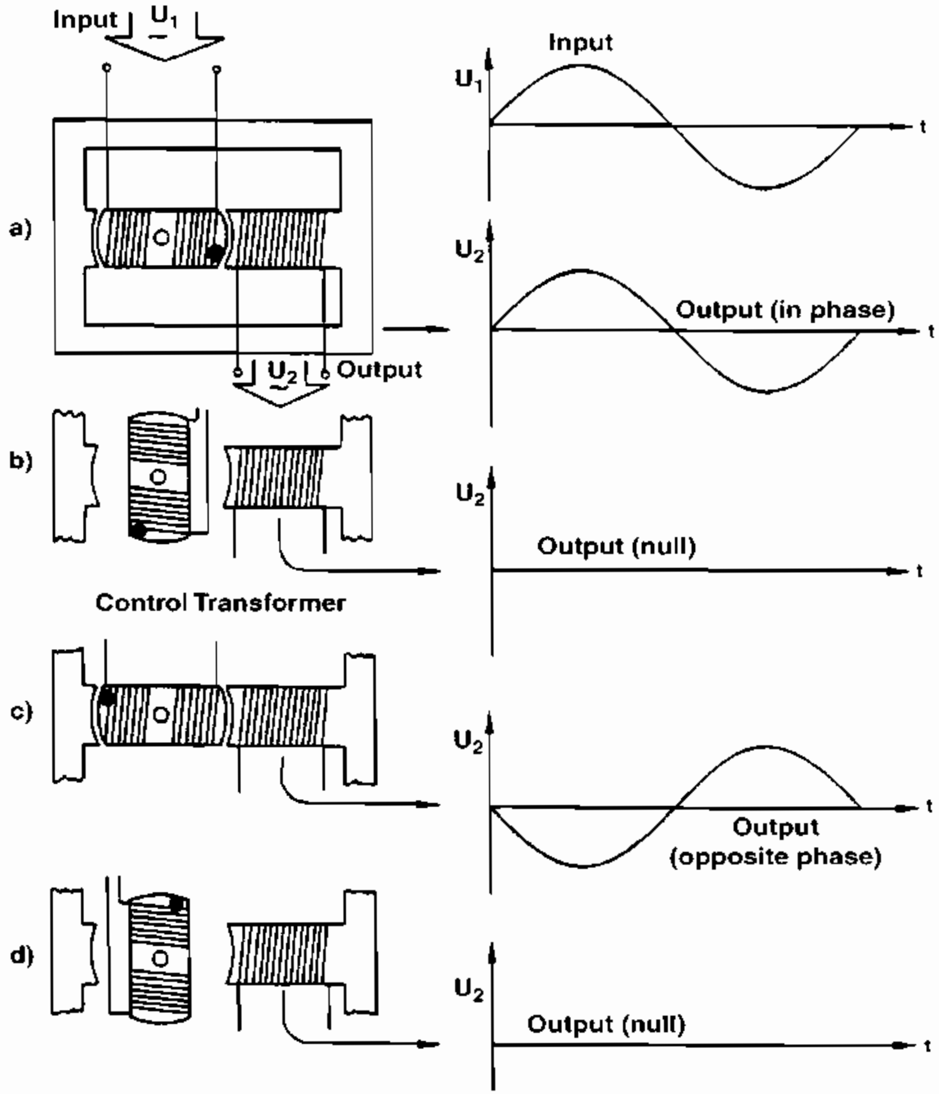
b) The primary coil is 90° clockwise rotated. No magnetic flux goes through the secondary coil. Output U_2 is null.

c) The primary coil is 180° in the opposite of the first position
The phase angle of the output voltage is opposite of the input voltage.

d) The primary coil is 270° rotated. The output is also null.
No magnetic flux goes through the secondary coil.

Positions in between the 4 shown cardinal positions will change the amplitude of the output, not the phase angle.

Figure 9: Output of a Control Transformer

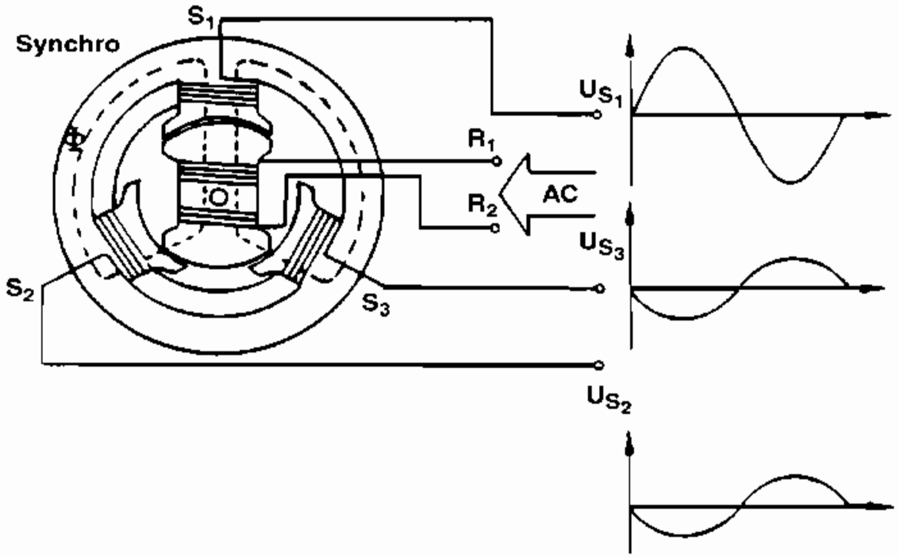


Synchros

Introduction

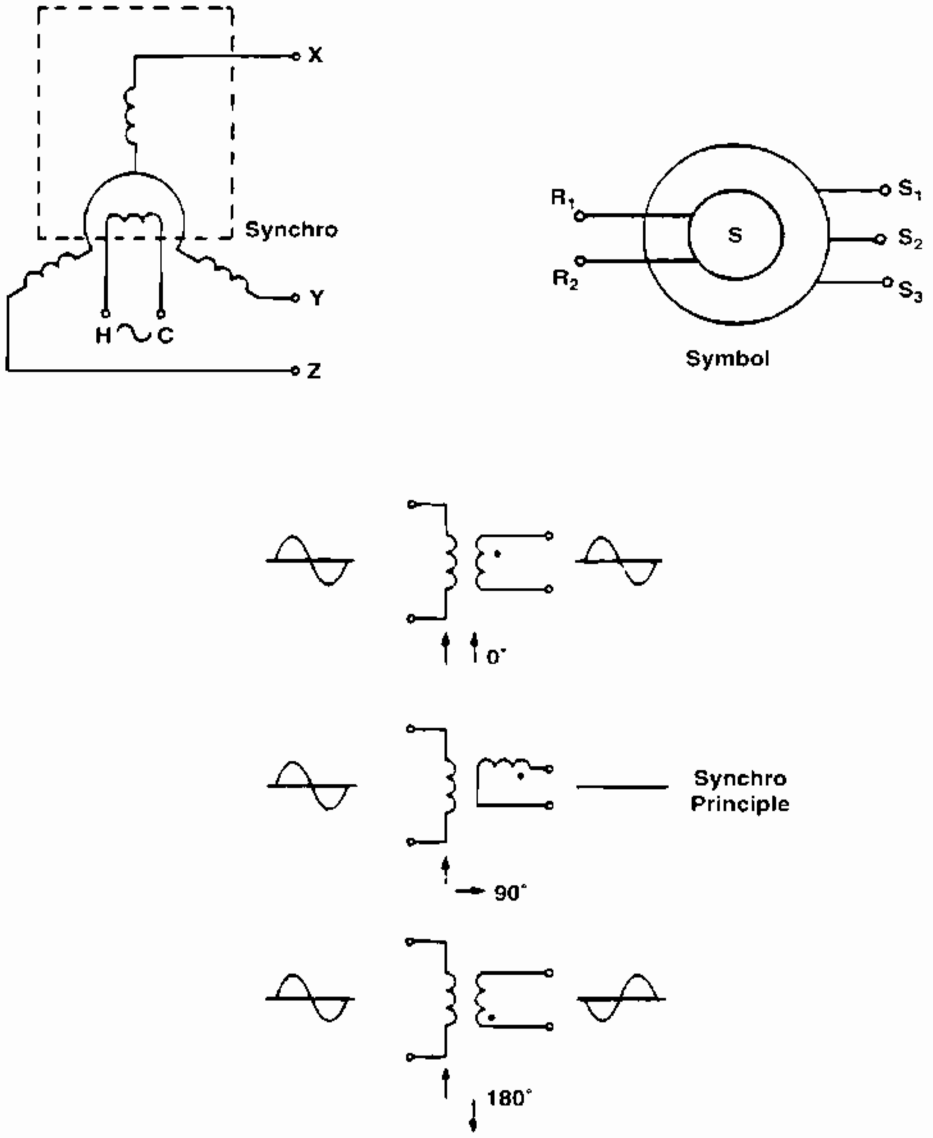
A typical synchro has a rotor and three stator coils. The coils in the stator are at 120 degrees with respect to each other. This unit acts like 3 control transformers contained in one unit.

Figure 10:



Synchros use 26 V AC or 115 V AC for excitation of the rotor The excitation makes a magnetic field in the rotor coil. This magnetic field induces a voltage in the stator coils. The voltages in the stator coils are in-phase or 180 degrees out-of-phase with respect to each other The voltage in the stator coils depends on the angle between the rotor coil and each stator coil. When we turn the rotor, the magnetic field in the stator also turns and the voltages in the stator coils change.

Figure 11: .



Direct Torquer Systems

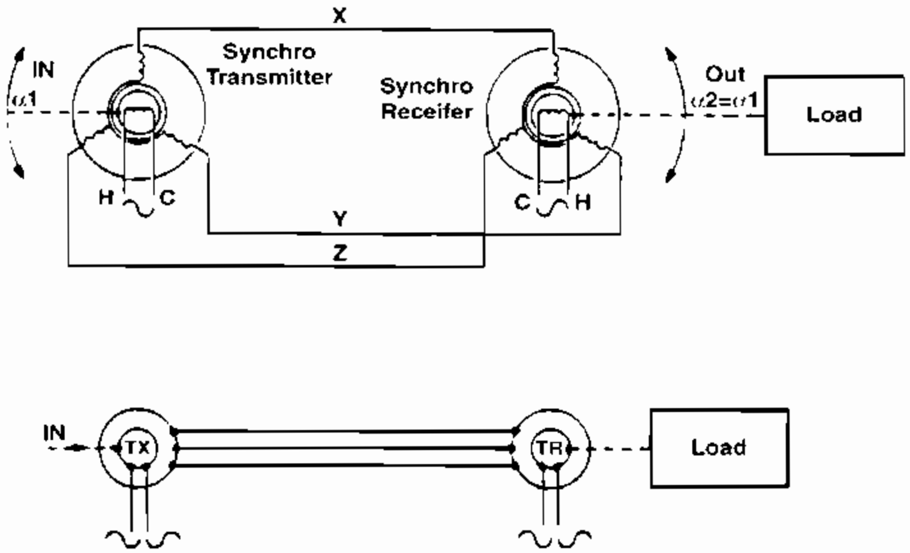
The output signal of a synchro is an AC signal which has angular information. The synchro's which make these signals are synchro transmitters.

These transmitters are of the old multi-coil type or of the latest solid-state type. The multi-coil type makes from a mechanical input a synchro signal, the second from an electrical input.

In a synchro system we connect the three output signals of a synchro transmitter to the three inputs of a synchro (receiver). The field that is made by the rotor of the synchro transmitter is now repeated in the stator of the synchro receiver.

Before the rotor of the receiver takes the position of the field in the stator we have to make a field in the rotor of the receiver This field must be 180° out of phase with the field made by the synchro transmitter. The rotor of the synchro receiver now goes to the same position as the rotor of the synchro transmitter. Any time we change the position of the rotor of the synchro transmitter the rotor of the receiver follows this turn.

Figure 12:



TX = Torque Transmitter = Synchro Transmitter
TR = Torque Receifer = Synchro Receifer

Servo Systems

The rotor of a synchro receiver gives a limited torque for other systems. When this torque is not high enough we have to use a servo system.

In a synchro-servo system the rotor of the synchro receiver gives a signal to a servo amplifier. In this system the rotor of the receiver is not connected to a supply source but it makes a signal from the stator-field in the receiver synchro. The output signal of the servo amplifier drives a motor. The motor drives, via a reduction gear, the rotor of the synchro receiver and a load.

When the output signal of the rotor of the synchro receiver is not zero, the servo amplifier drives the motor. The motor adjusts the position of the rotor of the synchro receiver and the load until the output signal of this rotor is zero. This output signal is zero when the angle between the rotor and the stator field is 90 degrees.

Figure 13: Servo System

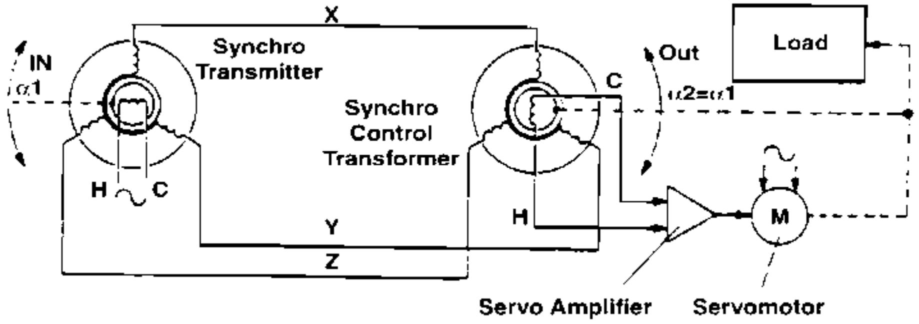
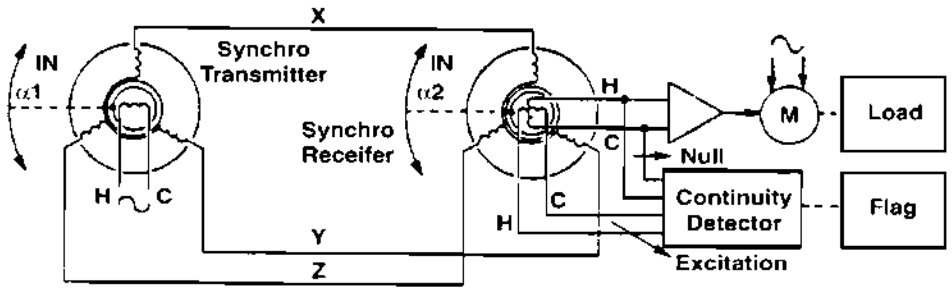


Figure 14: Monitoring

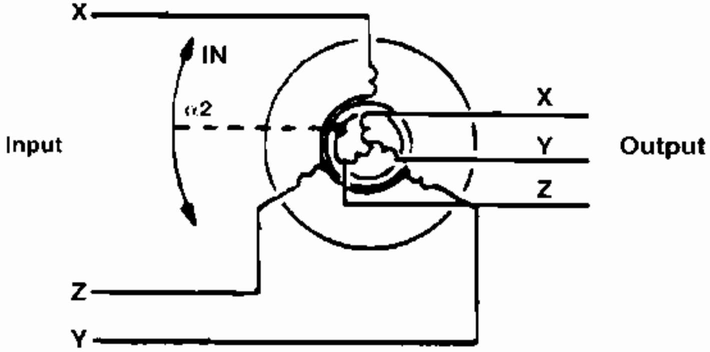
The output of the rotor of the synchro receiver is also zero when the transmitter supply fails or a rotor wire is broken. To make it possible to detect these failures there are synchro receivers with two rotor windings. These two windings are at 90 degrees with respect to each other. When the rotor of the synchro receiver is in the correct position, the output signal of one coil is zero and the output of the other coil is maximum. With these two signals it is possible to see if the system works properly. A continuity detector monitors the two output signals of the rotor coils and when everything is all right it enables a valid signal to, for example, a flag.



Differential Synchros

With a differential synchro it is possible to add or subtract angles. This synchro has three coils in the rotor and three coils in the stator at 120 degrees with respect to each other. When the rotor of this synchro is turned toward left or right, it adds or subtracts this angle from the angle the stator field has in the stator.

Figure 15: Symbol



The next diagram of a DG slaved compass system shows the usage of a differential synchro.

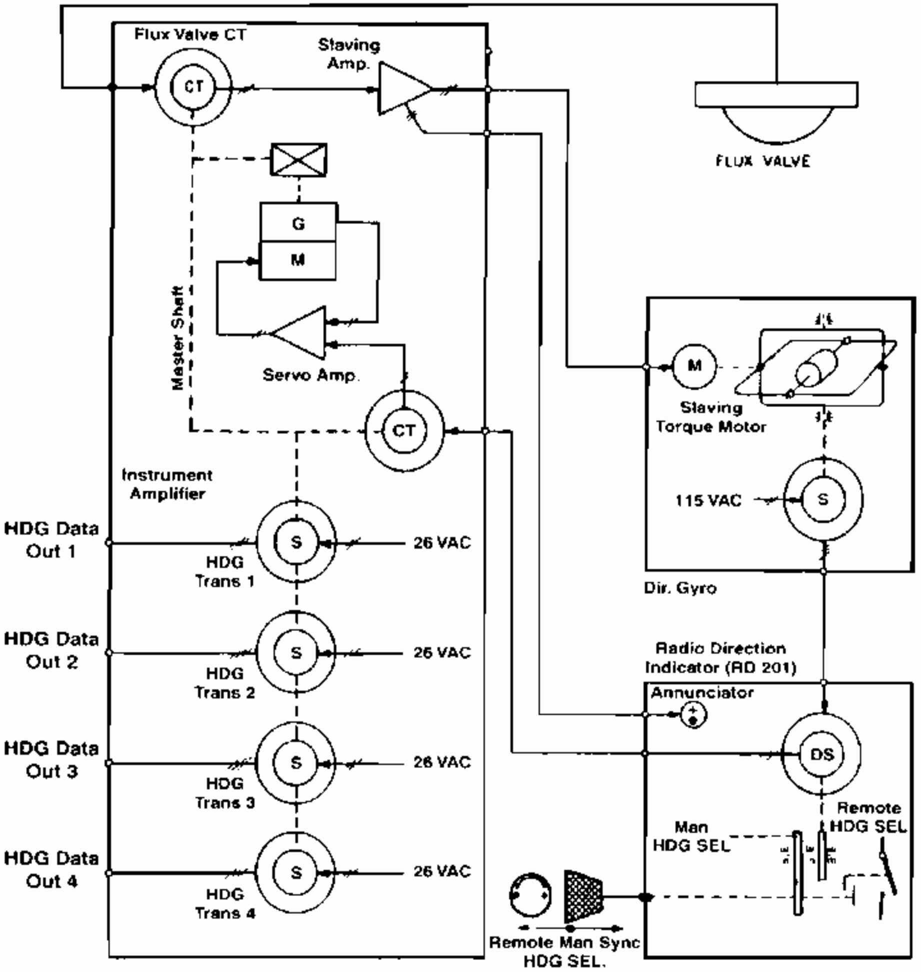
The flux valve sends the direction of the earth magnetic field to the flux valve control transformer.

If the mastershaft is not in the position which represents the magnetic heading, the slaving amplifier torques the directional gyro with a rate of 5 ^{0} per minute to the correct position.

The position of the directional gyro is transmitted via differential synchro to the master shaft. If the master shaft corresponds to the flux valve signal, the annunciator shows zero and the slaving is correct.

If the difference of mastershaft and earth magnetic field direction is to big, synchronizing takes to much time, so the pilot changes the DG output signal with the differential synchro to synchronize the compass manually, until the annunciator shows zero. In this case the DG will then maintain its own direction.

Figure 16: DS used to synchronize a Compass System



Resolvers

The resolver has two stator coils and a rotor coil. The two rotor coils and the two stator coils are at 90 degrees with respect to each other. A resolver makes from the signals in the stator coils sine and cosine signals.

Figure 17: Resolver

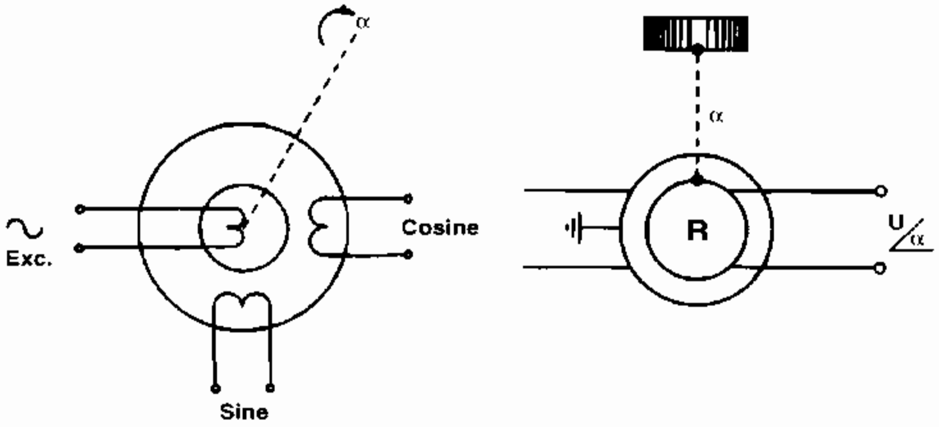


Figure 18: Sinus and Cosinus Signal depending of existing Angle

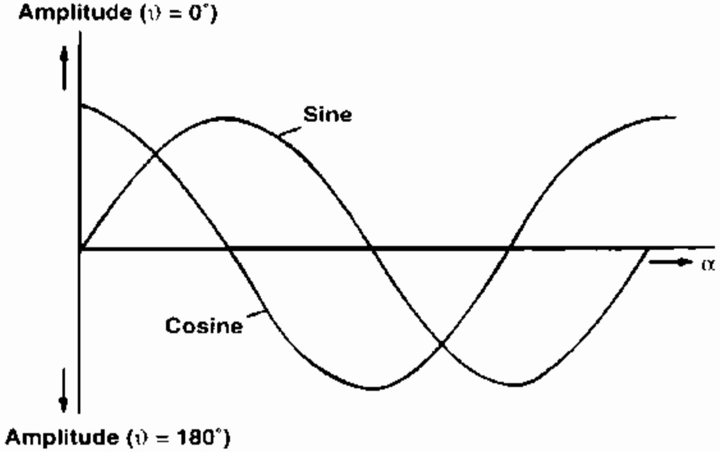


Figure 19: Resolver as Angular Transmitter

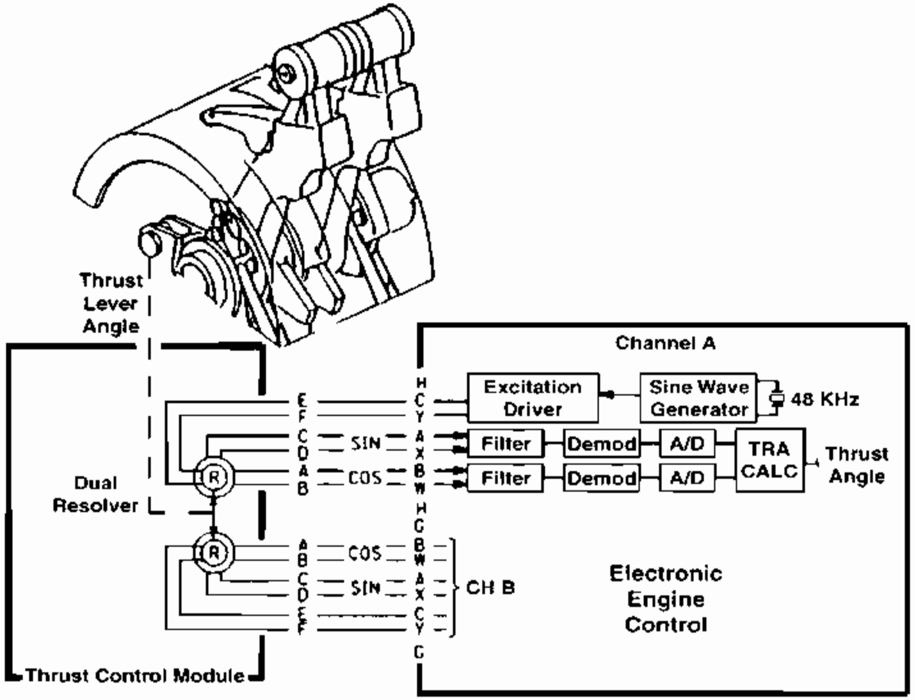
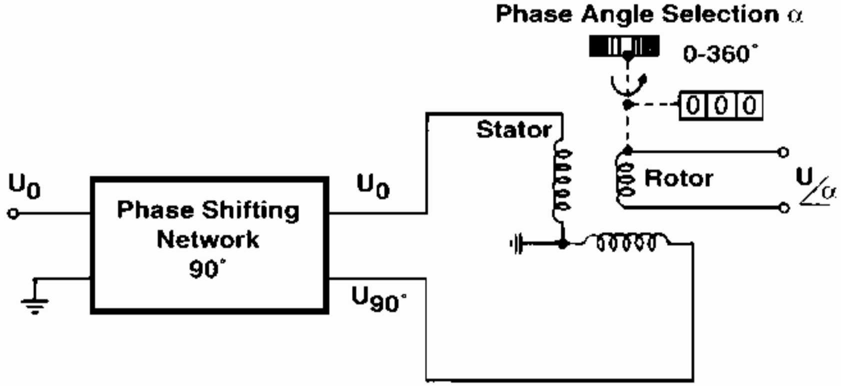


Figure 20: Resolver as Phase Angle Shifter 0 - 360°



Linear Variable Differential Transformer LVDTs

A transformer induces an output voltage in the secondary coil. According the direction of the windings, the phase angle is in (zero degr.) or opposite phase (180 degr.) The phase angle can be determined with dots.

Linear Variable Differential Transducers (LVDTs) change linear position information into electrical signals.

An LVDT has:

- one primary coil,
- a linear moveable iron core and
- two in serial connected secondary coils

The mechanical input changes the position of the iron core. The position of the core changes the magnetic coupling between the primary and the secondary coils. When the input moves the core in one direction, one of the secondary coils receives more magnetic flux. This induces a higher voltage in the coil

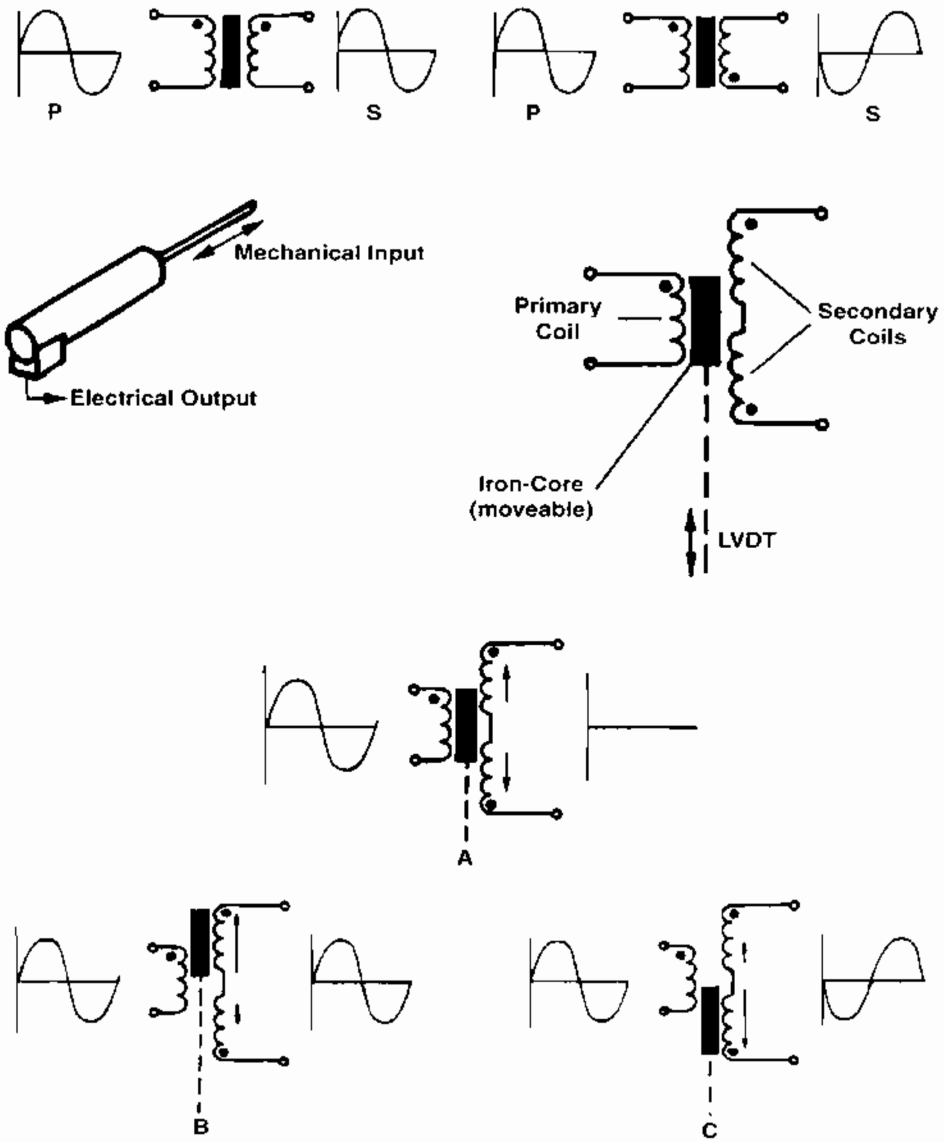
The other secondary coil receives less magnetic flux. This induces a lower voltage. The difference between voltages induced in the secondary stator coils is proportional to the mechanical position.

A. The position of the iron core is centred. The magnetic field induced by primary coil is equally divided between the secondary coils.Therefore the output voltage is zero.

B. The iron core has moved upward. Now there is more coupling to the upper coil and less coupling to the lower coil. The output voltage increases and is in phase with the excitation.

C. The iron core has turned downward. Now there is more coupling to the lower coil and less coupling to the upper coil. The output voltage increases and is in opposite phase with the excitation.

Figure 21: LVDT



Demodulation and Indication

The AC voltage from the LVDT is proportional of the deflection of the core and the phase is depending of the core direction. The signal must be phase-dependant demodulated. (Synchron demodulator)

The amplified signal goes via electronic switch. This closes periodically by the positive phase of the reference voltage. With no input signal the indicator shows zero.

Figure 22: Neutral Position

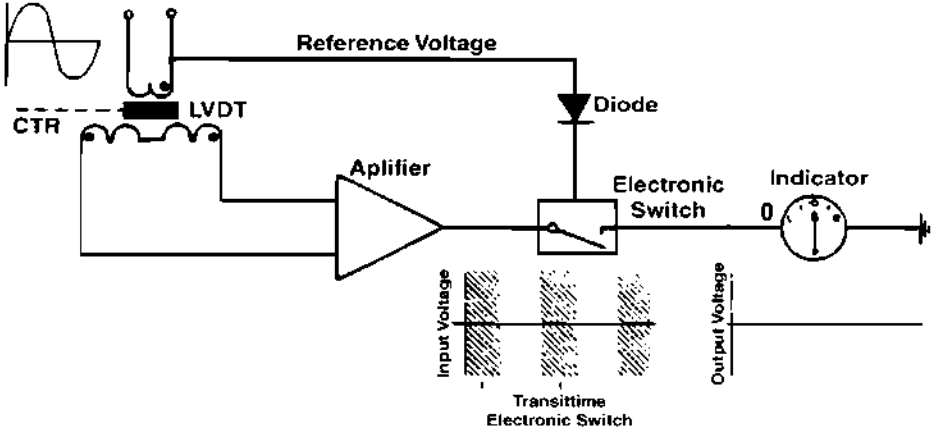
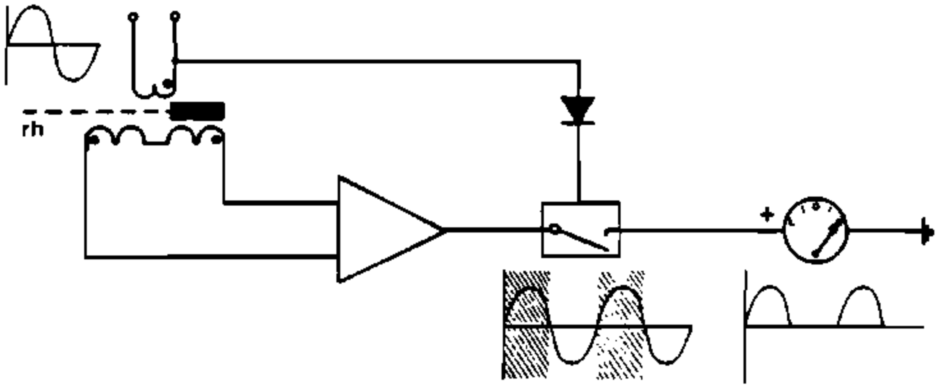
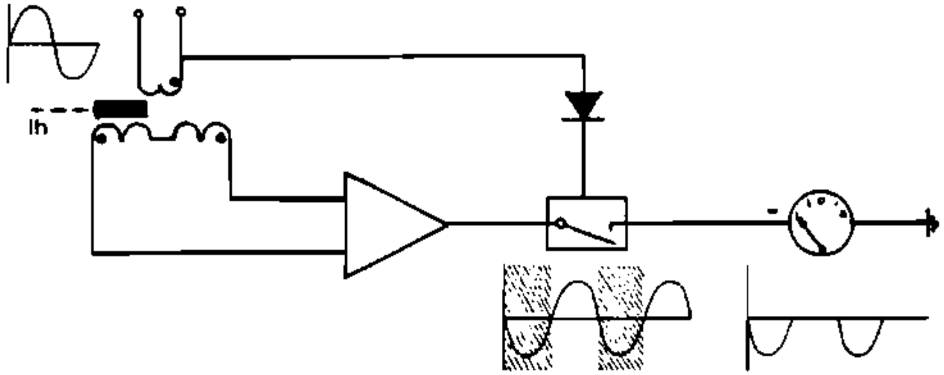


Figure 23: Deflection toward right



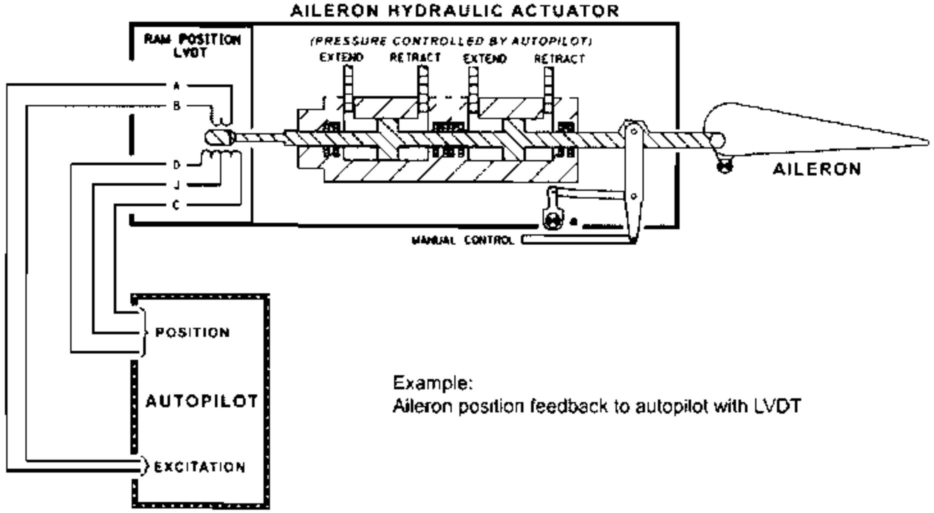
When the core moves to the right, the positive sine wave passes during transit time the electronic switch. The pointer of the instrument shows to the right side.

Figure 24: Deflection toward left



When the core moves to the left, the negative sine wave passes during transit time the electronic switch. The pointer of the instrument shows to the left side.

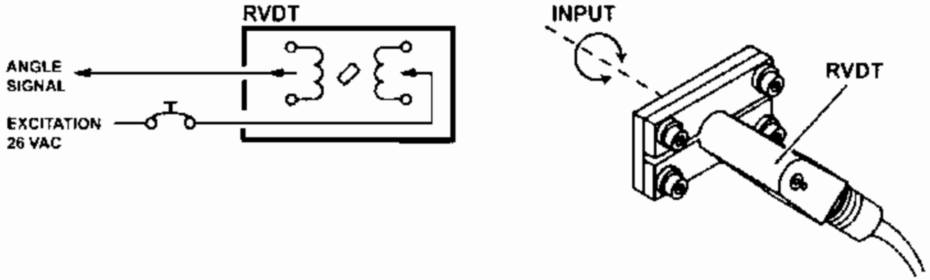
Figure 25: Usage of LVDT



Example:
Aileron position feedback to autopilot with LVDT

Rotary Variable Differential Transformer RVDT

Figure 26:



Rotary Variable Differential Transducers (RVDTs) change angular position information into electrical signals.

An RVDT has:

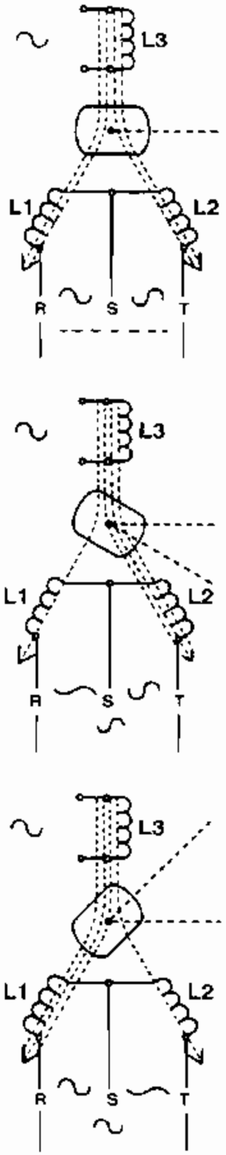
- a primary stator coil
- an iron rotor core
- two secondary stator coils.

The mechanical input changes the position of the iron core. The position of the core changes the magnetic coupling between the primary and the secondary stator coils. When the input rotates, one of the secondary coils receives more magnetic flux. This induces a higher voltage in the coil.

The other secondary coil receives less magnetic flux. This induces a lower voltage. The difference between voltages induced in the secondary stator coils is proportional to the rotated angle. This is an AC Ratio Signal.

The difference between rotation direction is that the output-voltage between R and T is of opposite phase. The output measured between R and T is an AC-RATIO signal which represents the rotated angle of the RVDT.

Figure 27:



Zero Position: The position of the iron core is zero. The magnetic field induced by primary coil L_3 is equally divided between L_1 and L_2. Therefore the voltage R-T is zero.

Rotated clockwise: The iron core has turned clockwise. Now there is more coupling between L_3 and L_2, and less coupling between L_3 and L_1. The voltage between T and S increases and the voltage between R and S decreases.

Rotated counter clockwise: The iron core has turned counter-clockwise. Now there is more coupling between L_3 and L_1 and less coupling between L_3 and L_2. The voltage between T and S decreases and the voltage between R and S increases.

Servo Motors and Tacho Rate Generators

Servo Loops

The DC servo motor loop is called a loop because of the closed nature of the system operation. The DC source is connected to the variable control potentiometer and to the follow-up potentiometer.

A servo amplifier amplifies the ratio signal and drives a motor with it. The motor drives a feedback device and a load. The signal from the feedback device also goes to the servo amplifier. The load is in the correct position when the difference between the ratio and the feedback signal is zero.

Servo Loop with DC Motor

Any time there is a difference between the two signals, the motor drives the load and feedback until both signals are equal. The polarity of the difference determines the direction of rotation.

Servo Loop with AC Motor

When we must have even more torque, it is better to use an AC motor. A chopper circuit makes AC from the DC signal. To drive the AC motor with this signal we need an extra amplifier. The rest of this system works like the DC servo system.

Figure 28: Servoloop with DC - Motor

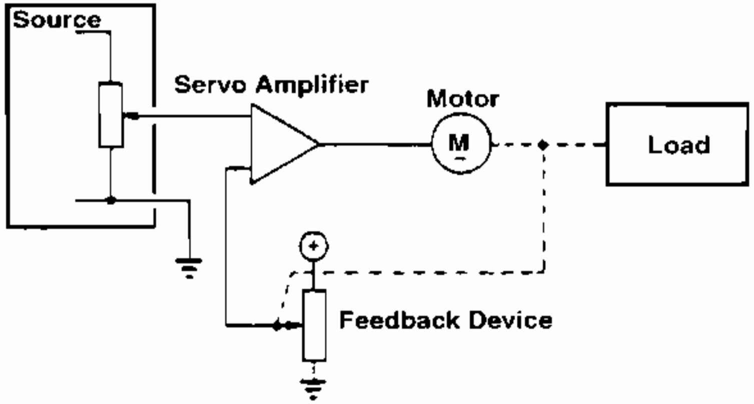
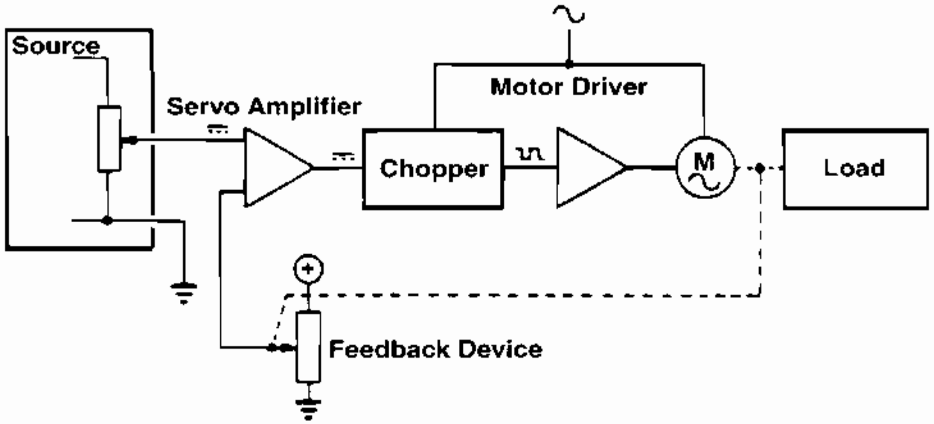


Figure 29: Servo Loop with AC - Motor



Two Phase Servo Motor

The AC two-phase inductance motor servo motor. It may be very small or it may be quite powerful. The construction of the stator has two fields. These two fields are represented symbolically by two coils drawn at right angles to each other.

Counter Clock Wise Rotation CCW

If a 400 Hertz voltage with a phase angle of 0° is connected to the variable field and an other 400 Hertz voltage with a phase angle of 90° The resulting field rotates at 400 revolutions per second. A capacitor in series with the fixed field shifts the voltage 90° of the variable field.

Rotation of the magnetic field in the motor tends to drag the rotor after it in the same direction. How fast the motor moves depends upon its load and the strength of the magnetic field, which effectively is dependent upon the strength of the variable signal.

Clock Wise Rotation CW

The phase of the variable signal has been reversed. This reverses the direction of rotation of the resultant field. The direction of motor rotation depends upon the phase of the variable signal, and the speed of rotation depends upon its amplitude.

Braked

Often times it is desirable to apply an electrical brake to a two-phase servo motor This can be done by disconnecting either the variable field or the fixed field. If only one field is left operative, the motor does not rotate because the field does not rotate. This tends to hold the rotor of the motor in a fixed position.

Servo motor loop using a control synchro input

It is typical of many such loops used throughout aircraft systems. Whenever the amplifier sees a signal of a particular phase, it drives the motor in a particular direction until the synchro rotor comes to a particular null. A signal of opposite phase from the synchro rotor drives the servomotor in the opposite direction. The synchro rotor therefore always is driven to a particular null.

The operating signal will come from some remote source whose mechanical position we want to duplicate in the operated item. For example, the remote source could be a directional gyro and the operated item could be a compass indicator.

Figure 30: 2 Phase Motor running CCW, CW and braked

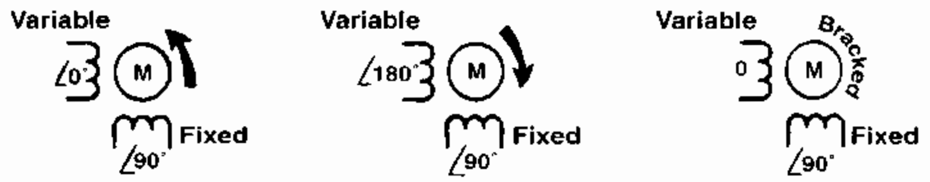
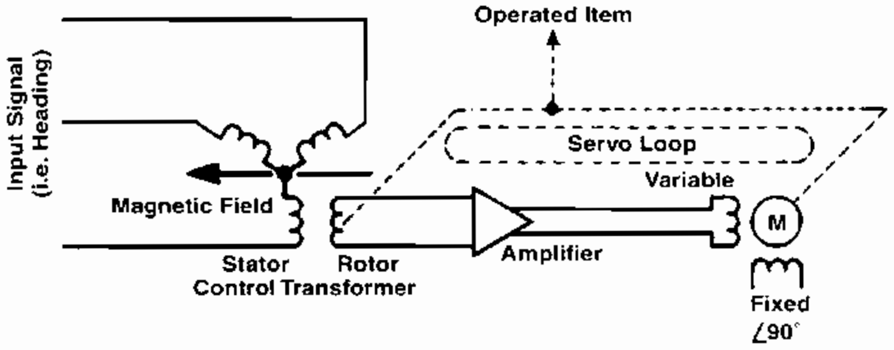


Figure 31: 2 Phase Motor in a Servo-Loop with Control Transformer



Tachometer / Rate Generator

Tachometer generator and rate generator are the same device. The output from a tachometer generator is in phase, or opposite phase angle with the excitation.

Tachometer not running

The powered fixed field is perpendicular to the variable field. The magnetic field is perpendicular to the variable field there is no transformer action and no signal out of the variable field winding.

Rotor turns in clockwise direction

The rotor as tending to drag the magnetic field along with it. A slow rate of movement of the rotor does not bend the magnetic field very much, whereas a greater rate of motion moves the field farther. The generated voltages increases in speed of the rotor.

A low rotor speed the small transformer coupling results in a small output voltage. At clockwise direction of rotation the output is a 400 Hz with a phase angle 180 degrees with a small voltage amplitude.

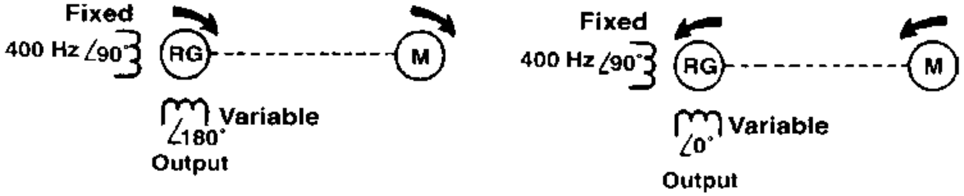
Speeding up the rotor displaces the magnetic field farther away from perpendicular, causing a larger voltage to appear at the output. The amplitude of the output is a direct function of the rotor speed.

Rotor turns in counter clockwise direction

The field has been moved away from perpendicular in the opposite direction, and therefore the phase of the output is opposite. The output frequency is independent of rotation speed 400 Hz.

One of the greatest uses of the rate generator is to provide inverse feedback signals in servo motor systems for speed limiting and smoothing functions. Another use is to provide rate signals.

Figure 32: Constant Frequency, variable Amplitude Output

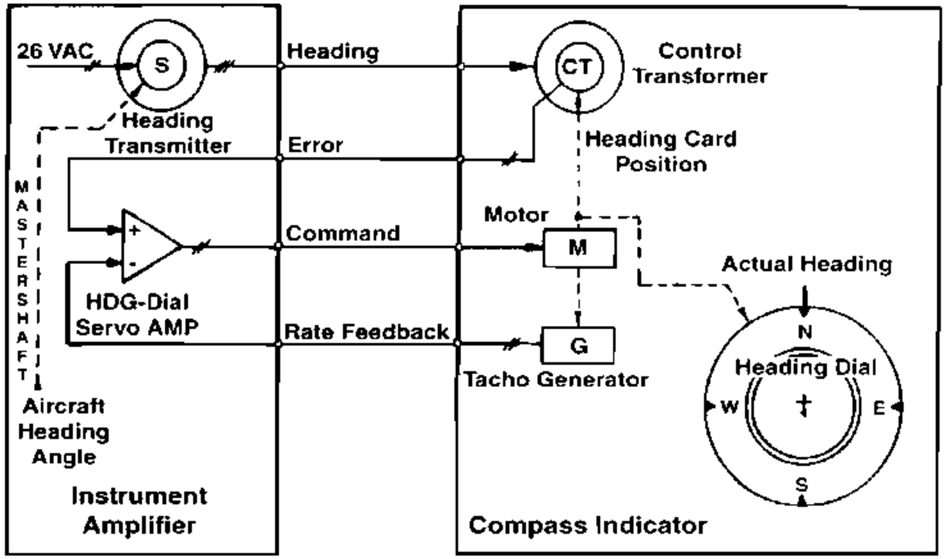


Example of a Servo Loop with Tacho Generator

The aircraft heading, represented by the angular position of the mastershaft, is send as heading signal to the control transformer. If the heading dial of the indicator does not correspond with the aircraft heading, an error signal results to the input of the amplifier The command signal drives the motor. If the heading card position is identical with the aircraft heading, the error output of the control transformer goes to null, so the motor stops.

The tacho generator produces a signal proportional with the rotating speed of the motor with the heading dial. The rate feedback is opposite applied to the amplifier. This reduces the rotating speed of the indicator to prevent overshooting and oscillations when the scale reaches its final position.

Figure 33: Heading Dial Servo Loop with Rate Feedback



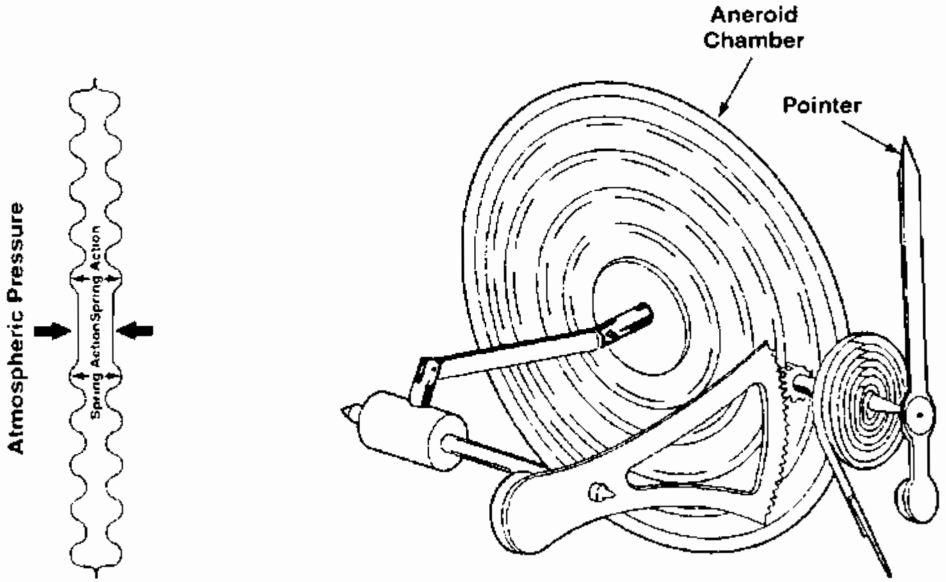
Pressure Measuring Instruments

Pressure is the amount of force acting on a given unit of area, and all pressure must be measured from some known reference. Absolute pressure is measured from zero pressure, or a vacuum. Gage pressure is measured from the existing atmospheric pressure, and differential pressure is the difference between two pressures.

Absolute Pressure Instruments

This instrument uses a sealed, evacuated, concentrically corrugated metal capsule as its pressure-sensitive mechanism. The concentric corrugations provide a degree of springiness that opposes the pressure of the air. As the air pressure increases, the thickness of the capsule decreases, and as the pressure decreases, the capsule expands. A rocking shaft, sector gear, and pinion multiply the change in dimension of the capsule and drive a pointer across a calibrated dial.

Figure 34: Aneroid



Gage Pressure Instruments

Gage pressure is measured from the existing barometric pressure and is actually the pressure that has been added to a fluid.

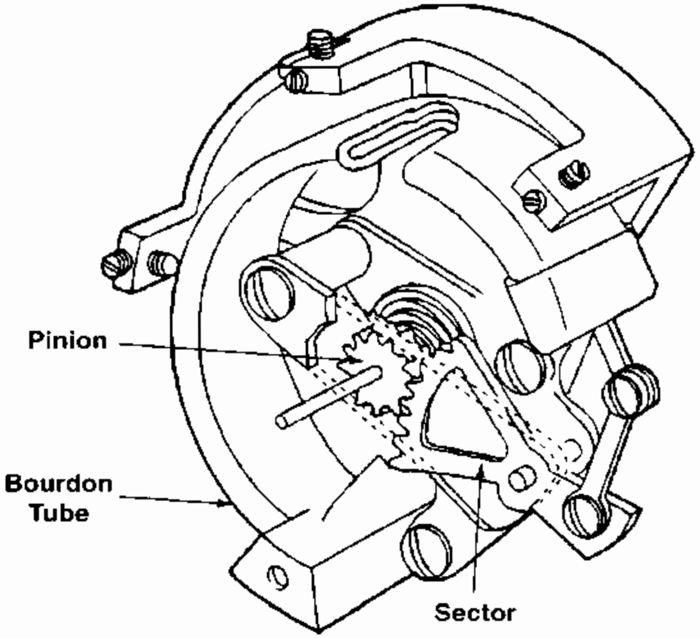
Burdon Tube

A Bourdon tube is typically used to measure gage pressure. This tube is a flattened thin-wall bronze tube formed into a curve. One end of the tube is sealed and attached through a linkage to a sector gear. The other end is connected to the instrument case through a fitting that allows the fluid to be measured to enter.

When the pressure of the fluid inside the tube increases, it tries to change the cross-sectional shape of the tube from flat to round. As the cross section changes, the curved tube tends to straighten out. This in turn moves the sector gear, which rotates the pinion gear on which the pointer is mounted.

Bourdon tube instruments measure relatively high pressures like those in engine lubricating systems and hydraulic systems.

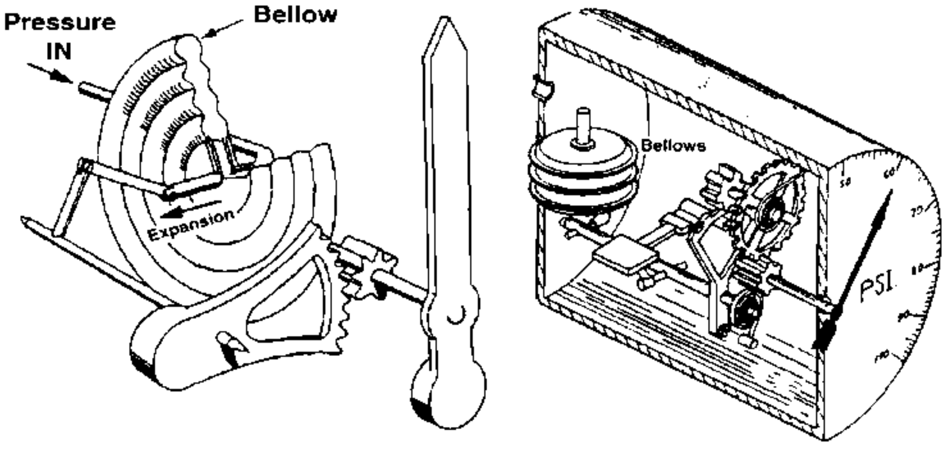
Figure 35: Burdon Tube



Bellows

Lower pressures such as instrument air pressure, deicer air pressure, and suction are often measured with a bellows mechanism much like an aneroid capsule. The pressure to be measured is taken into the bellows. As the pressure increases, the bellows expands and its expansion rotates the rocking shaft and the sector gear. Movement of the sector gear rotates the pinion gear and the shaft on which the pointer is mounted.

Figure 36: Bellow Mechanism and Instrument

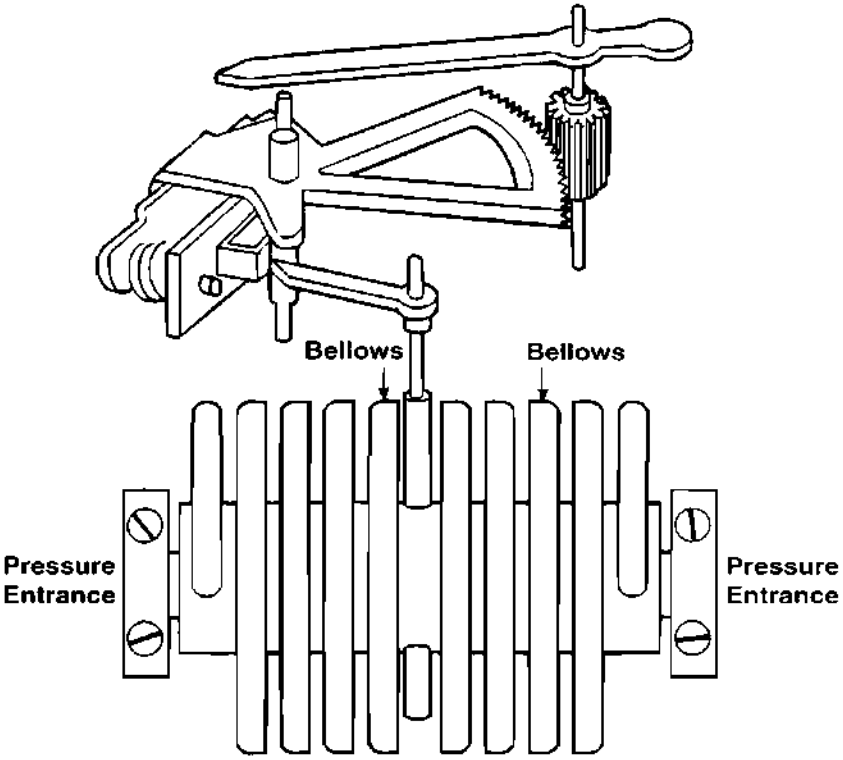


Differential Pressure Instruments

A differential pressure is simply the difference between two pressures. A differential bellows like that in the figure below is a popular instrument mechanism that can be used to measure absolute, differential, or gage pressure.

When used to measure differential pressure, as it is when used as a fuel pressure gage, one bellows senses the air pressure at the carburetor inlet, and the other bellows senses the fuel pressure at the carburetor fuel inlet. A differential bellows can be used to measure gage pressure by leaving one of the bellows open to the atmosphere and the other connected to the pressure to be measured.

Figure 37: Differential Bellows with Indication Mechanism



Strain Gages

This electric passive devices are used to detect forces. The resistance of strain-gages varies with the force applied to it. The metallic wire consists of a chrome-nickel alloy. The length and the diameter of the conductor changes as a function of the force. Expanding force increases, shortening force decreases the resistance.

This sensors are used for different applications. Structure monitoring, force sensors, pressure transducers and weight measuring. Inside pressure sensors, the pressure affects is changed into force.

Figure 38: Strain Gage

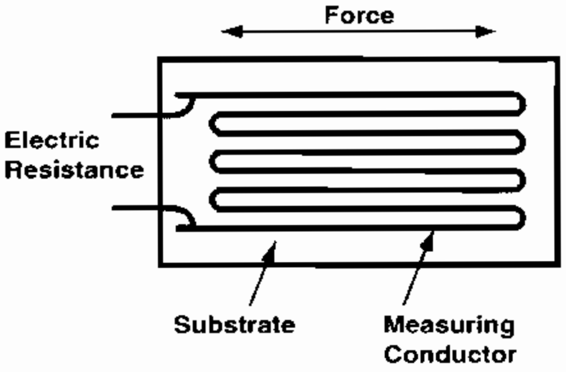
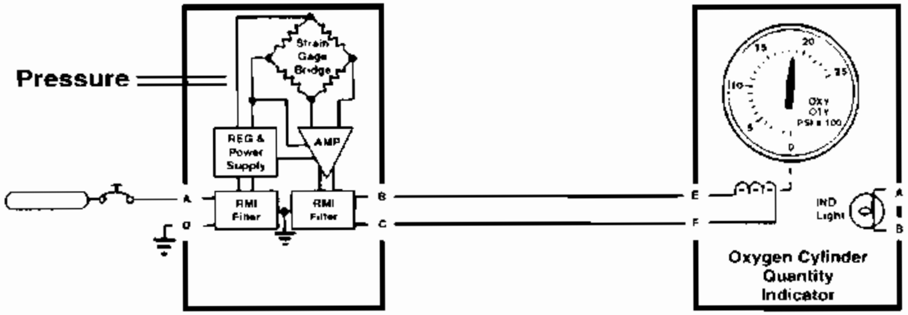


Figure 39: Pressure Indication using Strain Gage Bridge

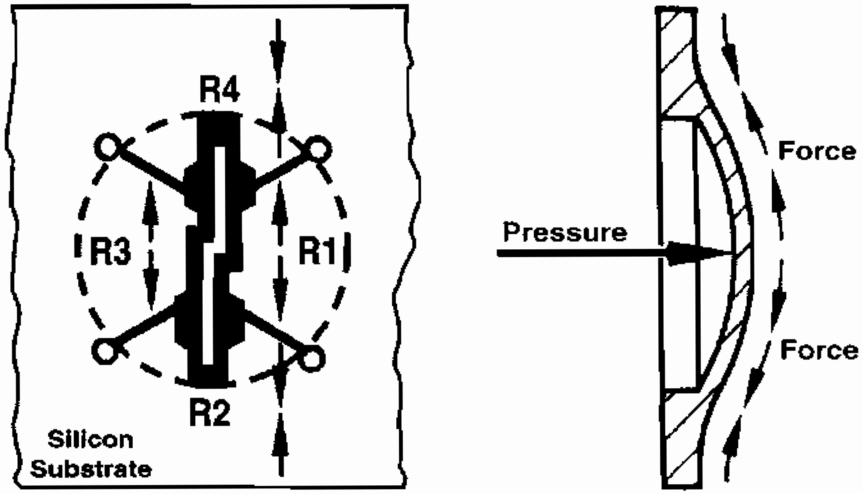


Piezo-Resistive Sensors

P- or N- conducting elements are diffused into a pure silicon substrate. This so called piezo-resistive effect changes the resistance with a much higher sensitivity a metallic strain gage does.

Semiconductor based sensors in many different forms. The substrate of the pressure sensor shown below has a dimension of 3.5 x 3.5 mm Inside there is a bridge with 4 elements.

Figure 40: Piezo Resistive Element



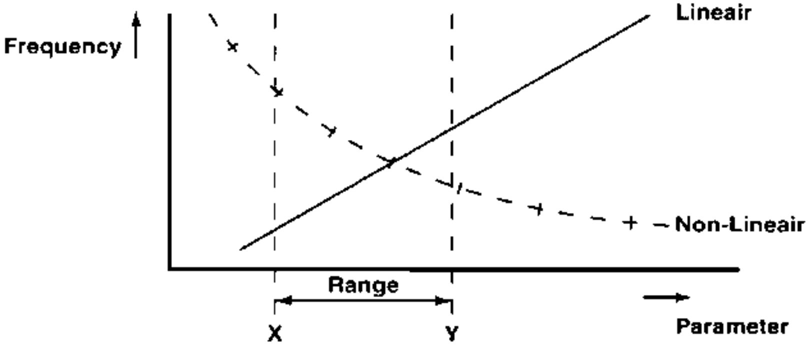
Variable Frequency Signals

A variable frequency signal has a frequency which is controlled by a certain parameter. A device with a variable output frequency makes such a signal. The frequency varies, under control of the parameter, between a high and a low frequency. These limit frequencies are different from device to device and depend on the design of the device.

A control voltage, a variable capacitor, or a variable resistor are, for example, parameters that control the frequency.

Frequency counters, microprocessor system and special moving coil meters are all devices that work with variable frequency signals.

Figure 41: Linear Parameter Output after Conversion



This very sensitive and accurate pressure transducer is used inside airdata computers. The oscillator coil assembly oscillates the diaphragm. Its resonant frequency increases with the applied pressure against the vacuum reference inside the transducer.

The output frequency, proportional to the pressure is easily changed inside the computer, into a digital signal. The temperature sensing resistor compensates influences of the ambient temperature.

Figure 42: Vibrating Diaphragm Transducer

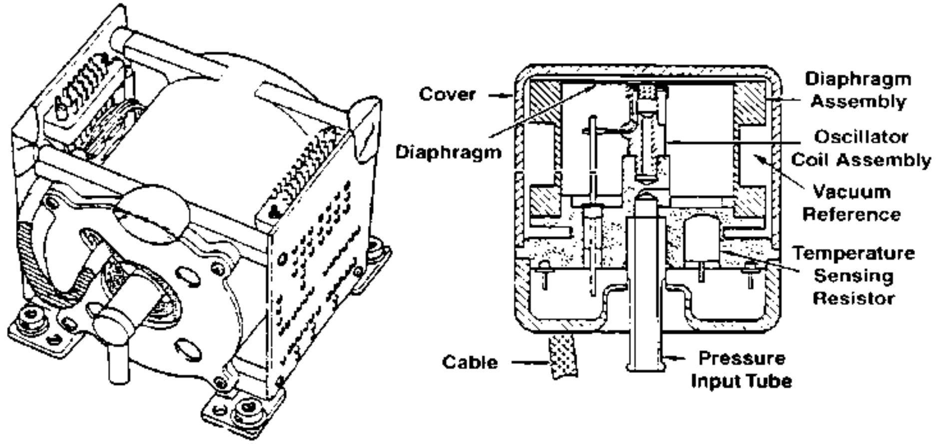
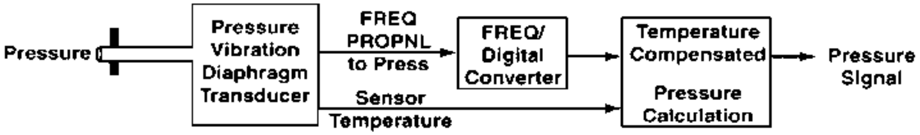


Figure 43: Pressure to Digital Conversion



Temperature Indication

Temperature is one of the most important measurements in the aircraft operation. Operational temperatures range from well below freezing for outside air, fuel, oil, air-conditioning and pneumatic air to around 1000°C for exhaust gas temperatures.

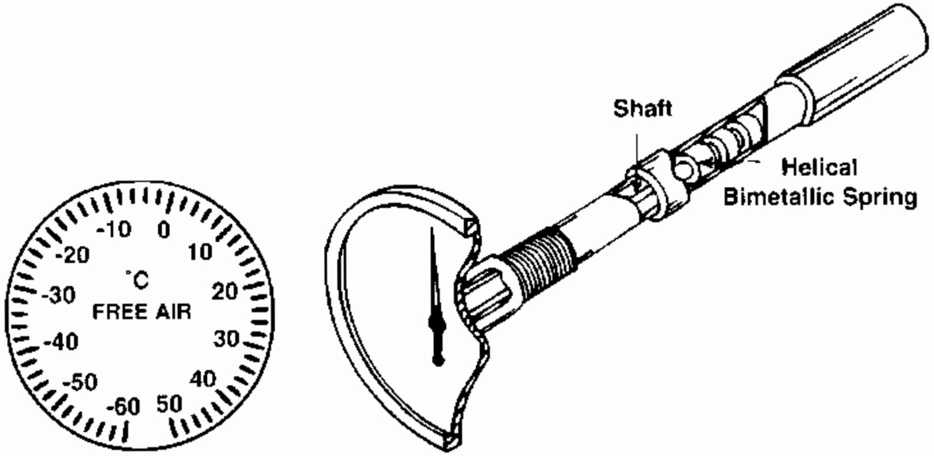
Nonelectrical Temperature Measurements

Most solids, liquids, and gases change dimensions proportional to their temperature changes. These dimensional changes may be used to move pointers across a dial to indicate changes in temperature.

Bimetallic

Most small general aviation aircraft have an outside air temperature gage protruding through the windshield. This simple thermometer is made of strips of two metals having different coefficients of expansion welded together, side by side, and twisted into a helix, or spiral. When this bimetallic strip is heated, one strip expands more than the other and the spiral tries to straighten out. A pointer is attached to the metal strip in such a way that, as the temperature changes, the pointer moves across a dial to indicate the temperature.

Figure 44: Bimetallic Outside Air Temperature Indication



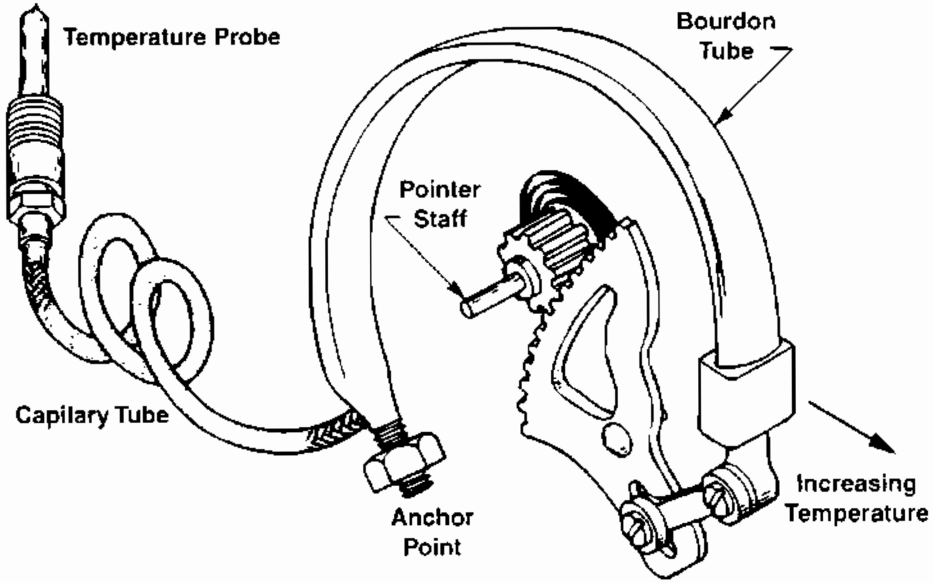
Gas Expansion

Temperature is determined by measuring the pressure of the vapors above a highly volatile liquid. The vapor pressure varies directly as the temperature of the liquid.

Bourdon tube consists of a hollow brass or bronze elliptical-shaped tube formed into a semi-circle. One end of the tube is open and connected to the fluid to be measured. the opposite end of the tube is sealed. As pressure is applied, the elliptical tube changes shape and tends to straighten the semi-circle curve. The bourdon tube need to bee attached to a mechanical linkage and pointer to create a usefull instrument.

A thin-wall, hollow metal bulb is connected to Bourdon tube by a capillary tube, that has a very small inside diameter. The bulb is filled with a volatile liquid such-as methyl chloride which has a high vapor pressure, and the entire bulb, capillary, and Bourdon tube are sealed as a unit. The bulb is placed where the temperature is to be measured and, as its temperature changes, the pressure of the vapors above the liquid changes. This pressure change is sensed by the Bourdon tube, which moves a pointer across a dial that is calibrated in degrees Fahrenheit or Celsius.

Figure 45: Remote Temperature Indication with Bourdon Tube

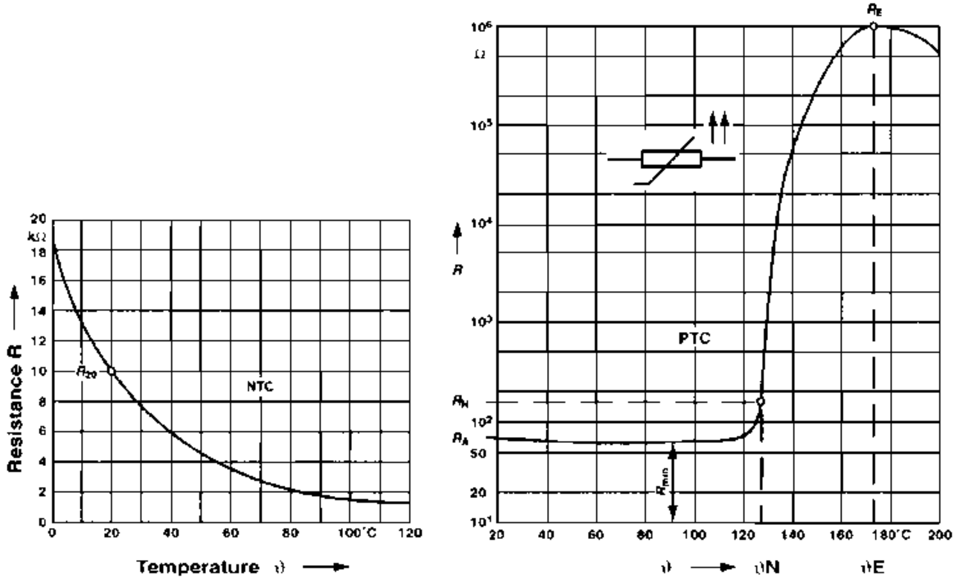


Temperature Dependant Resistors

The NTC (Negative Temperature Coefficient) resistor. It's resistance decreases at increasing temperatures. So it is called: High temperature conductor. (Heissleiter)

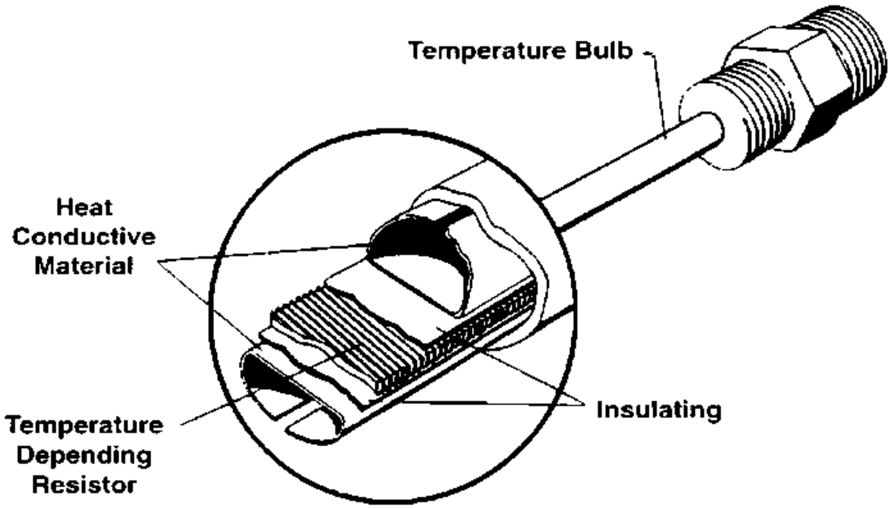
The PTC (Positive Temperature Coefficient) resistor. It's resistance increases with increasing temperature. So it is called: Low temperature conductor: (Kaltleiter)

Figure 46: Resitance verus Temperature



The temperature sensing bulb consists of a coil of fine nickel-chrome wire encased and sealed in a thin stainless steel tube. This bulb is immersed in the fluid whose temperature is being measured. The resistance of the nickel-chrome wire varies directly with its temperature. At the low end temperature, the bulb resistance is approximately 20 ohms, at its high end, its resistance is about 200 ohms.

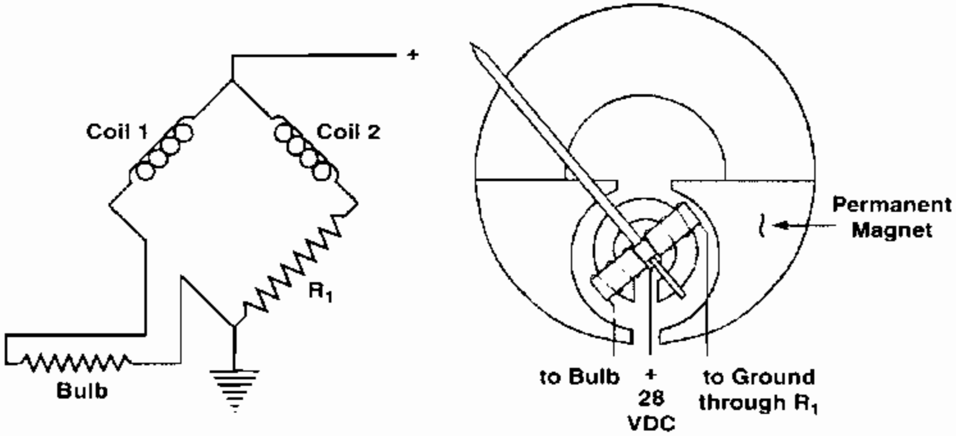
Figure 47: Resistance Temperature Bulb



Ratio Meter Circuits

The instrument uses two coils mounted on the indicator needle. When the temperature is low and the bulb resistance is low, more current flows through the coil 1 and the bulb than flows through coil 2 and resistor R1. The resulting magnetic field pulls the needle toward the low side of the dial. When the temperature is high and more current flows through coil 2 and R1 than coil 1 and the bulb, the needle deflects toward the high side of the dial.

Figure 48: Ratiometer with Moving Coil Instrument



Bridge Circuits

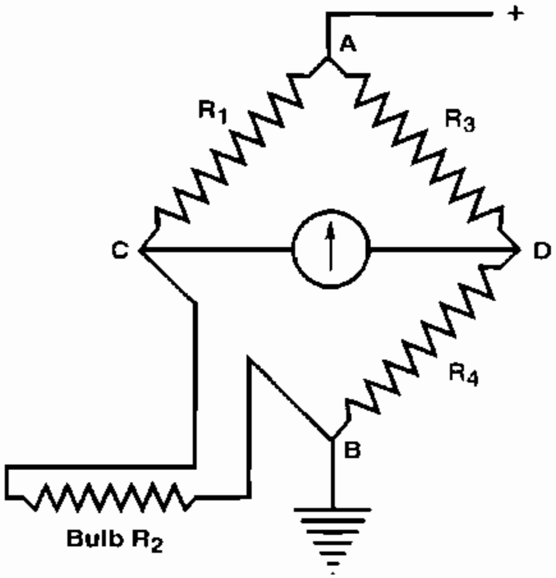
(Wheatstone) Bridge circuits are a special type of complex circuit often used in electrical measuring and controlling devices. The figure below shows a typical bridge circuit used to measure temperature. Resistor R_2 is a temperature probe. It resistance changes as its temperature changes.

When the bridge is electrically powered, electrons finds two path through which they can flow. They can flow through resistors R_1 and R_2 or they can flow through resistors R_3 and R_4.

If the four resistors have values such that the ratio of the resistance R_1 to R_2 is the same as the ratio of R_3 to R_4, then the voltage at point C will be the same as the voltage at point D. Because there is no voltage drop (no voltage difference) across the indicator, no current will flow through it. In this condition, the bridge is said to be balanced.

Resistor R_2 is variable, and as it changes from the value that balanced the bridge, a voltage drop will be developed across the indicator that causes current to flow through it. As the resistance of R_2 goes up, current flows C to D. If the value of R_4 goes down below the balance value, current flows from D to C.

Figure 49: Wheatstone Bridge Circuit



Thermocouples

Higher temperatures, like those found in the exhaust gases of both reciprocating and turbine engines, are measured with thermocouples.

A thermocouple is a loop made of two different kinds of wire welded together at one end to form a hot, or measuring junction. For example chromel and alumel wires. The coil of current-measuring instrument is connected between the wires at the other end to form a cold, or reference junction.

The hot junction is held against the cylinder head in the spark plug gasket and a voltage is produced in the thermocouple whose amount is determined by the difference in temperature between the hot and cold junctions. This voltage difference causes a current to flow that is proportional to the temperature of the cylinder head.

Figure 50: Thermo Couple Principle

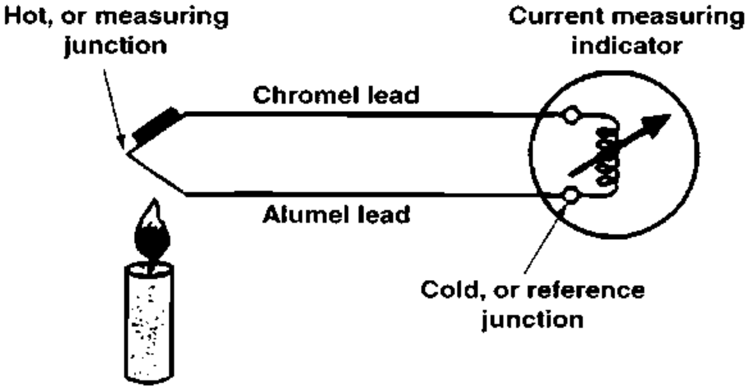


Figure 51: Cylinder Head Temperature (Spark plug gasket)

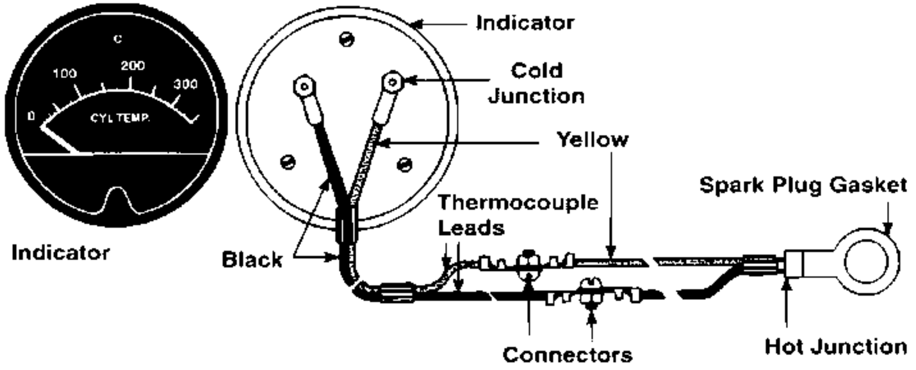
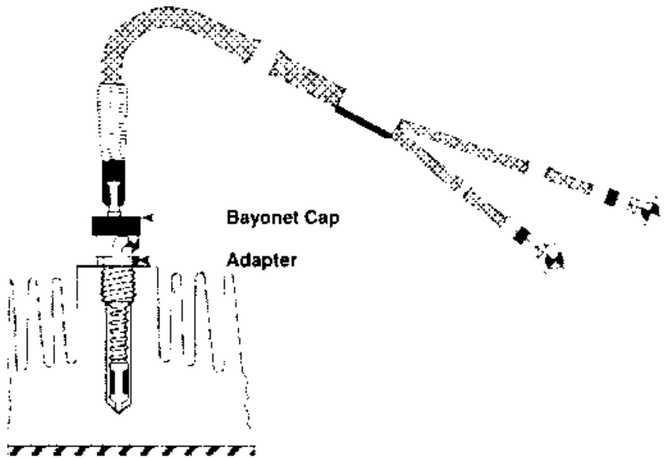


Figure 52: Thermo Couple (Bayonet Type for Cylinder Head)

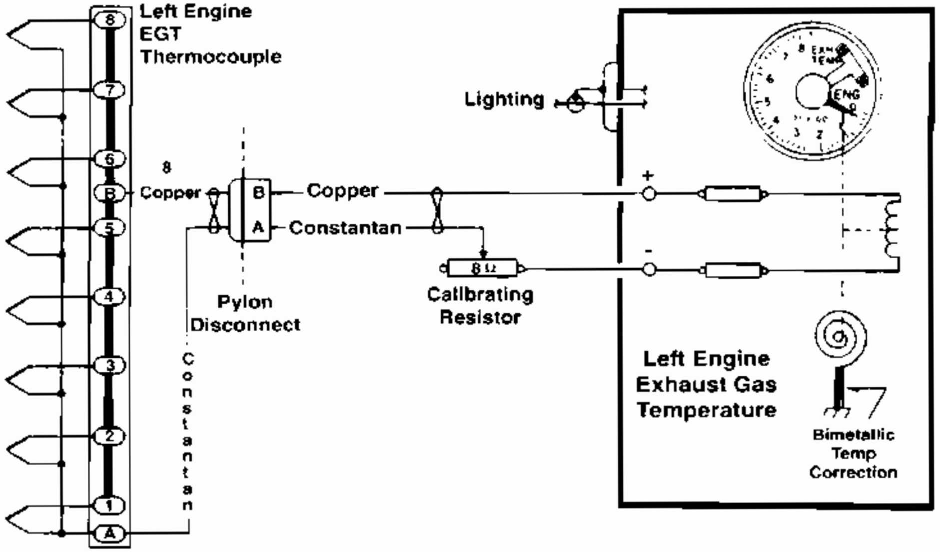


Thermocouples for Jet Engines

The exhaust gas temperature EGT system for a turbine engine is similar to that for a reciprocating engine except that several thermocouples are used. These are arranged around the exhaust so they can sample the temperature in several locations.

For accurate temperature indication, the reference junction temperature must be held constant. This is not practical to do this in an aircraft instrument, so the indicator needle is mounted on a bimetallic hairspring in such a way that it moves back as the cockpit temperature increases. This compensates for reference junction temperature changes.

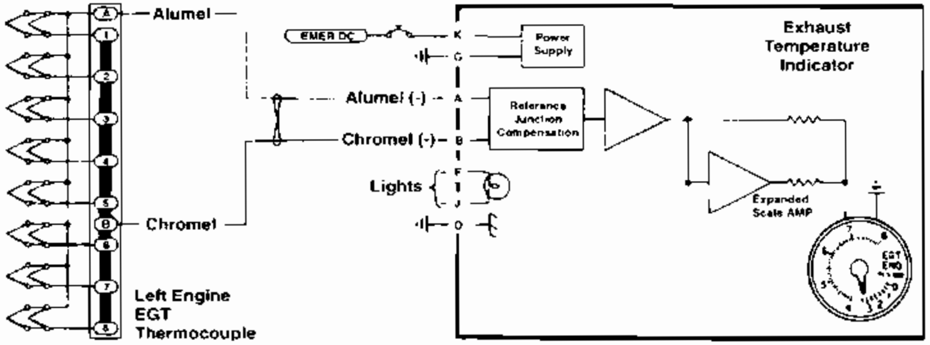
Figure 53: EGT Indication (Copper Constantan)



Small indicators operates without any additional electrical power except for the illumination. For more complex indicators, in example non linear scales, electrical power supply is used for the amplifiers and motors inside the indicator

- Chromel (alloy of chromium and nickel)
- Alumel (alloy of aluminium and nickel)

Figure 54: EGT Indication (Chromel Alumel)



Quantity Indication System

DC Electrical Indicators

A common quantity indicating system for fuel and oil operates on direct current. These systems consists of a variable resistor as a tank unit or transmitter and a current measuring instrument as the indicator.

The tank unit consists of either a wire wound resistor or a segment of composition resistance material and a wiper arm driven by float moves across this resistance material to change the resistance as a function of the fuel level in the tank.

The ratio meter-type minimizes the error that would be caused by variations in system voltage. Current flows through both coils and both the fixed resistor and the tank unit.

Figure 55: Variable Resistor and Permanent Magnet Rotor Indicator

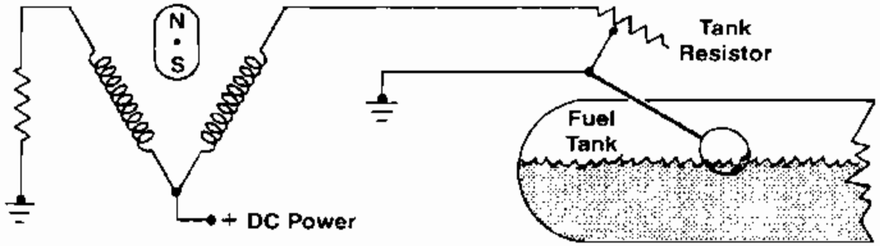
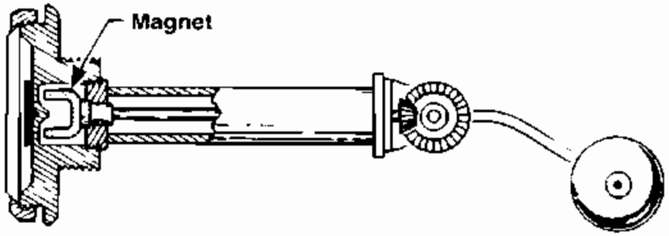
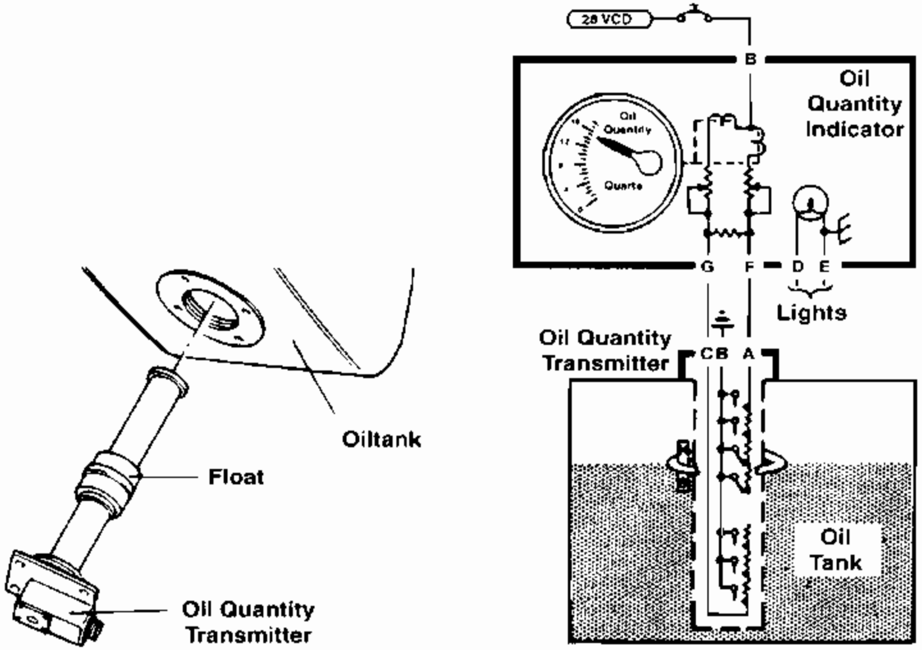


Figure 56: Mechanical Float Type Gauge



This oil quantity transmitter is a variable reed switch type resistor. The reed switch operates by a magnet in a float. The current to the indicator is depending of the activated resistors in the probe.

Figure 57: Probe with magnetic Float and Reed Switches



Capacitance Quantity System

Capacitance type fuel quantity measuring system that measures the mass of the fuel, rather than just its level in the tank. This is an electronic system that measures the capacitance of the probe, or probes, which serve as the tank sender units. A capacitor, can store electrical charges, and it consists of two conductors called plates separated by some form of dielectric or insulator. The capacity of a capacitor depends upon three variables: the area of the plates, the separation between the plates, which is the thick-ness of the dielectric, and the dielectric constant of the material between the plates. The probes in a capacitance fuel quantity indicating system are made of two concentric metal tubes which serve as the plates of the capacitor. The area of the plates is fixed, as well as the separation between them, so the only variable we have is the material which separates them.

These probes are installed so they cross the tank from top to bottom, and when the tank is empty, the plates are separated by air which has a dielectric constant of one. When the tank is full, the dielectric is fuel which has a constant of approximately two. In any condition between full and empty, part of the dielectric is air and part is fuel, and so the capacity of the probe varies according to the level of fuel in the tank.

One of the big advantages of this system is that the probes can be tailored for tanks of all sizes and shapes, and all probes in the aircraft can be connected so the system integrates their output to show the total amount of fuel on board.

The dielectric constant of the fuel is approximately two, but it varies according to its temperature and so a compensator is built into the bottom of one of the tank units. It is electrically in parallel with the probes and cancels the changes in dielectric constant as the temperature of the fuel changes.

Figure 58: Capacitors Current depending on Frequency and Capacitance

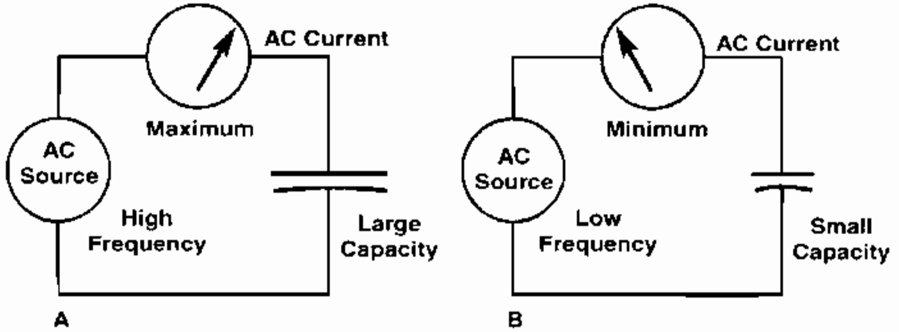


Figure 59: Capacitors Current depending on Liquid Level

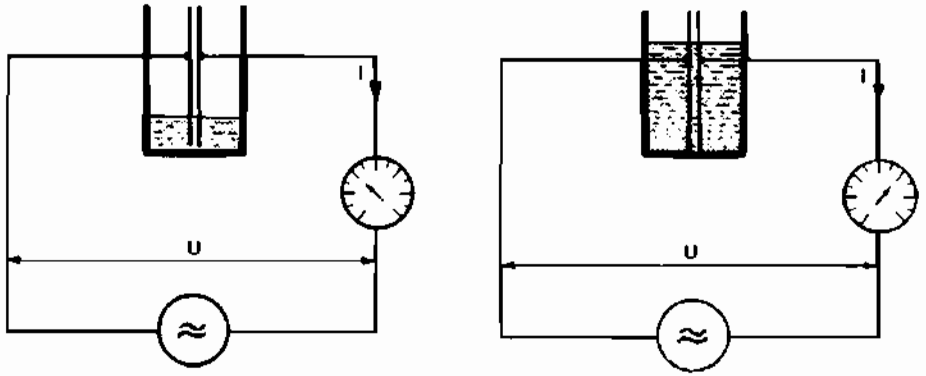
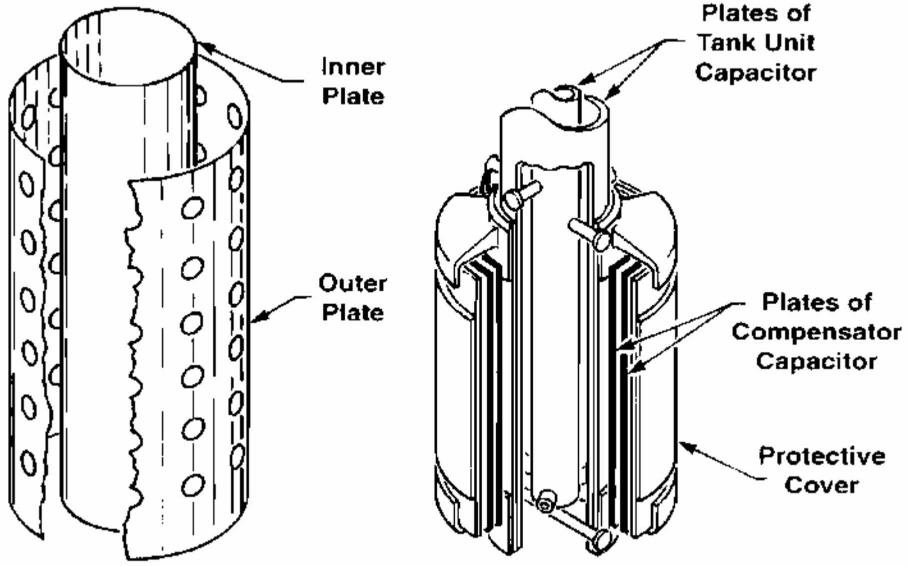


Figure 60: Quantity Probe without and with Compensator



Capacitance Bridge

The entire system acts as a capacitance bridge. This is a balanced circuit consisting of transformer taps A-B and capacitor C1, the tank probe, balanced by transformer taps B-C and the reference capacitor C2. When the impedance of the two halves of the bridge are equal, there is no flow through the indicator, but when the capacity of the tank unit changes, the bridge unbalances and the indicator shows the amount of change.

Quantity Indicator

The actual circuit is slightly more involved. The compensator is in parallel with the tank probe in one side of the bridge, between the amplifier and a tap on the empty calibrating potentiometer. This is all connected to one side of the power supply transformer secondary winding. The other half of the bridge receives its power through the full calibrating potentiometer The capacitor in this half of the bridge is the reference capacitor inside the instrument case, and it is in parallel with a capacitor in the balancing circuit.

When the tank is filled, the bridge unbalances and the amplifier senses the unbalanced condition and sends a signal to the two-phase servo motor. This motor compares the signal from the amplifier with a reference signal taken from the primary of the power transformer, and since the two signals are out of phase, the servo motor runs and drives both a balancing potentiometer and the pointer of the indicator. The balancing potentiometer changes the impedance of its half of the bridge until the bridge rebalances. When the bridge is balanced, the signal from the amplifier exactly cancels that from the transformer and the servo motor stops.The pointer indicates the number of pound or kilogrammes of fuel on board. As fuel is used from the tank, the capacitance of the tank unit changes again, unbalancing the bridge, the servo motor runs until the bridge rebalances and the servo motor stops with the pointer again indicating the amount of fuel on board.

This system has a test feature: a test switch shorts out part of the inductance in one side of the bridge, this drives the indicator towards Empty. As soon the test switch is released, the pointer goes right back to the correct indication.

Calibration is done by a screwdriver adjustment to the Empty and Full calibration potentiometers. When the tank is empty, the Empty calibrating potentiometer is adjusted until the gauge reads Empty, then the tank is filled and the Full calibrating potentiometer is adjusted until the indicator reads Full.

Figure 61: Capacitance Bridge

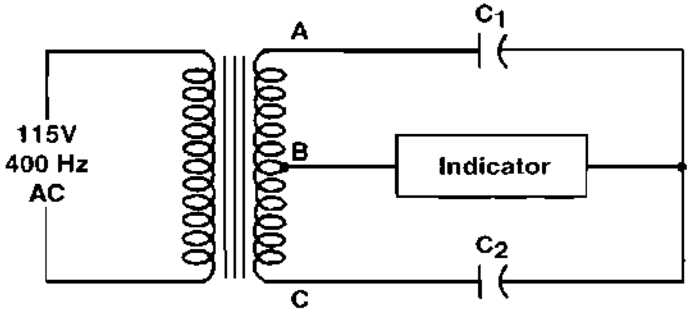
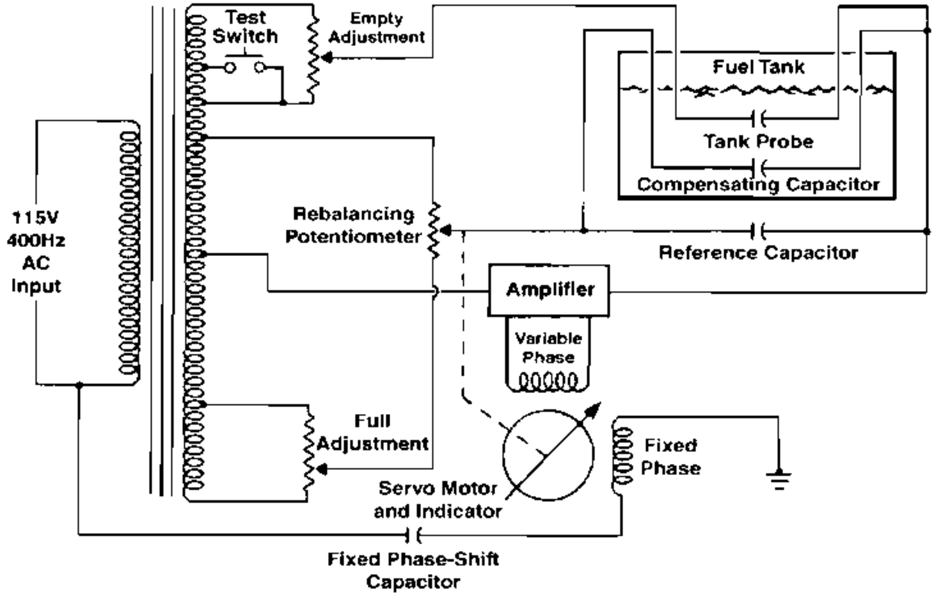


Figure 62: Quantity Indicator (Capacitance Bridge analog)

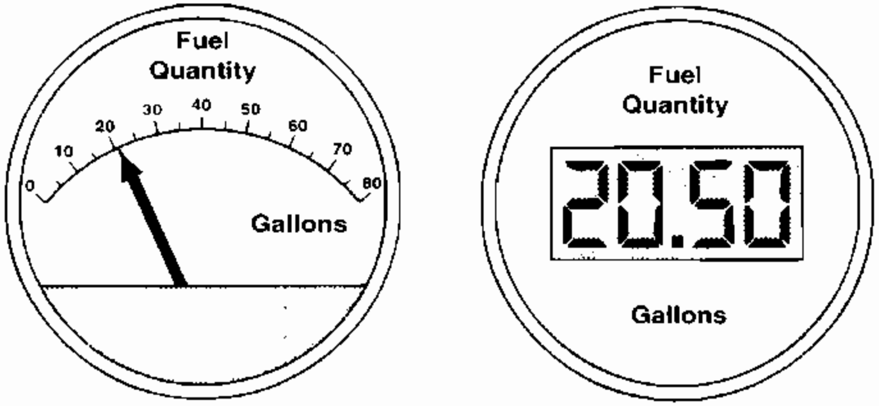


Digital Fuel Quantity Indicating System

Today the digital technology is also incorporated into quantity indicating system.

Basically the system uses capacitance probes. The indicating system converts by processors the capacity into fuel weight.

Figure 63: Analog and Digital Display



Analog Display
20.5 Gallons

Digital Display
20.5 Gallons

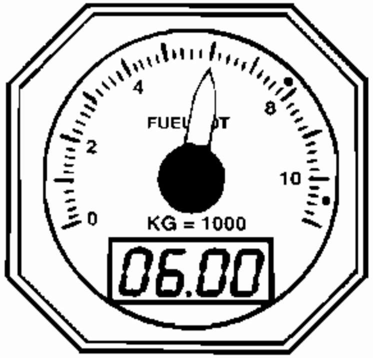
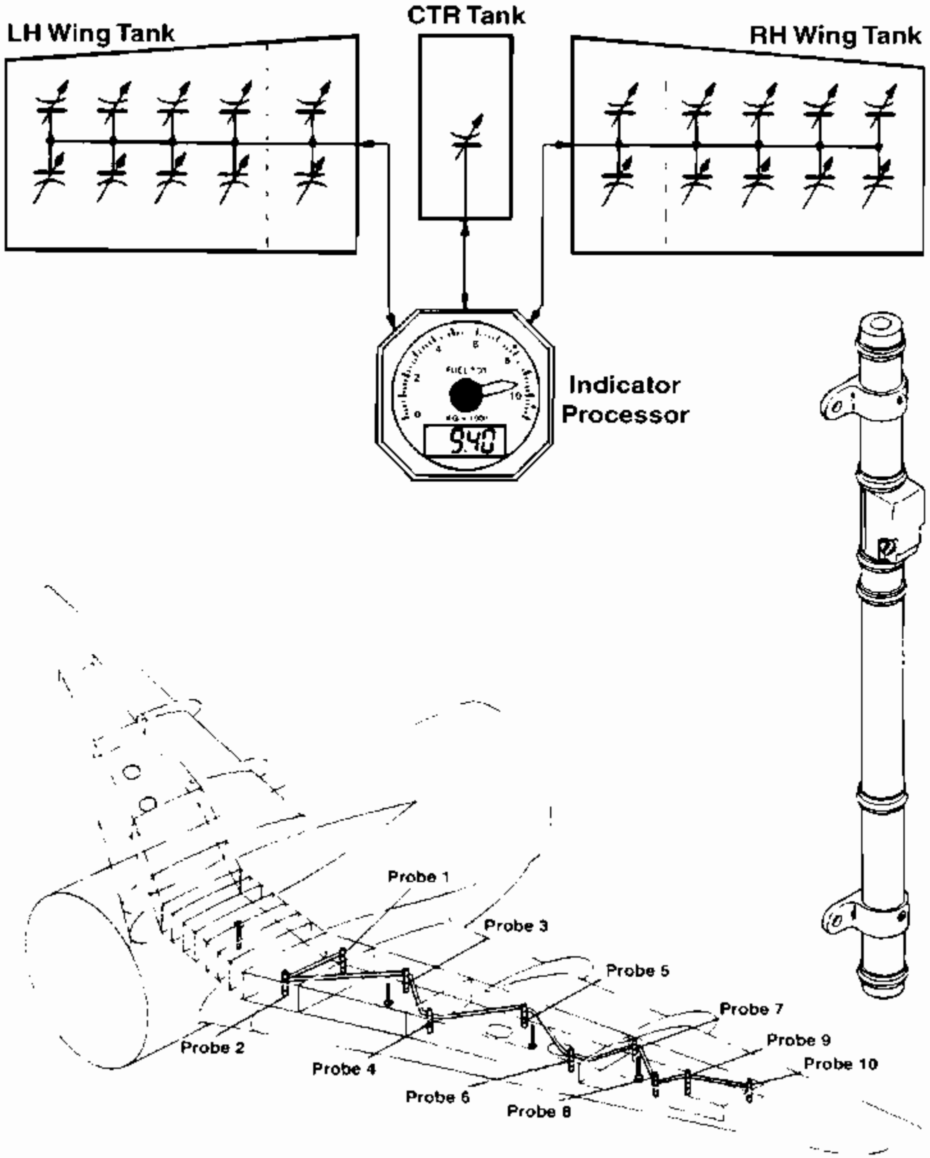


Figure 64: Probes and Digital Indicator with integrated Processor



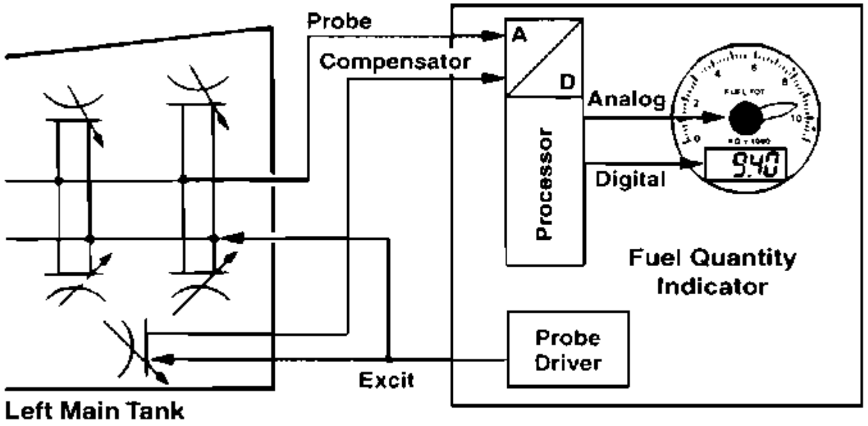
Digital Fuel Quantity Indication Circuit

The Indicator contains a power supply unit, a probe driver, a analog to digital converter and a processor unit. A combined digital read-out with analog pointer and scale eases a safe reading.

The probe driver sends a drive signal to the tank probes and compensator For example with an excitation frequency of 1 kHz. Fuel quantity information comes back from the probes into the Indicator. The compensator senses the dielectric constant of the fuel used to calculate the fuel weight.

The analog signals coming from the probes and the compensator is converted to digital by the A/D-Converter The processor calculates the fuel weight in kg. or lbs. to control the pointer and read-out.

Figure 65: Fuel Quantity Indicator (Digital)



Digital Fuel Quantity Indication System

The fuel quantity indication computer provides actual fuel quantity and temperature indication on the ECAM. The actual quantity to the Multi Tank Indicator and Fuel Quantity Preselector located in, or outside of the aircraft used for refueling.

Refuel valves closes if actual fuel weight reaches preselected value. The quantity preselector is used for automatic refueling, from refuel panel.

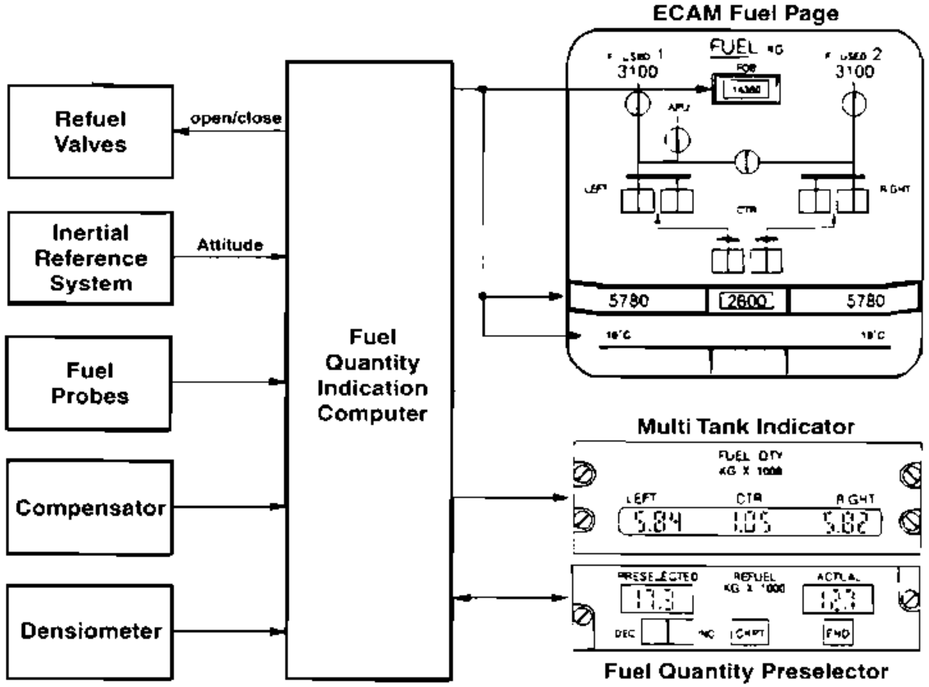
Aircraft attitude signal compensates influences of pitch and roll angles.

A set of capacitance probes in each tank provides fuel level and temperature.

Compensator senses dielectric constant of the fuel.

Densiometer senses density of the fuel, for fuel weight determination.

Figure 66: Fuel Quantity Indication System



Air Data

The flight environment data system comprises the pitot static system. This determines following data of the atmosphere:

- Static pressure
- Total- or Pitot- Pressure
- Total- or Ram- air temperature

Out of those data instruments or computers derives:

- Altitude
- Vertical Speed
- Velocity
- Temperature

International Standard Atmosphere ISA

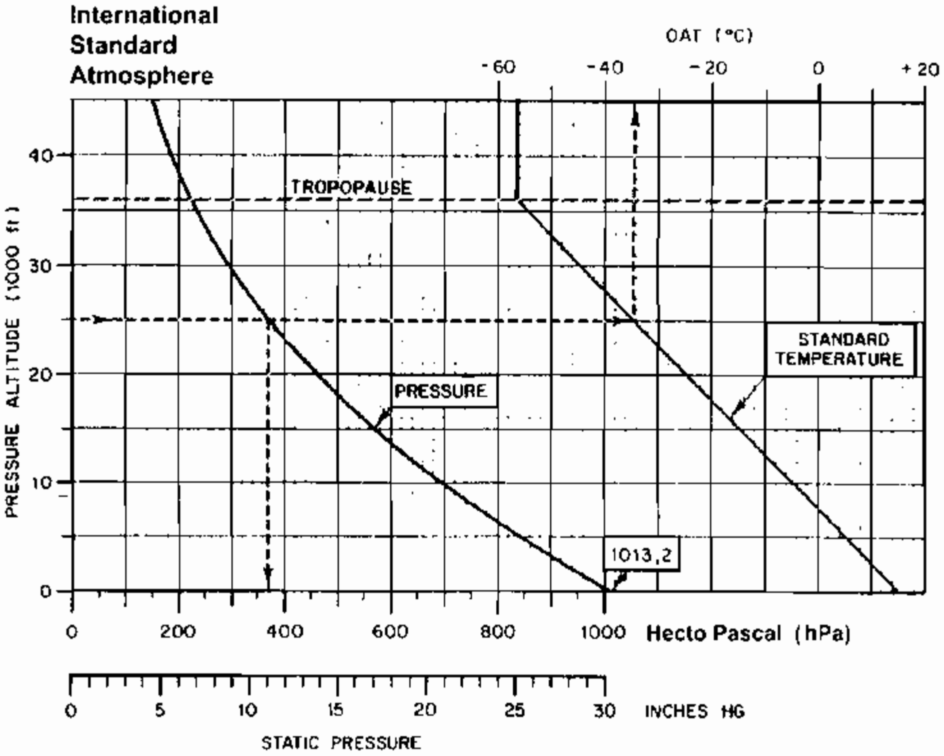
Altitude according Air-Pressure

The pressure decreases with increasing altitude. The rate of pressure-change is not linear with the change of the altitude. At sea level the pressure decreases 1 hPa every 28 feet. The altimeter senses the air pressure and shows the altitude according ISA.

Temperature versus Altitude

The temperature in the troposphere decreases linear with minus 2°C per 1000ft. According ISA the standard temperature at sea level is 15°C. Higher than 36'000 feet (tropopause) the temperature stays constant at minus 56.5°C (Stratosphere).

Figure 67: International Standard Atmosphere ISA



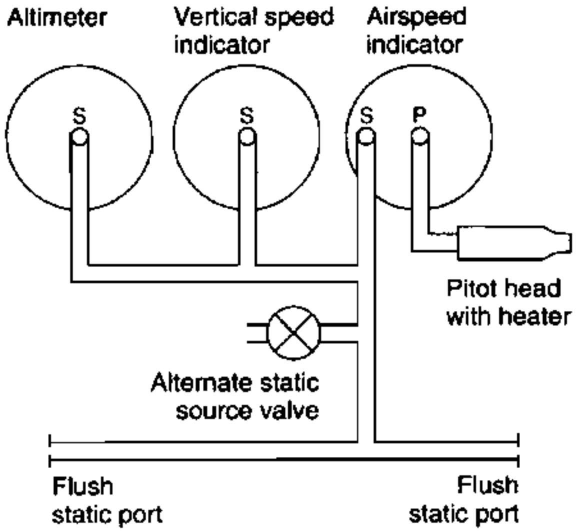
Pitot Static Systems

One of the most important instrument systems is the pitot-static system. This system serves as the source of the pressures needed for the altimeter, airspeed indicator, vertical speed indicator and air data computer.

Light Aircraft

The pitot tube for light aircraft is connected directly to the center opening of the airspeed indicator. The two flush static ports, one on either side of the fuselage, are connected together and supply pressure to the airspeed indicator, altimeter, and vertical speed indicator. An alternate static air valve is connected into this line to supply static air to the instruments if the outside static ports should ever cover over with ice. The alternate air is taken directly from the cockpit of unpressurized aircraft, but pressurized aircraft pick it up from outside of the pressure vessel.

Figure 68:



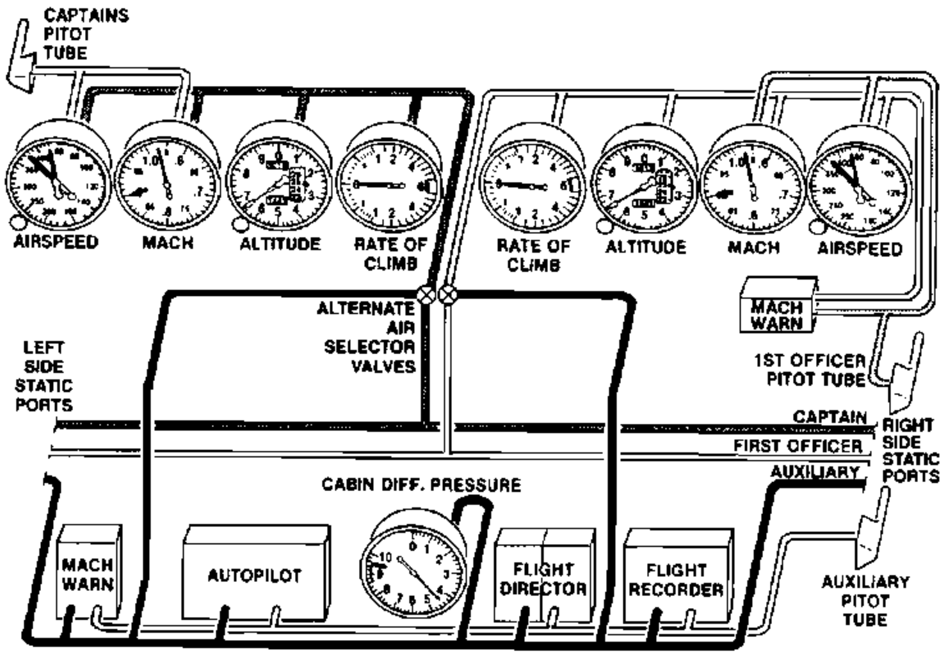
Large Aircraft

Large jet transport aircraft have a more complex pitot-static system. The pitot tube on the left side of the aircraft supplies the captain's instruments. Static pressure for all of the instruments is obtained from the captain's static source. The alternate static source valve allows this to be taken from the alternate static sources.

The right-hand pitot tube supplies pitot air pressure to the first officer's instruments and Mach/Indicated Airspeed warning system. All the first officer's static instruments connect to the F/O static source, and can also be connected to the alternate static source.

The auxiliary pitot tube picks up ram air for the auto pilot, yaw dampers, overspeed warning system, and flight recorder. The alternate static source supplies air to these instruments plus the two flight directors and the reference for cabin differential pressure.

Figure 69:

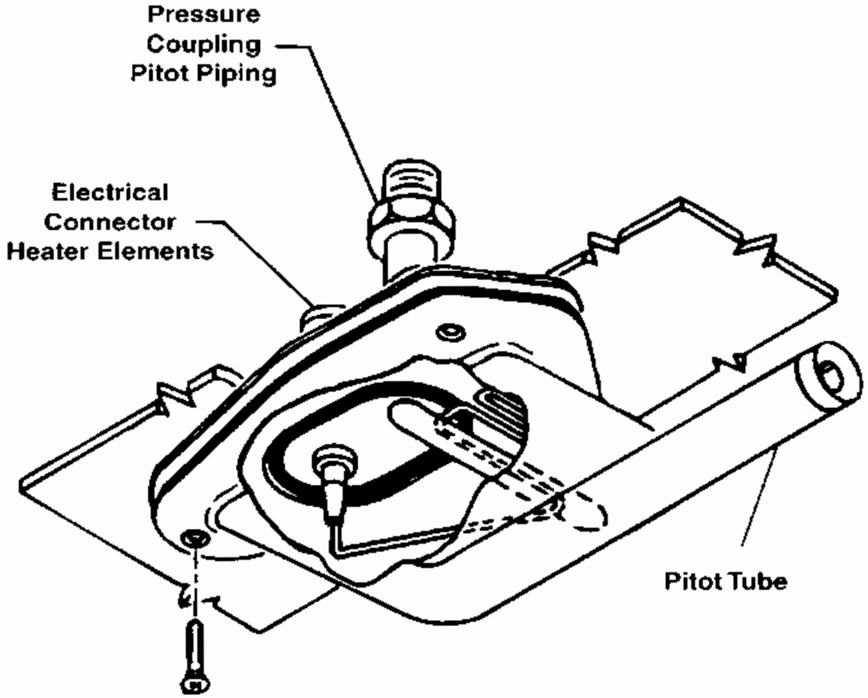


Air Data Sensors

Pitot Tube

A tube with an inside diameter of approximately 6 mm is installed on the outside of an aircraft so, that it points directly into the relative airflow over the aircraft. This tube, called a pitot tube, picks up ram air pressure and directs it into the center hole in an airspeed indicator. An electrical heater in the head prevents building up ice.

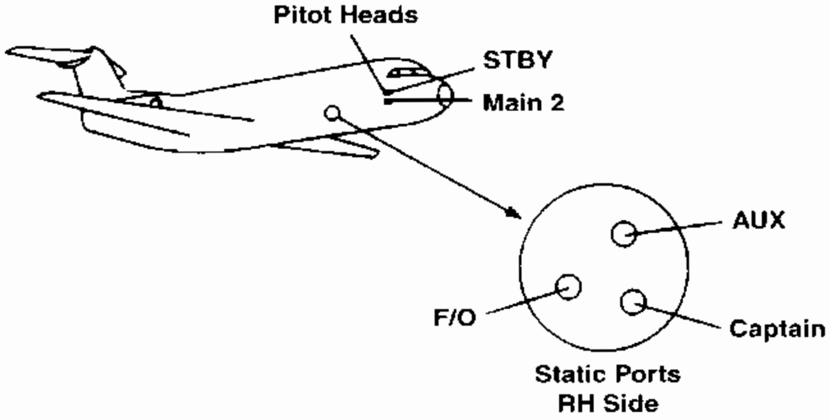
Figure 70:



Static Probe

Small holes on either side of the fuselage or vertical fin or small holes in the pitot-static head sense the pressure of the still, or static air. This pressure is taken into the case of the altimeter, airspeed indicator, and vertical speed indicator

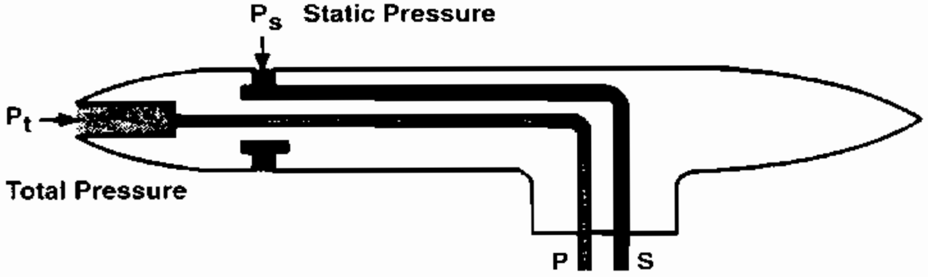
Figure 71:



Combined Pitot- Static Probe

Total pressure or impact air is taken into the front of the head. Static air pressure is taken in through holes or slots in the bottom and sides of the head.

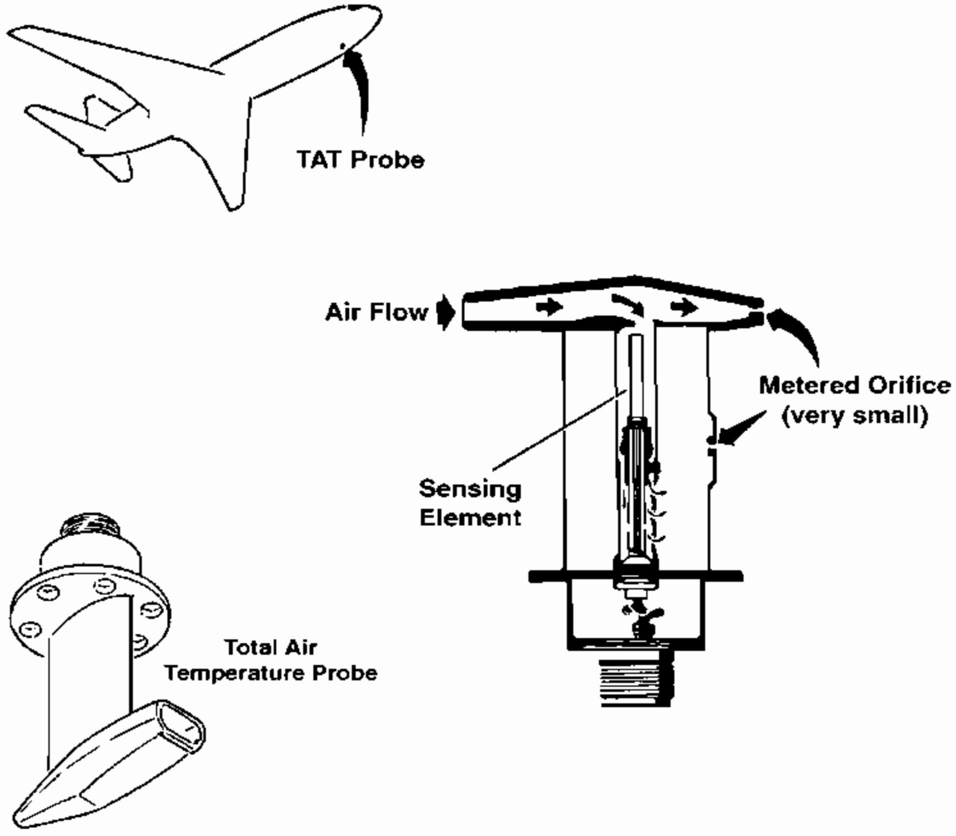
Figure 72:



Total Air Temperature Probe TAT/RAT

The outside temperature is sensed with a probe who contains a temperature dependant resistor (Platinium). Its positive temperature coefficient is linear over the existing temperature range. The probe is heated to prevent building up ice.

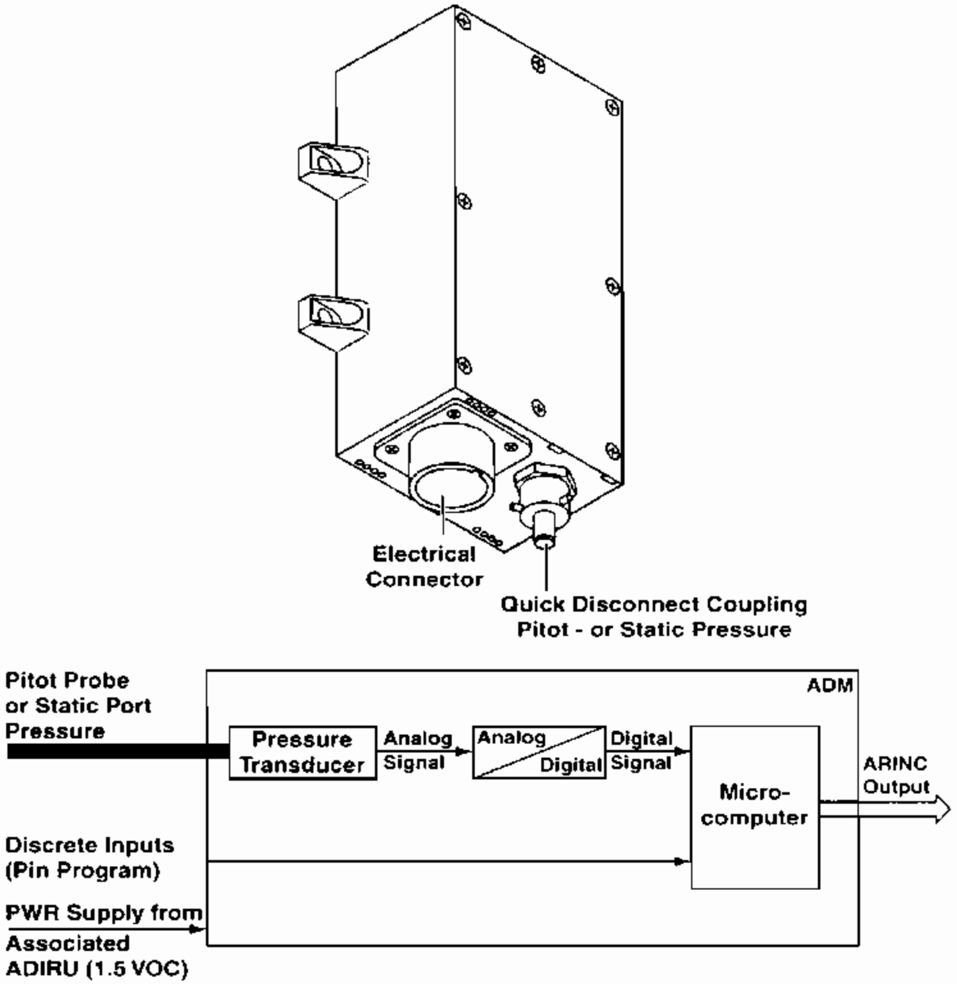
Figure 73:



Air Data Module

Airdata modules converts pitot or static pressure in to digital output signal. The modules are connected with a short piece of hose to the pitot- respective static-probe. The output is transmitted in ARINC 429 format to the airdata computer

Figure 74:



Altimeters

An altimeter is simply a barometer that measures the absolute pressure of the air. This pressure is caused by the weight of the air above the instrument and, naturally, this pressure constantly changes. Also, as the aircraft climbs above the earth's surface, there is less air stacked on top of the aircraft and the absolute pressure decreases. By measuring this change of absolute pressure, the aircraft's altitude can be determined.

The altimeter is one of the oldest flight instruments, and some of the early balloon flights carried some form of primitive barometer which served to indicate the height. The standard altimeter used in many of the early airplanes has a simple evacuated bellows whose expansion and contraction are measured by an arrangement of gears and levers that transmit the changes in dimensions into movement of the pointer around the dial. The dial is calibrated in feet, and since a change in the barometric pressure changes the pointer position.

It is extremely important that the altitude indication be accurate, and that the pilot be able to quickly read the altitude within a few feet. These requirements are complicated by the fact that the pressure lapse rate, the decrease in pressure with altitude, is not linear: that is, the pressure for each thousand feet is greater in the lower altitudes than it is in the higher levels. The bellows are designed with corrugations that allow the expansion to be linear with a change in altitude.

The barometric scale is calibrated in either inches of mercury, millibars or hektopascal. A knob on the outside of the instrument case, rotates the scale and, through a gear arrangement, the mechanism inside the case. The baro setting is used for the correct altitude measurement. (Altitude, flight-level or height above ground.

Figure 75:

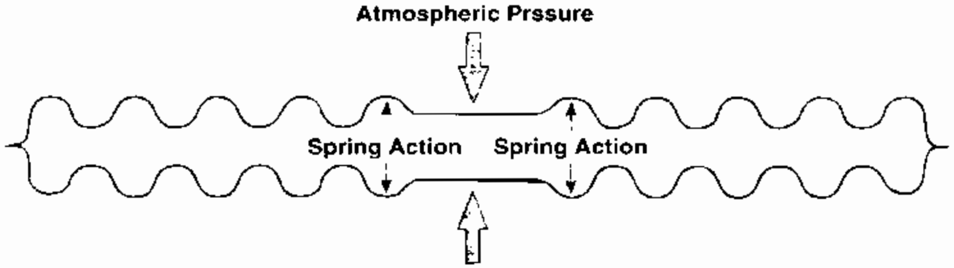
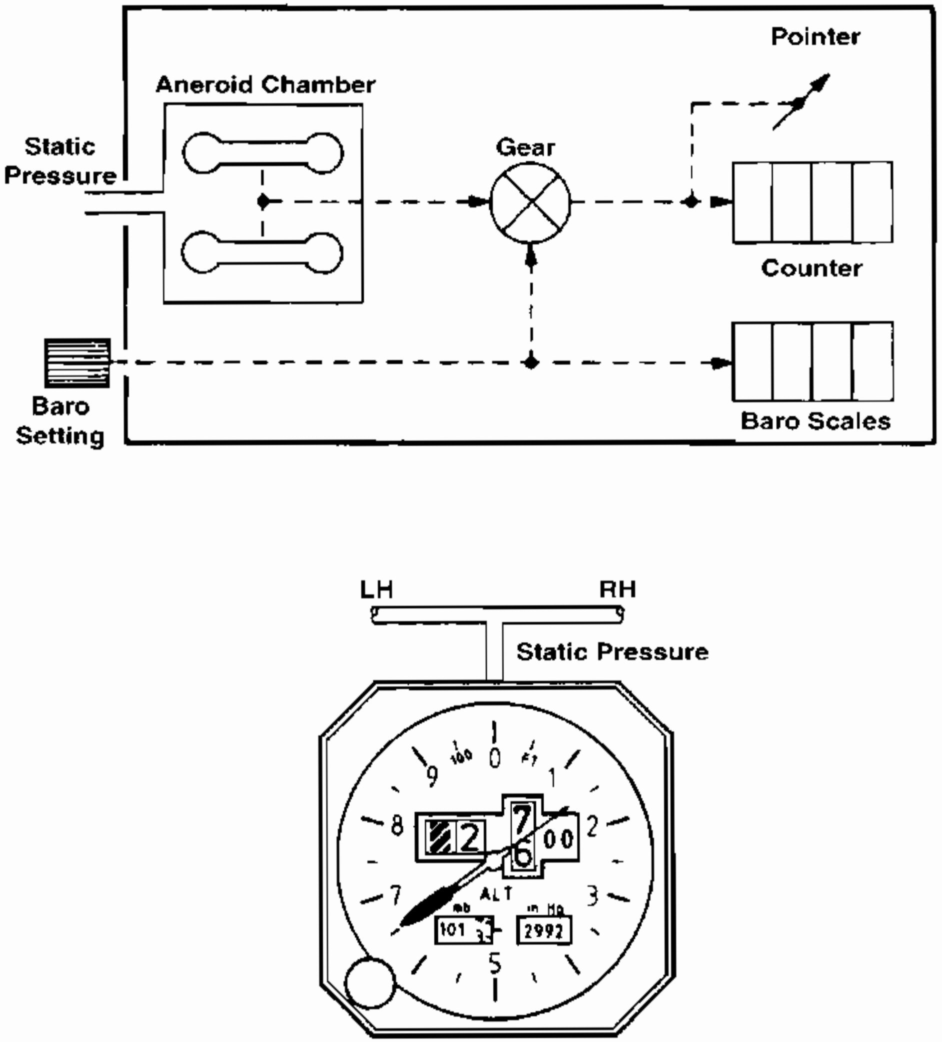
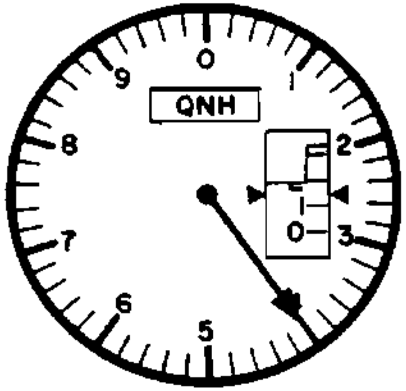


Figure 76:



Types of Altitude Measurement

QNH (Normal Height) setting

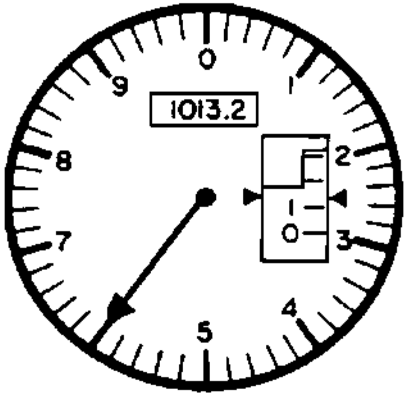


An altimeter can measure height above almost any convenient reference point, and for most flying, it measures the altitude above the existing sea level pressure level. This is called **indicated altitude** and is read directly from the indicator when the altimeter QNH setting is placed in the barometric window.

Airport control towers give the pilot the altimeter setting which is their **local barometric pressure corrected to sea level**. When the pilot puts this barosetting, the altitude measurement starts at sea level pressure. All elevations on aeronautical charts are measured from mean sea level (MSL), and therefore with a bit of simple arithmetic, the pilot can easily and accurately find the aircraft' s height above any charted position. When the airplane is on the ground with the local altimeter setting in the barometric window, the altimeter should indicate the surveyed elevation of the airplane's parking space.

Indicated altitude gives us a measure of terrain clearance at low altitudes.

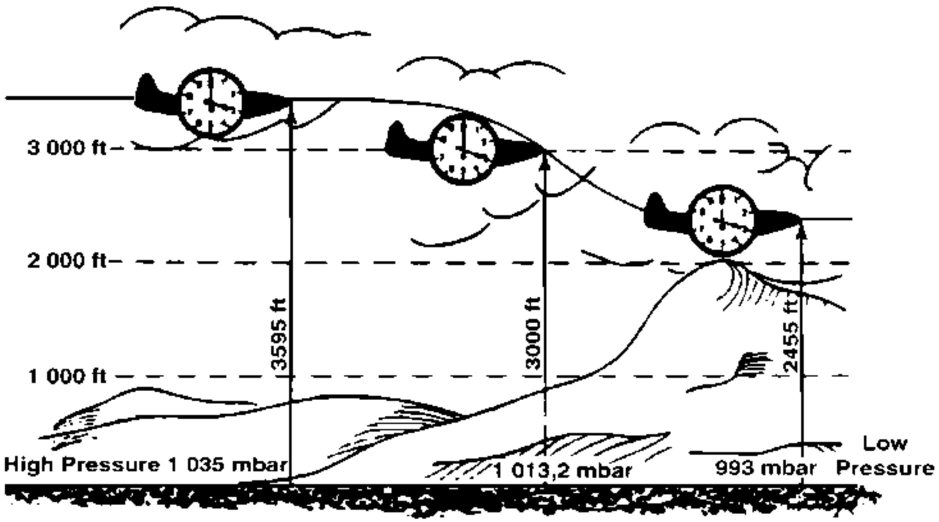
STD (Standard) or QNE (Normal Elevation) setting



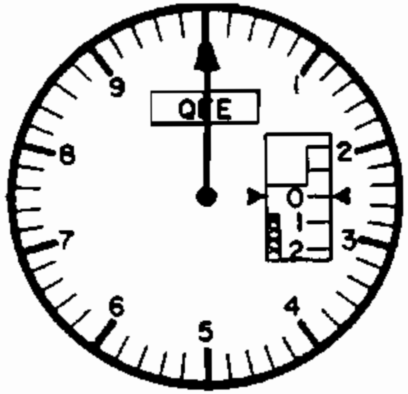
For vertical separation between aircraft flying at higher altitudes, pressure altitude or flight level is used. When the barometric pressure scale is adjusted to standard sea level pressure, 29.92 inches of mercury or 1013.2 mbar or hPa, the altimeter measures the height above this **standard pressure level**. This is not an actual point, but is a constantly changing reference. The reason is that all aircraft in the upper level have their altimeters set to the same reference.

If an airplane flying at a constant 3000 feet pressure altitude, for example, may vary its height above the existing sea level pressure, all of the aircraft flying in this same area will vary the same amount and the separation between the aircraft will remain the same. When an aircraft is flying with the altimeter set to indicate pressure altitude, it is operating at a flight level. Flight level 320 is 32'000 feet, pressure altitude.

Figure 77:



QFE (Field Elevation) setting



When the baroscale is set, that the altimeter shows an altitude of zero, with the aircraft on ground, the baroscale shows the local air-pressure of the parking field.

If the pilot gets via radio the local baro pressure (QFE) of the airfield, during approach the altimeter shows the height above ground. Touching the ground, the altimeter shows an altitude of zero.

This barosetting is seldom used and is replaced by radio altimeters.

Flight Level, Altitude, Height and Elevation

Altitude

The altitude is the vertical distance between aircraft and sea-level.

The barosetting therefore is QNH.

Height

The height is the vertical distance between aircraft and the terrain.

The barosetting therefore is QFE.

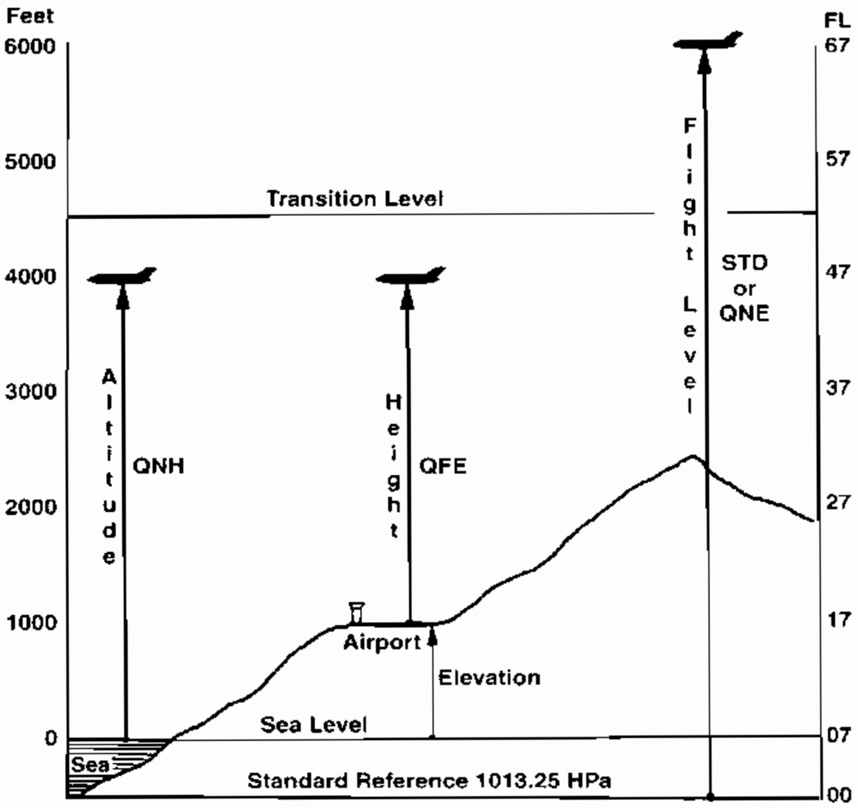
Flight Level

The flight level is the vertical distance between aircraft and the standard pressure reference. This point can be above sea-level if high pressure exists or below sea-level if a low pressure exists. The barosetting therefore is QNE.

Elevation

The elevation is the vertical distance from sea level to the airport or obstacle (mountains and hills).

Figure 78:



Altimeter Indicators

For many years, altimeters had three pointers, the long one making a complete round each 1,000 feet, a short, fat pointer making a complete round for each 10,000 feet, and a third pointer geared so that it would have made one trip around the dial for 100,000 feet if the instrument were to go that high. The range of these altimeters is usually 20,000, 35,000, 50,000 or 80,000 feet.

Because of the ease of misreading these altimeters, the more modern instruments combine a drum scale with a single pointer. The drum gives the thousands of feet in digital form, and the pointer indicates the hundreds of feet as it makes one trip around the dial for one thousand feet.

Encoding altimeters are pneumatic altimeters. They have an electronic device in them that sends a digital code to the radar beacon transponder. When the transponder replies to the interrogation of the air traffic control radar on the ground, a numerical read-out appears on the screen beside the return for the aircraft.

Position error is inherent with static systems, and is caused by the static port not always being in undisturbed air. This error varies with each aircraft design and it changes with airspeed and altitude. The servo altimeter has a built-in compensation system that tailors the instrument to the particular aircraft and minimizes this error for the full range of flight speeds and altitudes.

Instrument or mechanical error is produced from the instrument itself and is divided into different aspects:

Scale error. The altimeter must indicate the same altitude shown on the master indicator or manometer within a specified allowable tolerance.

Hysteresis. The reading taken with the altitude increasing must agree with the readings at the same pressure level when the altitude is decreasing. A specified tolerance is allowed for this test.

After effect. The altimeter must return to the same indication, within tolerance, after the test as it had when the test began.

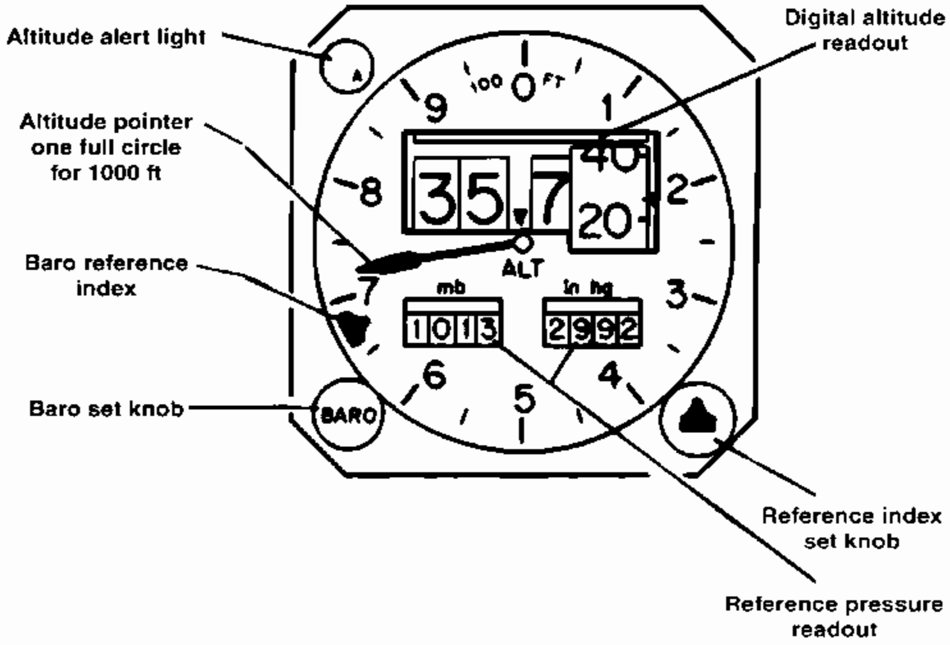
Friction. Two altitude readings are to be taken at each pressure level, one before and one after the instrument is vibrated. There should be no more than a specified difference between the two readings.

Case leak. A low pressure is trapped inside the case and it should not leak down more than a specified amount in a given period of time.

Barometric scale error. The correlation between the barometric scale and the indication of the altimeter pointers must be correct within the allowable tolerance.

Figure 79:

Figure 80:



Vertical Speed Indicator

The rate-of-climb indicator, more properly called the vertical speed indicator. Its main function is that of helping the pilot establish a rate of ascent or descent that will allow them to reach a specified altitude at a given time.

The vertical speed indicator has as its operating mechanism a bellows, or pressure capsule, similar to that of an altimeter, except that rather than being evacuated and sealed, it is vented to the inside of the instrument case through a diffuser which is an accurately calibrated leak. The principle of operation of one type of vertical speed indicator. When the aircraft begins to climb, the pressure inside the capsule begins to decrease to a value below that inside the instrument case, and the capsule compresses, causing the levers and gears to move the pointer so it will indicate a climb. The pressure inside the case now begins to decrease by leaking through the diffuser. This leak is calibrated so that there will always be a difference between the pressure inside the capsule and that inside the case that is proportional to the rate of change of the outside air pressure. As soon as the aircraft levels off, the pressure inside the case and that inside the capsule will equalize, and the indicator will show a zero rate of change.

Figure 81:

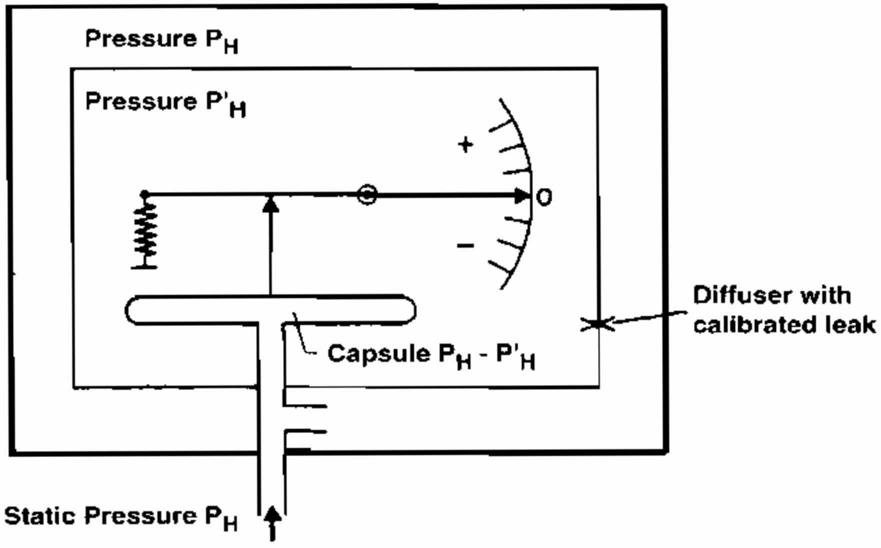
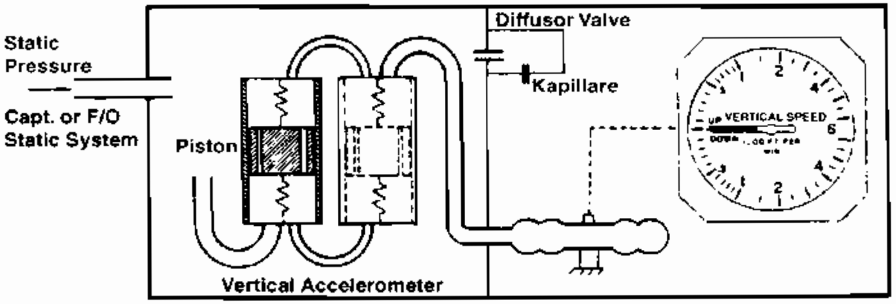
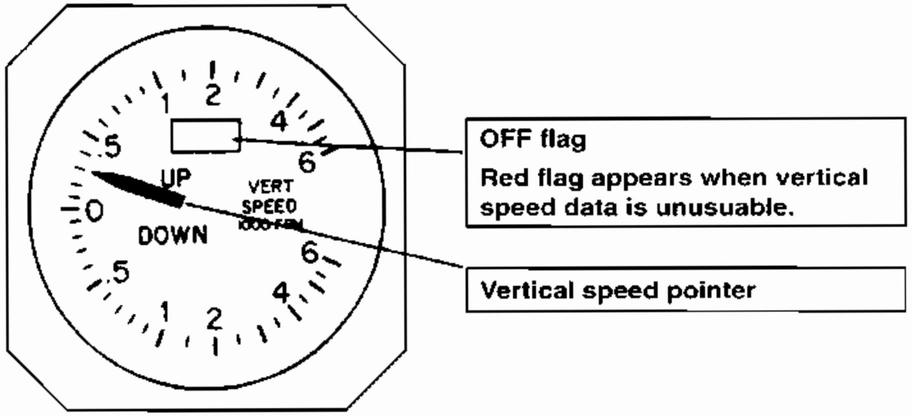


Figure 82: Instantaneous Vertical Speed Indicator



An IVSI uses a mechanism similar to a conventional VSI but it also has an accelerometer-operated air pump, across the capsule. When the aircraft noses over to begin a descent, the inertia of, the accelerometer piston causes it to move upward, instantaneously increasing the pressure inside the capsule and lowering the pressure inside the case. This change in pressure gives an immediate indication of a descent. At this time, the lag of the ordinary VSI has been overcome and it begins to indicate the descent, there is no more inertia from the nose-down rotation, and the accelerometer piston will be centered so the instrument will be ready to indicate the leveling off from the descent.

Figure 83:



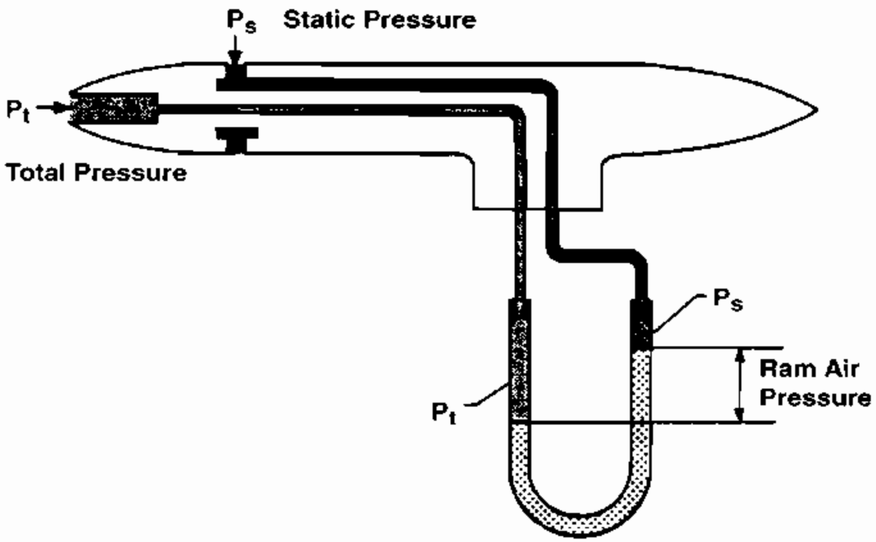
OFF flag
Red flag appears when vertical speed data is unusuable.

Vertical speed pointer

Airspeed Indicators

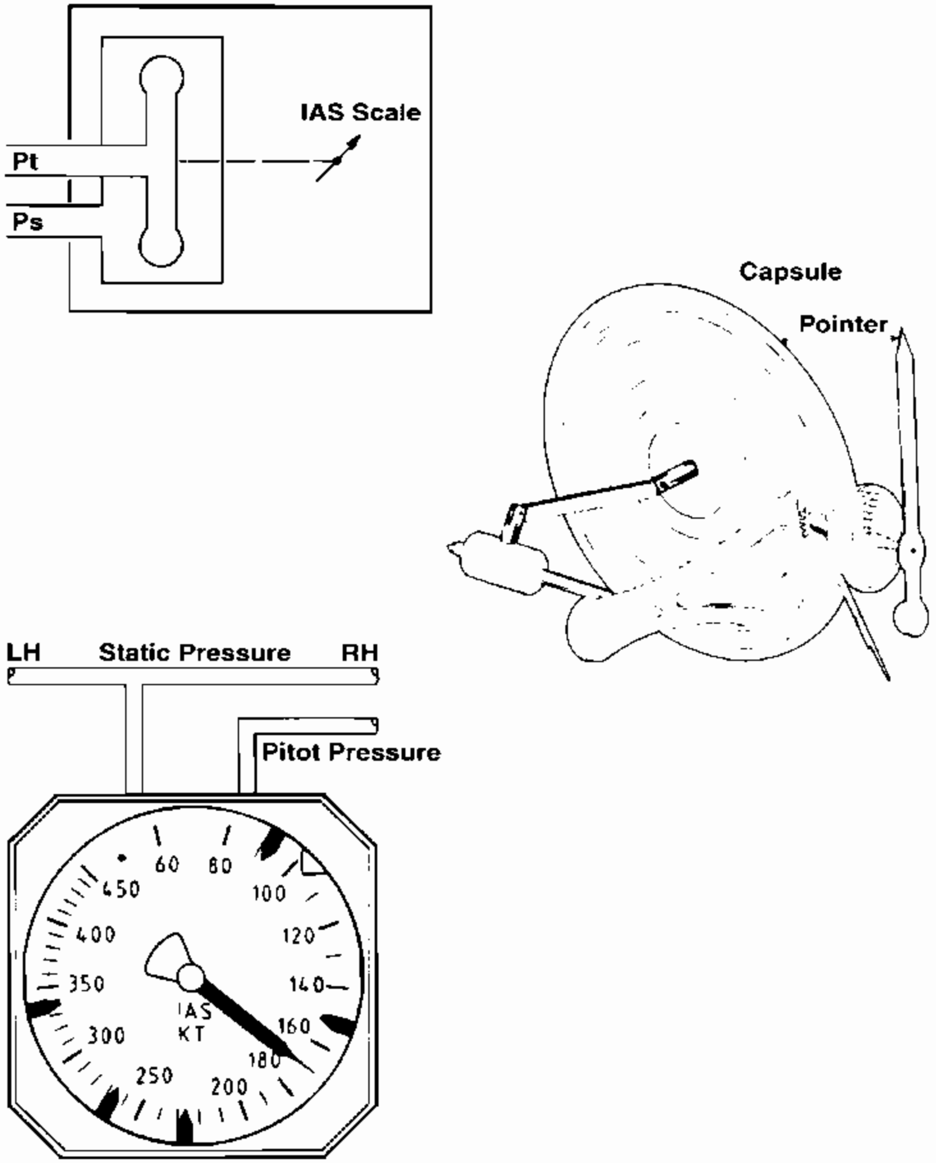
An airspeed indicator is a differential pressure gauge that measures the difference between the pitot and the static pressure. It consists of an airtight case in which a thin metal capsule is mounted. Pitot pressure (Pt) is taken into the capsule and the inside of the case is connected to the static pressure source (Ps). The capsule expands in proportion to the difference between the pitot and the static pressure, and this expansion is measured by a mechanical linkage and is displayed as a pointer moves over the dial which is graduated in miles per hour, knots or kilometers per hour.

Figure 84:



The above pitot tube shows that the Ram Air Pressure is the difference between Total Pressure and Static Pressure. If the airspeed is zero, Pt is equal Ps, so the Ram-Air-Pressure is zero.

Figure 85:



Speeds

IAS

The uncorrected reading of an airspeed indicator is called indicated airspeed, and while it relates to the stalling speed of the aircraft, it is of little use to the pilot for navigational purposes.

CAS

For navigation we must convert indicated airspeed into true airspeed, but we usually go through an intermediate step, calibrated airspeed. It is almost impossible to find a location for the static port that is entirely free from airflow distortion, and any distortion produces an error. This error is so small that for practical purposes it is often ignored.

TAS

Calibrated and true airspeed are the same under standard sea level atmospheric conditions, and to find the true airspeed under non-standard conditions we must apply a correction for the temperature and altitude to the calibrated airspeed. This is normally done with a computer, or with one of the hand-held electronic calculators. Light aircrafts airspeed indicators have a movable dial that may be rotated to align a set of temperature and altitude scales so the pointer will indicate the computed true airspeed.

No matter what type of airspeed indicator is used on the aircraft, its accuracy relies heavily on the correct operation of the pitot-static system.

GS

Groundspeed represents the actual speed of the airplane over the ground. It is true airspeed adjusted for wind. A headwind decreases groundspeed, while a tailwind increases it.

1 Knot (Kt) = 1 Nautical mile (NM) per hour

1 NM = 1 arcminute along the earthequator or meridian (Great-Circle)

(360 degrees a 60 minutes = 21'600 arcminutes ≈ 40'000 km)

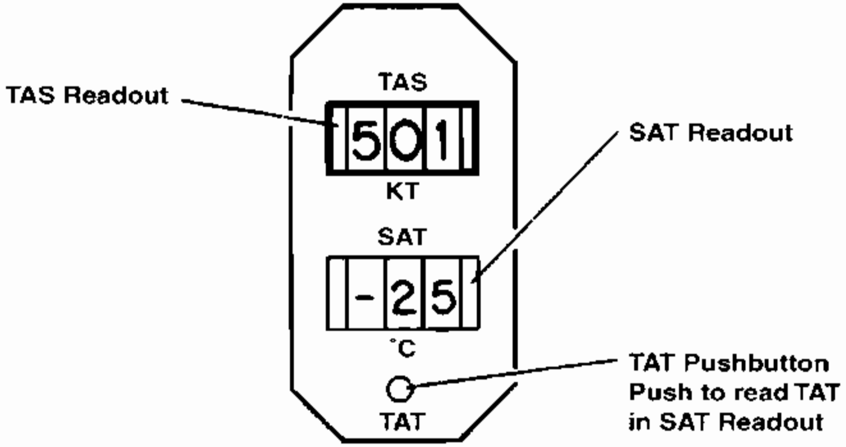
1 NM = 1.852 km

True Airspeed Indicators

There are true airspeed indicators that incorporate not only the airspeed capsule, but a temperature sensor and an altitude bellows that modifies the indication of the airspeed indicator and produces a true airspeed indication.

Electrically driven indicator showing the TAS calculated by the airdata computer The same instrument will also show outside air temperatures.

Figure 86:



Temperatures

Total Air Temperature

The TAT is the temperature of the air compressed by the impact of the flying aircraft. At higher airspeeds the temperature is increased.

This temperature is used for the power setting of the engines.

Static Air Temperature

The SAT is the temperature of the real undisturbed air around the airplane. The Airdata computer reads the TAT from the temperature probe and needs the Mach number to calculate the SAT.

This temperature is used for navigational purposes and to inform the passengers about outside air temperature.

Altitude versus IAS/Mach

The chart illustrates the difference between indicated airspeed, true airspeed, and Mach. True airspeed and indicated airspeed are the same at sea level; however, as altitude increases, holding a constant indicated airspeed results in continually increasing true airspeed. For an example, 400 indicated airspeed at sea level becomes about 450 true at 10,000 feet, and about 550 true at 20,000 feet.

The Mach numbered lines are drawn on the basis of a standard day air temperature chart; 0.9 times the speed of sound at sea level would be about 600 knots true airspeed, but from about 36,000 feet on up, 0.90 Mach equals only 525 knots true airspeed.

If a particular airplane is not supposed to fly faster that 390 knots indicated, and not more than 0.885 Mach, it could fly 390 knots indicated until it got to 21,000 feet. Above that altitude, the indicated airspeed would have to decrease in order not to exceed maximum Mach. Flying an indicated airspeed as high as 390 knots above 21,000 feet would result in transonic or supersonic speeds.

Figure 87: Mach varies as a result of temperature and altitude.

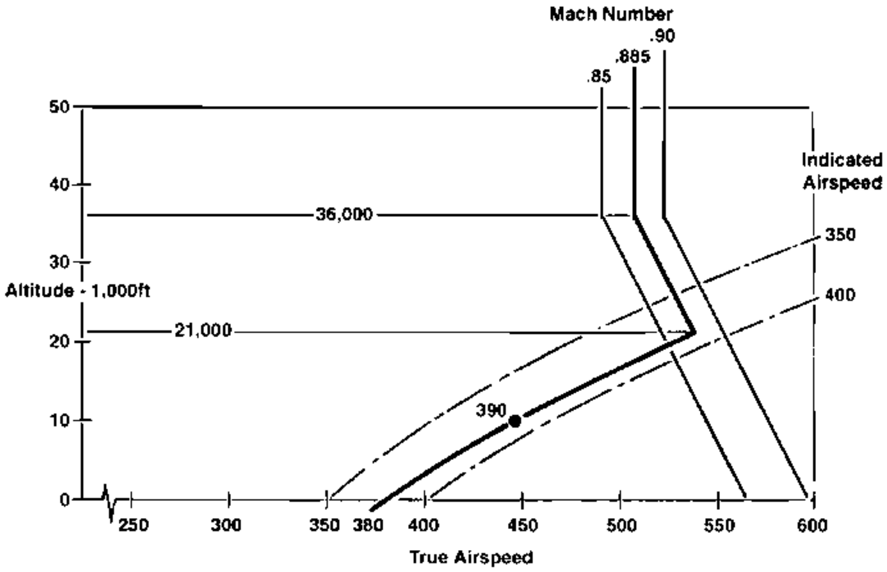
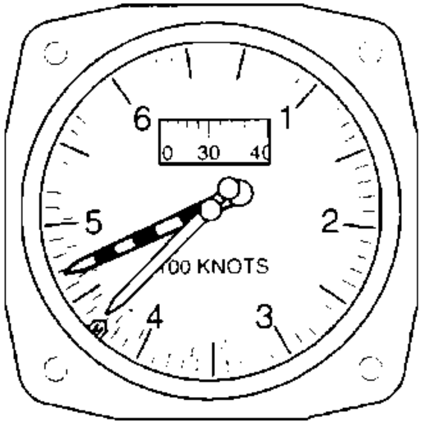


Figure 88: Maximum allowable airspeed indicator



Airplanes that are not designed to fly at sonic airspeed must never be allowed to reach their critical Mach number. That is, they must never be flown at a speed that will allow the airflow over any part of the aircraft to reach sonic velocity. When this happens, shock waves form and serious aerodynamic problems can result. Airplanes whose maximum speed is limited by structural considerations have their never-exceed speed marked by a fixed red line on the dial of the airspeed indicator. But if the maximum speed is limited by the critical Mach number, the fixed red line is replaced by a red pointer (Barber pole) that is driven as a function of altitude.

Overspeed Warning

The maximum operating limit speeds Vmo / Mmo is a airspeed or mach number who should not be exceeded. Warning alerts the pilots, if the limit is exceeded. For example: Below 23'000 ft the airspeed is limited to 372 kts. Above this flight level the speed is limited to Mach 0.88.

The warning can be triggered from an overspeed warning switch, mach airspeed indicator or airdata computer.

Figure 89: Overspeed Warning Switch

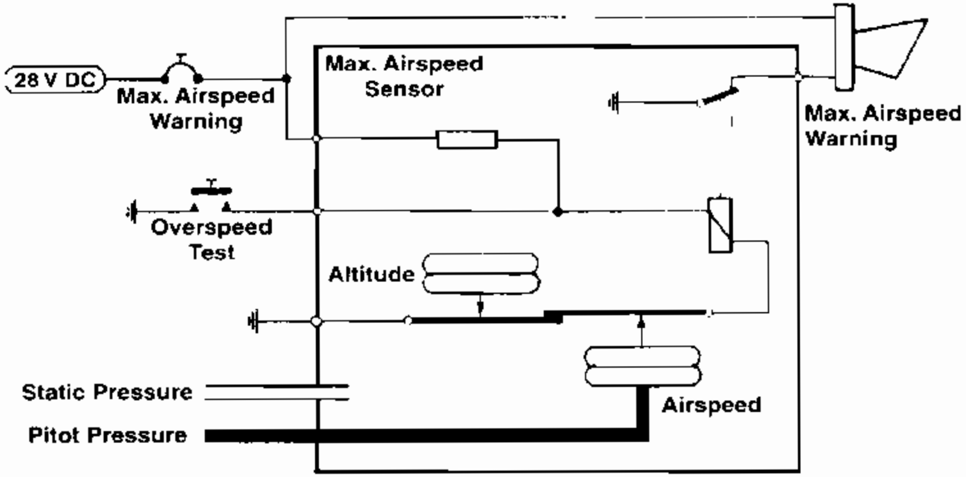
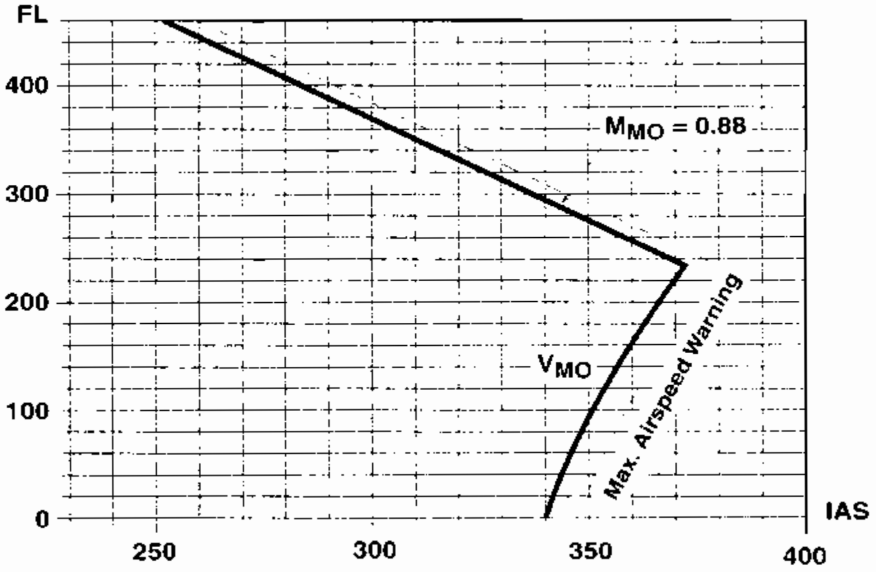


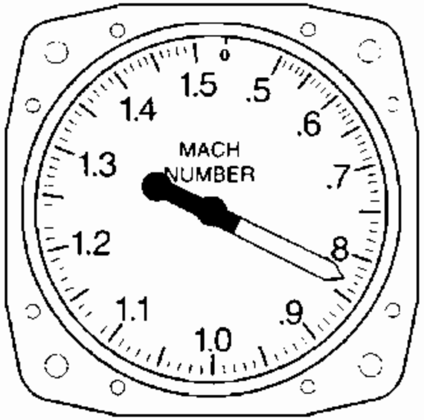
Figure 90: VMO, MMO versus Flight Level



Mach Meter

When airplanes fly at or near the speed of sound, a measurement is needed that compares the speed of the airplane with the speed of sound. This measurement is called the Mach number. An indication of Mach one occurs when the airplane is flying at the speed of sound. Below the speed of sound, the indication is given as a decimal fraction, and above Mach one, the indication is an integer with a decimal. For example, flight at Mach 1.25 is flight at an airspeed of 1.25 times the speed of sound at that altitude. Mach 0.75 is flight at an airspeed of 75% of the speed of sound.

Figure 91:



Mach = Aircraft-speed (TAS) / Speed of sound

The speed of sound decreases at decreasing outside temperature (TAT).

The Machnumber increases if the aircraft climbs with constant TAS.

Combination Airspeed Indicator

The increased value of instrument panel space aboard modem aircraft, and the need to integrate as much of this information as possible has brought out one instrument that combines the airspeed indicator with the Machmeter and also shows the maximum allowable operating airspeed. This instrument also includes "bugs" that are small indicators around the periphery of the dial that may be manually set to indicate the correct speed for certain flight conditions such as that needed during takeoff or an approach to landing.

Figure 92:

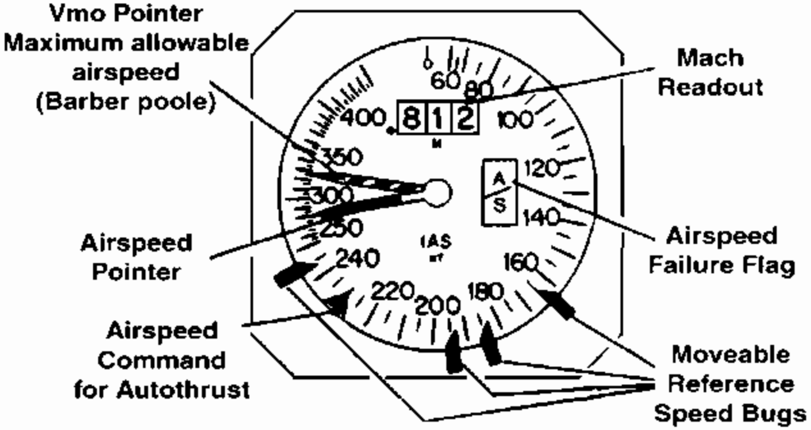
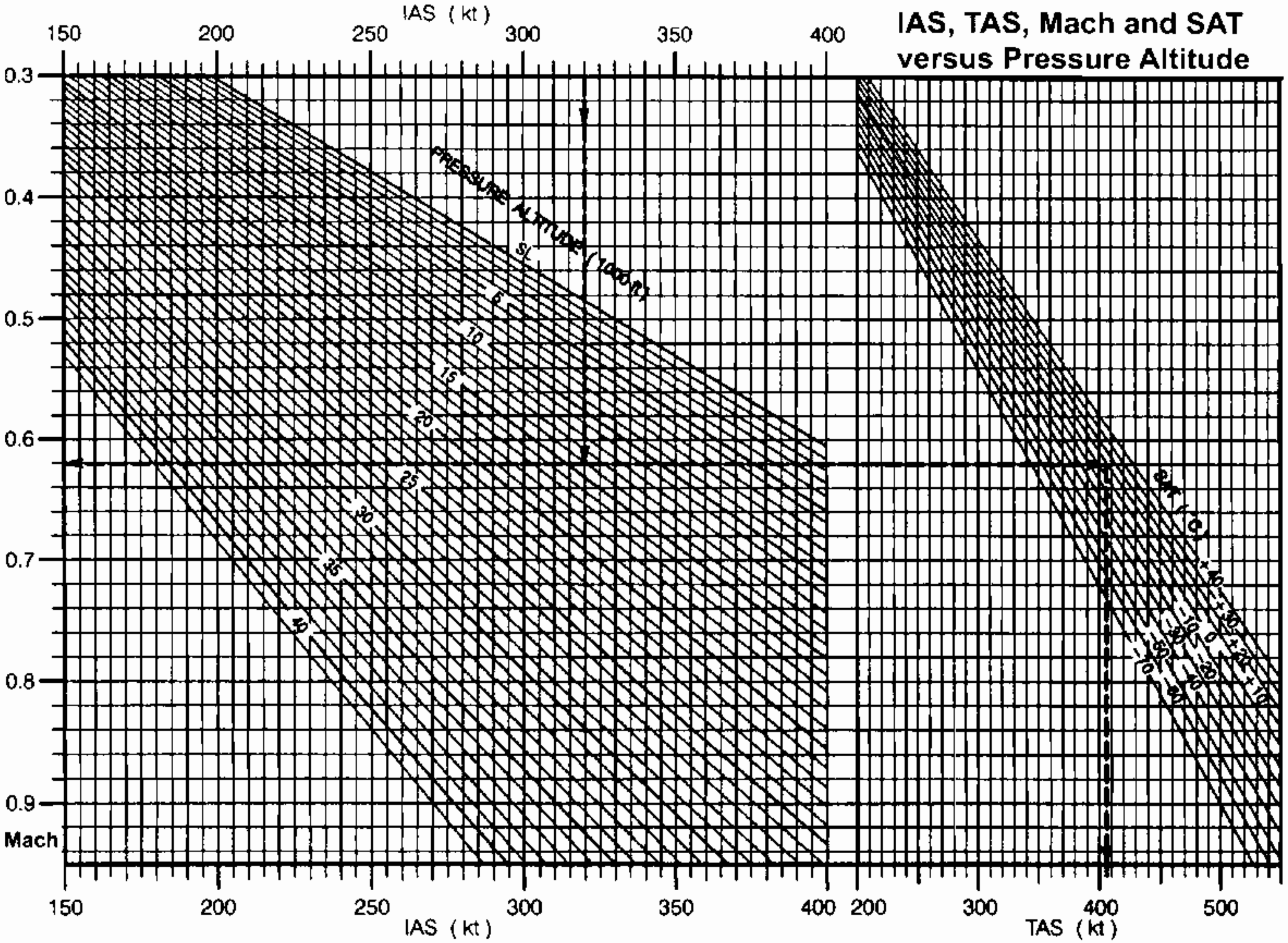


Figure 93: Graph Relationship IAS, TAS, MACH and SAT



EXAMPLE :

IAS 320 KT
PRESSURE ALTITUDE 14' 000 FT
SAT + 10 °C

FIND :

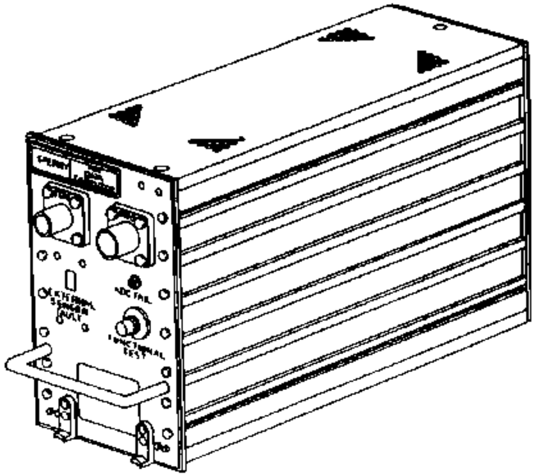
TAS 406 KT
MACH 0.62

Air Data Computer

The air data computer samples: discretes, total temperature, total and static pressures, baro setting, angle of attack and total temperature.

All results are send to the users like instruments, displays, Auto flight and navigation systems.

Figure 94:



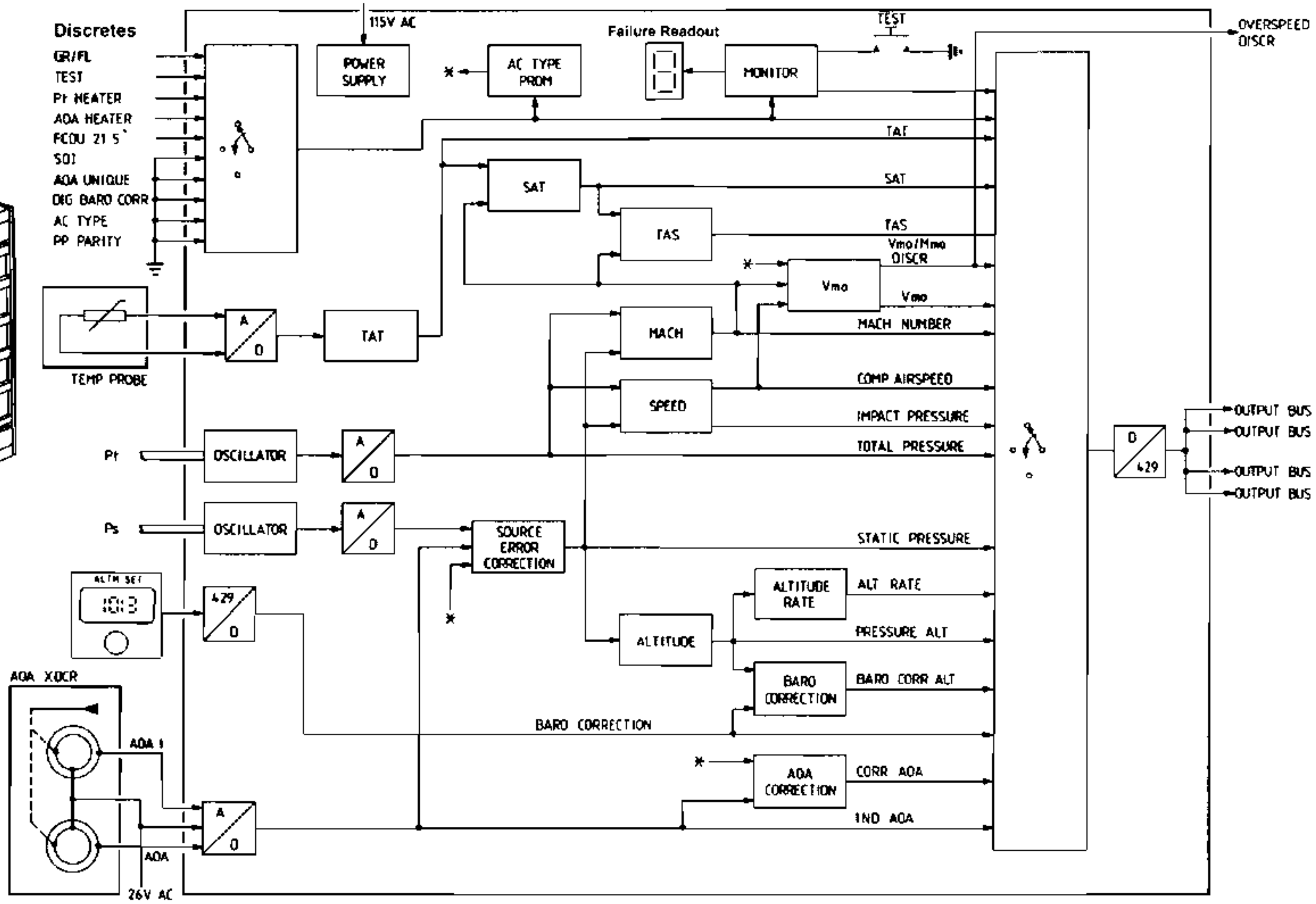
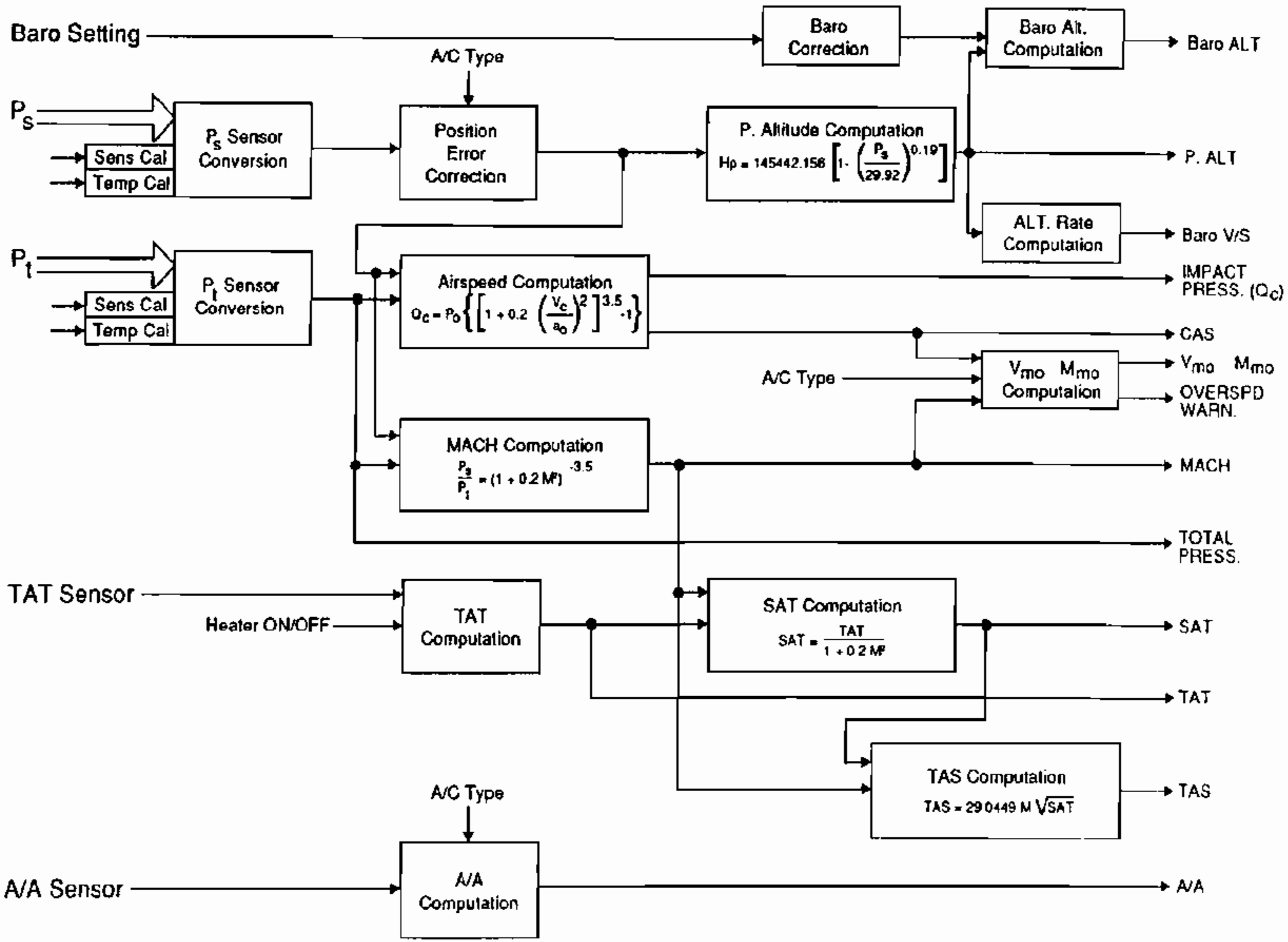


Figure 95: Air Data Computation Model



Examples of Airdata Systems

Figure 96: Physical Instruments, Airdata Computer and other Users.

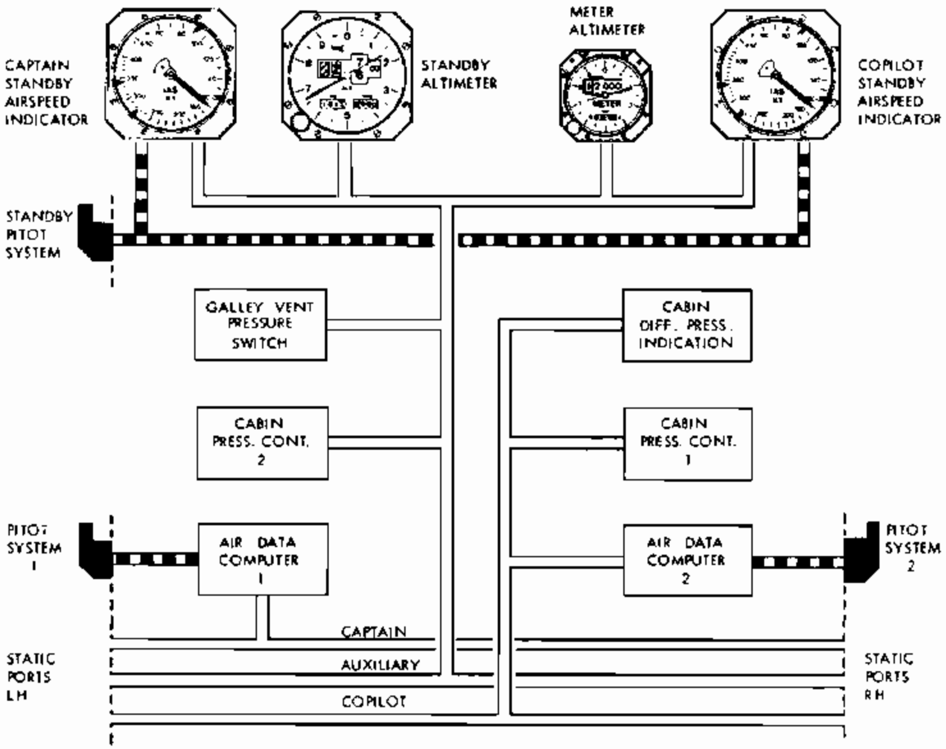


Figure 97: Instruments getting air data from Central Airdata Computer

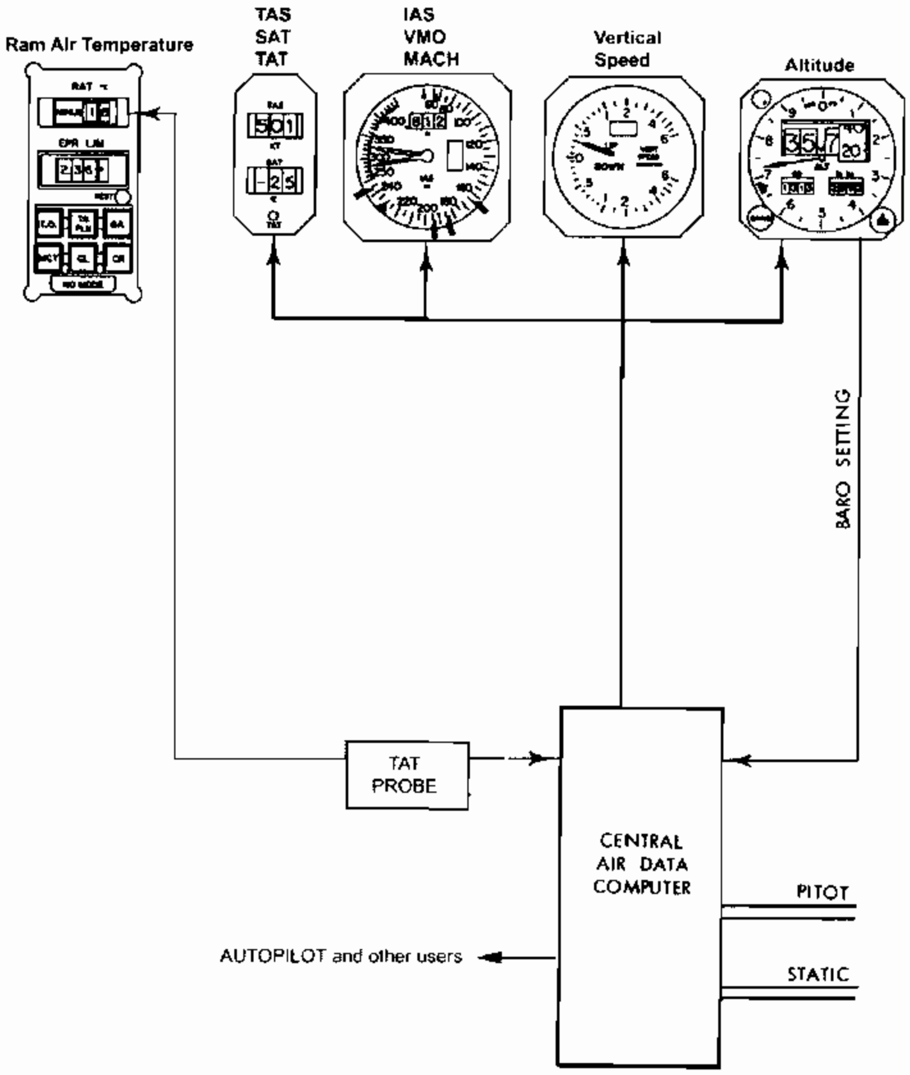


Figure 98: Central Airdata Computer with EIS and other Systems.

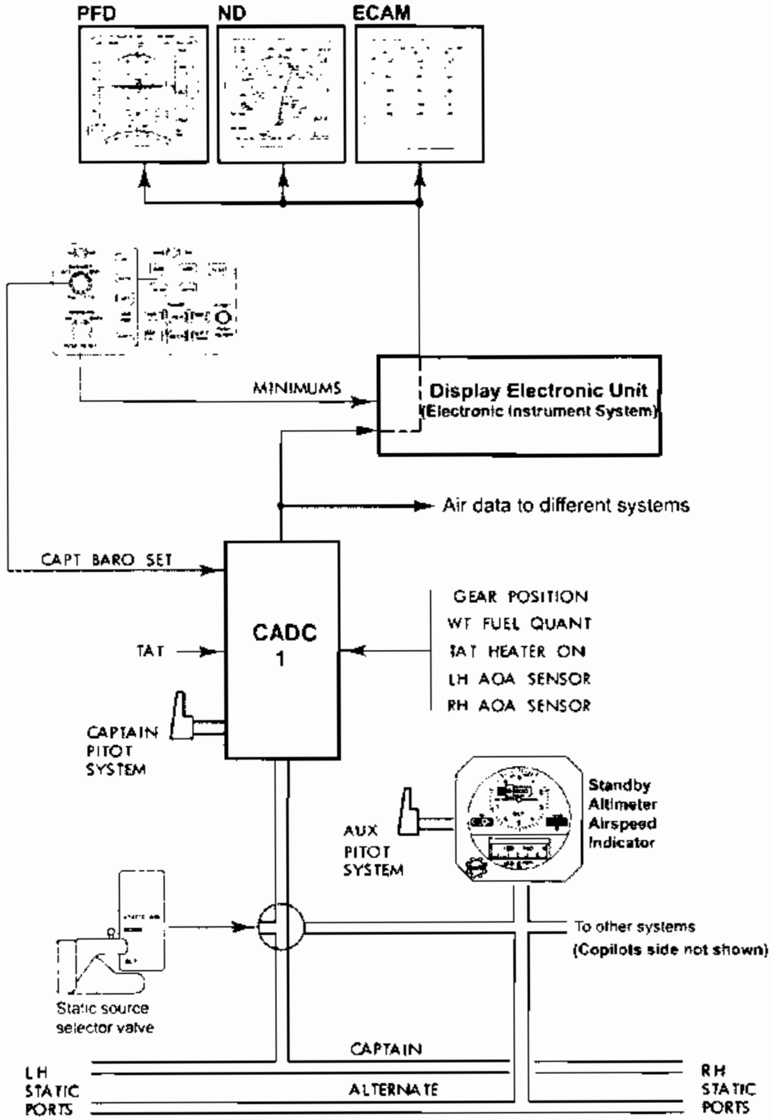
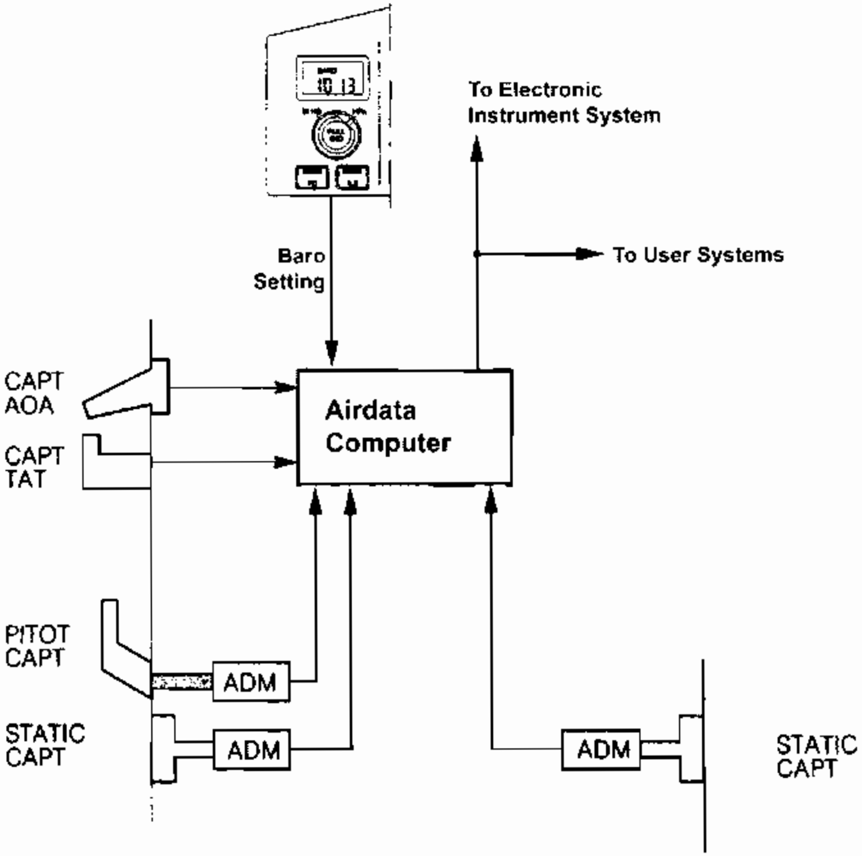


Figure 99: Pitot- and Static Pressure from Air Data Modules.



Gyros

A gyroscope is a small wheel with its weight concentrated in its rim. When it spins at a high speed, it exhibits two interesting characteristics: rigidity in space and precession. Directional gyros and gyro horizons are attitude gyros, and they make use of the characteristic of rigidity in space. Rate gyros such as turn and slip indicators and turn coordinators use the characteristic of precession.

Rigidity in Space

Let' s assume that a gyro having no friction in its bearings, but with a power source to keep it spinning, positioned at a certain place on the equator, at noon we would see the tail of the arrow. By the time the earth rotated 90 degrees, at six p.m., we would see the side of the wheel with the arrow pointing to the right. At midnight we would again be in line with the arrow, only this time it would be pointing at us. By six a.m., we would again see the side of the wheel. Now, however, the arrow would be pointing to the left. This characteristic makes the gyroscope (Greek = view the earth rotation) valuable to us as a stable reference for determining both the attitude and the direction of the aircraft carrying the gyro.

Also the earth represents as a very large gyro and will maintain its direction in the space.

Figure 100: Rotating Earth

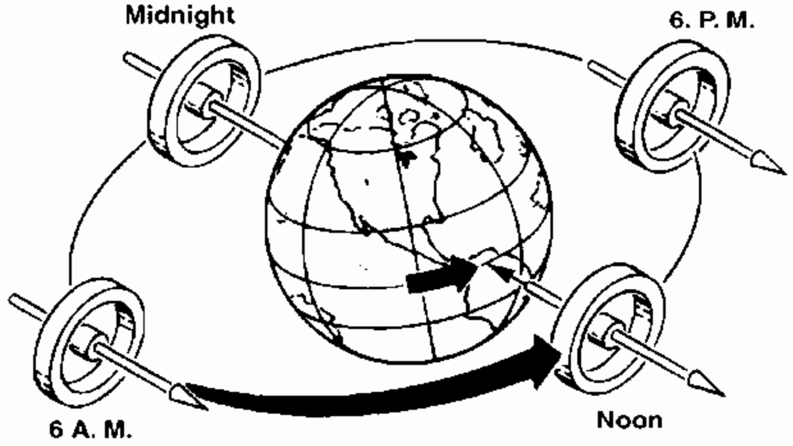
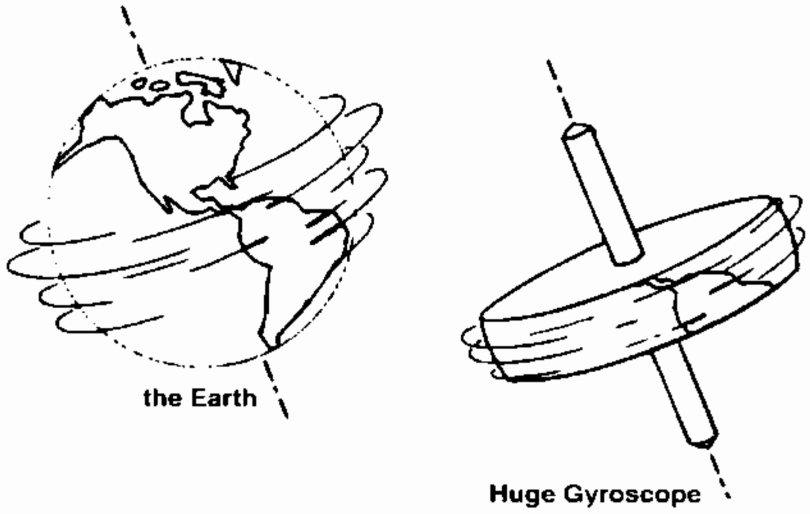


Figure 101: Earth as a Gyro



Precession

If a force is applied to a spinning gyroscope, its effect will be felt, not at the point of application, but at a point 90 degrees from the point of application in the direction of rotation of the wheel. If a gyro is spinning in the plane and a force is applied to the top of the wheel, it will not topple over as a static body would; it will rather rotate about its vertical axis. This rotation is called the precession of the gyro. If one of the bearings which supports the gyro shaft has friction, it will produce a force that will cause precession.

Precession is not desired in a directional- or vertical gyro, but it may be used in a rate gyro because the amount of precession is related to the amount of force that caused it. We use rate gyros to measure the rate of rotation of the aircraft about one or more of its axes.

Figure 102: Rotating Mass

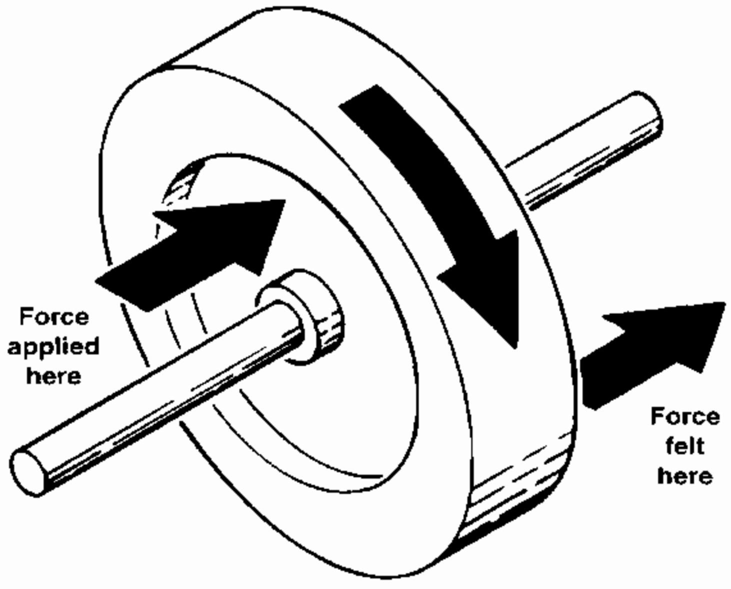
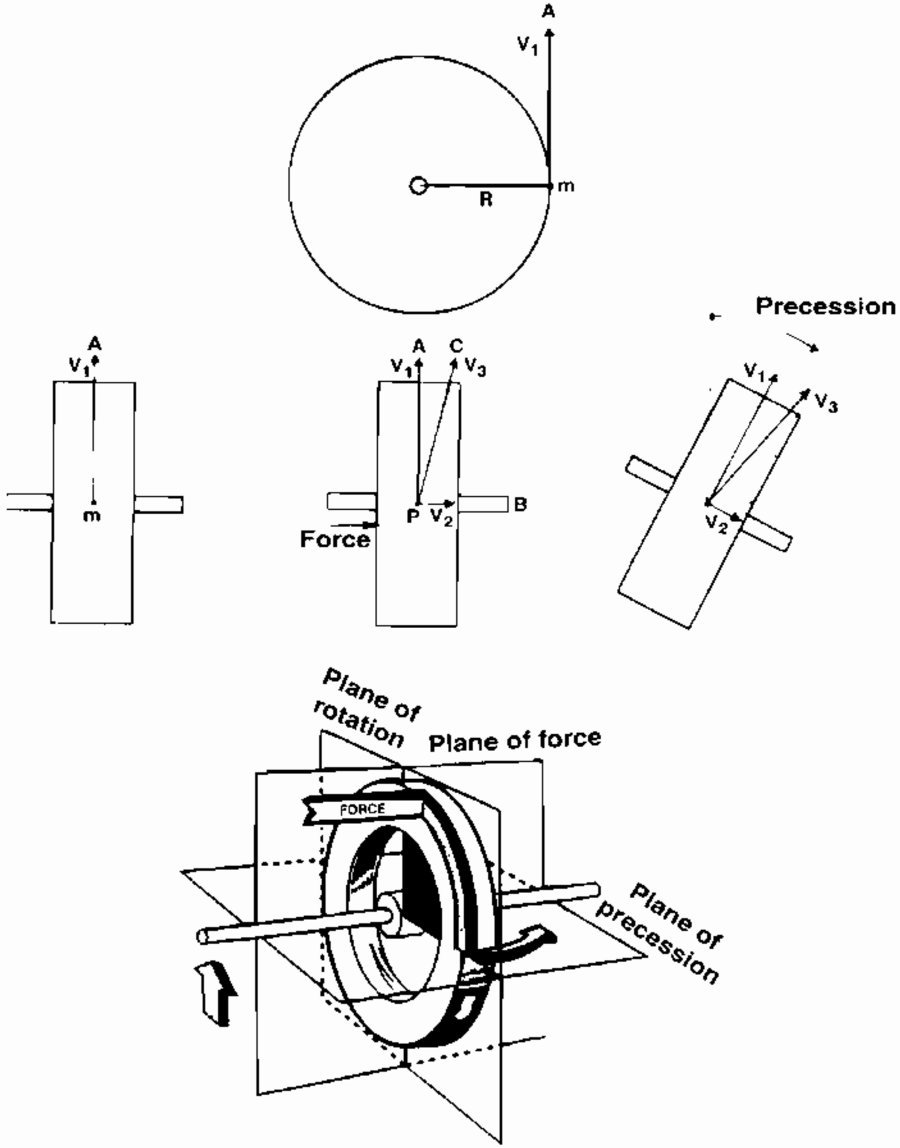


Figure 103: A Mass in motion is keeping its direction



Different Gyros

Vertical Gyro VG (2 degrees of freedom)
Sensing the angular displacement from vertically direction (Roll and Pitch Attitude)
Artificial Horizons, Attitude Indication and Attitude reference for autopilots etc.

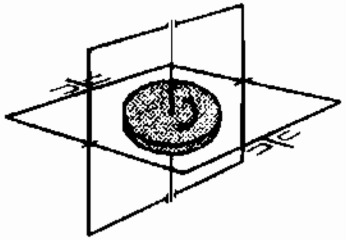
Directional Gyro DG (2 degrees of freedom)
Sensing the angular displacement of a horizontal direction (Azimuth, Heading)
Compass stabilisation, Heading reference for autopilots etc.

Rate Gyro RG (1 degree of freedom)
Sensing of aircraft angular rate around all 3 axies (Yaw, Pitch and Roll)
Turn and Slip Indicator, Turn Coordinator Indicator, Autopilot

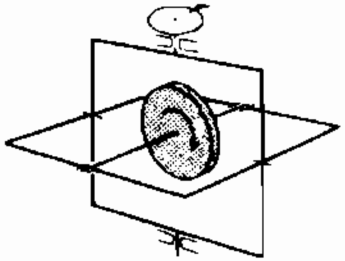
Rate Integrating Gyro RIG (1 degree of freedom)
Sensing the integral of the aircraft angluar rate
Plattform stabilisation for Inertial Navigation Systems.
(High accurancy and sensitivity)

Ring Laser Gyro RLG
Sensing the angular rate
Inertial Reference System
(Very high accurancy and sensitivity)

Figure 104:



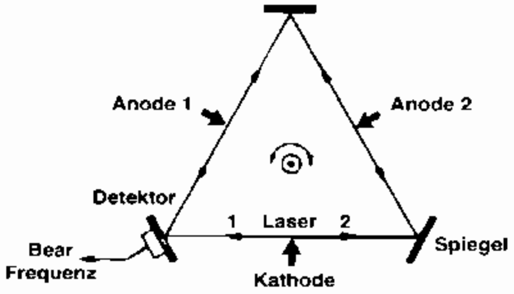
Vertical Gyro VG



Directional Gyro DG

Rate Gyro RG

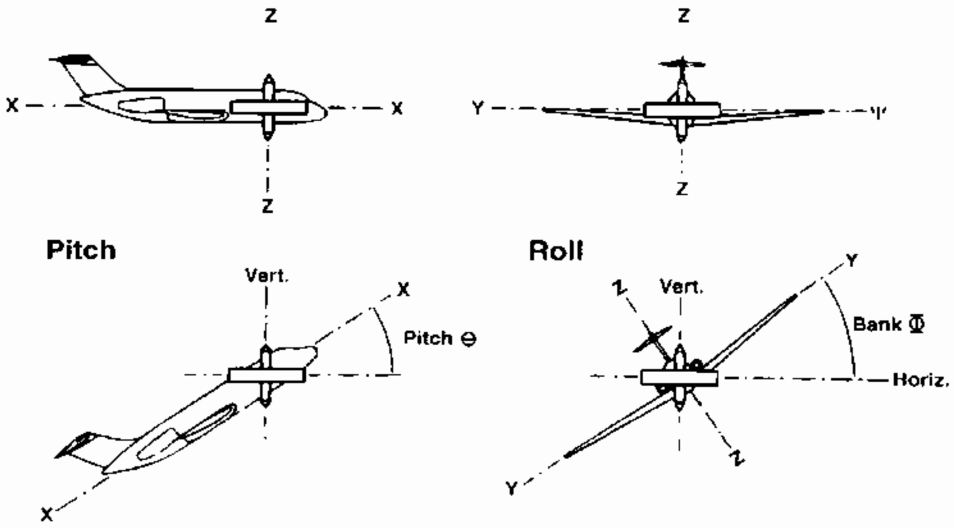
Rate Integrating Gyro RIG



Ring Laser Gyro RLG

Vertical Gyro

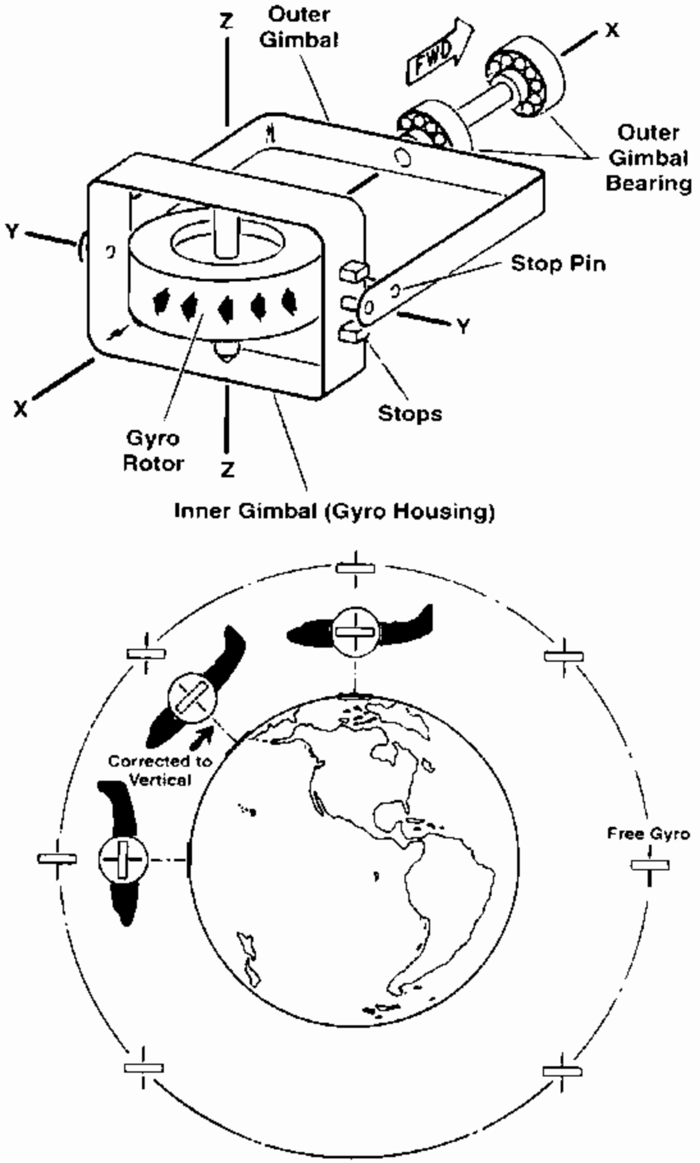
Figure 105:



The vertical gyro senses the relationship between the pitch and roll axes of the aircraft and a vertical line through the center of the earth, and it gives a stable reference so the actual pitch- and bank angle is known to keep the wings level.

The vertical gyro has two degrees of freedom. The axle of the wheel is always vertically directed. Vertical gyros are located inside horizon indicator or build in separate units as remote vertical gyros. Their Roll and pitch signals are used for artificial horizons, autopilots, flight directors and the weather radar antenna stabilisation.

Figure 106:



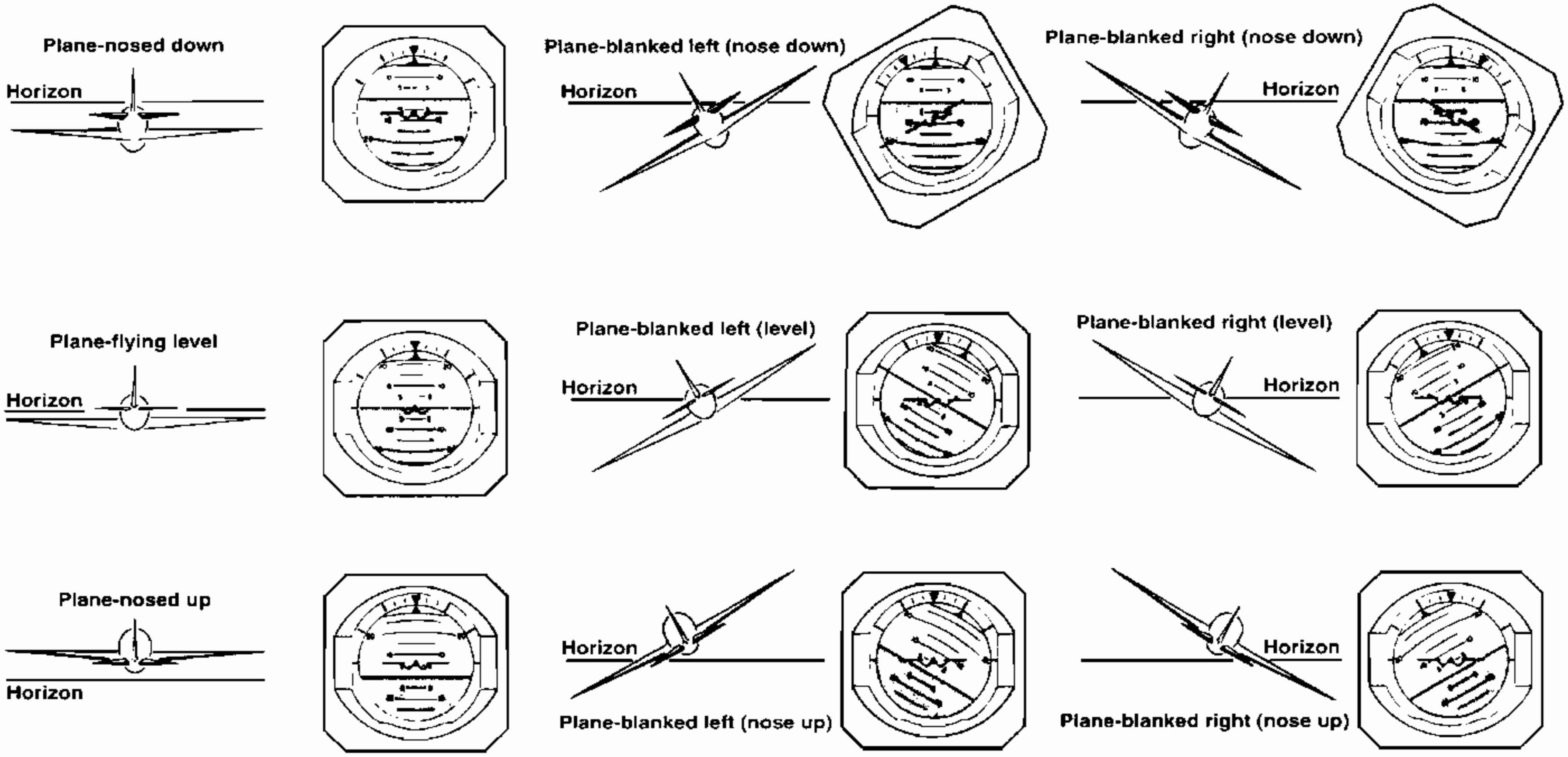
Attitude Indicator

The example shows the indication the pilot has when the airplane is:

- flying straight and descending, level or climbing.
- banking to the left and descending, level or climbing.
- banking to the right and descending, level or climbing.

When the nose of the aircraft is pitched down, the horizon moves up. If the aircraft banks to the right, the sphere moves toward left.The instrument shows the horizon as it would appear if we could actually see it.

Figure 107: .



Above the horizon, the dial is light colored, usually blue, to represent the sky, and below the horizon, it is brown or black representing the ground. Short horizontal lines both above and below the horizon help the pilot to establish pitch angles, and across the top of the instrument, a pointer may be aligned with index marks to establish the desired bank angle. These marks are located at 10, 20, 30, 60 and 90 degrees.

Erection of Vertical Gyros

The vertical direction to the earth center is sensed in unaccelerated flights with pendulums or weights of two rotating balls. Any unbalance acts with force to the gyro to erect its spin axis into the vertical.

By Air

The early artificial horizon uses a rotor with its spin axis vertical. It is spun by a jet of air. The housing which holds the rotor is mounted on two gimbals, allowing the aircraft to freely pitch and roll about the gyro. When the gyro is erect, air leaving the gyro housing exits equally through four vertical slots in the bottom of the housing. One-half of each of these slots is covered with a pendulum valve, mounted in such a way that any tilt of the rotor will open one valve and close the valve on the opposite side of the housing. Air now leaving through the slot in one side and not in the other creates a precessive force that will bring the gyro back to its upright, or erect position.

Figure 108:

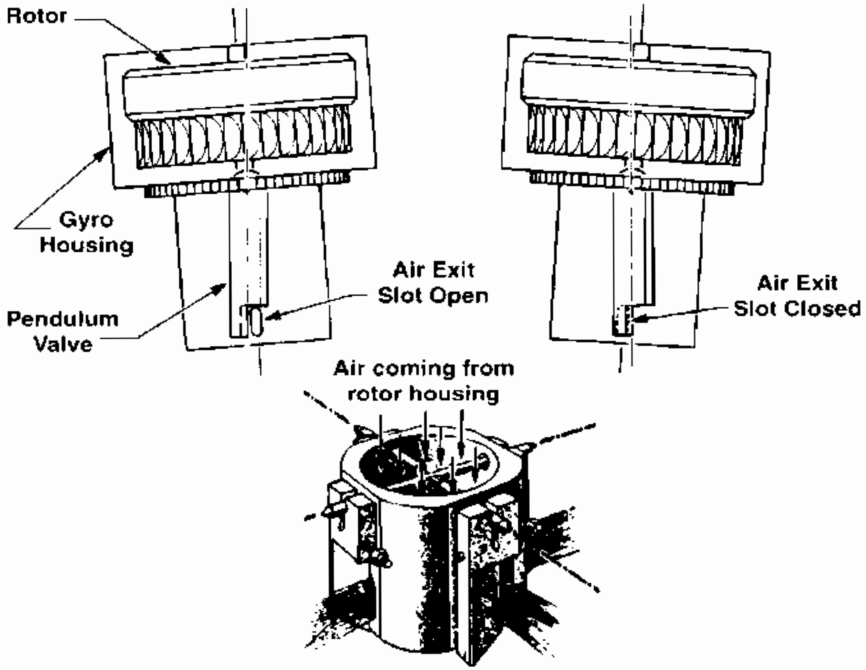
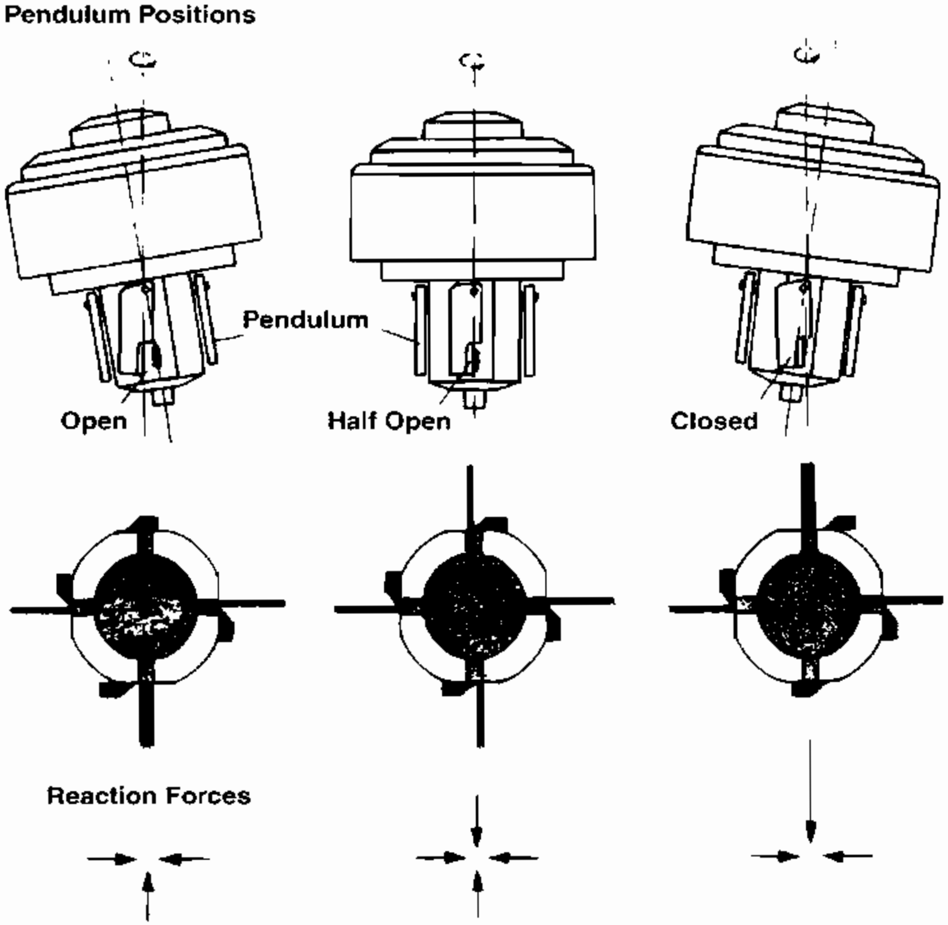


Figure 109:



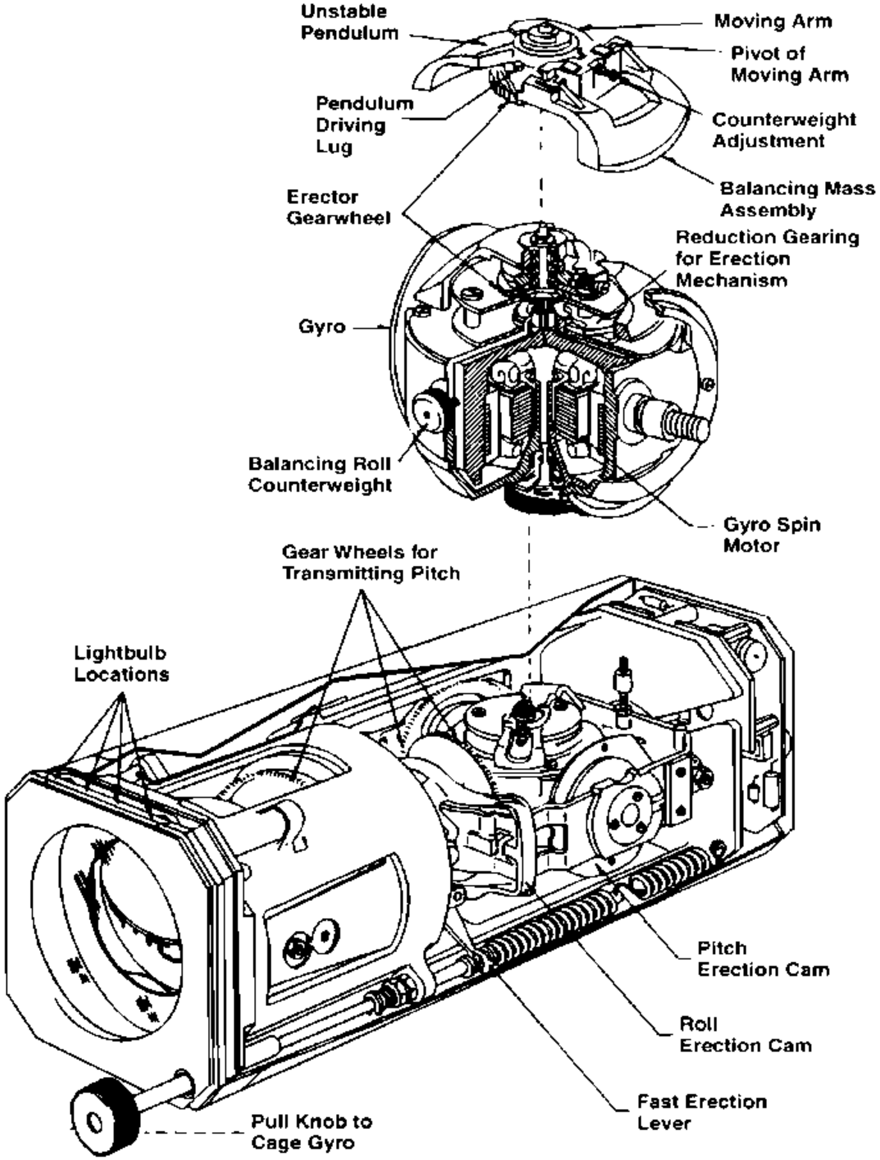
Erection of electrically driven Gyros

Newer attitude gyros are driven by electric motors. For those gyros there is a need of erection systems working with weights sensing the earth gravity.

Erection effect is caused when the unstable pendulum is accelerated ahead of the driving lug due to a significant horizontal acceleration. This creates a torque causing the precession in the corrective direction.

If the aircraft accelerates, erection suppression becomes operative, to prevent that the vertical gyro gets in a wrong vertical direction.

Figure 110: Horizon Indicator (Gyro Errected with Pendulum)



Gyro Erection with Balls

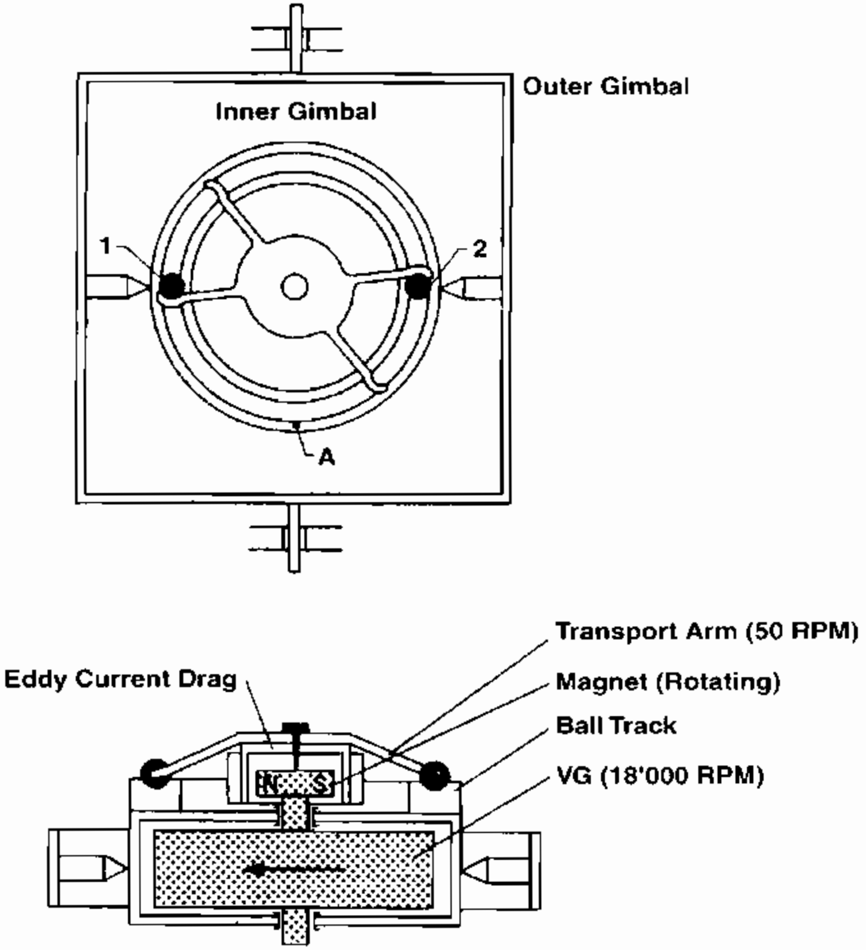
Two small steel balls moving on a circular track are driven by a slow moving transport arm. The eddy current drag reduces the speed from 18'000 rpm to 50 rpm.

If the gyro spin axis is vertical, the balltrack is situated horizontal. Both balls are situated in opposite position and in balance. No force is presented to the gyro.

If the gyro spin axis is not vertical, assumed point A is downward.
Ball 1 has to be raised up,
Ball 2 rolls down toward the stop of the transport arm.
In this case, the force is no more in balance. A force acts to the gyro. The gyro's precession raises point A upward until both balls are in balance.

During curve-flights the balls are mechanically blocked, to prevent that the gyro is tilted in a wrong vertical.

Figure 111: Gyro Errection with slowly rotating Balls

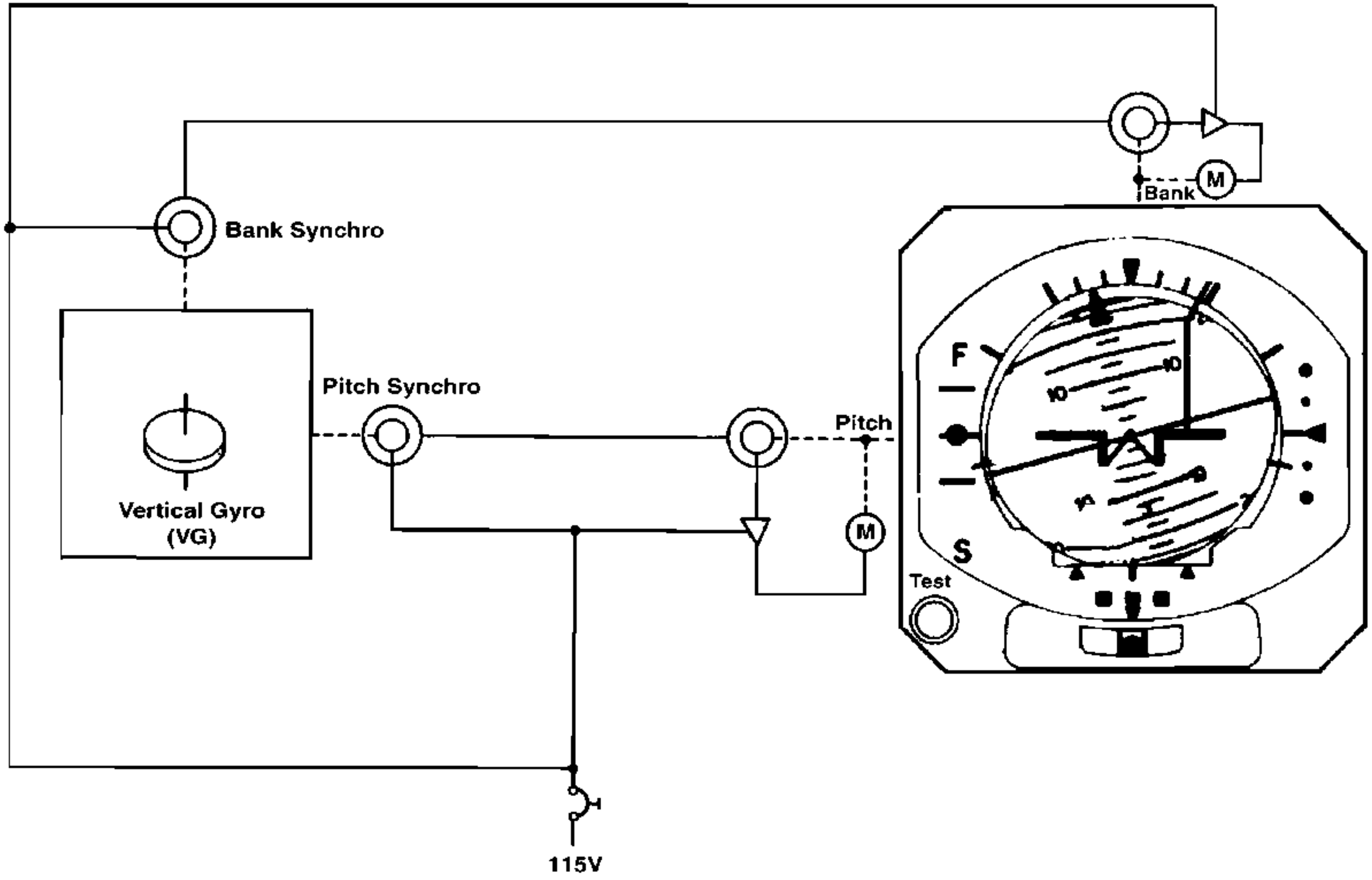


Remote Artificial Horizon Indicator

In larger airplanes the vertical gyro is a separate unit. The horizon indicator receives bank and pitch signals via synchros from VG. Amplifiers for the motors inside the horizon indicator are located in a separate unit or also located inside the Attitude Direction Indicator

The vertical gyro also serves other systems like autopilots and the weather radar with roll and pitch signals.

Figure 112:



Electrical Erection of VG

In order to maintain the spin axis vertically, two erection systems must be used, one in the roll axis and one in the pitch axis. The reaction of a gyro to an applied force makes it necessary to use erection forces at right angles to the desired direction of motion. This accounts for the pitch erection torquer mounted in the roll axis and the roll erection torquer mounted in the pitch axis.

A torquer is a frustrated motor. It never gets to turn anything, not even itself; but when called upon to do so, will try. A gravity sensing liquid switch, constructed on the principle of a carpenter's level, provides power to the torquer when the switch is not level. The torquer then provides the force to erect the spin axis vertically in one axis.

Roll erection torquing is cut off when the bank angle exceeds about 6 degrees and pitch erection is cut off if the acceleration is more than 2 kts/sec in square, to eliminate the tendency to erect to false sense of vertical.

The erection control applies for the first 3 minutes of gyro operation a higher voltage to the torquer for fast erection at start up of the gyro.

Bank and pitch synchros transmitting the angle between the gimbals to their users.

Figure 113: Liquid Level Sensor and Torque Motor

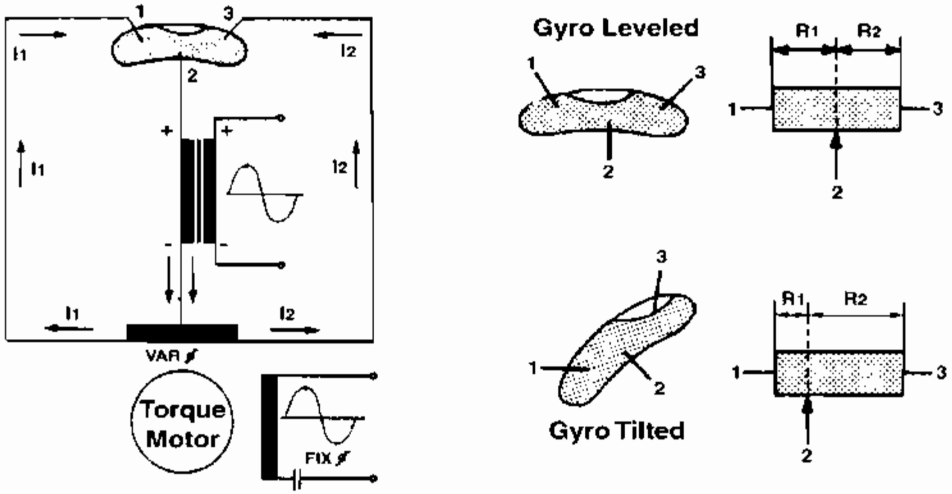
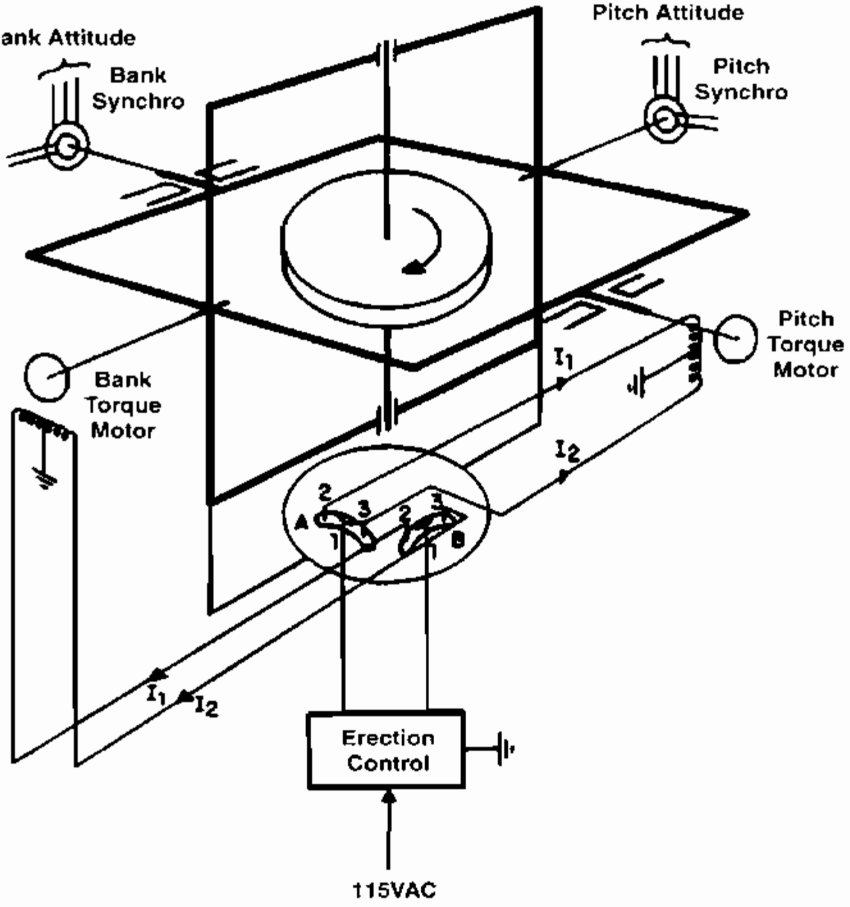


Figure 114: Vertical Gyro with electrical Erection

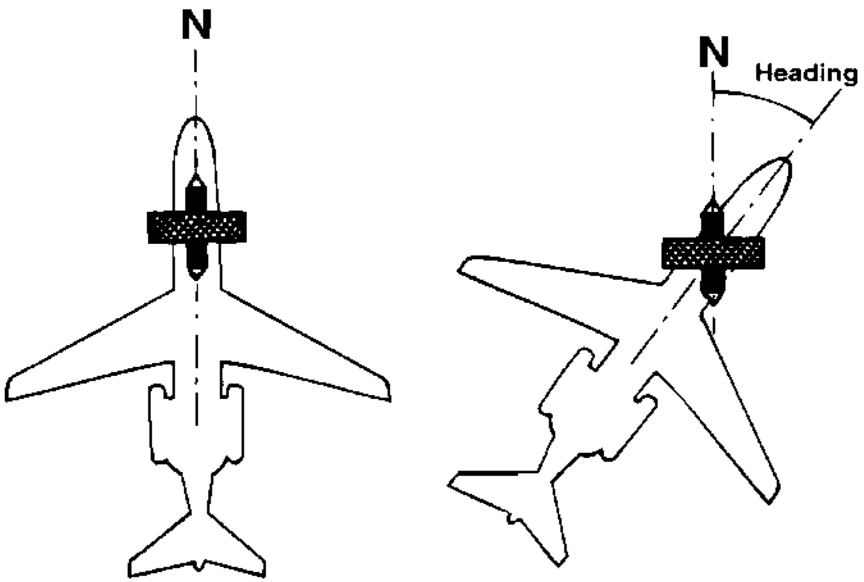


Directional Gyro

The most commonly used magnetic compass consists of a small permanent magnet soldered to a metal float and suspended in a bowl of liquid. This primitive type of direction indicator is quite adequate for visual flight when it is only occasionally referred to, but since it oscillates back and forth so much, we cannot use it as a heading indicator when we are flying on instruments.

If we have a freely spinning gyroscope set to align with the earth's magnetic field, we can visualize our heading and it does not oscillate. The main problem is that this instrument has no north seeking tendency, and so it must be set to agree with the magnetic compass every 15 minutes when it is not swinging back and forth.

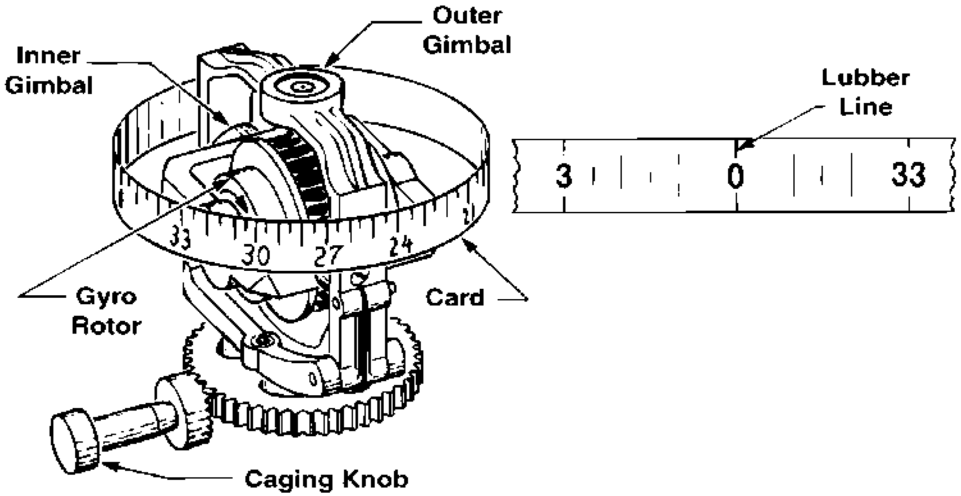
Figure 115:



Directional Gyro Indicator

Early directional gyros resembled the magnetic compass with its gyro rotor suspended in a double gimbal with its spin axis in a horizontal plane inside the calibrated scale, The rotor was spun by a jet of air impinging on buckets cut into its periphery. The caging knob in the front of the instrument could be turned to rotate the entire mechanism and bring the desired heading opposite the reference mark, or lubber line. The rotor remains rigid in space, as the aircraft turned about the gyro, the pilot had a reference between the heading of the aircraft and the earth's magnetic field.

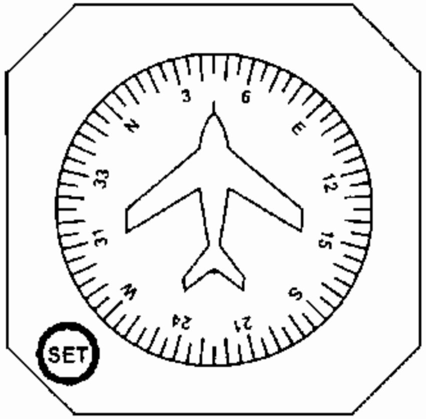
Figure 116:



Vertical Card Directional Gyro

The vertical card compass has instead of a simple lubber line in front of the card, a symbol of an airplane on its face, in front of the dial, with its nose pointing straight up, representing straight ahead. The circular dial is connected to the gyro mechanism, so it remains rigid in space and, as the airplane turns about it, the dial rotates. The knob in the lower left-hand corner of the instrument may be pushed in and rotated, so the pilot can turn the mechanism to get the dial under the nose of the symbolic airplane that corresponds to the heading shown on the magnetic compass.

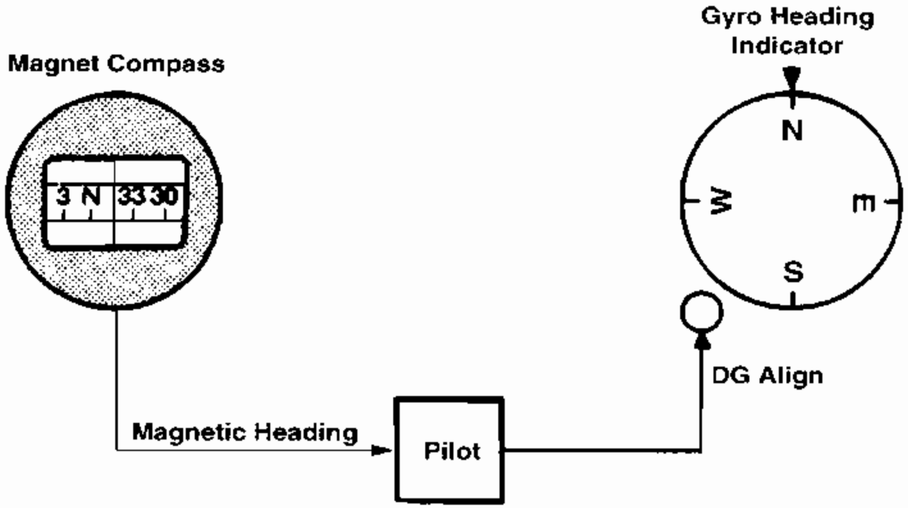
Figure 117:



Slaving of Directional Gyro

Directional gyro, must be set to agree with the magnetic compass, and it too must be periodically checked to be sure that it has not drifted out of agreement with the compass.

Figure 118:



Drift of Gyros

A free running gyro will maintain its direction in space. In relation to the earth, gyros appears to rotate and loosing its direction. This behaviour is called apparent drift caused by the earth rotation.

The earth rotation is 360° in one day this 15°/hour.

Directional Gyro

Earth Rate Apparent Drift = 15°/h x sin Latitude

	Latitude	Earth Rate **°/hour**
Equator	0°	**0**
Zurich	47°	**10.97**
Pole	90°	**15**

Vertical Gyro

Earth Rate Apparent Drift = 15°/h x cos Latitude

	Latitude	Earth Rate **°/hour**
Equator	0°	**15**
Zurich	47°	**10.23**
Pole	90°	**0**

The apparent drift consists of:

Earth Rate	Earth rotation
Transport Rate	Aircraft moves around the earth globe
Random Drift	Mechanical error

Figure 119: Apparent Drift of Directional Gyro

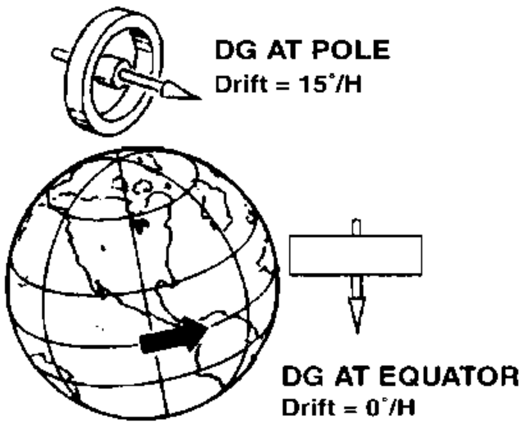
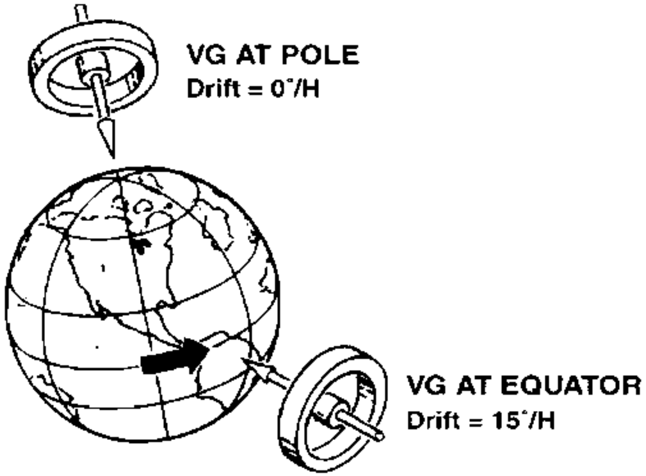


Figure 120: Apparent Drift of Vertical Gyro



Rate Gyro

Precession is the primary characteristic used for rate gyros. There are two basic rate gyros used for flight instrumentation, the turn and slip indicator and the turn coordinator. Rate gyros are also incorporated into a number of autopilot systems.

The basic difference between a rate gyro and an attitude gyro is in the mounting of the gyro itself, or in the number of degrees of freedom the gyro is given. An attitude gyro is mounted in a double gimbal and has freedom about two axes, while a rate gyro is mounted in a single gimbal and has freedom about only one axis.

Figure 121: Rate Gyro

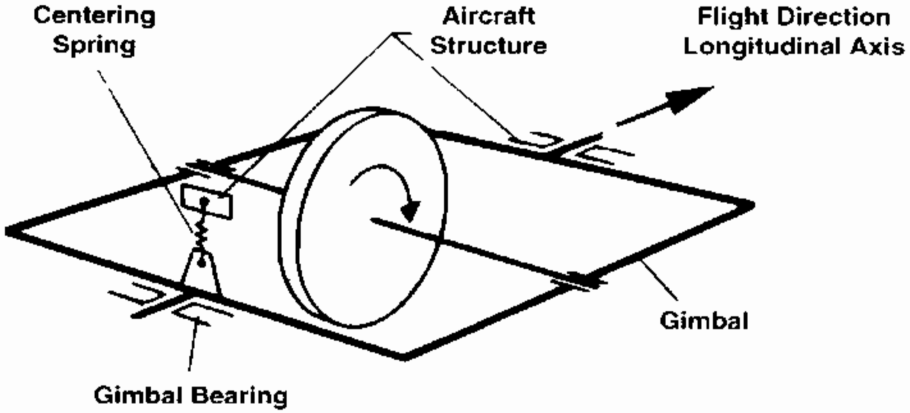
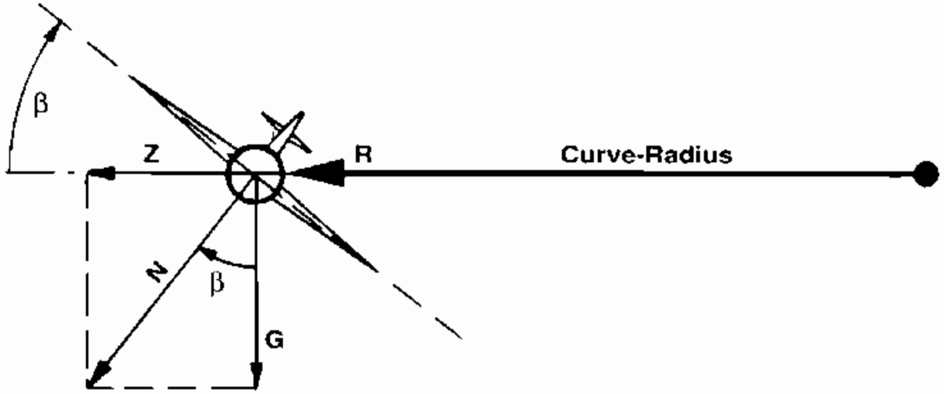


Figure 122: Courve Radius, Ground Speed and Bankangle



R = Curve Radius

β = Bankangle

Z = Zentrifugal Force

N = Normal Force

G = Weight Force

g = Earth gravity = 9.81 m/sec^2

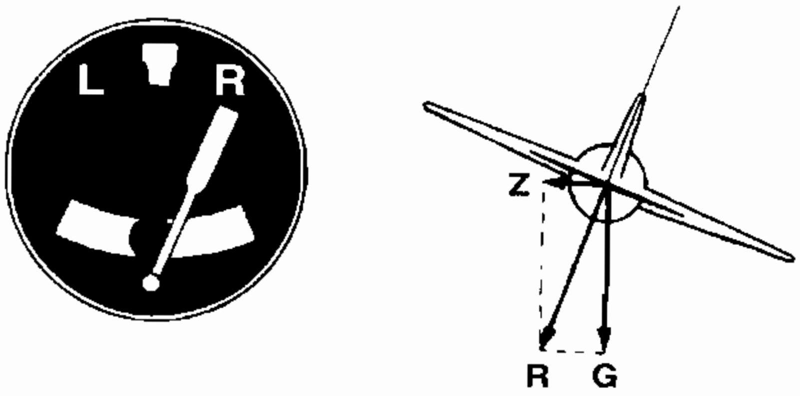
v = velocity

tg β = v^2 / R x g

Turn and Slip Indicaton

There are actually two instruments in one housing. The simpler instrument is an inclinometer set into the dial. This is a curved glass tube filled with a damping liquid, and riding in it is a black glass ball. When the aircraft is perfectly level and there are no other forces acting on it, the ball will rest in the bottom center of the tube between two marks. In flight, the ball indicates the relationship between the pull of gravity G and centrifugal force Z caused by a turn. The pull of gravity is affected by the bank angle: the steeper the bank, the more the ball wants to roll toward the inside of the turn toward the low wing. Centrifugal force, on the other hand, pulls the ball toward the outside of the turn. The greater the rate of turn, the greater the centrifugal force. A coordinated, or balanced, turn is one in which the bank angle is correct for the rate of turn, and the ball remains centered.

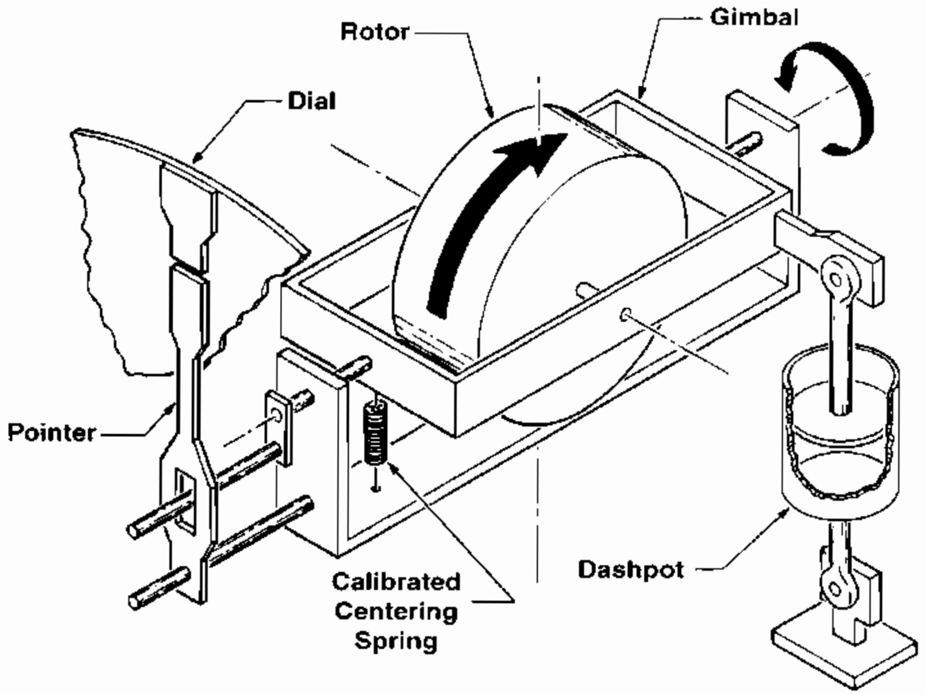
Figure 123: Indication courve correct flown



The gyroscopic part of the turn and slip indicator is a rotor, spun either by air or by an electric motor. This rotor has its spin axis parallel to the lateral axis of the aircraft, and the axis of the single gimbal is parallel to the longitudinal axis of the aircraft. A centering spring holds the gimbal level when there is no outside force acting on it. When the rotor is spinning and the aircraft rotates about its vertical, or yaw, axis, a force is carried into the rotor shaft by the gimbal in such a way that one side of the shaft is moved forward while the other side is moved back. Precession causes the rotor to tilt, as the force is felt, at 90 degrees to the point of application in the direction of rotor rotation.

This tilt is opposed by both a dashpot which smooths out the force, and by a calibrated spring which restricts the amount the gimbal can tilt. A pointer is driven by the gimbal in such a way that it indicates not only the direction of yaw, but the amount of its deflection is proportional to the rate of yaw.

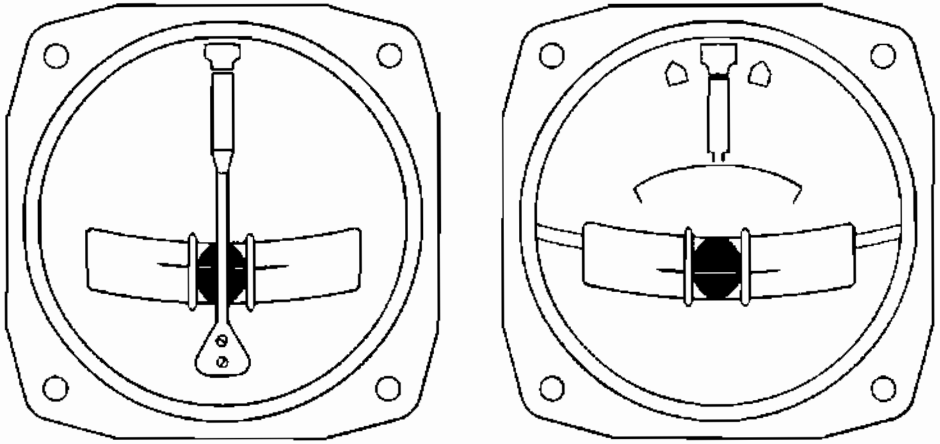
Figure 124: Rate Gyro inside Indicator



Turn and Slip Indicator

The dial of a turn and slip indicator is not graduated with numbers, but the amount of turn is measured in needle widths, and there are two standard calibrations. Some instruments are called two-minute turn indicators, and a standard rate turn of three degrees per second (360 degrees in 120 seconds) is indicated by the pointer leaning over one needle width. In a standard rate turn to the right, the left edge of the pointer aligns with the right edge of the index mark. Most of the newer turn and slip indicators are calibrated as four-minute turn indicators. With this calibration, the needle deflects one needle width for a turn of one-and-a-half degree per second (half-standard rate). Instruments calibrated for four minute turns have two small doghouse-shaped marks on top of the dial, one needle-width away from either side of the center index mark.

Figure 125:

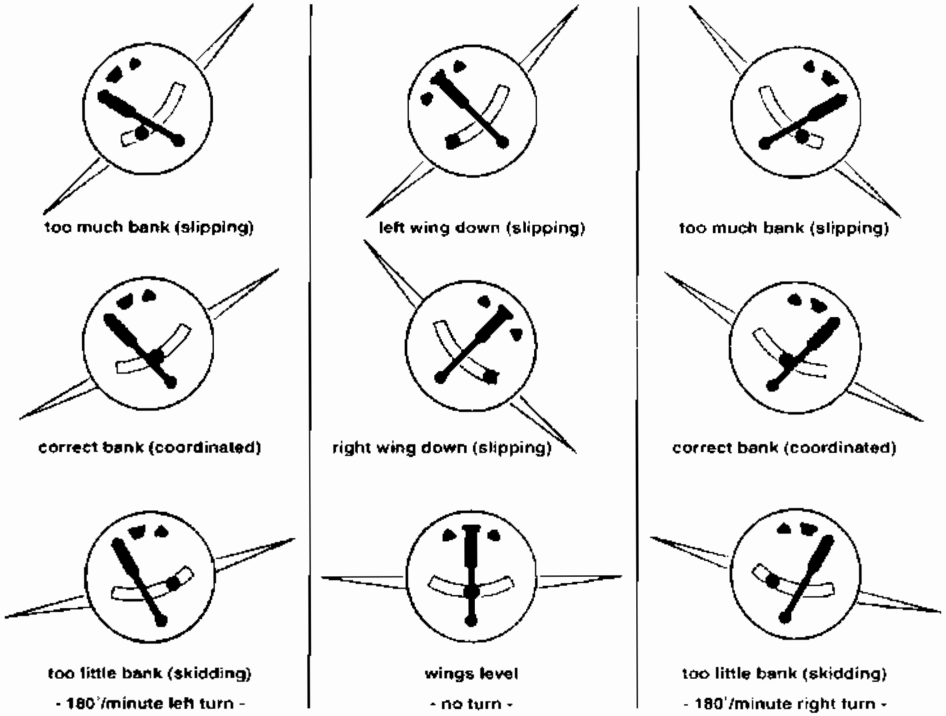


Two-minute turn indicator dial
(A)

Four-minute turn indicator dial
(B)

These instruments may also be marked ‘FOUR MINUTE TURN.” When the aircraft is rotating about its vertical axis at 1,5 degrees per second, the needle of the four-minute turn indicator aligns with the appropriate doghouse.

Figure 126: Example of Turn and Bank Indication

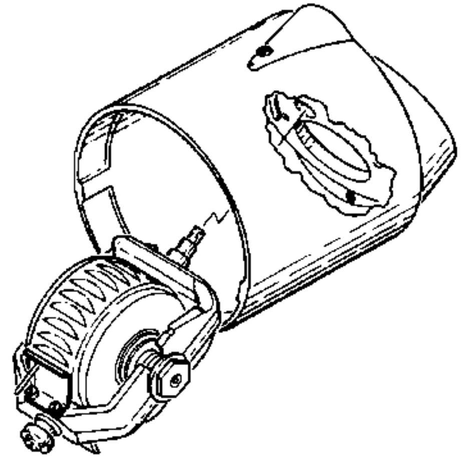


Turn Coordinator Indicator

A turn and slip indicator can show rotation about only the vertical axis of the aircraft yaw. But since a turn is started by banking the aircraft, that is, by rotating it about its longitudinal axis, a turn indicator would be of more value if it sensed this rotation also. The mechanism of a turn coordinator is similar to that used in a turn and slip indicator, except that its gimbal axis is tilted, usually about thirty degrees, so the gyro will precess when the aircraft rolls, as well as when it yaws. This is especially handy since a turn and slip indicator is affected by adverse yaw at the beginning of a turn, but a turn coordinator senses enough roll to cancel any deflection caused by adverse yaw.

Rather than using a needle for its indicator, the turn coordinator uses a small symbolic airplane with marks on the dial opposite its wing tips. When the aircraft is turned at a standard rate to the left, the wings of the symbolic airplane align with the mark on the left side of the instrument dial, the one marked "L". When the rate of yaw is correct for the bank angle, the ball will be centered between the two lines across the inclinometer.

Figure 127:



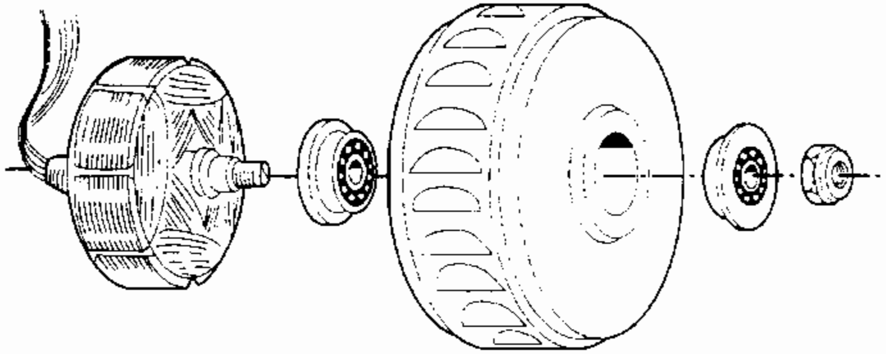
Gyro Instrument Power System

Electric Motors

In today commercial Aircrafts all gyros are driven by electric motors.

Their speed is between 6'000 and 20'000 RPM.

Figure 128:



Pneumatic System

For safety, the attitude gyros may be electrically driven and the rate gyro is driven by air, or the attitude instruments may be driven by air and the rate gyro electrically driven. Some gyroscopic instruments are dual powered.

Gyrowheels in pneumatic instruments are made of brass and have notches, or buckets in their periphery. Air blows through a special nozzle into the buckets and spins the gyro at a high speed.

Most there is used a vacuum system with ventury or a engine driven vacuum pump. For aircrafts flying higher than 18'000 ft there is a compressor system who provides enough airmass through the gyro.

Figure 129: Vacuum System with Ventury

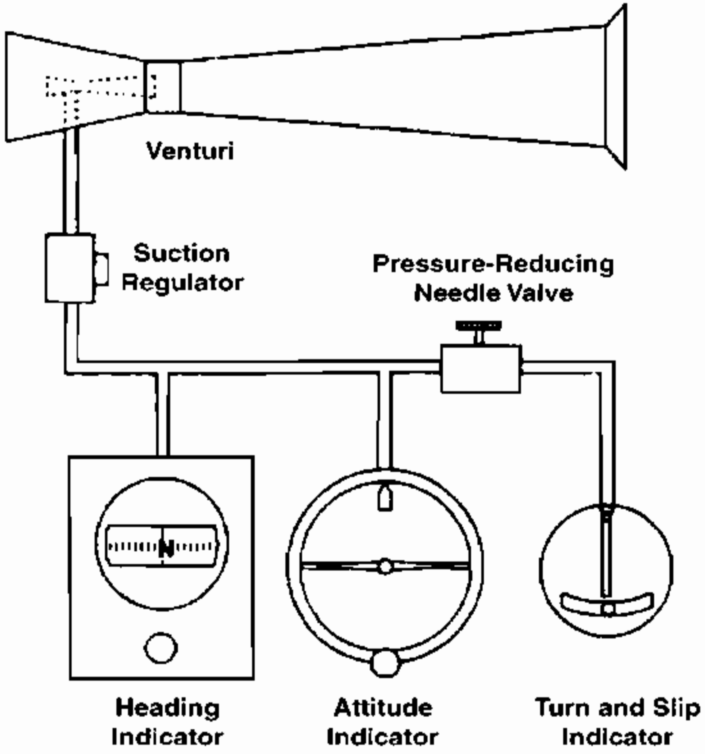


Figure 130: Vacuum System with Pump

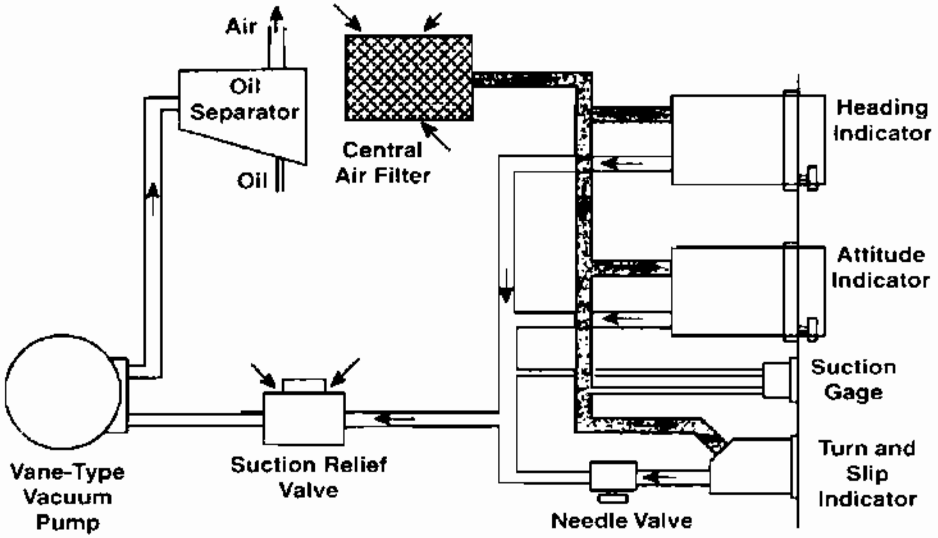
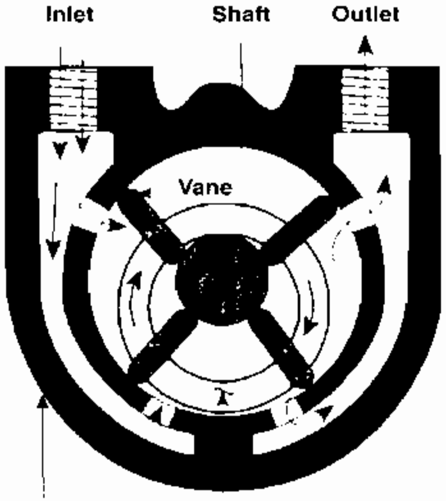


Figure 131: Engine driven Vacuum Pump

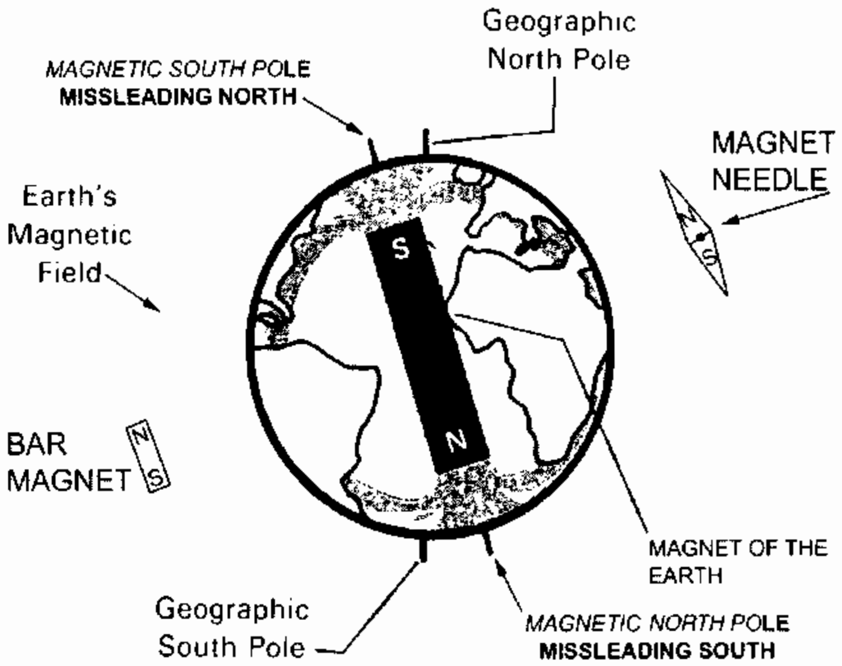


Compass

Earth Magnetic Field

The earth is a great sphere spinning in space, but it is also a huge permanent magnet with a magnetic north and a magnetic south pole. A freely suspended permanent magnet on the surface of the earth will align itself with the lines of flux linking the two magnetic poles, and it will maintain this alignment anywhere on the surface of the earth. Because of this alignment, navigation should be simple, but there are two problems with this alignment we must understand before we can use a magnetic compass for navigation. The geographic and the magnetic poles are not located together. The magnetic poles are located somewhere around 74°N 101°W 2000 km from the geographic poles and, to further complicate the situation, they move around continually, not enough to cause a big problem, but enough that our aeronautical charts must be periodically updated to give us the correction we need to compensate for this difference in location.

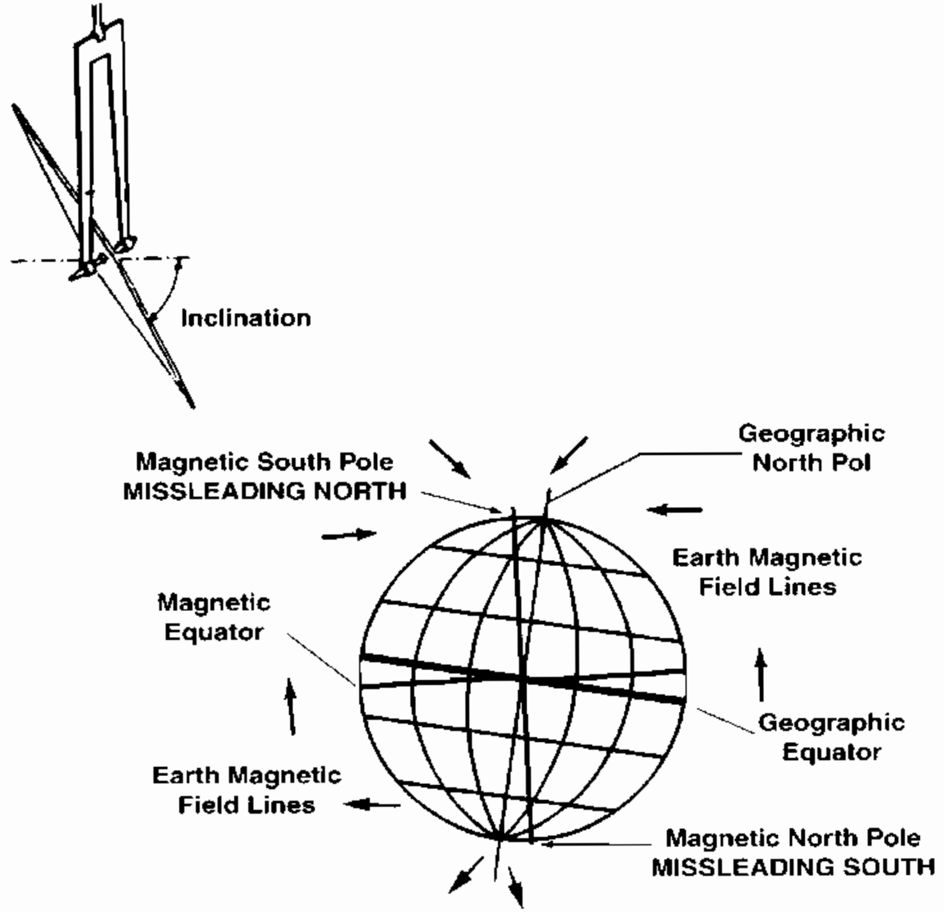
Figure 132:



Inclination

When the compass is pulled by the earth' s magnetic field, the compass' s magnet tends to point North and the magnet also tends to pull toward the earth' s surface. Near the poles this tilting force is the greatest, so the compass is no more useable. It diminishes as you approach the equator. To compensate for this tilting force, the compass float is weighted on the side nearest the equator. For aircraft which fly in the northern hemisphere, the weight is on the south end of the float.

Figure 133:



Variation

Since all of our charts are laid out according to the geographic poles, and the magnetic compass points to the magnetic poles, we have an error called variation. To simplify the correction for this error, aeronautical charts are marked with lines of equal variation, called isogonic lines. Anywhere along an isogonic line, there is a constant angle between the magnetic and geographic north poles. The variation error is the same on any heading we fly, and is determined only by the position on the surface of the earth. The correction required for variation error is found on aeronautical charts.

Figure 134:

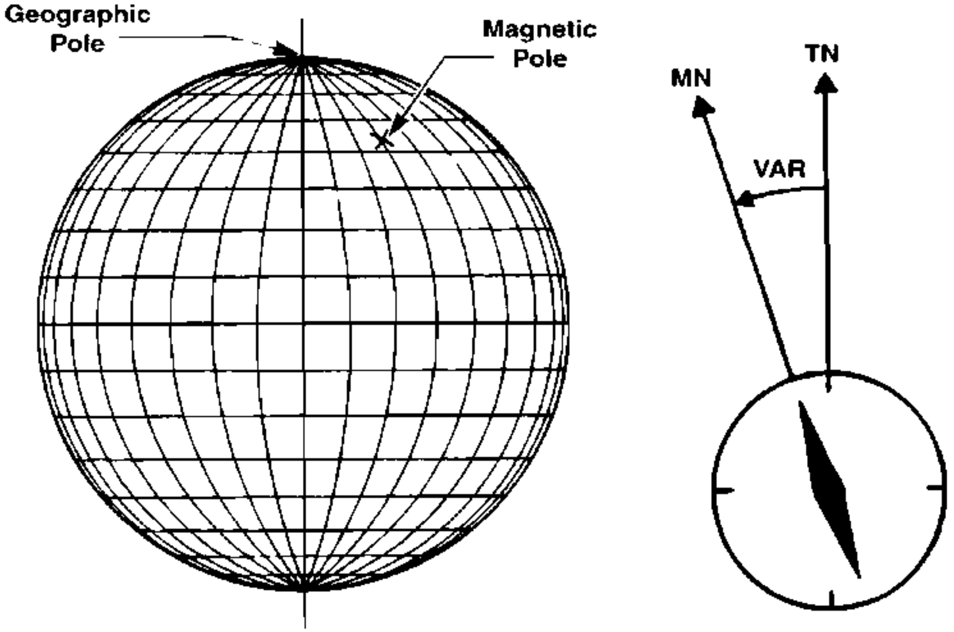
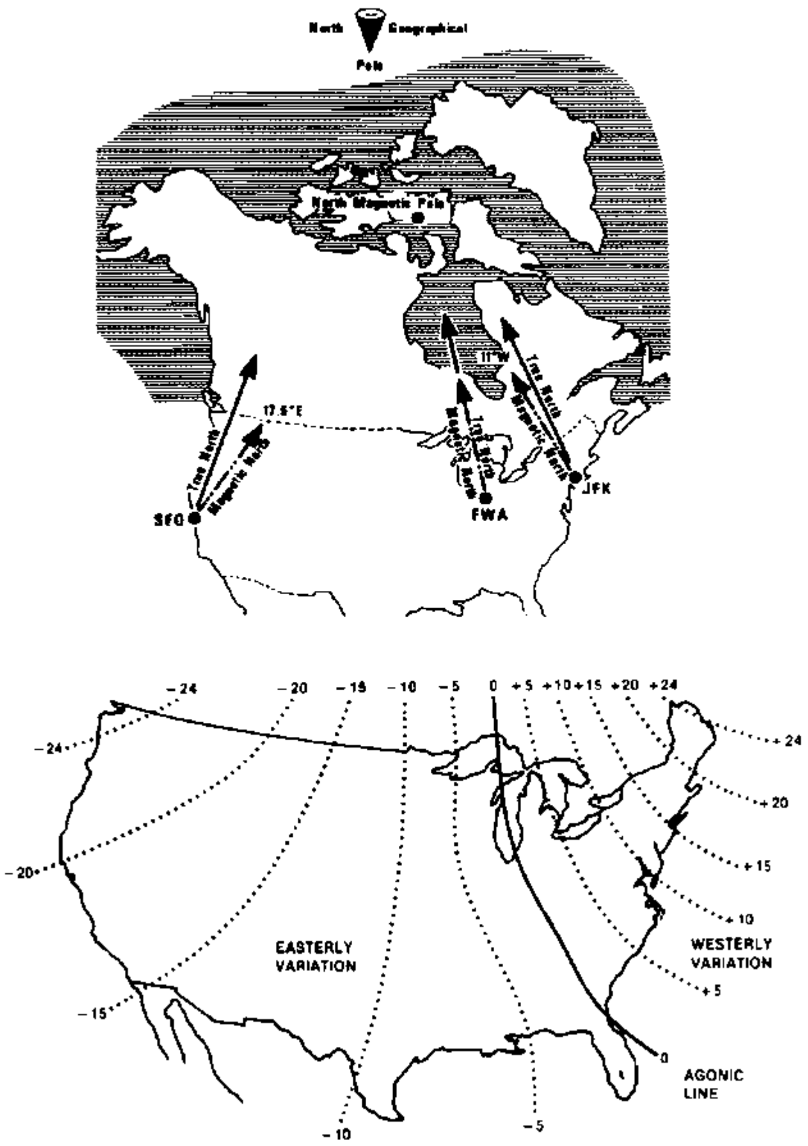


Figure 135:



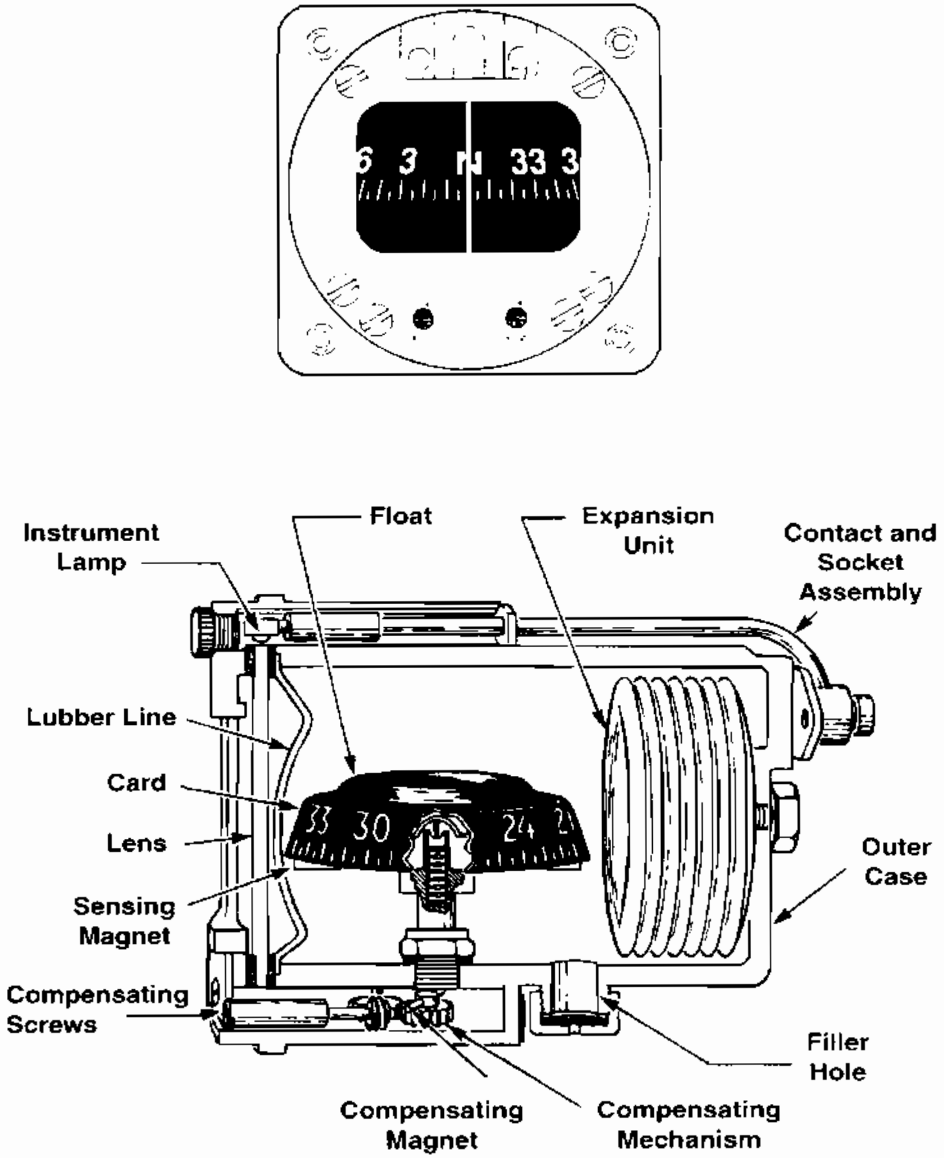
Magnet Compass

The magnetic compass is one of our simpler instruments. Its main body is a cast aluminium housing, and one end is covered with a glass lens. Across this is a vertical reference mark called a lubber line. Inside the housing and riding on a steel pivot in a jewel post is a small brass float surrounded by a graduated dial which is part of a cone. Around the full 360 degrees of the dial are 36 marks, representing the tens of degrees. Above every third mark is either a one- or a two-digit number representing the number of degrees with the last zero left off. Zero is the same as 360 degrees and is north. Nine is east, or 90 degrees, 18 is south (180 degrees), and 27 is 270 degrees, or west. Two small bar-type permanent magnets are soldered to the bottom of the float, aligned with the zero and 18 marks, north and south. The housing is filled with compass fluid, which is a hydrocarbon product very similar to kerosene, but with certain additives that keep it clear The housing must be completely full, with no bubbles, and to prevent damage to the housing when the fluid expands due to heat, an expansion diaphragm or bellows is mounted inside the housing. A set of compensator magnets is located in a slot in the housing outside of the compass bowl, and a small instrument lamp screws into the front of the housing and shines inside the bowl to illuminate the lubber line and the numbers on the card.

The compass heading is correct if:

- The aircraft is horizontal.
- There is no acceleration.
- The reading is corrected with the deviation-chard.

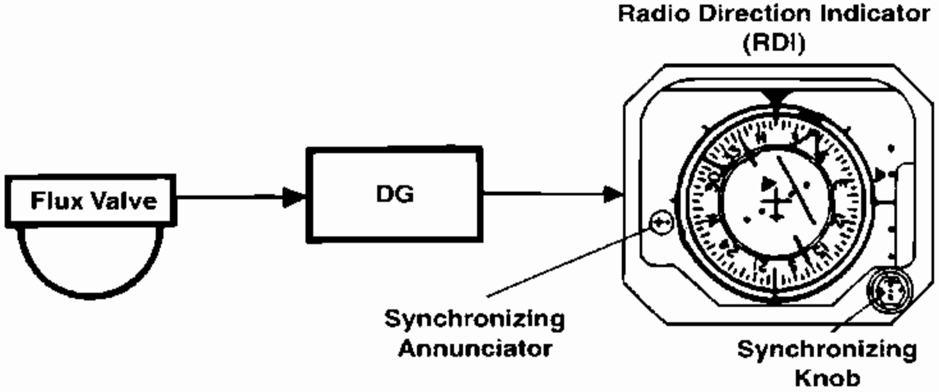
Figure 136:



Slaved Gyro Compass

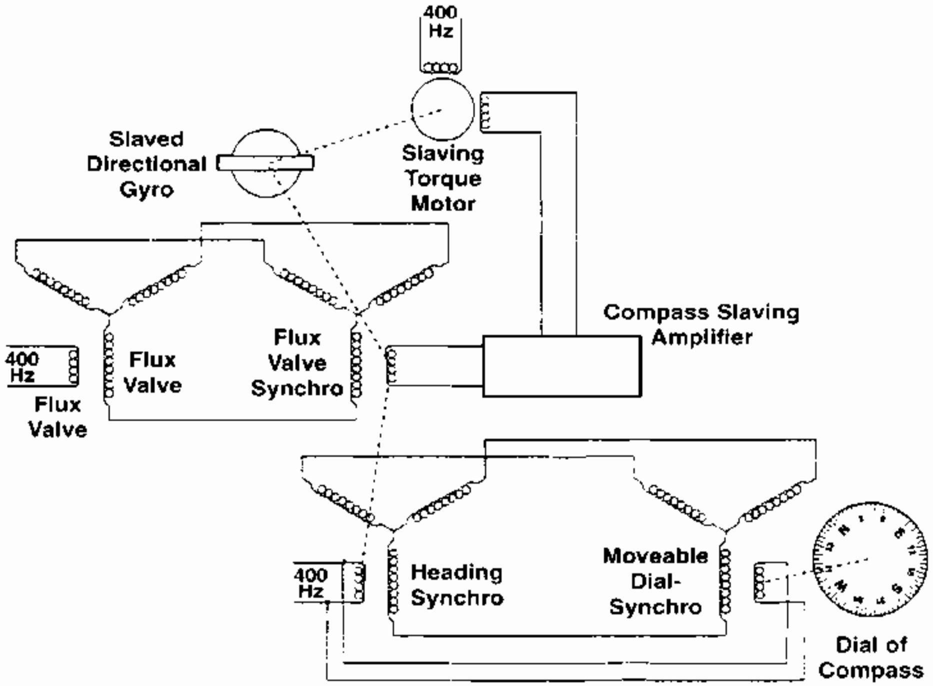
The modern directional gyro, like the gyro horizon, has been combined with other instruments to make it the versatile flight instrument it is today. One of the most useful combinations has been that of slaving the gyro to a magnetic compass. A flux gate, or flux valve, picks up an induced voltage from the earth' s magnetic field and after processing it, directs it to a slaving torque motor in the instrument that precess the gyro and rotates the dial until the airplane' s magnetic heading is under the nose of the symbolic airplane on the face of the instrument. This slaving gives the directional gyro all of the advantages of a magnetic compass without its most disturbing faults. In the more exotic direction-indicating instruments, the slaved directional gyro is combined with radio navigation systems so it will display information from the VOR, ILS, ADF or Area-Navigation system.

Figure 137:



The direction-seeking portion of the system consists of a flux valve that picks up is directional signal from the earth's magnetic field. This signal is amplified and sent into a slaving torque motor in the remotely-mounted directional gyro. This motor causes the DG to precess until it indicates the relationship between the nose of the aircraft and the earth's magnetic field. When the gyro precesses, it drives the rotor of an synchro transmitter which is electrically connected to a synchro motor inside the compass indicator named: Radio Magnetic Indicator RMI, Radio Direction Indicator RDI or Horizontal Situation Indicator HSI. That drives the heading dial. By using this mechanism, the actual magnetic heading of the aircraft at any time is shown by the position of the heading dial against the lubber line.

Figure 138:



Flux Valve

The flux valve is mounted in a wing tip or other location on the aircraft that has a minimum of magnetic interference caused by various electrical circuits. It has a highly permeable iron frame, or spider, made in the form of a segmented circle with three legs radiating out from its center. An excitation coil is wound around the center of the spider, and pick-up coils are wound around each of the three legs.

The excitation coil is excited with 400 Hertz whose field periodically saturates the arms of the spider and lowers its permeability. When no current flows, the arms are unsaturated and are able to accept lines of flux from the earth' s magnetic field, but when they are saturated, they will not.

The position of the flux valve is on a heading of magnetic north. The earth' s magnetic field enters the arm of the spider during that portion of the cycle when it can accept this flux and, as the field is alternately accepted and rejected, it cuts across the windings of the pick-up coils and generates a voltage in them. This voltage is amplified and used to drive the slaving torque motor. As the aircraft turns to another magnetic heading, the relationship between the flux lines in each of the three arms of the spider changes, and for every heading there is a different phase relationship generated in the pick-up coils.

The varying three-phase AC voltage in the pick-up coils is carried into the slaved gyro control has where its output controls the variable phase voltage that is sent into a two-phase slaving torque motor in the directional gyro. This slaving torque motor applies a precise force on the directional gyro that causes it to turn until it satisfies the signal being sent from the flux valve. The synchro system rotates the dial of the RMI until it agrees with the signal from the flux valve.

Figure 139: Cut View

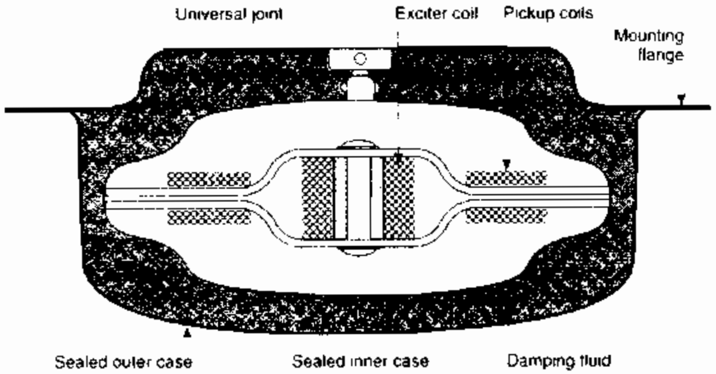


Figure 140: Spider

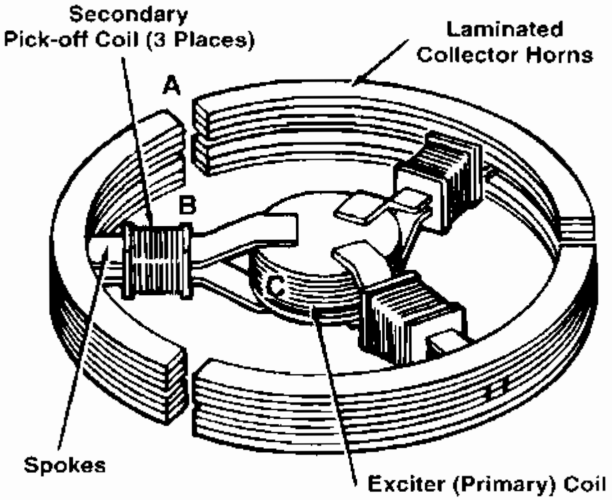
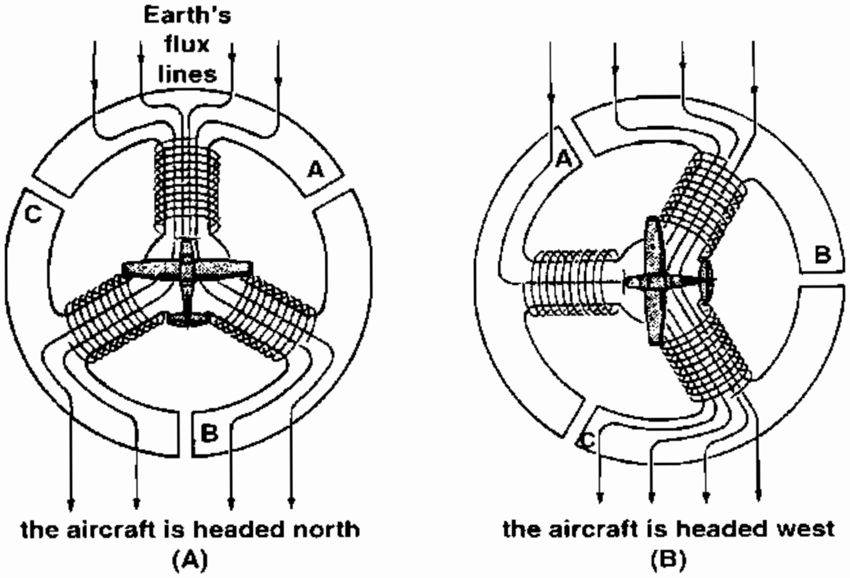


Figure 141: Spider and Earth Magnetic Field



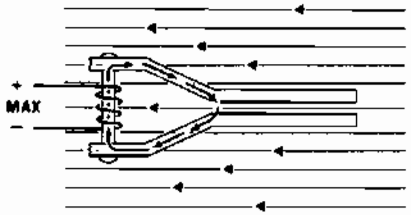
the aircraft is headed north
(A)

the aircraft is headed west
(B)

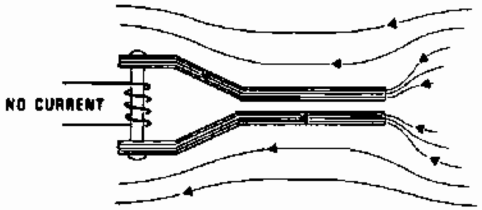
How the fluxvalve works

One spider leg of the flux valve frame, including the center post and the exciter winding is shown.

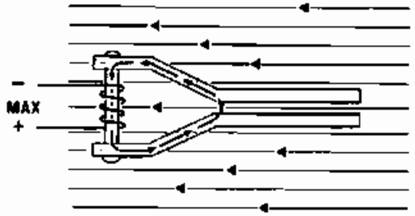
The exciter winding current is at maximum, magnetically saturating the spider leg. The earth's magnetic field is shown surrounding the spider leg in an undistorted pattern. Since the spider leg is already saturated with magnetic current generated by the exciter winding, the earth's field is no more distorted than it would be by passing through air or glass.



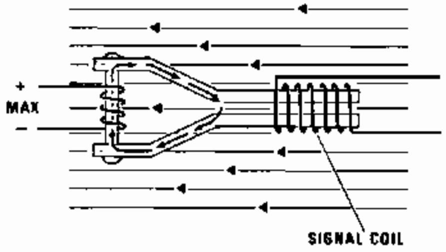
The exciter current has reached a null, and the spider legs have no magnetic flux from the exciter current. The earth's field sees this leg as a path of less reluctance (magnetic resistance) and is drawn into the spider leg.



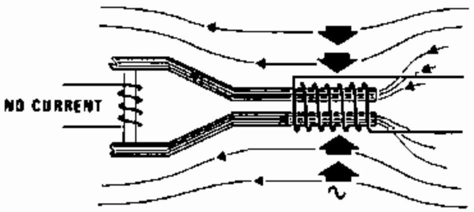
The exciter current has again reached maximum and has driven the earth's field out of the leg.



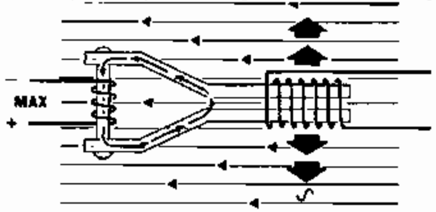
A signal coil is shown wrapped around the spider leg and the condition is the same as in left first figure with none of the earth's field in the spider leg.



The exciter current has reached a null. While the earth's field was moving into the leg it was cutting the windings of the signal coil. This is the same action performed in a transformer or generator to produce a voltage. While the field was cutting the windings of the signal coil, it generated a voltage of a particular polarity because the direction of movement of the earth's field was inward.



The exciter current at maximum and the spider leg saturated. This time the earth's field moved outward, so the polarity of the generated voltage was reversed.



The exciter winding uses a voltage derived from aircraft power with its frequency of 400 Hertz. The effect on the earth's field movement is the same whether the spider leg is saturated with magnetic current of one direction or the other.

1. Excitation flux goes thru zero.
   The iron core is not saturated. (low reluctance)
   The earth flux passes the iron core.

Between 1 - 2 the excitation flux increases. Due of increasing saturation of the iron, the earth magnetic field begins to drive out of the core.
Maximum voltage is induced.

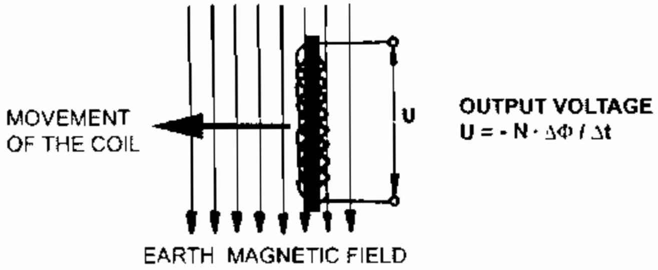
2. Excitation flux is the maximum.
   The iron core is saturated. (high reluctance)
   The earth magnetic field is displaced out of the core.

Between 2 - 3 the excitation flux decreases. Due of decreasing saturation of the iron, the earth magnetic field begins to go back in the core.
Maximum voltage is induced.

3. Excitation flux goes thru zero.
   The iron core is not saturated. (low reluctance)
   The earth flux passes the iron core.

The exciter current reaches a maximum twice during each cycle and a null twice during each cycle, the frequency of the earth's field-induced signal in the signal coil is double the frequency of the exciter voltage (800Hz)

Figure 142: Moving Coil in a constant Field will not cause a Output Voltage



The principle of voltage generation with a coil moving (flying) in a magnetic field can not be applied for compass systems. The flux Φ should be alternatively increased and decreased over a short time period Δt, to induce an output voltage U. The magnetic field of the earth can be assumed as a homogeneous field with:

$$35\ \mu T = 35\ \mu Vs/m^2 = 0.35\ Gauss$$

Figure 143: Saturation of Iron will displace the Earth Magnetic Field

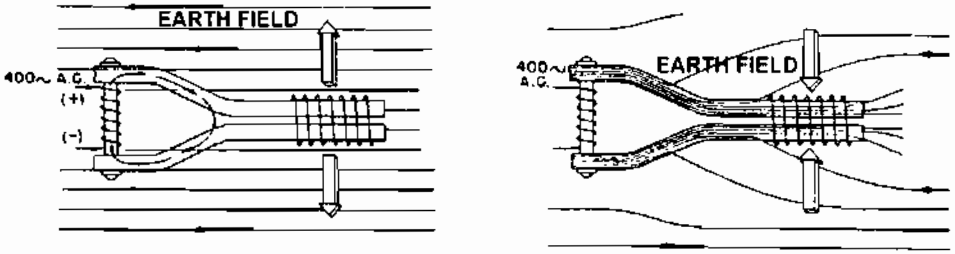
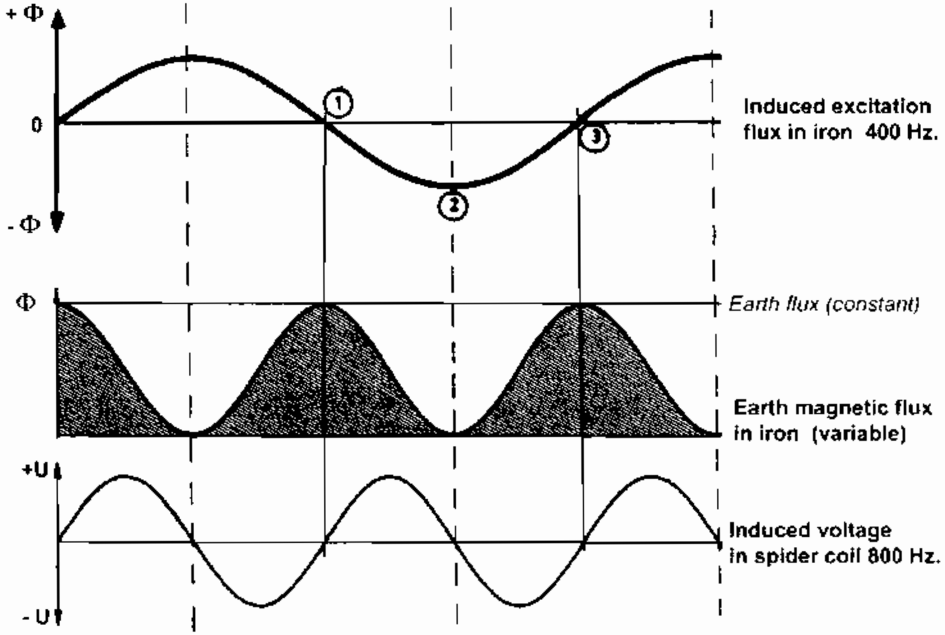


Figure 144: Excitation, Magnetic Flux in Iron and Signal Output



Compass Systems

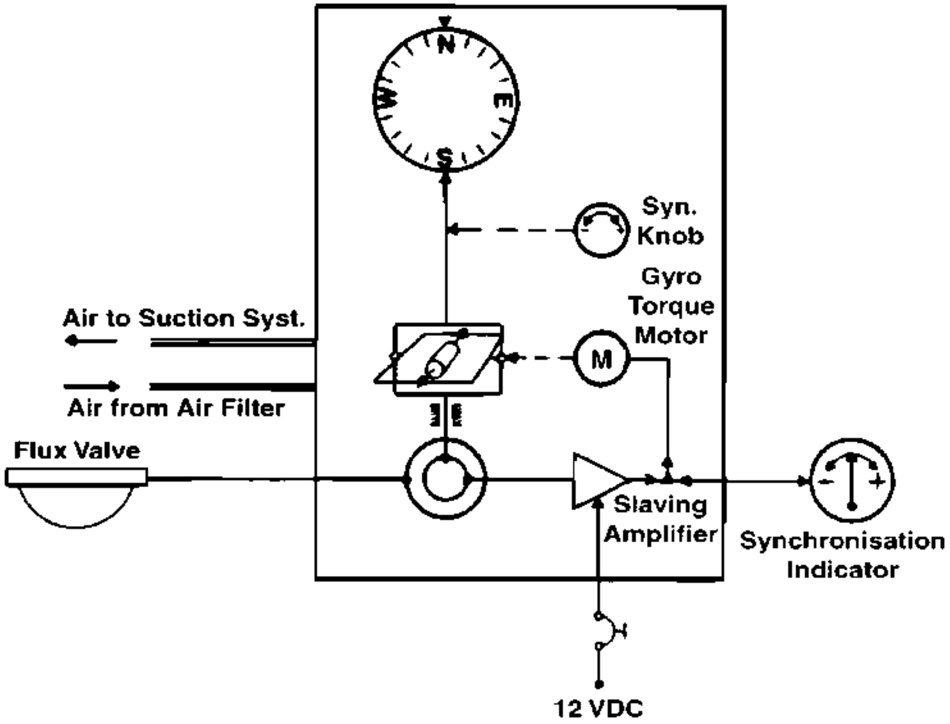
Light Aircraft

The flux valve is located in the aircraft tail or wing tip to prevent any influence of magnetic field induced by electric currents. The flux valve senses the direction (heading) of the earth magnetic field.

The heading is routed to a synchro. If the directional gyro is not coinciding with the earth magnetic field, a synchro output voltage is applied to slaving amplifier. The gyro torque motor produces a force to the gyro gimbal. The DG moves by precession to the actual magnetic heading direction.

As long the compass is not synchronized with the earth magnetic field, the synchronisation indicator is deflected toward + or -. For quick synchronisation the pilot rotates the DG direction by SYN knob in + or - direction until the synchronisation indicator is centred. Then the heading dial coincides with the flux valve angle information.

Figure 145:



MD-80 Compass System

For redundancy two independent compass systems are installed.
Captains RDI and first officers RMI is provided from compass 1
Captains RMI and first officers RDI is provided from compass 2

If one of both system fails, each crew member has still one compass read-out.
If both system failed both pilots has to read the heading from a magnetic stand-by compass.

The Instrument amplifier gets the flux valve heading and slaves the directional gyro as long the mastershaft does not coincide. The direction of the directional gyro is repeated to the mastershaft. Four heading synchros feeding the heading to the display and other systems.

Figure 146: Lay Out

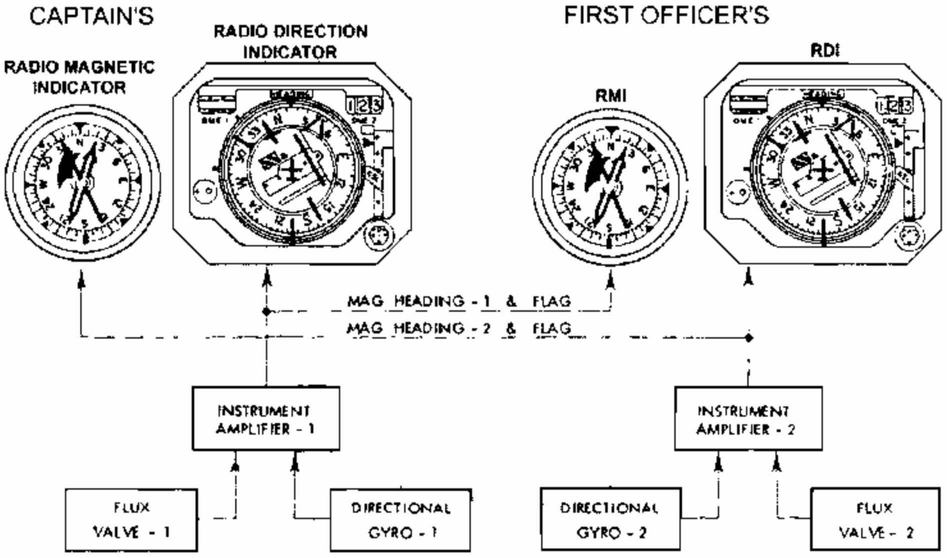
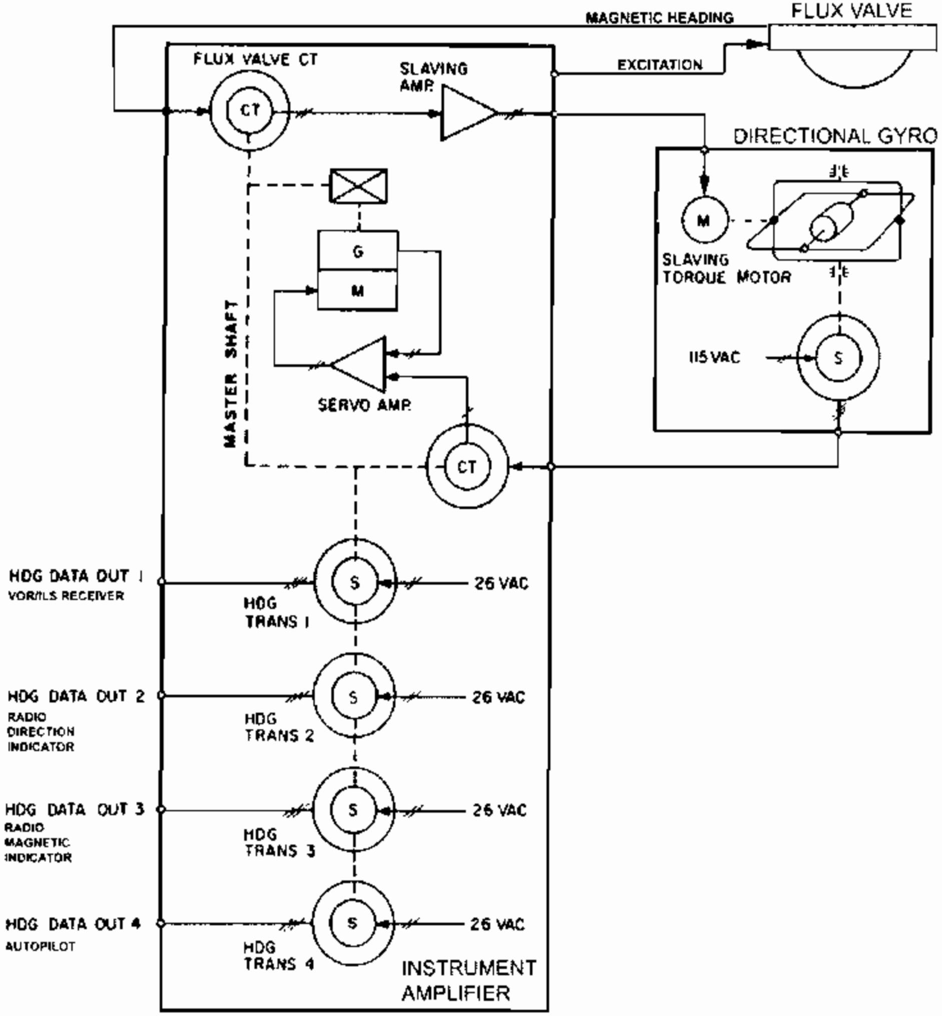


Figure 147: Gyro stabilized Compass



Manual synchronisation of compass system

In the previous example has a disadvantage.

The slaving rate of the directional gyro is very slow (2° - 5° per minute). This causes a very long synchronisation time after applying electrical power. Lets assume the position of mastershaft is 170° apart from flux valve signal. The synchronisation will take more than one hour.

To fast synchronizing the compass, the user may manually rotate the DG output signal. After this is done the gyro is not directed to magnetic north but together with the rotation angle of the differential synchro it represents the heading reference.

The synchronisation annunciator shows a plus or dot if the compass is not synchronized. Rotating the knob located on the RDI in the same direction will synchronize to the correct direction. If the knob is rotated opposite the annunciated + or dot, the compass will show 180° wrong because of the second (wrong) null position of a synchro control transformer.

Figure 148: Indicator with Synchronizing Knob and Annunciator

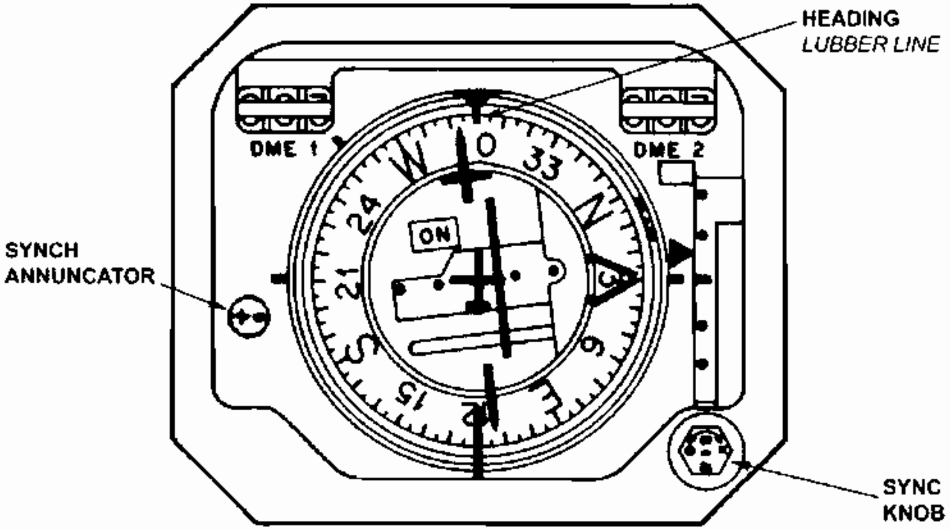
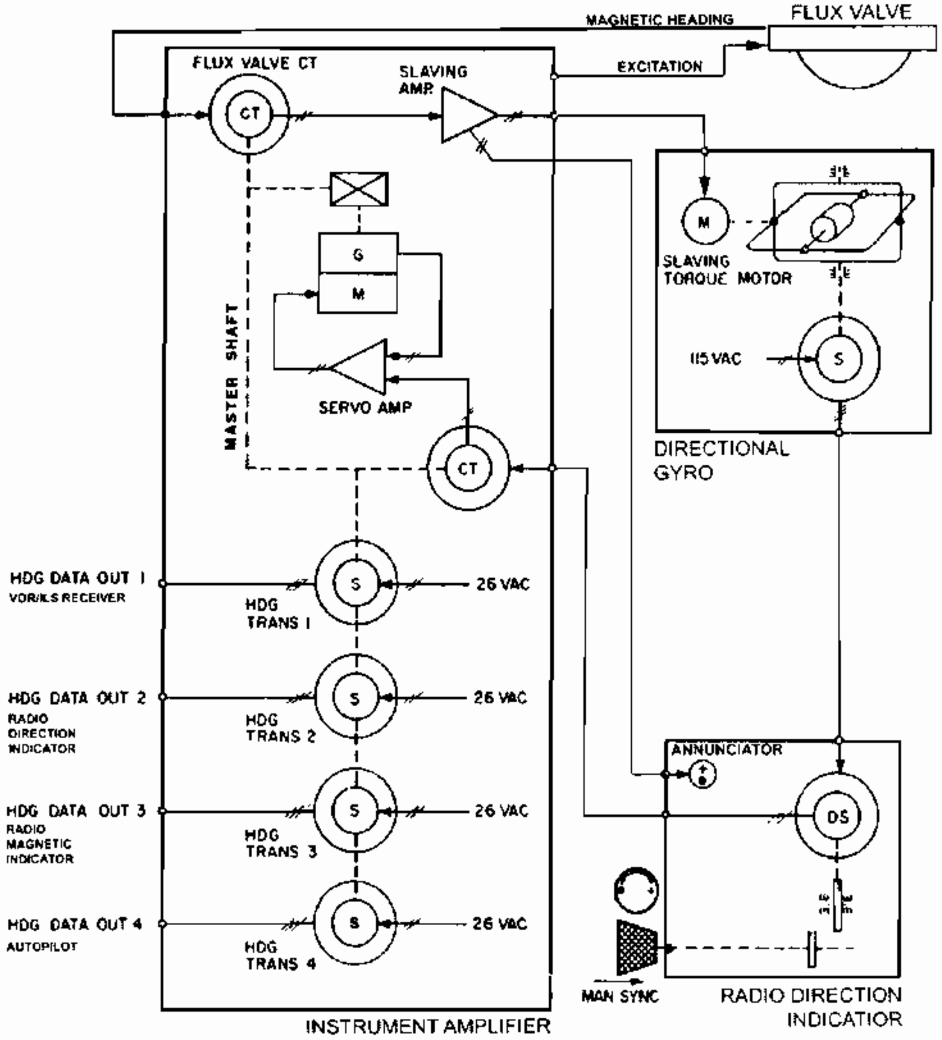


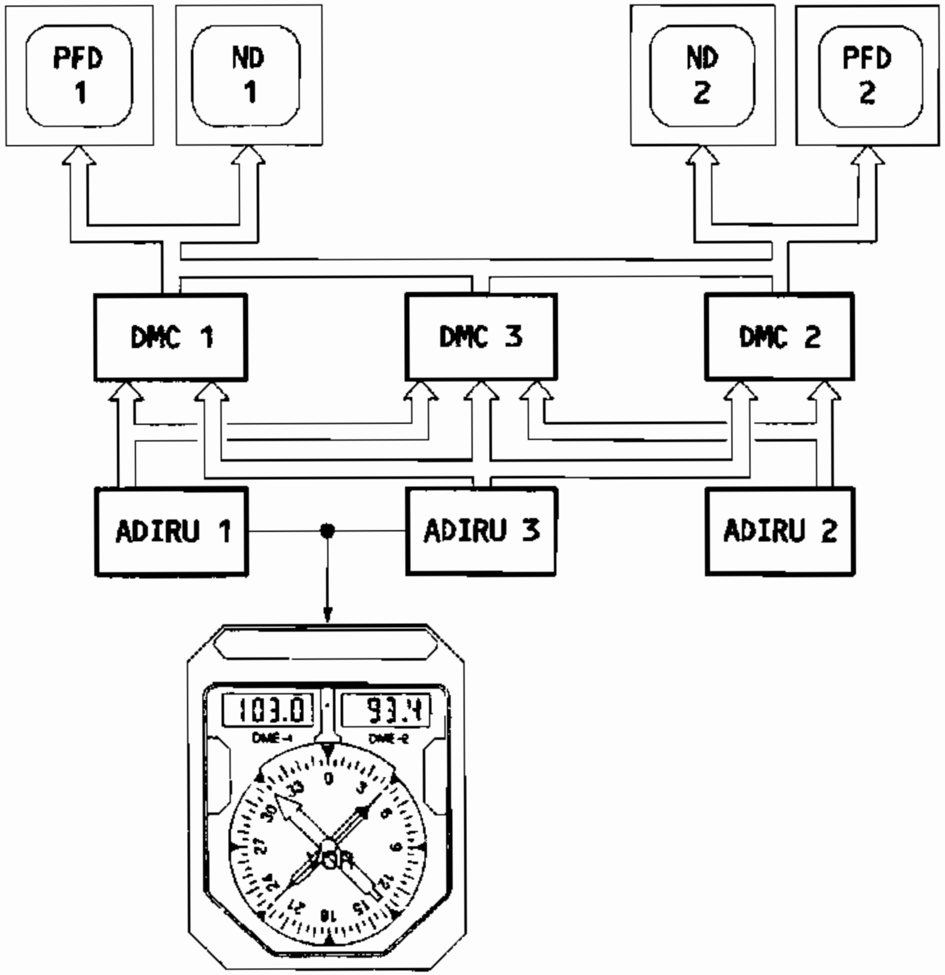
Figure 149: Compass with Synchronisation



New Technology

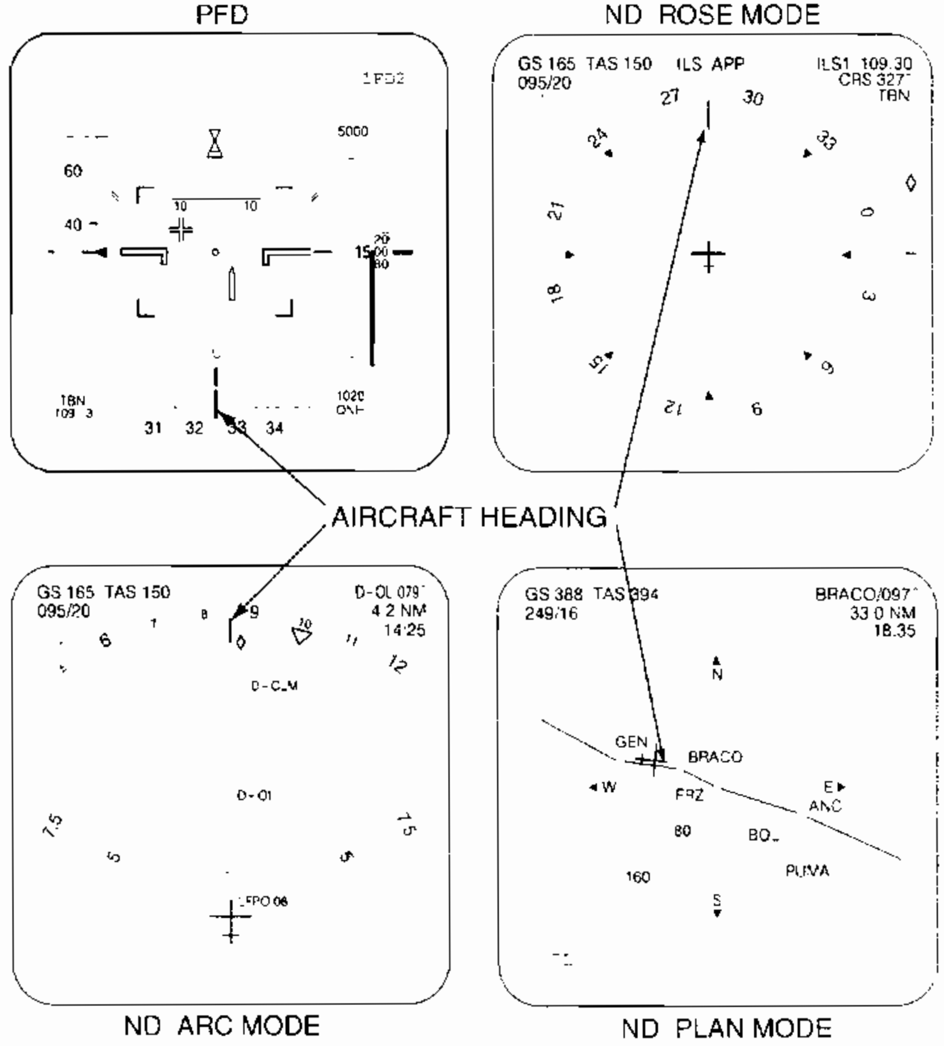
The IRS part of the ADIRU provides aircraft heading to the EFIS and DDRMI. The magnetic heading is derived from true heading. Magnetic variations are stored inside IRS memory. No flux valves are used any more. The DDRMI Dual Distance Radio Magnetic Indicator shows magnetic heading from ADIRU 1 or ADIRU 3.

Figure 150: Layout



PFD and ND showing the magnetic or depending of aircraft and operation mode the true (directed to geographic north) or magnetic heading. If the ND operates in PLAN- mode, the horizontal situation is directed true north upward.

Figure 151: Glass Cockpit

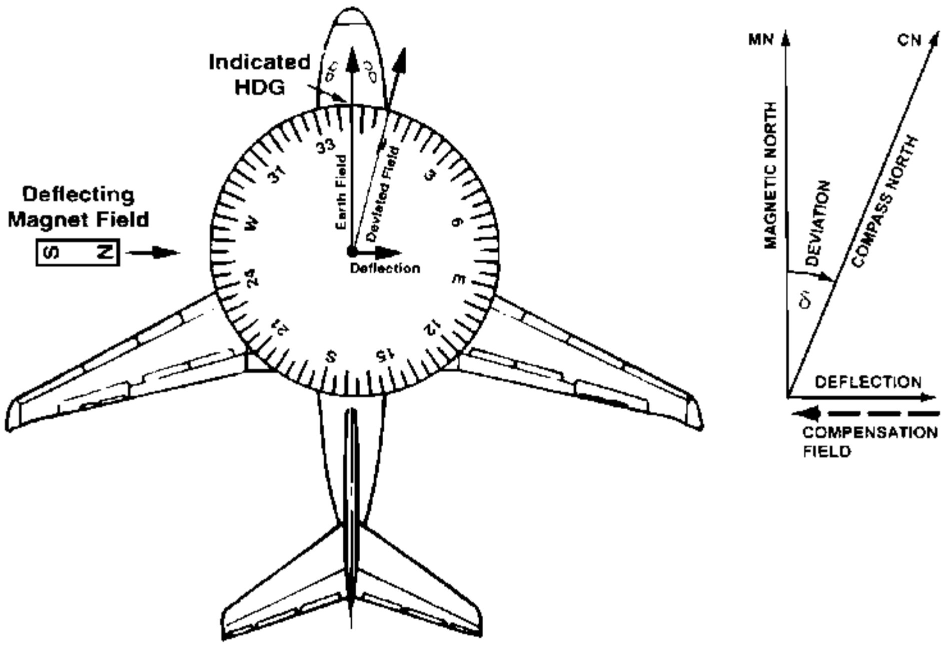


Compass Errors

Deviation and its Compensation

The error inherent in magnetic compasses is called deviation, and it is caused by the magnetic fields in the aircraft interfering with those of the earth. A magnetic field surrounds any wire carrying electricity, and almost all of the steel parts of an aircraft and the engine have some magnetism in them. Magnetos and both alternators and generators have strong magnets in them, and these are all so close to the compass that they influence it.

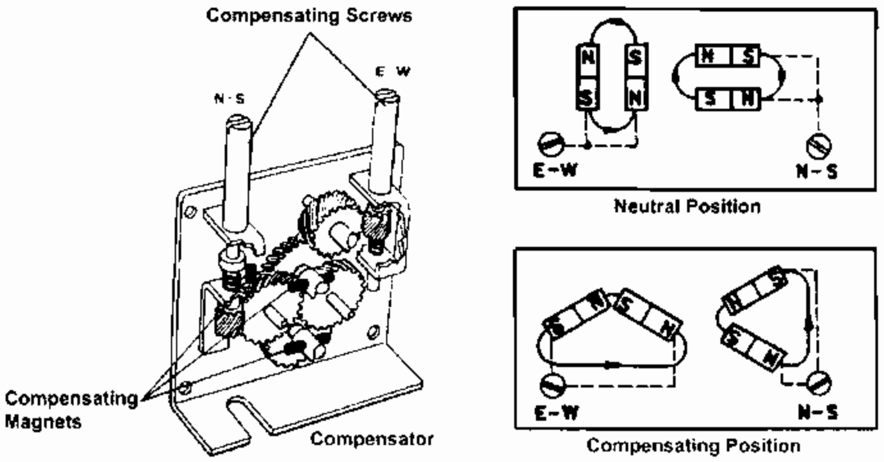
Figure 152:



Error Compensation and Error Chart

Aircraft compasses are equipped with two or more small compensator magnets in the housing. They may be adjusted to cancel the effect of all of the local magnetic fields in the aircraft. Any uncorrected error caused by this local magnetism is called the deviation error, and it is different for each heading we fly, but it does not change with the location of the aircraft. The magnetic compass must be compensated to reduce the errors. After the error has been minimized, a chart is made of the error that remains, and it is slipped into a holder mounted on the compass bracket or on the instrument panel adjacent to the compass so the pilot will be able to apply the correction in flight.

Figure 153: Local Compass Compensator with Magnets

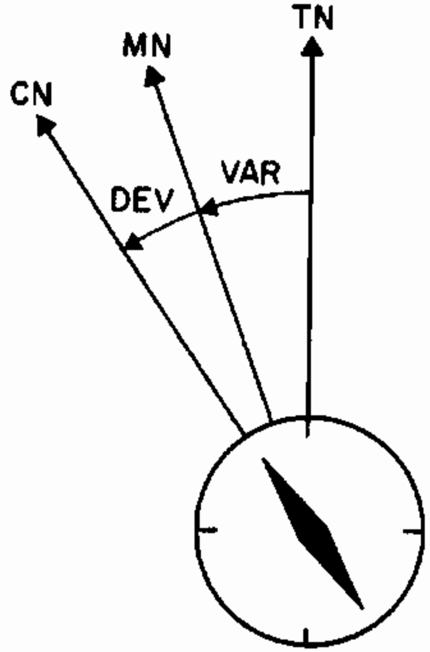


Neutral Position

Compensating Position

Figure 154: Compass Error Chart, Deviation and Variation

FOR	STEER	FOR	STEER
N	357	S	181
30	26	210	211
60	58	240	241
E	89	W	272
120	120	300	302
150	152	330	331



- **Deviation** is the difference between:
  Direction to Magnetic North Pole MN(2000 kKm. away from TN) and
  Indicated compass heading CN
  The deviation can be compensated and/or with an error chart corrected.
- **Variation** is the direction difference between:
  True North TN (Geographic Northpole) and
  Magnetic North Pole MN(2000 km. away from TN)
  The variation depends from aircraft position and is not compensable.

Compass Errors Overview

Index error

Causing:	Misaligned installation of compass or flux valve.
Correction:	Alignment of compass or flux valve. Remote compensators with special adjustment (INDEX)

One cycle error

Causing:	Magnetic fields induced by electric wires or magnetized steel parts.
Correction:	Compensating magnets or calibrated currents thru the flux valve. Remote compensators with special adjustment (N-S/E-W)

Two cycle error

Causing:	Deflection of the earth magnetic field lines by steel parts like screws. Asymmetric impedance of the cable from flux valve to the system.
Correction:	Using of messing screws and non ferro-magnetic materials around. Remote compensators with special adjustment (TRANSMISSION)

Coriolis

Causing:	Rotation of the earth deflecting the compass of a N-S moving aircraft's compass or flux valve.
Correction:	None. This small influence can not be compensated.

Remote compensator

Installed in commercial aircraft makes compensation of compass errors easier.

Figure 155: Index-, One Cycle- and Two Cycle Error

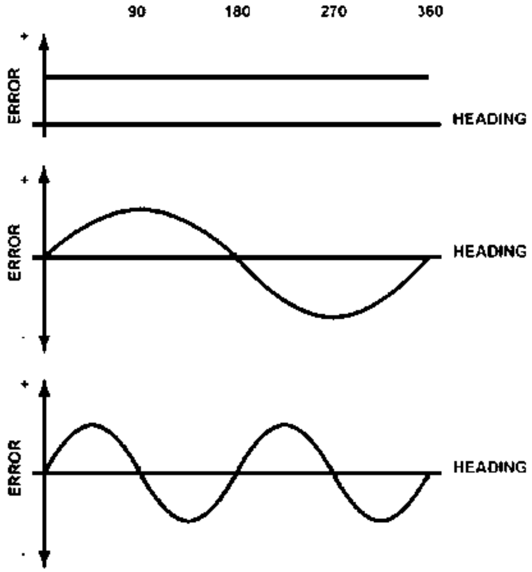
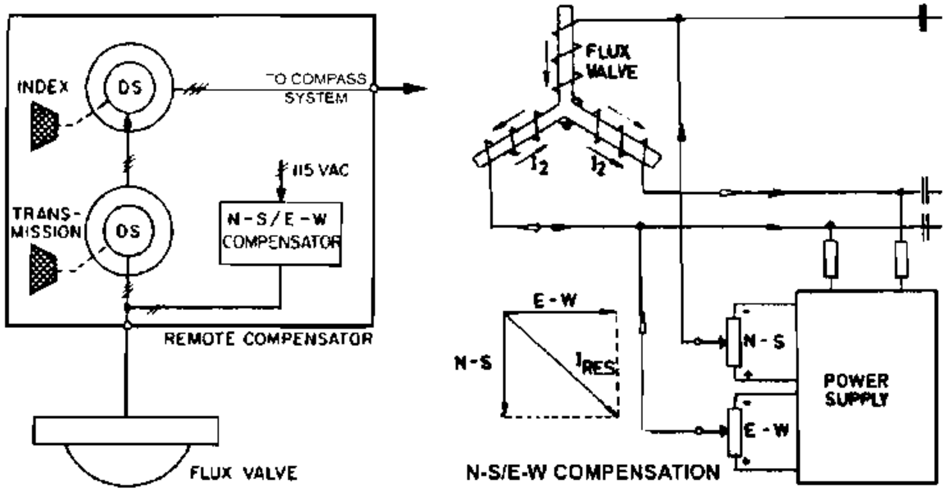


Figure 156: Remote Compensator

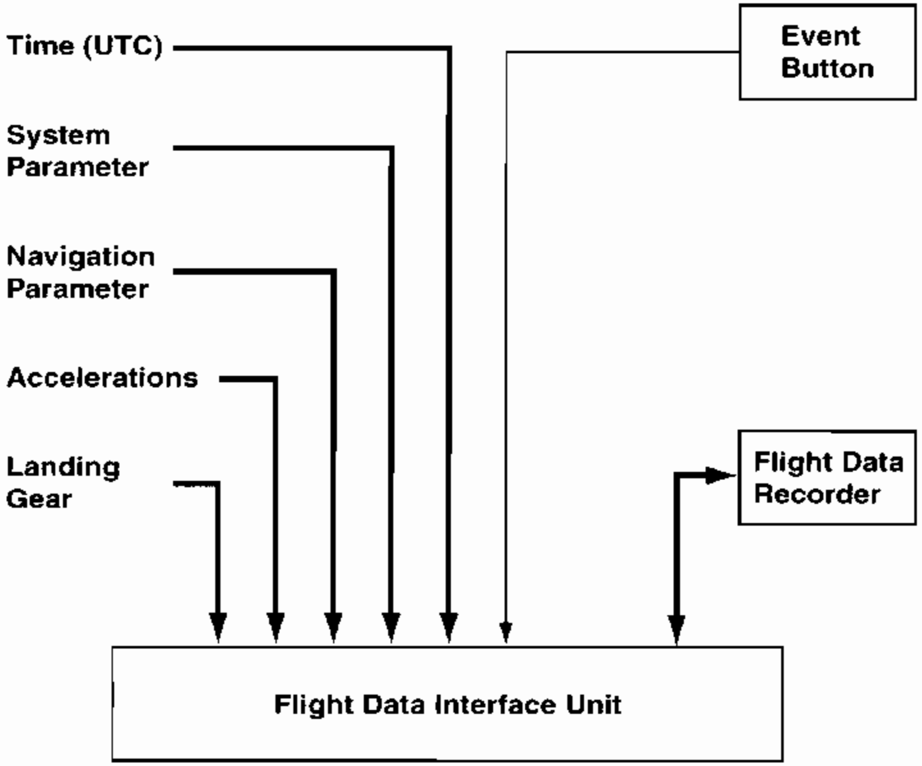


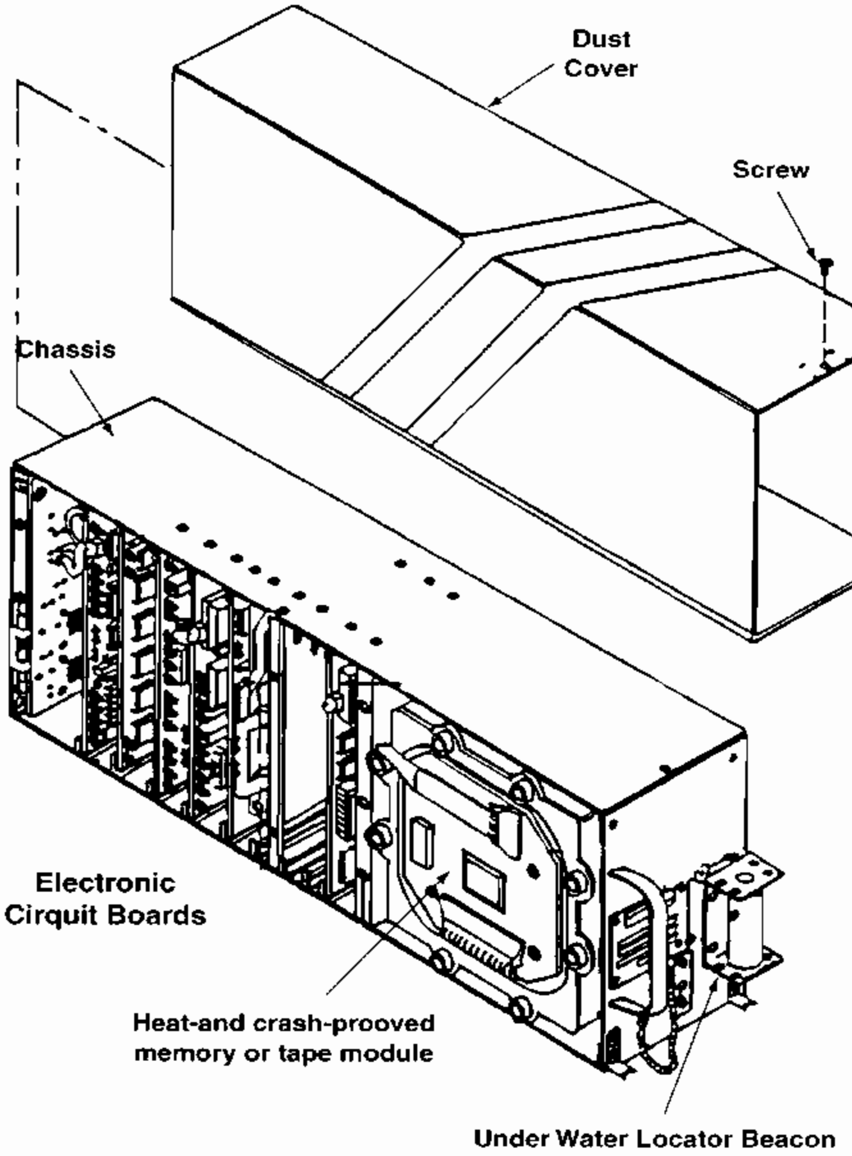
Flight Data Recording

The flight data recorder is crash proof in order to withstand an accident, records the mandatory parameters. Early recorders etched the vertical acceleration, altitude, speed, heading and time in a heat resistant and impact protected metall foil.

Today the digital recorder gets about 50 mandatory parameter via flight data interface unit and the parameter are stored for 25 - 50 hours on a magnetic tape or solid state memory.

The underwater locator beacon will transmit a 37kHz tone if it is immersed in water to locate the recorder after an accident.





Typical Flight Data Recording System

The purpose of the Digital Flight Data Recorder System (DFDRS) is to record various critical flight parameters in a solid state memory to fulfil the mandatory requirements of crash recording.

The DFDRS basically includes a Flight Data Acquisition Unit, a Flight Data Recorder (FDR), a Linear Accelerometer, an Event push button and a control panel to meet the minimum requirements.

The Flight Data Acquisition Unit is a computer which collects various basic Aircraft System parameters and converts them by internal processing.

The flight data recorder is located in the rear part of the aircraft. It stores, in a solid state memory the data of the last 25 hours collected by the FDAU. The memory board is located in a mechanical protected box. The front face of the FDR includes an Underwater Locator Beacon.

The aircraft systems send basic parameters to the Flight Data Acquisition Unit (FDAU) via various system computers. The information about the aircraft is given to the FDAU directly by pin programming.

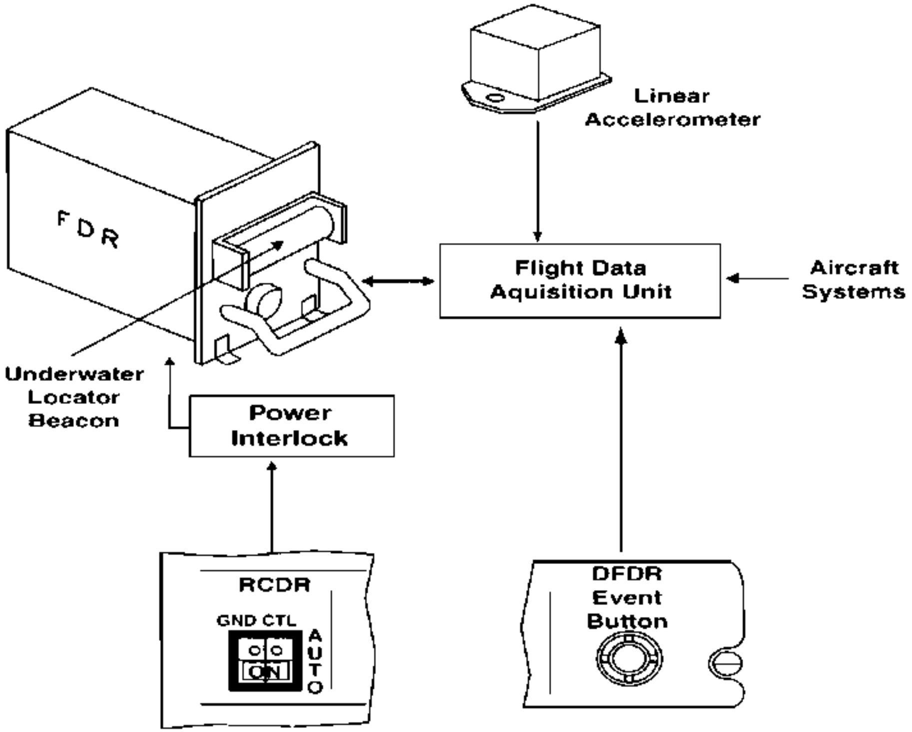
The Linear Accelerometer is installed at the aircraft center of gravity to provide the three axes acceleration data.

When pushed, the EVENT push button is used to record an event mark in the Flight Data Recorder (FDR) memory. The EVENT push button is located on the pedestal.

Power Interlock. The Flight Data Recorder is automatically supplied with power when one engine is started and will stop five minutes after the last engine shutdown.

For test and maintenance purposes on ground as well as for preflight check, it is possible to supply power to the FDR by pressing the ground control push button on the overhead panel.

Figure 157: System



Parameter

The Flight Data Acquisition Unit collects many different mandatory parameters for recording. Today about 300 parameters are recorded. In earlier versions between 6 and 50.

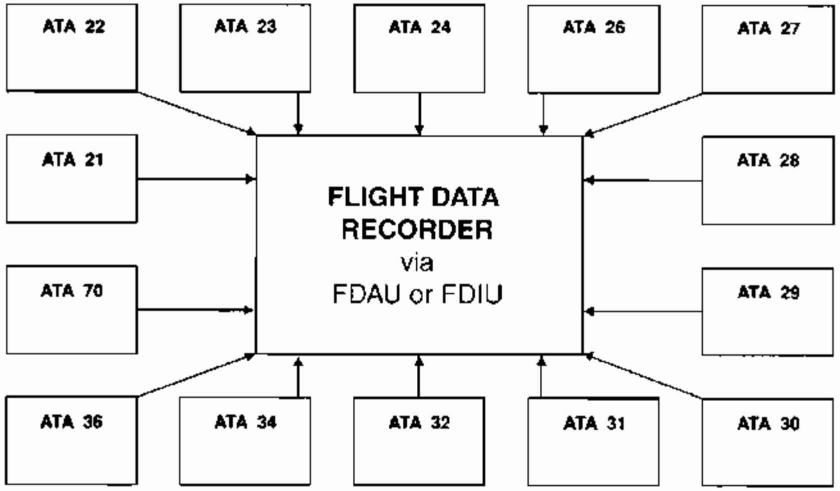
Here some example:

- 21: Temperatures, Pressures, Airflows
- 22: Engagement and Operational Modes
- 23: HF VHF Transmission Activities (PTT)
- 24: Power Distribution Configuration, Switching
- 26: Fire and Smoke Warnings
- 27: Various Flight Controls
- 28: Configuration, Quantities
- 29: Pressure, Quantity, Temperatures
- 30: Configuration, Pressure, Temperatures
- 31: Warnings, Time
- 32: Configuration, Brake
- 34: Airdata, Position, Heading, ILS, Warnings
- 36: Configuration, Pressure, Temperature
- 70: EGT, EPR, N1, N2, Oil Temp, Thrust

The parameter input is in following format:

- analog
- digital
- discrete

Figure 158: Data Source



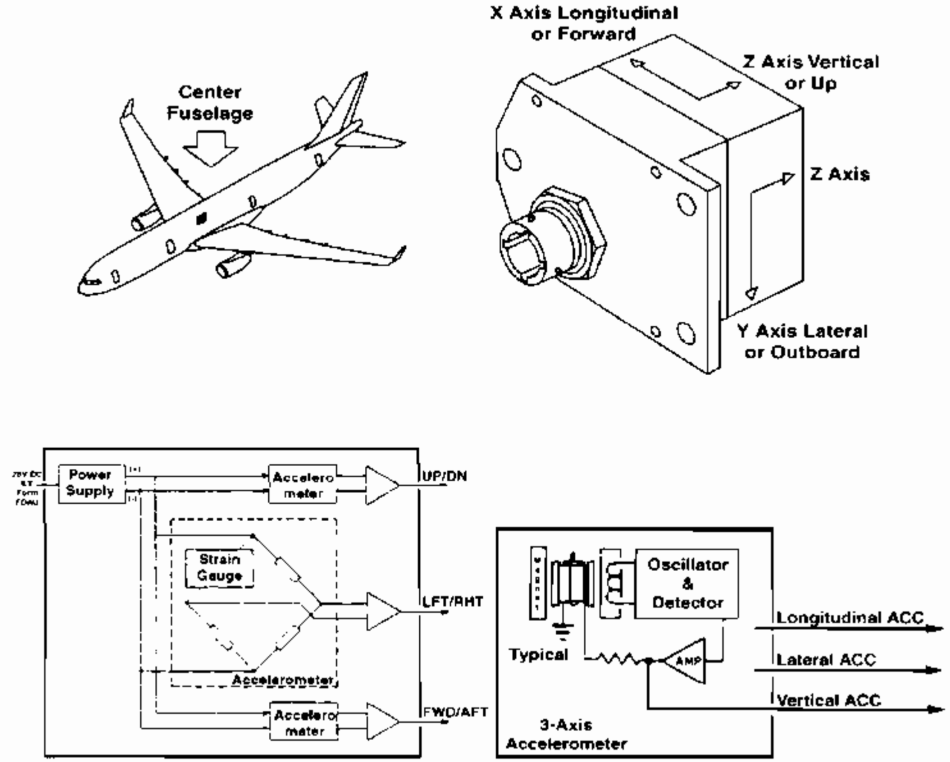
Three Axis Accelerometer

The three axes accelerometer detects acceleration along the longitudinal, the lateral and the vertical axes. The unit is at the center of gravity of the aircraft.

The unit has for each axes a sensor. The sensor has a bar, which bends, when there is an acceleration. The resistance value of the strain gauge changes when the bar bends. The strain gauge is a part of a resistance bridge and results in a change in the output voltage.

Or the acceleration force moves a pendulum in the sensing mechanism. The detector forces the sensing-mass always to center position. The current from the amplifier is proportional with the acceleration.

Figure 159:



Underwater Locator Beacon

You find the underwater locator beacon on the front panel of the flight data recorder. The beacon has a high impact case which contains: - a mercury battery - a water sensitive switch - an electronic timer module - a piezo - electric transducer.

After water entry it transmits every second a 37,5 kHz pulse. The range of the beacon is 2 miles in any direction and the system operates for about 30 days. At one side of the beacon is an end cap with the name BATTERY ACCES, the other end cap contains the water switch. Keep the switch end of the beacon clean and replace the battery when the label "REPLACE BATTERY BY·" tells you to do so.

Figure 160:

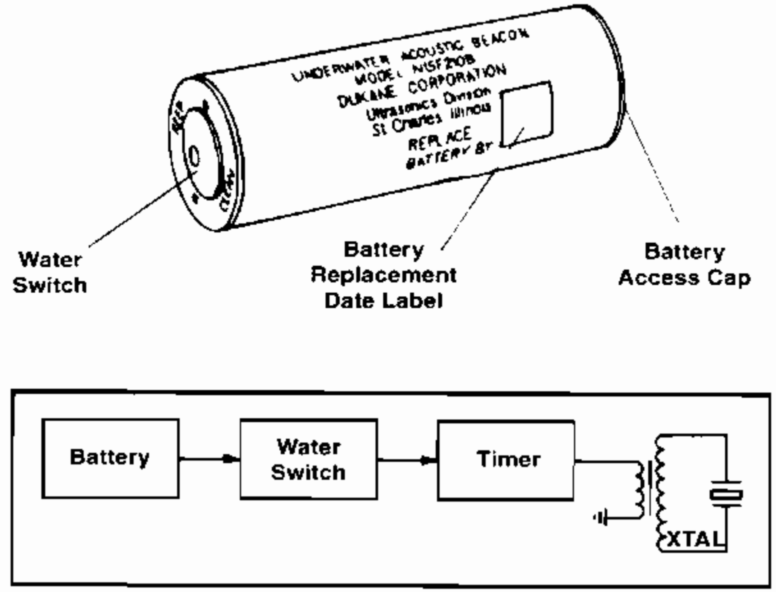
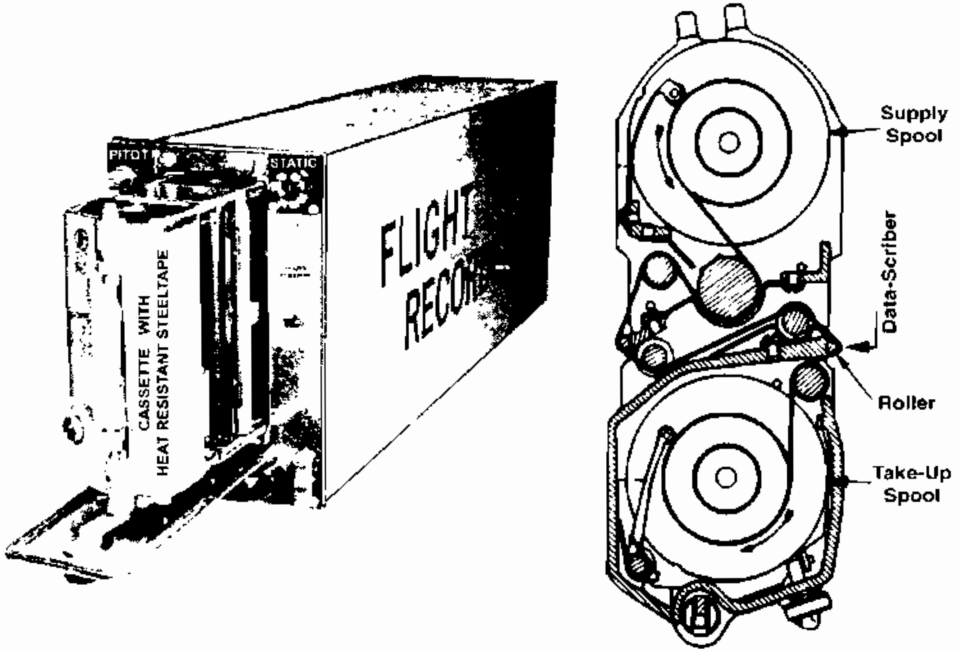


Figure 161: Flight Data Recorder and Tape Cassette (mechanical)



Flight data recorders are developed since world war II. In the 1960ties the recorder scratched the most parameters with diamond needles in to a heat resistant metal foil. The metal foil has to be replaced when it was filled up with data.

For accident research, it was a time consuming work to find all missing tape fragments and reading out the cause.

Figure 162: Functional Principle of ancient Flight Data Recorder

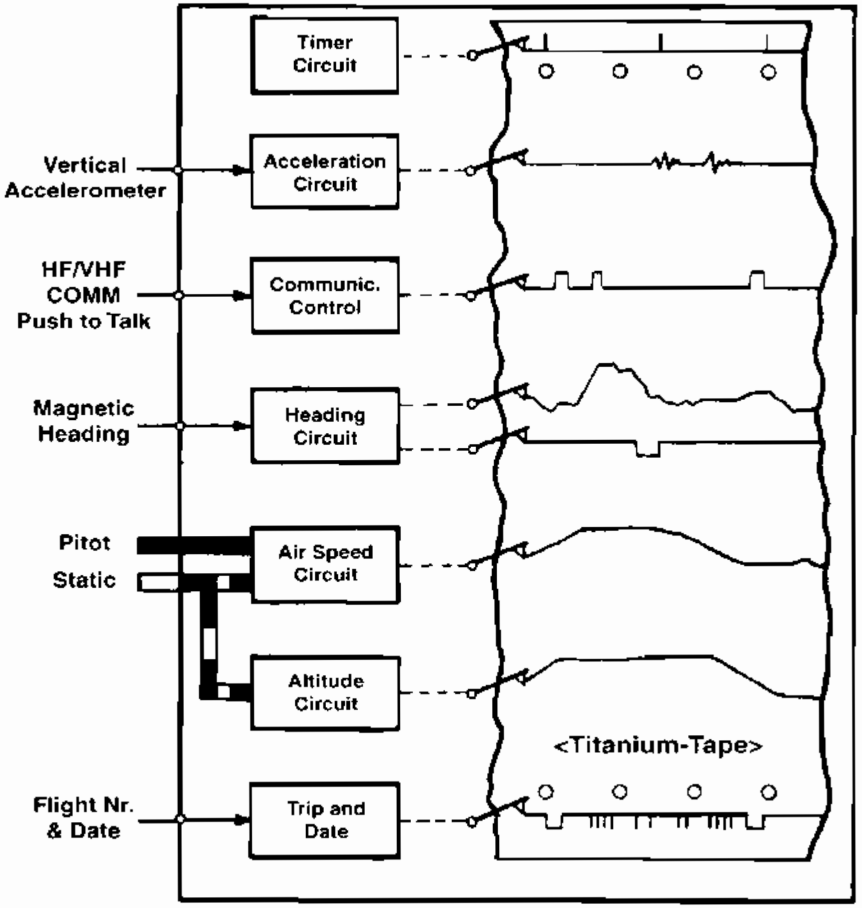
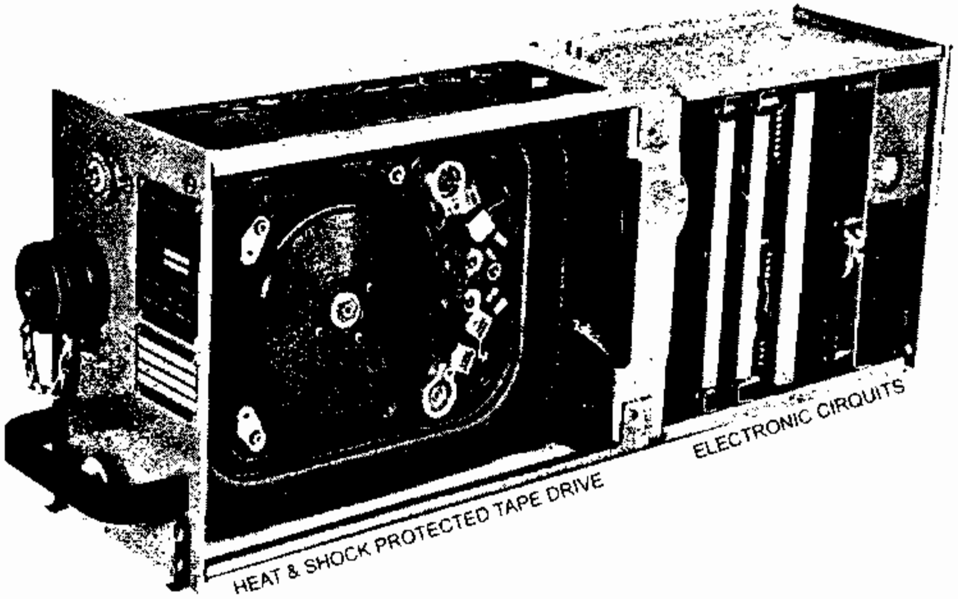
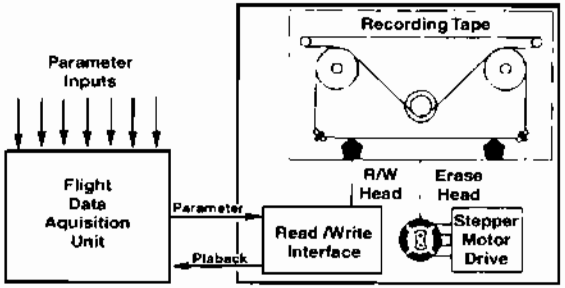


Figure 163: Digital Flight Data Recorder DFDR (with Tape)





Recording Capacity: 25 Hour

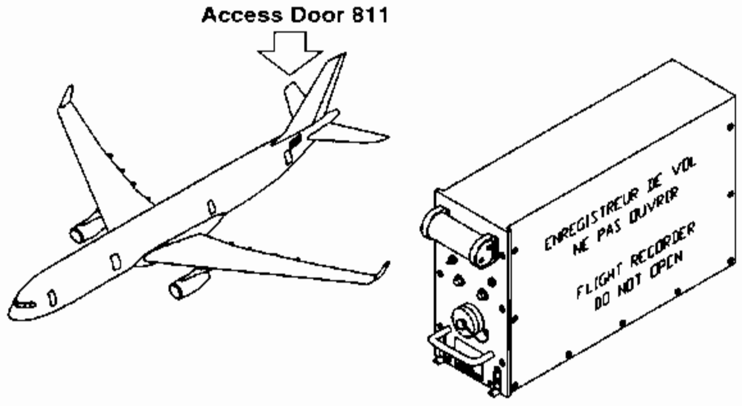
Heat resistant: 1100°C for 30 minutes

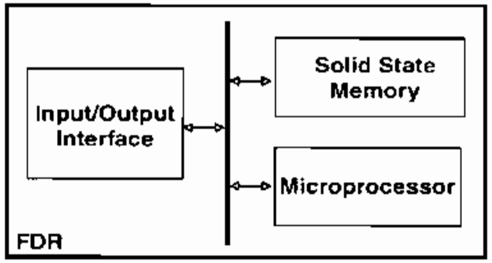
Shock resistance: Tape: 100 G Solid State: 3400 G for 6 ms

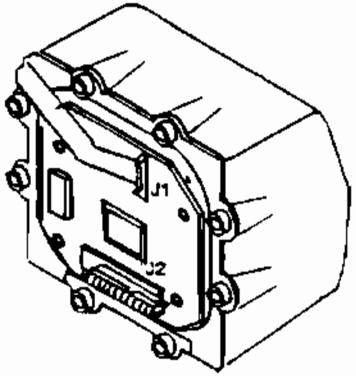
Saltwater proof: 6000 meter for 1 month

Mean Time Between Failure MTBF: Tape 7000 hrs. Solid State 15'000 hrs.

Figure 164: Solid State Digital Flight Data Recorder SSDFDR





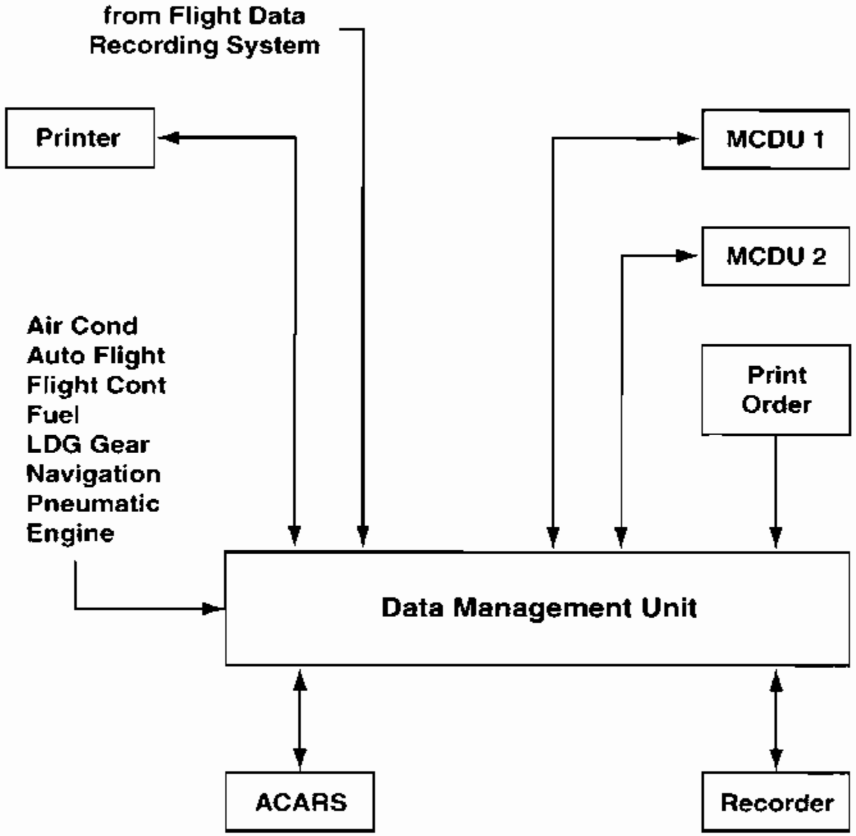


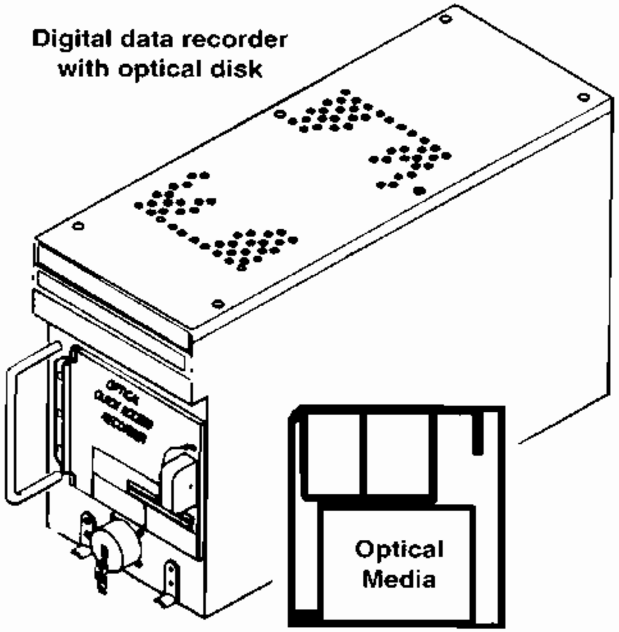
ADAS - AIDS - ACMS

The AIDS Aircraft Integrated Data System
or ADAS Aircraft Data Acquisition System
or ACMS Aircraft Condition and Monitoring System

accepting a large amount of engine and aircraft system data for the analysis for trouble shooting, system engineering, procedure evaluation and flight crew sections by ground computer.

The data are stored on magnetic tapes or optical disks. A printer prints the aircraft data. On request data may be transmitted to the homebase via ACARS. The MCDU 's are used to operate the system and for data reading.





13.9 Lights (ATA 33)

Introduction

Lighting systems illuminate everything from cargo compartments to the pilots instrument panel. Exterior lights are required to ensure safe operations during night flights. Emergency lights are important for escaping from the airplane in a dangerous situation. The aircraft technician must become familiar with aircraft lighting circuits in order to service these systems properly.

Maintenance and Inspection of Lighting Systems

Most lighting circuits are relatively low maintenance items. Periodic inspections of the wire for chaffing and hardware security, corrosion of components, and general condition of the circuit should be performed during routine inspections.

- Lamp replacement is generally the most needed repair for lighting systems, and one must always be carefully to install the correct bulb. Several variations of a given lamp may fit the same socket. Be sure to install a bulb with the correct voltage and power requirements.
- Before discarding expensive sealed light beams, verify their functionality with Ohmmeter. Corroded contacts may be the cause.
- When dealing with any high-intensity flashing lamp or strobe system, be careful to avoid electrical shock. The system operates on a high voltage and requires a few minutes to discharge itself if the lamp is defective. Always allow a strobe system to stay in the OFF position for approximately five minutes prior to maintenance.
- Halogen and strobe light bulbs are sensitive to the oil or grease which may come from touching the glass portion of the bulb. If ordinary body-grease is left on the glass, it may cause the glass to concentrate heat in that area during operation and crack the glass. Be sure to avoid touching a strobe bulb without the proper protection.

Exterior Lights

There are a variety of exterior lighting systems. These include position, landing, taxi, anti-collision and wing inspection lights.

The exterior lighting system fulfils various functions:

- illuminating the runway and taxiway
- illuminating the wing leading edges and engine air intakes
- indicating the aircraft position and direction
- reducing collision risk in flight and on ground.

Overview Exterior Lights

- White flashing strobe lights are installed in each wing tip leading edge and one in the tailcone, facing rearward. When anticollision strobe lights and anticollision beacon lights flash, a timing system controls them in order to flash alternately in a synchronized fashion.
- Red flashing anticollision beacon lights are installed: one on the lower and one on the upper fuselage at the aircraft center line.
- Runway turn off lights illuminate the lateral areas of the runway. They are installed on the nose landing gear.
- A fixed landing light is installed on each wing.
- Take- off and taxi lights are installed on the nose landing gear in a fixed position. All lights go off automatically when the landing gear is retracted.
- Wing and engine scan lights are installed on each side of the fuselage to enable the flight crew to visually detect ice on engine air intakes and leading edges.
- Navigation lights give an external visual indication of the position of the aircraft and its direction of flight.
- Logo Lights are installed on the horizontal stabilizer to illuminate the company logo.

A fixed Take Off Light and a Retractable Landing Light is shown on following page.

Figure 1: Exterior Lights of a commercial Aircraft

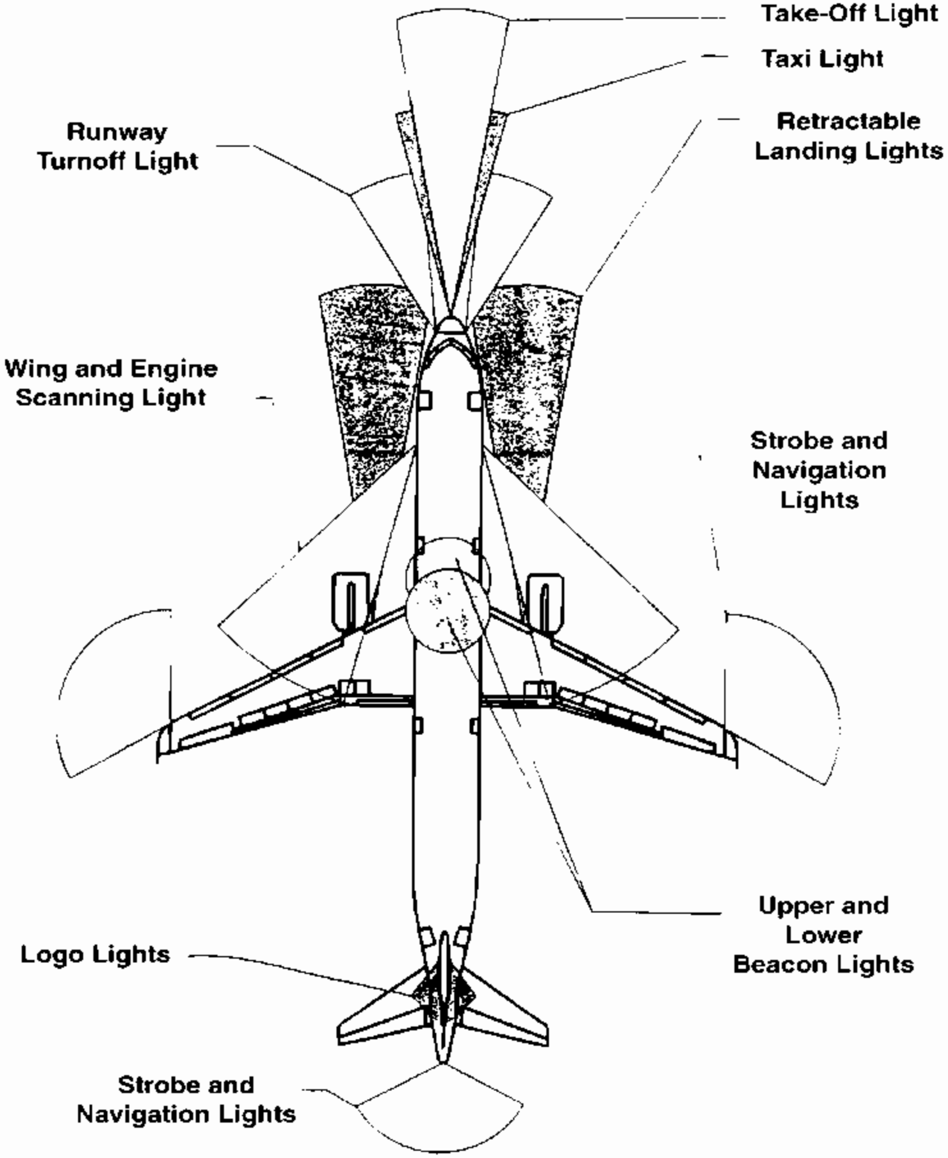


Figure 2: Fixed Lights installed at Nose Landing Gear

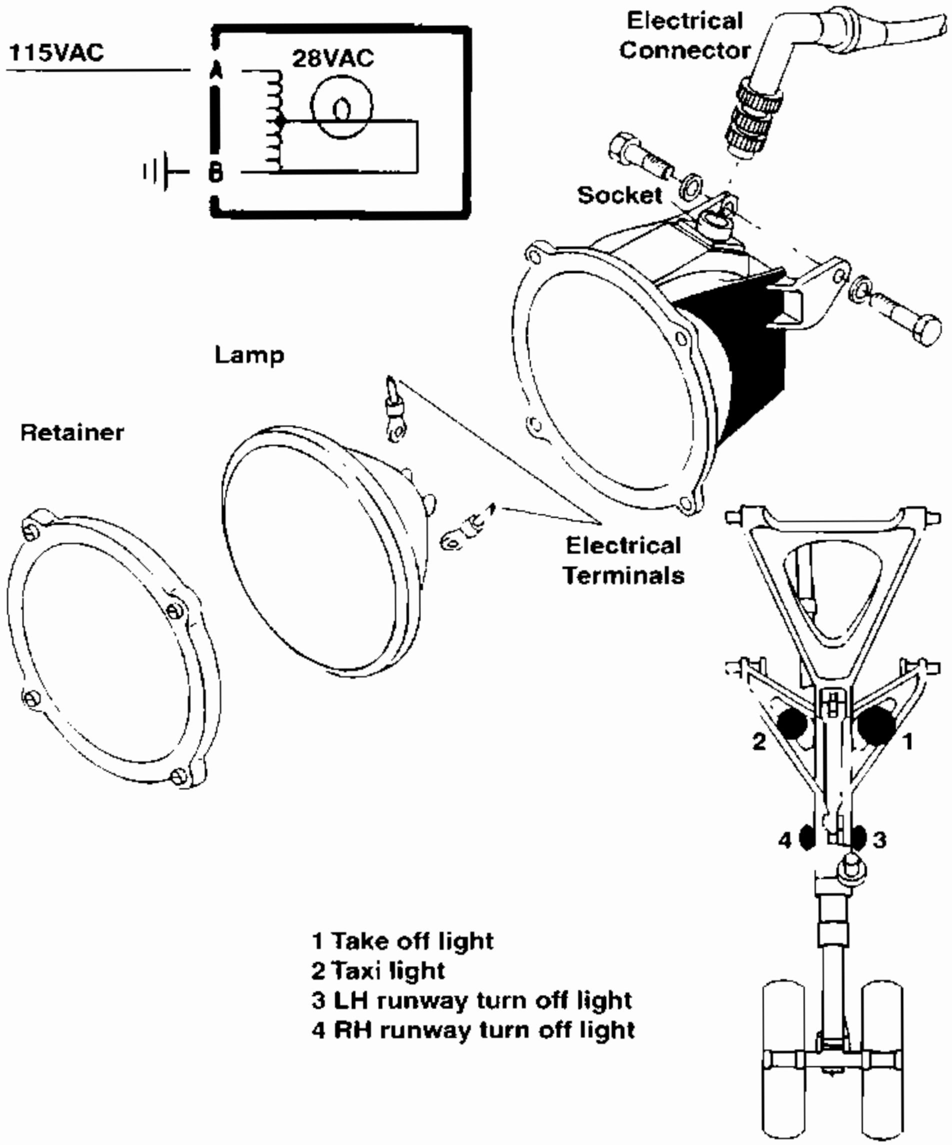
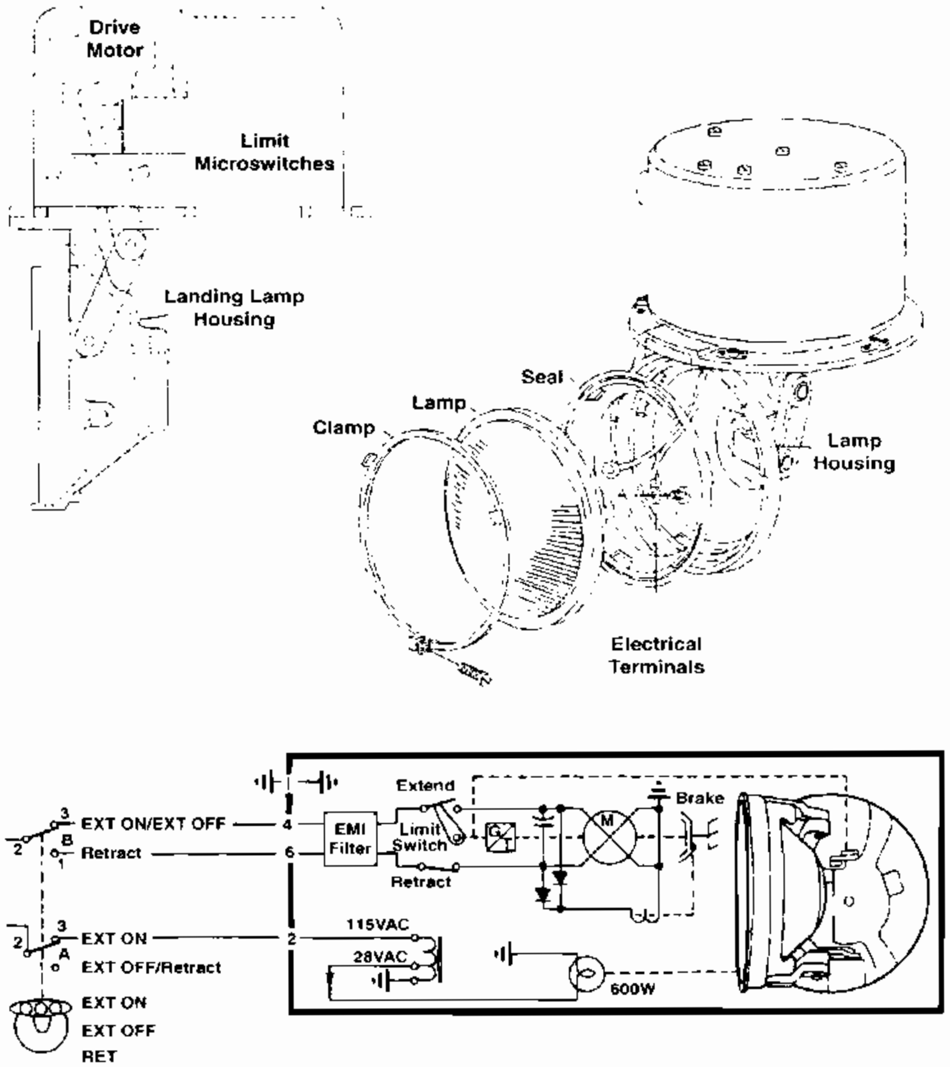


Figure 3: Retractable Landing Light



Position Lights

Position lights are used to indicate the position of an aircraft during night operations. If pilots can identify the position of another aircraft from its position lights, they may safely navigate around that aircraft, hence position lights are often referred to as navigation lights. One or more position lights must be located on each wing tip and the tail of the aircraft. The right wing tip must have a green coloured light, the left a red light and the tail must have a white light. These lights are required on any aircraft certified for night flight.

In commercial aircrafts a dual system gives the possibility to select the second system if one bulb has failed. Bulb replacement can be done at convenient time.

Figure 4: Position Lights

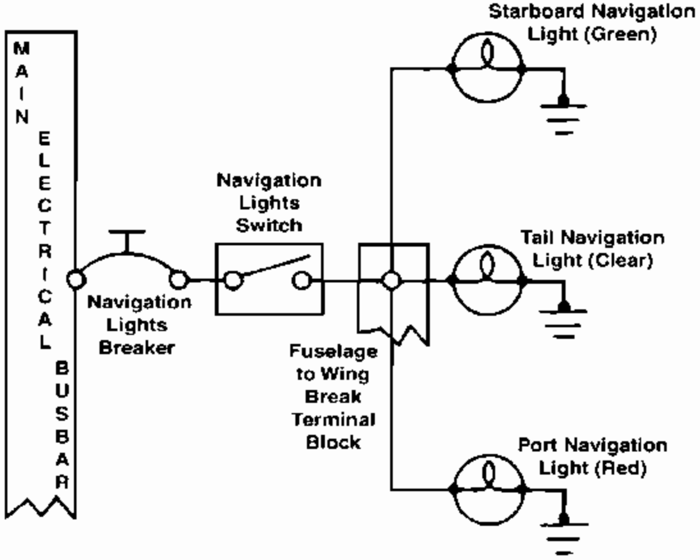
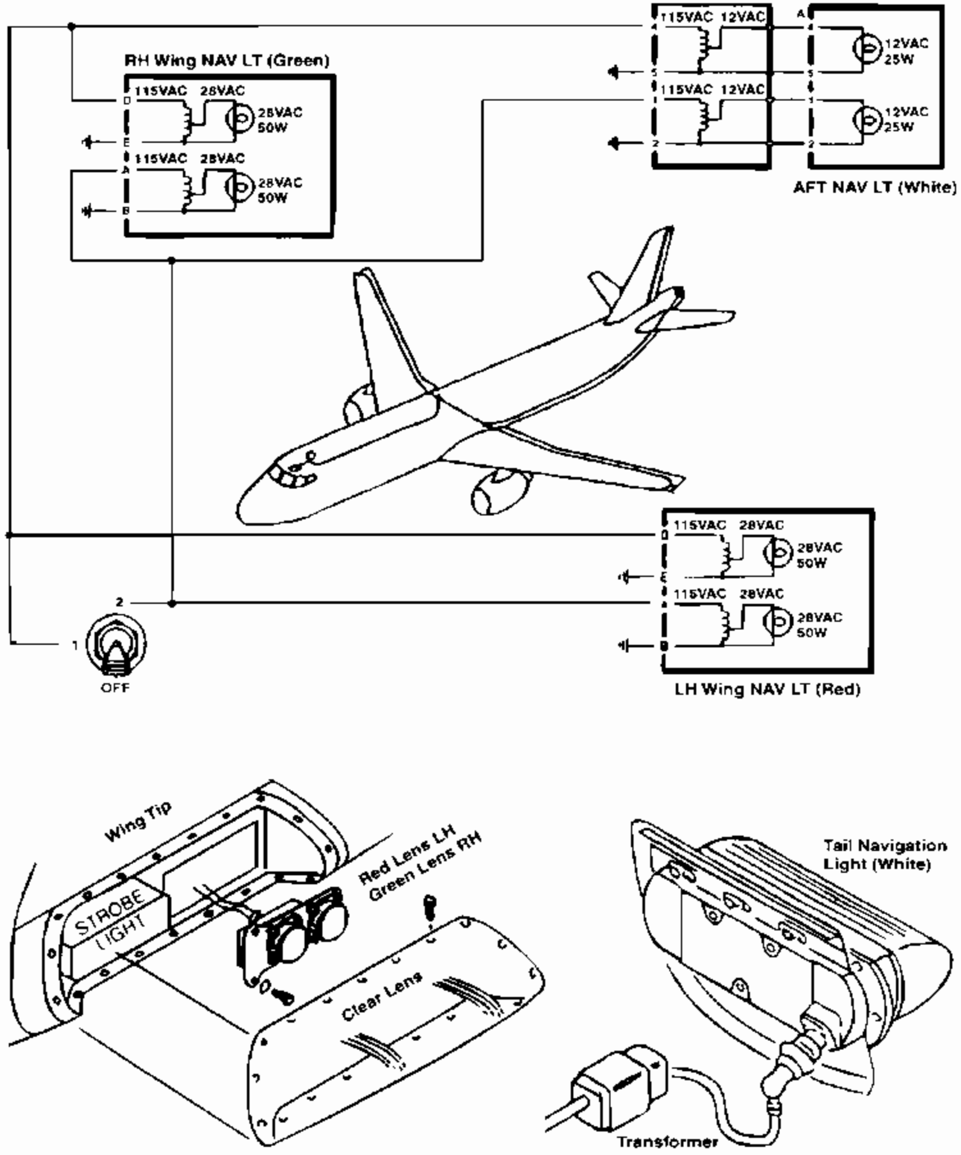


Figure 5: Position Lights Dual System



Anti-Collision Light

Anti-collision light are found in two basic styles. Older aircraft were originally equipped with rotating beacons either on top of the vertical stabilizer or on top or bottom of the fuselage. Newer systems utilize solid state electronics to create a flashing- or strobe-type light. The rotating beacon system typically contained a stationary light bulb and a rotating reflector covered by a red glass lens.

Figure 6: Rotating Beacon Light

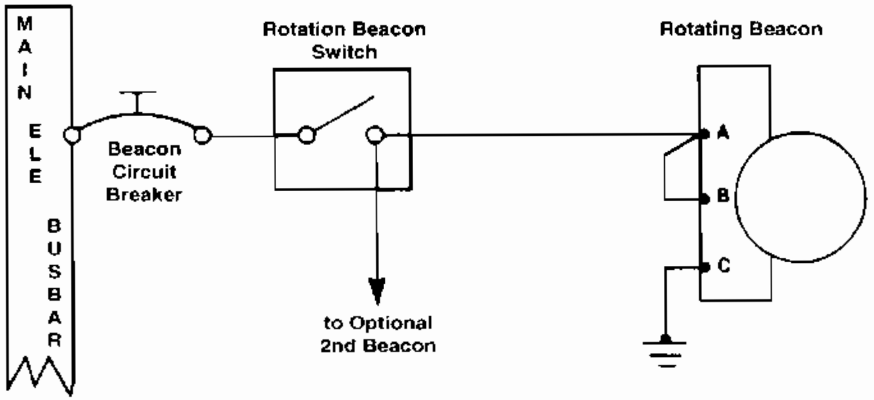
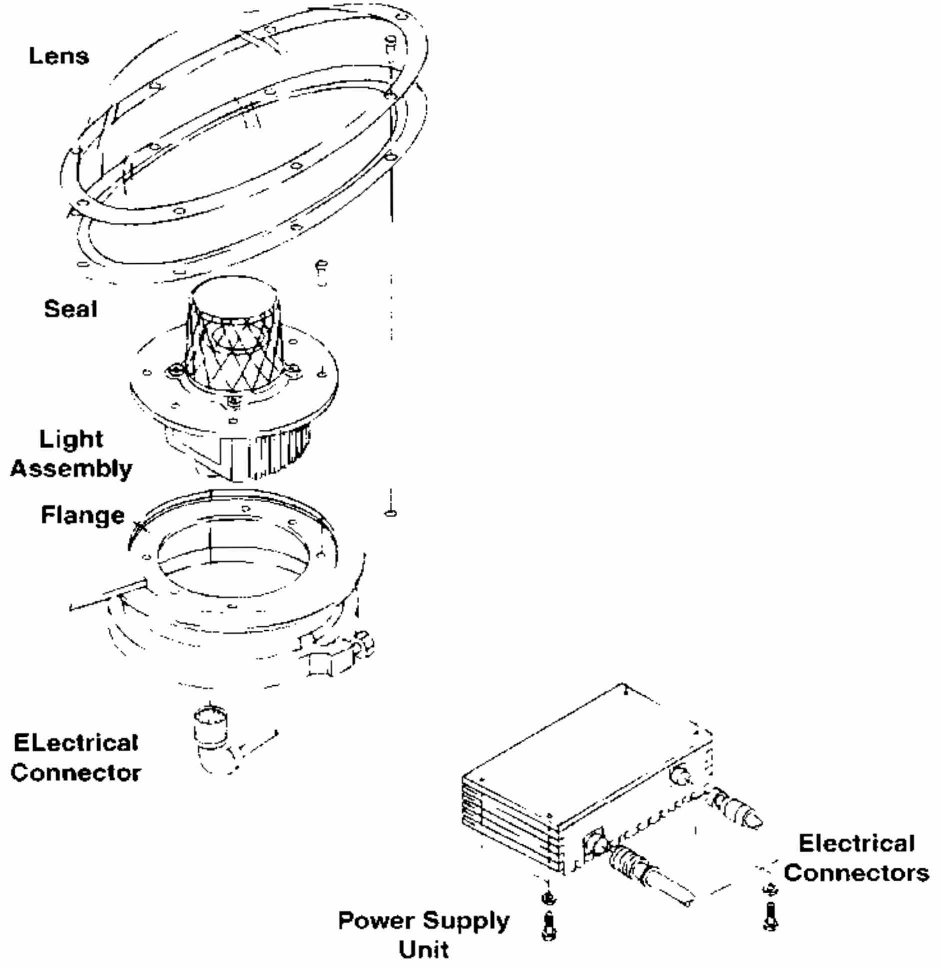


Figure 7: Flashing Beacon Light



Strobe Light

The strobe light has an extremely bright flash produced by a Xenon tube which requires approximately 400 Volts. The high voltage is produced by the strobe power supply which uses a capacitor charging system to achieve this high voltage.

Modern aircraft are required to have 3 white strobe lights. One on each wing and one at the tail. Coordinated flashing of the strobe lights and the anticollision lights is controlled by a synchronisation connection between the power supply units.

- Be careful, the voltage to the xenon flash tube assy is dangerous.

Figure 8: Flashing Strobe Light

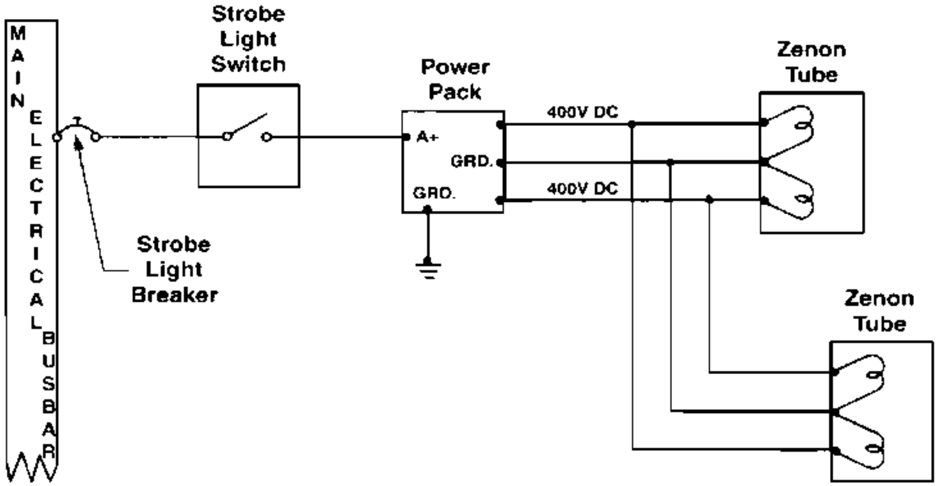
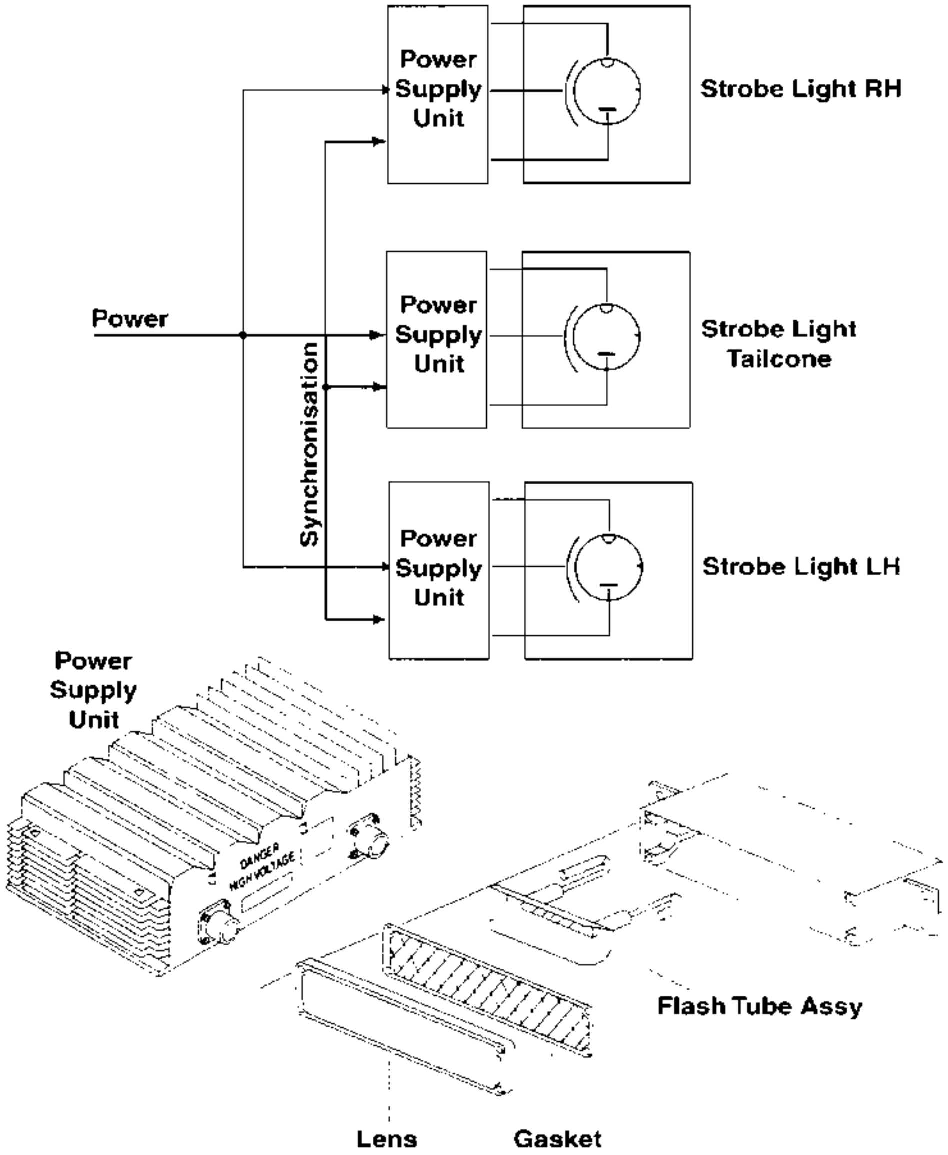


Figure 9: Strobe Light System



Interior Lights

There are a variety of interior lights found on modern aircraft, including instrument lights, overhead lights, step lights and reading lights to mention a few. In general, these lights can be divided into two basic categories: incandescent and fluorescent lights.

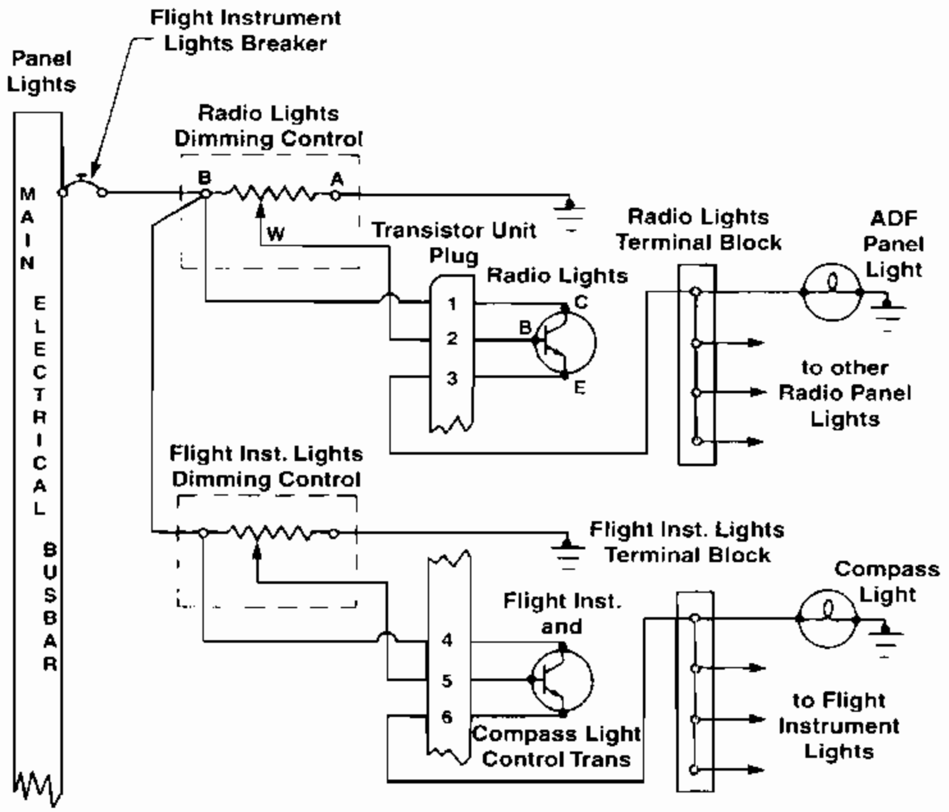
Incandescent Lights

Incandescent lights use a small coil of wire, called a filament, which glows in a white light when current flows through it. Lights can operate in a bright or dimmed position. Incandescent lamps are often dimmed using a solid-state circuit to control the current to the lamps. A potentiometer is used to control the input signal to the transistor, thus controlling the current to the light.

Electro Luminescent Light

Another type of interior lighting system has recently been introduced to aircraft instrument panels, signs and emergency exit or escape path markings. The Electro Luminescent (EL) panel contains a fluorescent paste sandwiched between two layers of plastic. The paste glows when an AC voltage is applied to the panel. The light glows through the unpainted areas of the plastic, typically displaying the needed letters and/or numbers. Electro-Luminescent panels operate only with alternating current, most light aircraft with EL Systems use a static inverter specifically designed for the Panel. (See Emergency Lights)

Figure 10: Dimmer Circuit



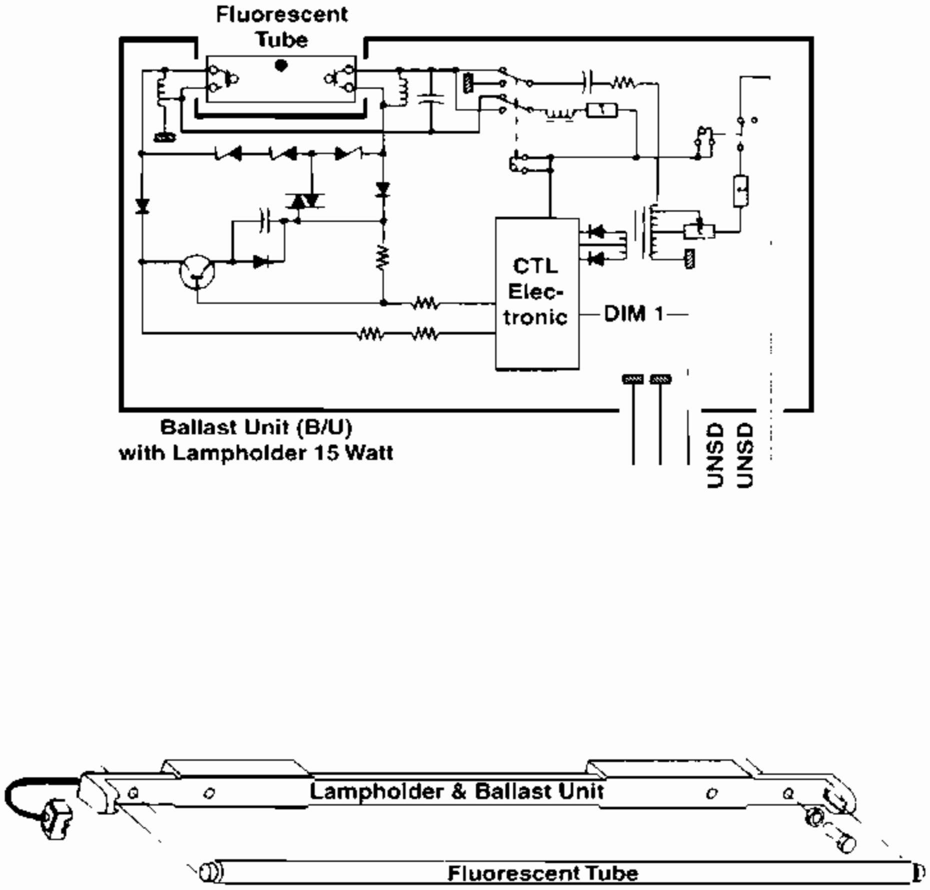
Fluorescent Lights

Fluorescent lights are made of a gas-filled glass tube which glows when a high AC voltage is applied to heated electrodes at each end. The electrodes emits electrons. This free electrons strike atoms of mercury vapour in the tube and this produces an ultraviolet light. The invisible ultraviolet light strikes the phosphorous coating on the inside of the tube and it glows in a white light. The conversion of one kind of light to another is known as fluorescence.

Fluorescent lamps are much more efficient than incandescent lamps, however they require the use of ballast-transformers and AC voltage. Therefore, fluorescent lamps are found only on large commercial aircraft.

Fluorescent lamps can operate in a bright or dimmed position. The fluorescent tube is in the dim position when a reduced voltage is applied to the ballast-transformer. In the bright position, the nominal voltage is applied to the fluorescent tube. Today's electronic-ballast's are weight-saving, starting the fluorescent-tube faster, their tube is no more flickering during start and operation.

Figure 11: Fluorescent Armature



Cockpit Lighting

The cockpit lighting system enables the crew to easily see all equipment details, inscriptions and indications, whatever the level of darkness. It is especially used at night.

The cockpit lighting system comprises:

- Dome lights and lighting strips
- Map holder lighting
- Console and floor lighting
- Center instrument and standby compass lighting
- Reading lights and center pedestal lighting
- Outlet plugs and coat stowage lighting.

Dome Lights

Dome lights providing a shadow less general cockpit lighting.

Map Holder Lighting

Map holder lighting is provided at the Captain and First Officer stations.

Console and Floor Lighting

Briefcase stowage, side console and floor lighting is provided at the Captain and First Officer stations.

Center Instrument and Standby Compass

The center instrument panel is illuminated by a set of lights located below the glareshield. The standby compass is provided with integral lighting.

Reading Lights and Pedestal

Individual reading lights are provided at the Captain and First Officer stations. Located in the middle of the overhead panel, a flood light provides illumination of the center pedestal.

Instrument and Panel Integral Lighting

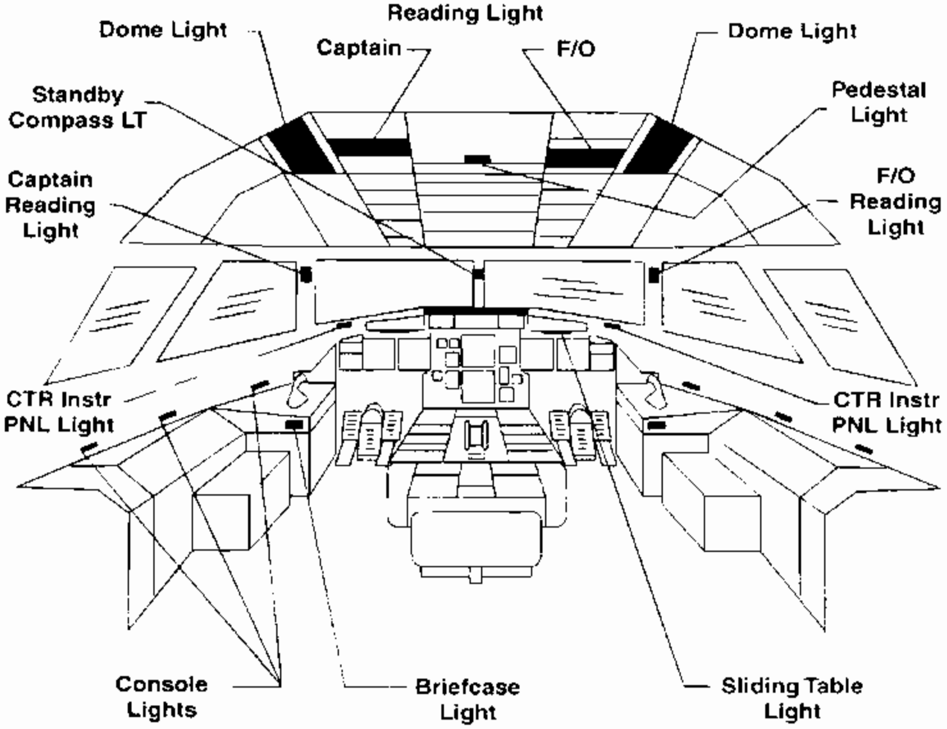
All the instruments installed in the cockpit other than the cathode ray tubes are integrally lit. The lights, illuminating the instruments, are equipped with a dimming control. The instrument and panel integral lighting is achieved in different ways.

- by the miniature lights
- by the Light Emitting Diodes (LEDs)
- by Electro Luminscence (EL)

Annunciator Light Test and Dimming

The integrity of all annunciator lights can be tested and their intensity can be dimmed.

Figure 12: Cockpit Illumination



Emergency Lighting

In passenger airplanes there are emergency lights installed to provide illumination of the cockpit and cabin. The power therefore is provided from separate batteries.

All exits are marked with special signs, guiding the passengers to the doors if dense smoke in the cabin exists.

Exterior lights at over wing emergency doors and other doors illuminating the outside area

Cabin

The emergency lighting system illuminates the cabin in the event of a failure of the general lighting system. The emergency lights are installed in the main and cross aisle ceiling panels.

Exits

The emergency lighting system illuminates the exit location signs and exit marking signs at each cabin door.

Floor Proximity Escape Path Marking

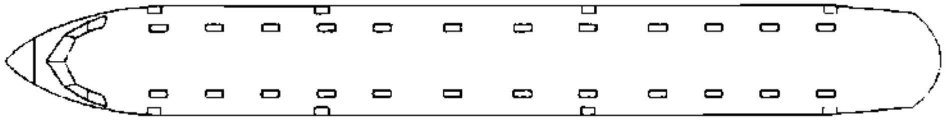
The floor proximity emergency lighting system is an additional system to show the passengers where the emergency exits are, in case there is smoke in the passenger compartment and the emergency lights are not visible.

Electroluminescence strips with blocks and arrows pointing towards the emergency exits are installed on the floor. Electroluminescence EXIT sign panels are on the wall just above the floor near each emergency exit.

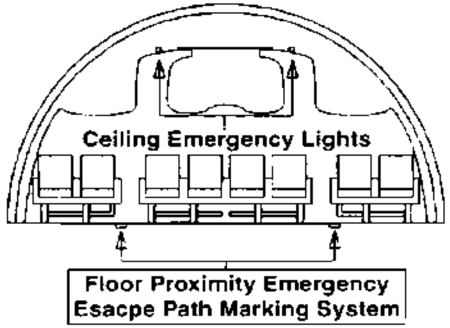
Battery power supply units which are also used for the emergency lights, supply the floor proximity emergency lighting system.

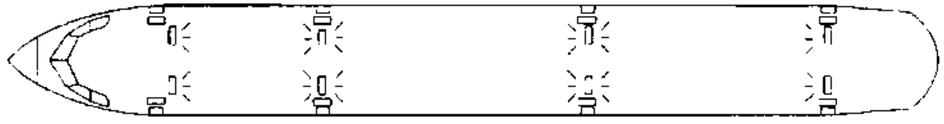
Static inverters supply 115 V 400 Hz to the system. The inverters are installed below the floor panels. The color of the floor proximity emergency lighting or EXIT signs can be changed by using different filters to mate with the color of the carpet or side panels.

Figure 13: Arrangement of Cabin Emergency Lights

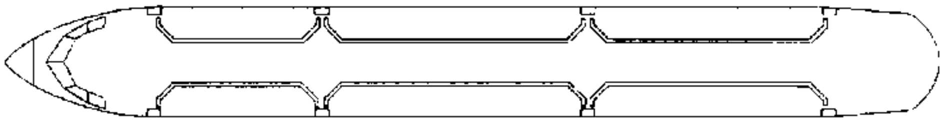


Cabin Emergency Lighting





Exit Marking



Escape Path Marking

Electro Luminescence EL

Electroluminescent strip lighting eliminates the need for bulbs, sockets, diffusers and reflectors. Without filaments to break, the lighting can withstand extreme shock, vibration and high or low temperatures without failure. Numerous tests and operating experience prove that the EL system will continue operating under very high G forces, and after considerable structural damage. Electro Luminescence as an area light source is more easily seen through smoke than are incandescent or other point sources of light at considerably higher brightness.

Figure 14: Escape Path Marking System

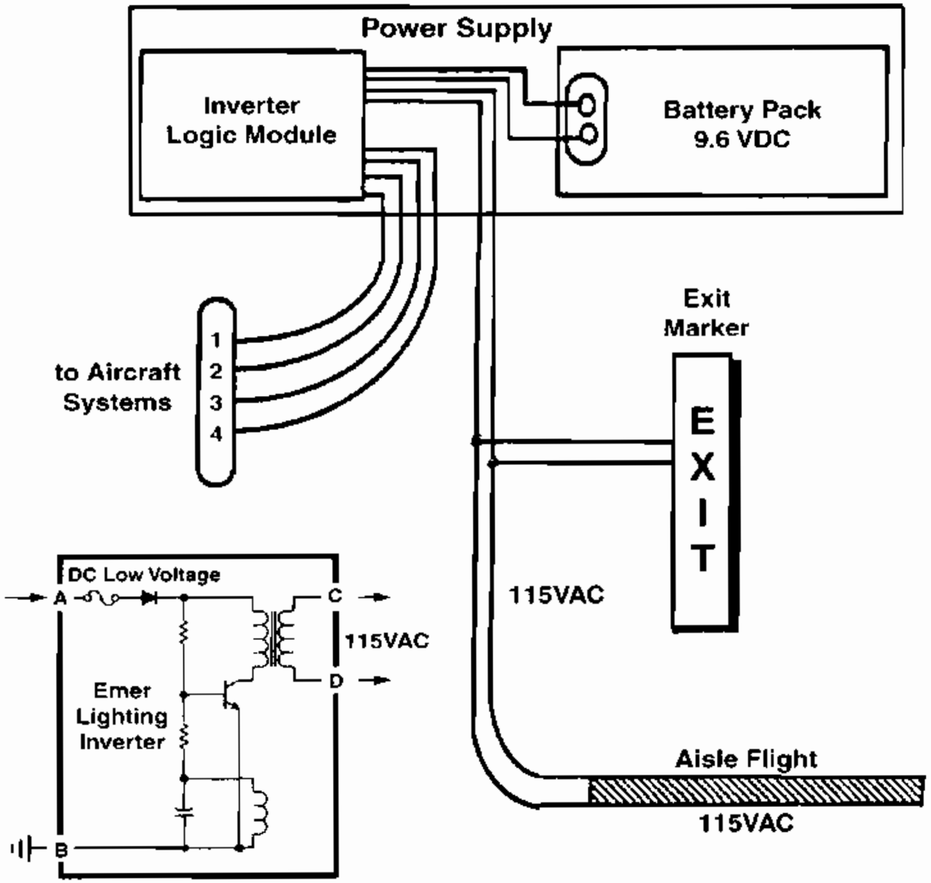
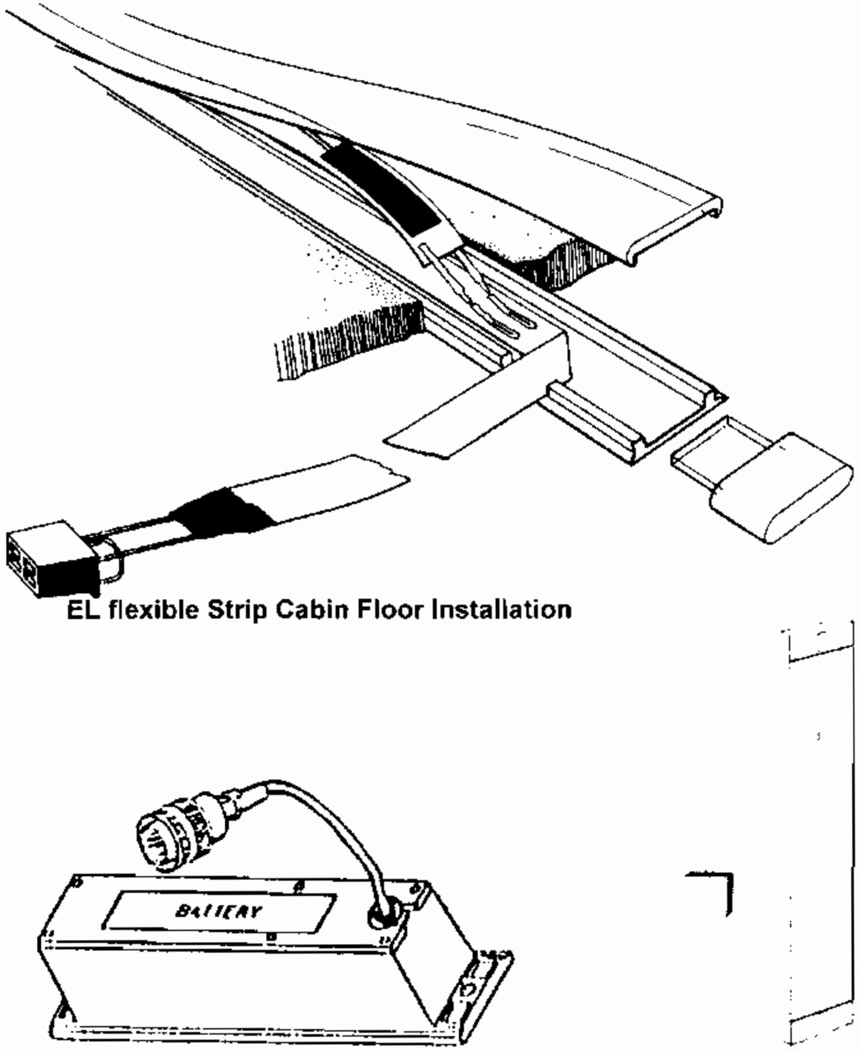


Figure 15: Escape Path Marking Components



EL flexible Strip Cabin Floor Installation

Battery Pack with Inverter

EL-Exit Sign

13.10 On Board Maintenance Systems (ATA 45)

Central Maintenance System

Introduction

Acquisition

The acquisition of aircraft system data is performed by 4 major electronic systems:

- the Electronic Centralized Aircraft Monitoring (ECAM) system which monitors the operational data in order to display warnings and system information,
- the Flight Data Recording System (FDRS) which is mandatory and records aircraft operational parameters for incident investigation purpose,
- the Central Maintenance System (CMS) which monitors the BITE data in order to record the system failures,
- the Aircraft Condition Monitoring System (ACMS) which records significant operational parameters in order to monitor the engines, the aircraft performance and to analyse specific aircraft problems.

Consolidation

In normal operation, the ECAM permanently displays normal aircraft parameters and the ACMS and FDRS permanently record aircraft system parameters.

When an anomaly is detected by an aircraft system, the ECAM displays the abnormal parameter or function and its associated warning and the CMS records the failure information detected by the system BITE.

Retrieval

All the information can be retrieved through:

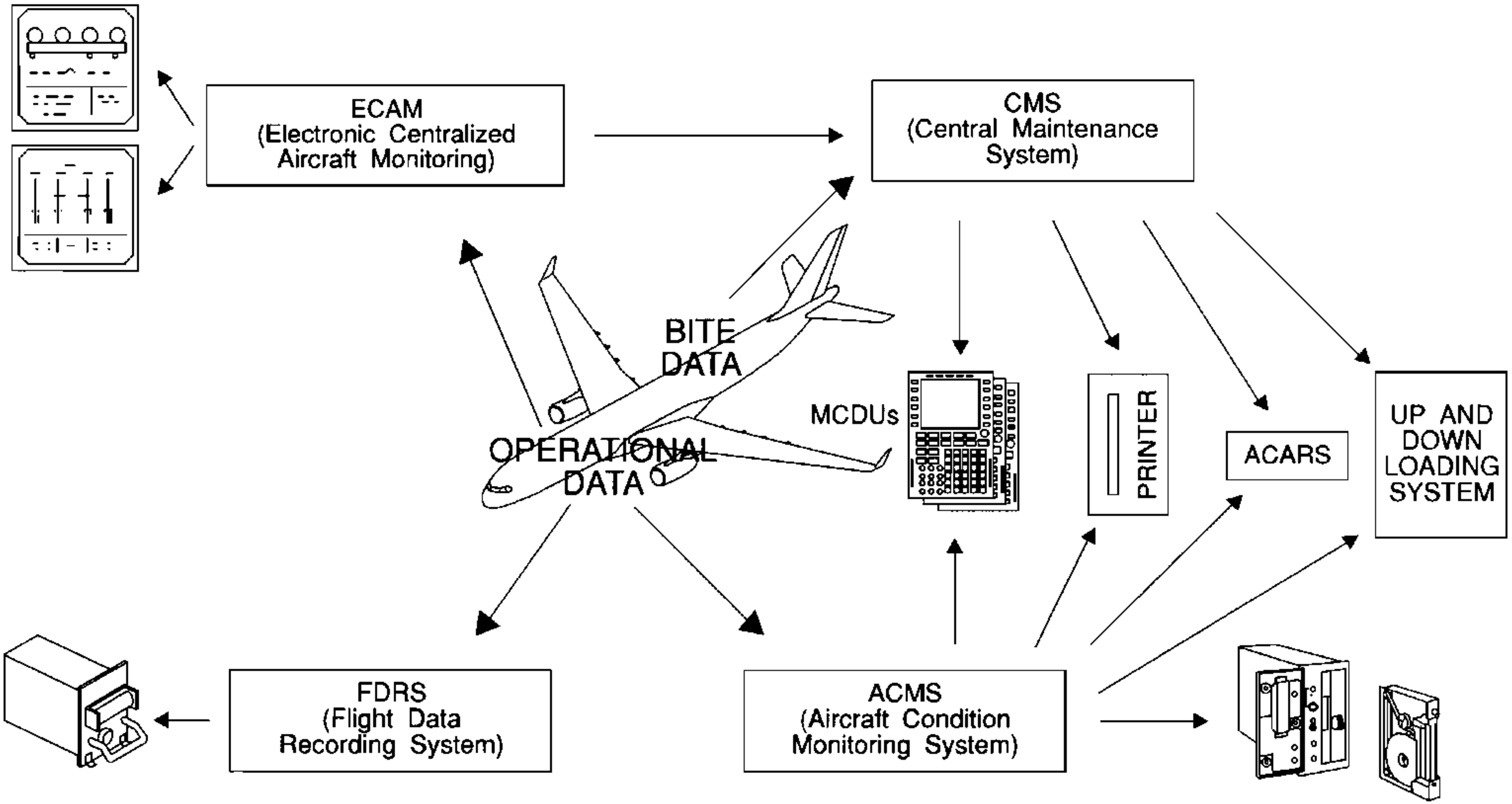
- the cockpit Multipurpose Control Display Unit,
- the ECAM displays,
- the cockpit printer,
- the down loading system,
- a ground station via ACARS,
- and the recorders.

Analysis

Maintenance operations can be divided into 3 groups:

- minor trouble shooting which is performed with the help of the ECAM and the CMS through the MCDUs and the printed or ACARS down-linked reports.
- in-depth trouble shooting which is performed with the help of the CMS and the ACMS through the MCDUs and printed reports.
- long term maintenance which is performed with the help of the ACMS and the FDRS through printed, ACARS down- linked and down- loaded reports or recorded tapes.

Figure 1: On Board Maintenance Facilities



BITE Philosophy

General

A system is composed of LRUs which can be: computers, sensors, actuators, probes, etc. Most of these Line Replacable Units (LRUs) are controlled by digital computers. For safety reasons, these LRUs are permanently monitored, they can be tested and trouble shooting can be performed. In each system, a part of a computer is dedicated to these functions: it is called Built In Test Equipment. In some multi- computer systems, one computer is used to concentrate the BITE (Built- In Test Equipment) data of the system.

BITE

During normal operation, the system is permanently monitored: internal monitoring, inputs/outputs monitoring, link monitoring between LRUs within the system.

FAULT DETECTION

If a failure occurs, it can be permanent (consolidated) or intermittent.

ISOLATION

After failure detection, the BITE is able to identify the possible failed LRUs and can give a snapshot of the system environment when the failure occurred.

MEMORIZATION

All the information necessary for maintenance and trouble shooting is memorized in a Non Volatile Memory.

Concept

The BITE information stored in the system BITE memories is sent to a centralized maintenance device. The manual tests (SYSTEM TEST and SPECIFIC TESTS) can be initiated via this centralized maintenance device.

Its main advantages are:

- single interface location (cockpit).
- easy fault identification.
- reduction of the trouble shooting duration.
- simplification of the technical documentation
- standardization of the equipment.

Test

The test function can be divided into 4 groups.

POWER UP TEST

The power up test is first a safety test. The purpose of a safety test is to ensure compliance with the safety objectives. It is executed only on ground after long power cuts (more than 200ms). Its duration is function of the system which is not operational during the power up test.

If the aircraft is airborne, the power up test is limited to a few items to enable a quick return to operation of the system. The typical tasks of a power up test are: test of microprocessor, test of memories, test of ARINC 429 and various I/O circuits, configuration test.

CYCLIC TESTS

These tests are carried out permanently. They do not disturb system operation.

The typical tasks of a cyclic test (also called IN OPERATION TEST) are: Watchdog test (a watchdog is a device capable of restarting the microprocessor if the software fails), RAM test. Permanent monitoring is performed by the operational program (e. g. ARINC 429 messages validity).

SYSTEM TEST

The purpose of this test is to offer to the maintenance staff the possibility to test the system for trouble shooting purposes

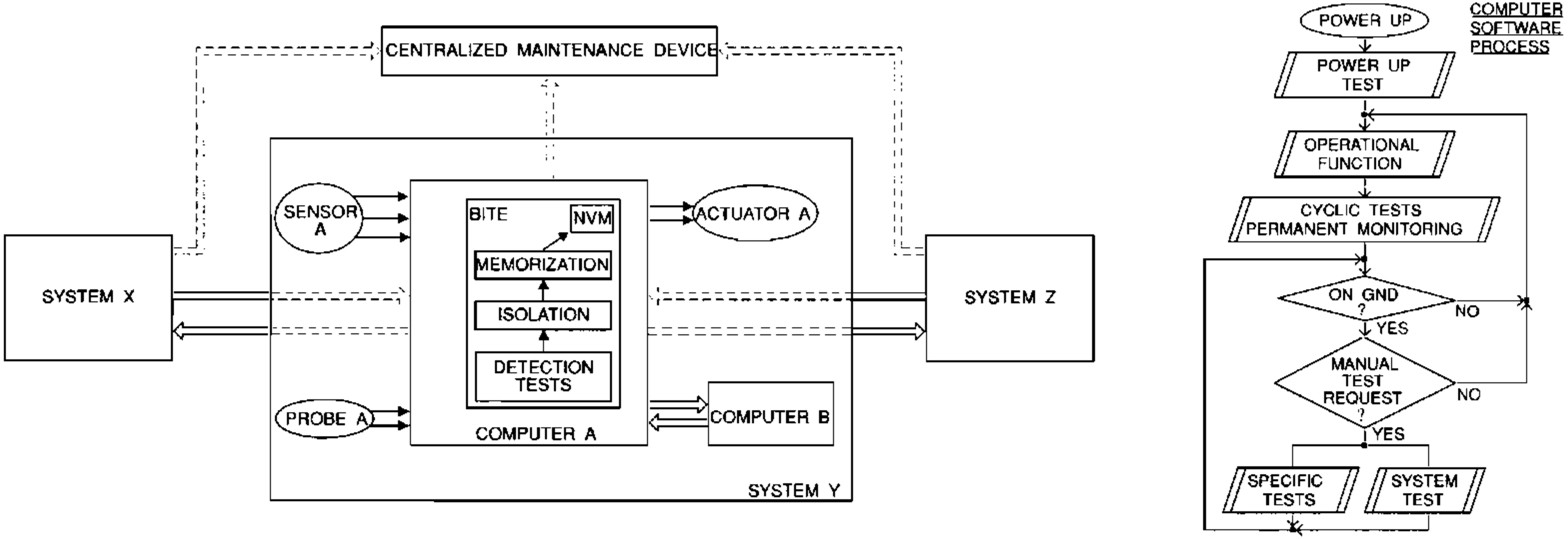
This test can be performed after the replacement of a LRU in order to check the integrity of the system or sub-system. It is similar to the POWER UP TEST but it is more complete. It is performed with all peripherals supplied.

SPECIFIC TESTS

For some systems, specific tests are available. The purpose of these tests is to generate stimuli to various command devices such as actuators or valves.

They can have a major effect on the aircraft (automatic moving of slats or flaps, engine dry cranking).

Figure 2: BITE Philosophy



Architecture

General

The Central Maintenance System or also called Centralized Fault Display System is composed of one or two Maintenance Computers and the aircraft system BITEs. Build In Test circuits are build in in most system LRU's.

The CMC interfaces are:

- MCDUs,
- a printer,
- the Aircraft Communication Addressing and Reporting System (ACARS),
- a data loader called Multifunction Disk Drive Unit (MDDU).
- Central Maintenance Computer (CMC) or
  Centralized Fault Display Interface Unit (CFDIU)

The Central Maintenance Computers continuously scan the buses coming from the A/C systems.

If a failure message, from a system BITE, is present on a bus, the CMC or CFDIU copy and store it.

They also store the Electronic Centralized Aircraft Monitoring (ECAM) messages generated by the Flight Warning Computers.

BITE

In each aircraft system computer, a BITE monitors the system and memorizes the failures. The A/ C systems are divided into three types, depending on their capabilities and their connection to the CMCs.

Multipurpose Control and Display Unit MCDU

The Multipurpose Control and Display Unit is the operator's interface with the Central Maintenance System. Any two of the three MCDUs may be operated simultaneously.

Printer

Most of the Central Maintenance System reports may be printed. The printer provides the Post Flight Report (PFR) print which is the main maintenance tool.

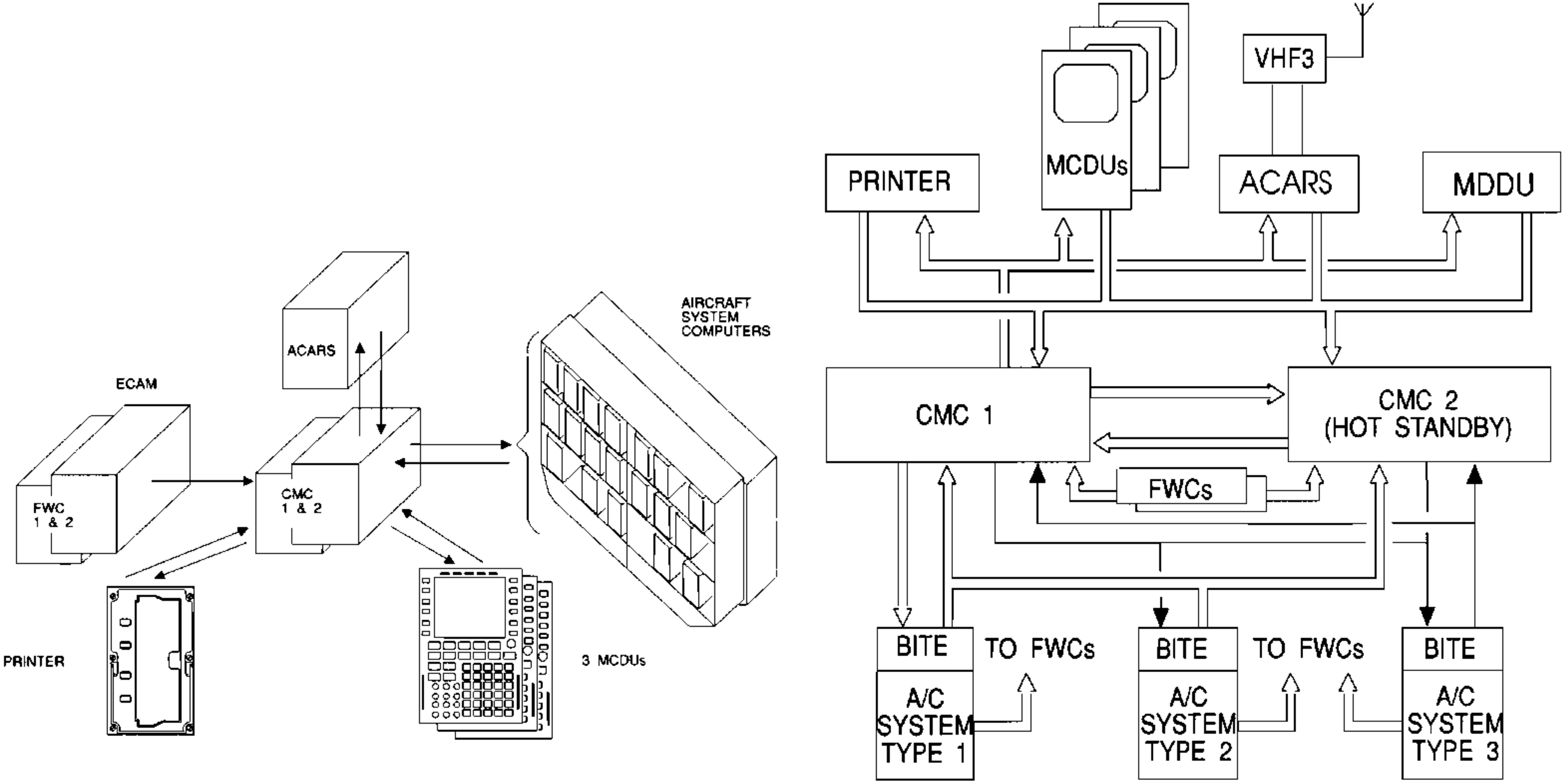
Aircraft Communication Addressing and Reporting System ACARS

Data may also be transmitted to the ground through the Aircraft Communication Addressing and Reporting System (ACARS).

Multifunction Disk Drive Unit MDDU

Data may also be loaded into the CMCs through the Multifunction Disk Drive Unit.

Figure 3: System Architecture



Condition Monitoring

General

The main functions of the Aircraft Condition Monitoring System (ACMS) are to perform engine condition, APU condition and aircraft performance monitoring as well as trouble shooting assistance. It collects, records and processes aircraft system data which can be retrieved through the MCDU, on a memory support or printed.

Architecture

The ACMS consists of:

- The Data Management Unit (DMU) including a Smart ACMS Recorder (SAR). The DMU may contain a Personal Computer Memory Card International Association (PCMCIA) interface,
- Flight Data Interface Unit (FDIU),
- an "on-ground" equipment called Ground Support Equipment (GSE),
- an optional Digital ACMS Recorder (DAR).

DMU

The DMU collects, stores and processes various aircraft system data. This data can be stored in the internal DMU memory, the PCMCIA card or the DAR, if installed. The collected data is used to generate various condition reports. These reports can be stored in the internal DMU memory or on the PCMCIA card.

FDIU

The Flight Data Interface Unit (FDIU) part of the Flight Data Recording System. It sends the same parameters as the Digital Flight Data Recorder (DFDR) to the DMU. These parameters will be recorded on the PCMCIA card.

Aircraft Systems

Various aircraft systems are connected to the FDIU. These input sources provide the FDIU with engine parameters, APU parameters and aircraft parameters.

SAR

The SAR is a DMU function. This function allows the recording of compressed data, programmable through the GSE. SAR data can be stored in the internal DMU memory or on the PCMCIA card.

DAR

The purpose of the DAR is to store data on an optical disk for on ground performance, maintenance or condition monitoring tasks. Preprogrammed selection of data can be done through the GSE. DAR data can also be stored on the PCMCIA card.

MCDU

Multipurpose Control and Display Units (MCDU) are connected to the DMU, to display data, program and also control the system. Compared to the GSE, the programming facilities offered by the MCDU are very limited.

The main functions of the MCDU within the ACMS are:

- online display of selected parameters,
- display of the list of the stored reports and SAR files,
- manual request of reports and SAR/DAR recording.

Printer

The printer is used to print reports generated by the DMU as well as most of the ACMS MCDU displays. The printer can be automatically controlled by the DMU, manually controlled from the MCDU or activated using the ACMS PRINT pushbutton.

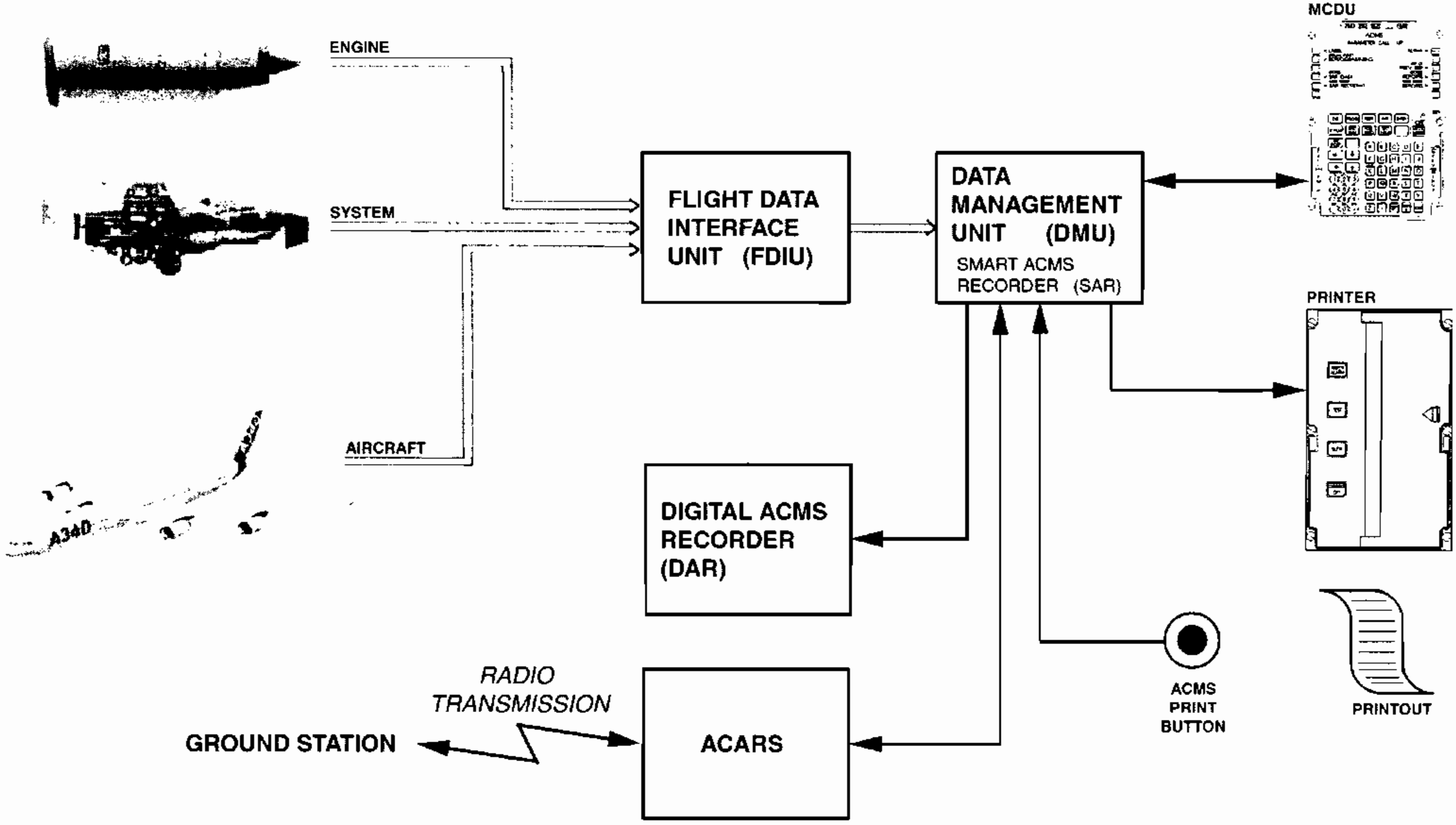
ACARS

The Aircraft Communication Addressing and Reporting System can be used to send reports and to broadcast parameters generated by the ACMS to a ground station via radio transmission.

- VHF Voice Data Radio,
- Satellite Communication System or
- Gate-Link acting as a Wireless Local Area Network (LAN) when aircraft is ground.

The download of reports can be automatically initiated by the DMU or manually initiated from the MCDU. The ATSU can also receive, and send to the FDIMU, requests from the ground.

Figure 4: Aircraft Condition Monitoring System



Ground Support Equipment GSE

The GSE is based on a compatible personal computer able to read 3.5 inch floppy disks and PCMCIA disks. The GSE software provides the following main functions:

Reconfiguration function and Readout function. The reconfiguration function allows the configuration of the customer database (trigger conditions, layout of recording space). The readout function allows display, print out and analysis of recorded data.

Data Loader

The data loader is used to upload data into the ACMS (operational software, customer databases), download data on a 3.5 inch floppy disk for GSE analysis (reports, SAR data).

PCMCIA Interface

The PCMCIA interface accepts high capacity and removable PCMCIA disks. On the PCMCIA disk can be stored ACMS reports, SAR data, DFDR data and DAR data. The disk space ratio is programmable by the GSE. The PCMCIA interface can also be used as a portable data loader to upload ACMS software and databases or to download recorded data.

Figure 5:

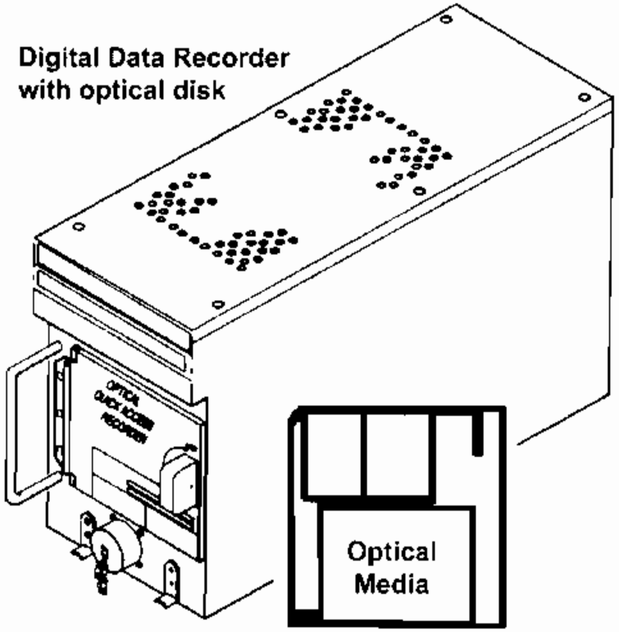


Figure 6: Ground Support Equipment

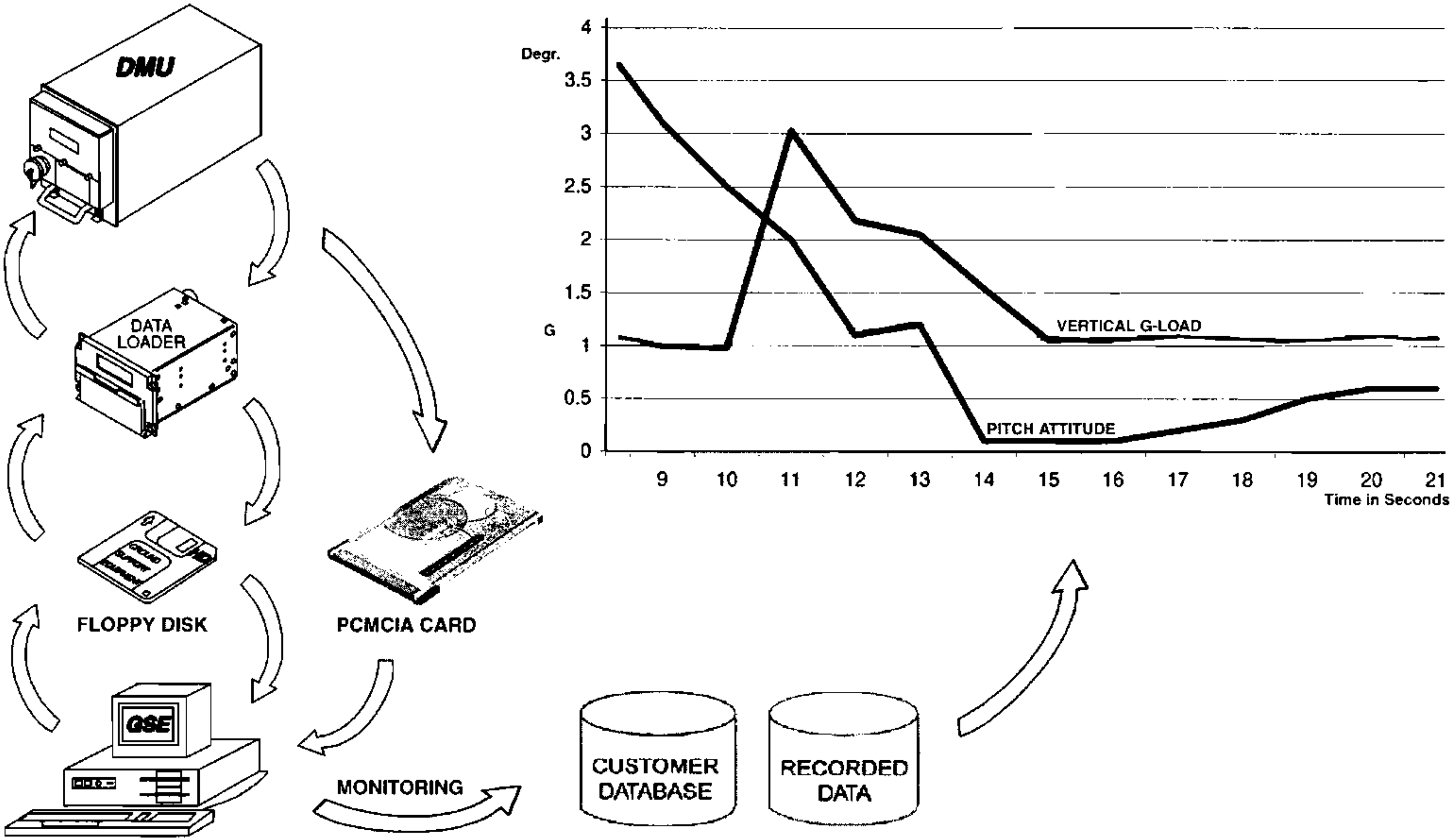
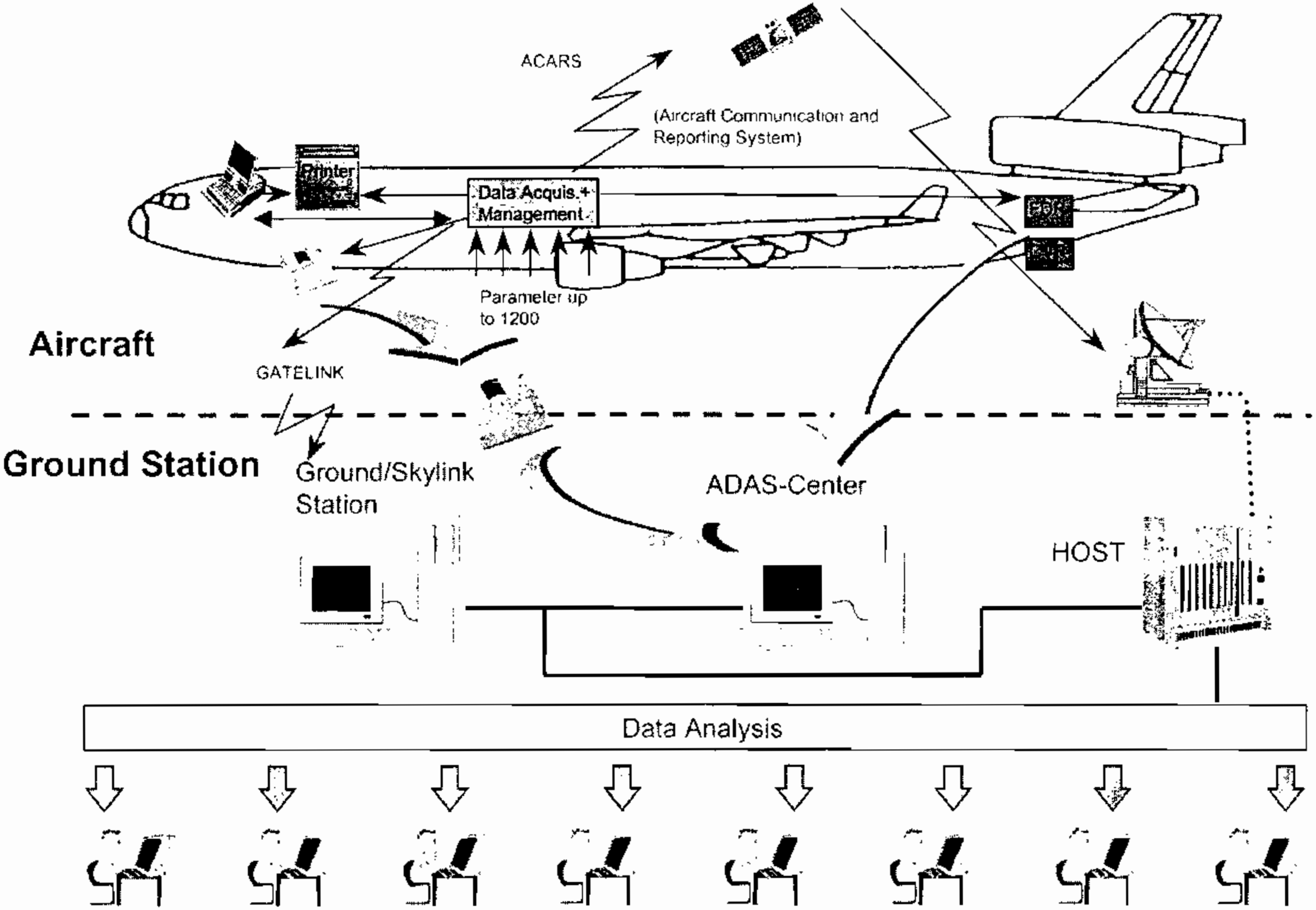


Figure 7: Aircraft Data Acquisition System and ground based Data Analysis



Structure Monitoring

Structure monitoring comprises the instrumentation of a structure with a sensor system that monitors how the surroundings load the structure. An advanced software system receives the data, interprets it and reports the structure's condition to the operator. Real-time feedback to the operator means that overloading may be avoided and any damage to the structure may be discovered quickly. Comprehensive knowledge of the objective condition of the structure allows condition-based maintenance, black-box recorder functionality and investigation of incidents.

The technology is well suited for applications such as condition monitoring of oil platforms, wind turbines and bridges.

In civil aviation, such systems come into action only during development and certification of an aircraft.

Damage Tolerance Monitoring

The term "Damage Tolerance Monitoring" describes short and correct what it exactly does.

A good example is the the permanent monitoring of the vertical acceleration of an aircraft during landing. A hard landing can make serious damage to the structure and must be avoided in any case.

If happend, the computer registers the excessive acceleration during touchdown. This is reported e.g to the pilot or maintenance personnel and the necessary action can be carried out.

Data Loading

General

The data loading system is an interface between the aircraft computers and ground data processing equipment used to update software and data bases or to retrieve aircraft system data. The MDDU can operate in two modes: automatic mode and manual mode.

The manual mode is only used to down load data while the automatic mode is used to up and down load data. According to the operation to be performed, the disk which is used has to contain specific information (e. g. configuration file).

The data loading system includes two rotary selectors for system selection. It also includes a Multi- purpose Disk Drive Unit (MDDU).

If the Multi- purpose Disk Drive Unit is not installed, Up and Down Loading functions can be performed through a connector by using a portable data loader. (see module 5).

Before performing an up data loading operation, refer to the relevant procedure for the corresponding system in the Aircraft Maintenance Manual.

Up Loading

The aircraft system computers use the loading system to update their data base (for example the FMGEC Flight Management Guidance and Envelope Computer) or to modify parts of their operational software (for example the ACARS Management Unit).

Down Loading

The down loading system is used to down load, to a 3.5 inch disk, the data recorded by certain computers during aircraft operation (for example the Aircraft Condition Monitoring System).

Components

The MDDU contains:

- an electronic unit composed of a power supply, Input/ output and CPU / Floppy Disk Drive Contol boards,
- a Disk Drive installed on shock mounts,
- a window with 16- character alphanumerical LCD display,
- a door protecting access to the Disk Drive.

The data support is a 3.5 inch double face, high density disk (1.44 megabytes). This disk is in MS- DOS format. It can be read or written on ground by IBM- PC Ground Support Equipment (GSE).

Abnormal Operation

Other messages displayed on the MDDU window inform the operator of the transfer status:

TRANSFER FAILURE: If the MDDU has to stop data transfer (up or down loading) for any reason, this message is displayed.

UNIT FAIL: The MDDU displays this message if a hardware failure is detected during the self- test. In this case, the MDDU stops all operations.

DISK ERROR: If the MDDU cannot read or write data disk (incorrect formatting, write- protected, disk damaged, etc.), it will interrupt operations and display this message.

Figure 8: Multipurpose Disk Drive Unit MDDU

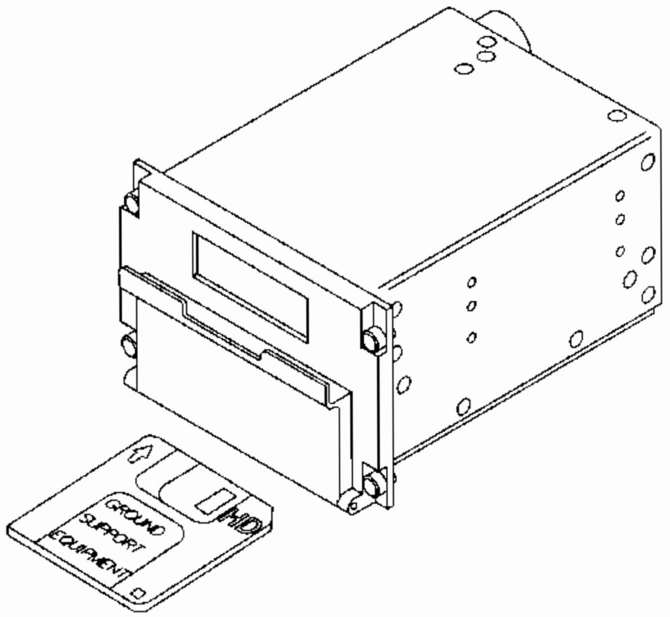
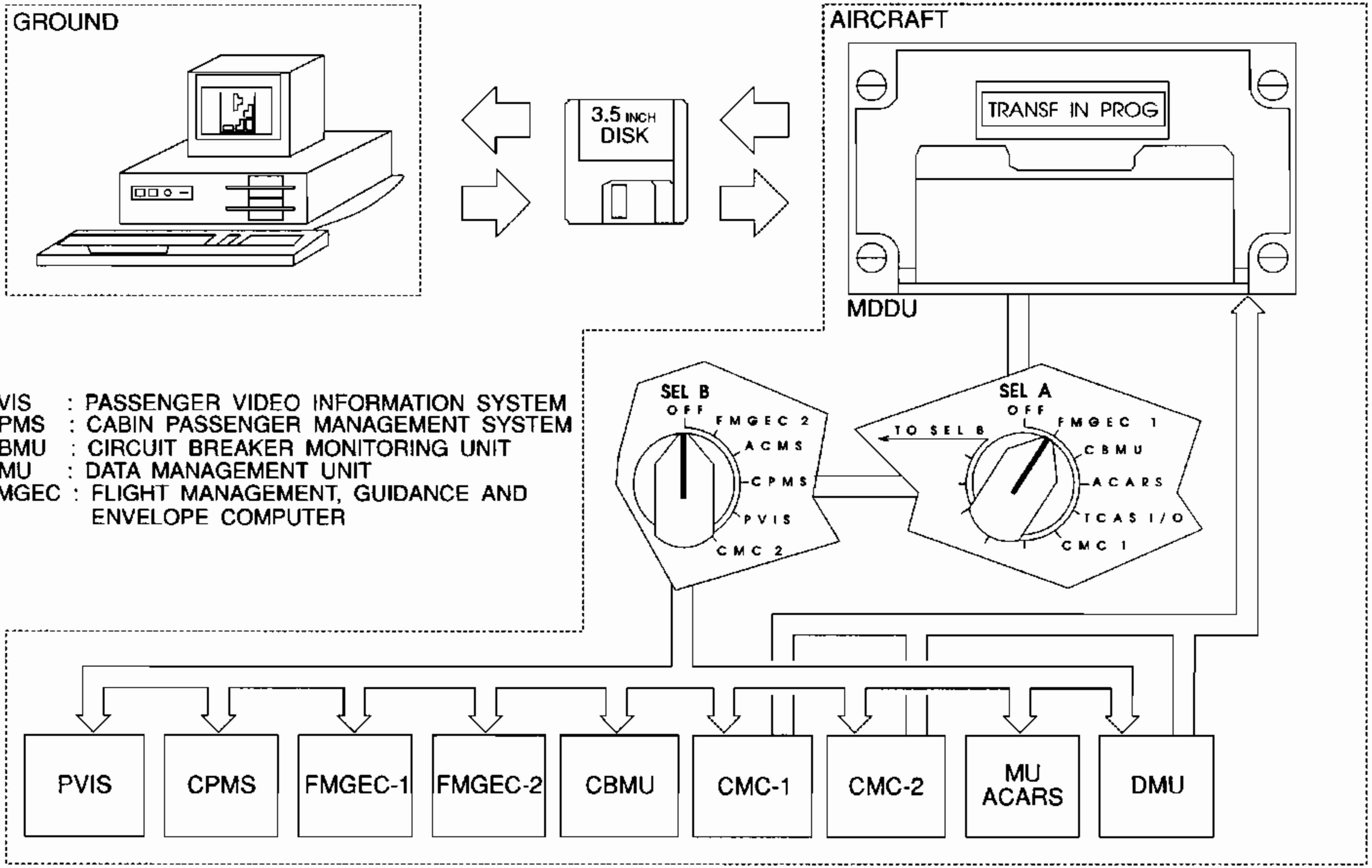


Figure 9: Data Loading System



Electronic Library

General

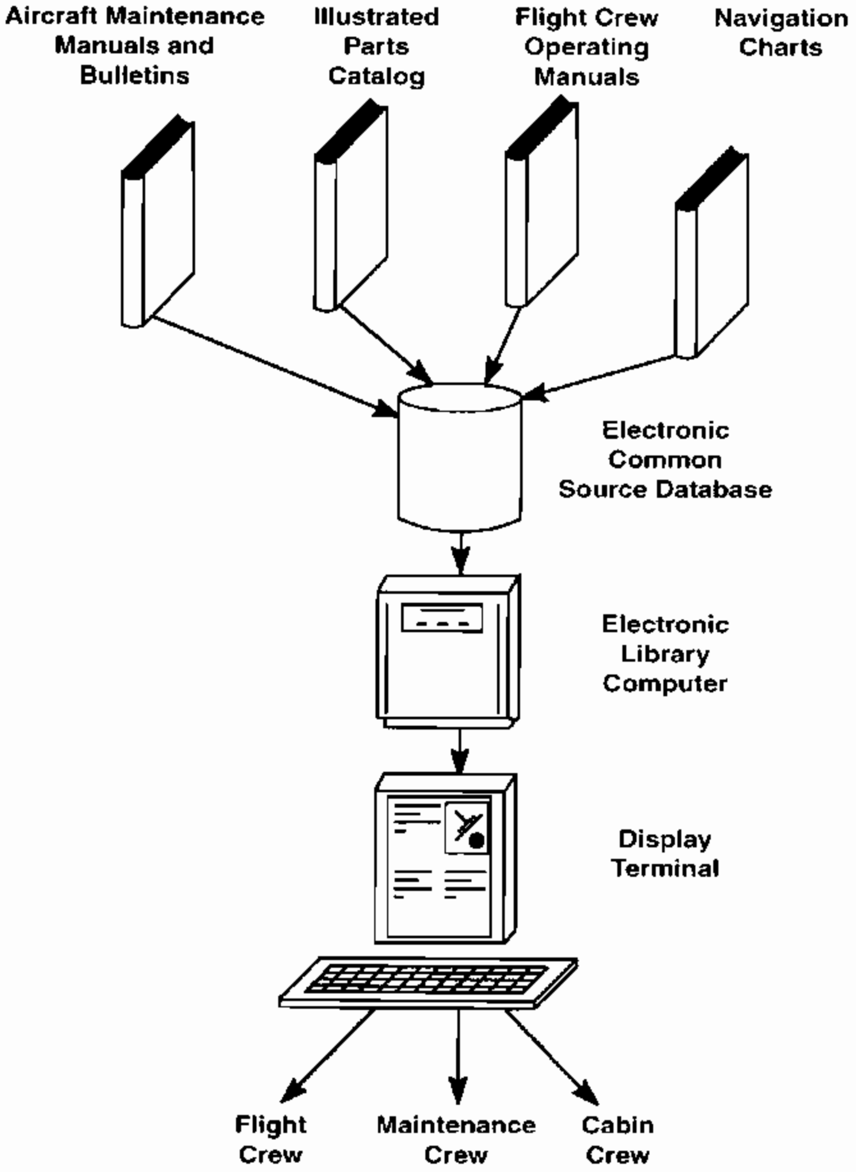
The Electronic Library System (ELS) is an information management system designed to provide airline personnel with timely access to the information necessary to operate and maintain an aircraft. The system provides airline flight, maintenance, and cabin crews with instantaneous access to information contained in tens of thousands of pages of operational manuals, procedures, and navigation charts. Wherever possible, the information is provided in a task-oriented manner so that it can be used more efficiently and accurately. The long-term objective of the ELS is to eliminate the airline's need to carry and update paper documentation on board the aeroplane.

In addition to timely access to information, flight crews will also have enhanced avionics functionality due to ELS mass storage capabilities. Maintenance crews will benefit because the Onboard Maintenance Systems (OMS) will be combined with the Electronic Library System in an integrated maintenance and fault-reporting environment. In addition to the benefits of cabin crew access to operational and procedural information, the mass storage and file server function contained within the ELS allows new levels of passenger service capabilities.

The airborne Electronic Library System is only a portion of the overall ELS solution. Extensive ground applications using the information to be contained in the airborne system are already in place at most airlines today. The challenge for the industry is to provide the airlines with an airborne system that complements existing and future ground-based systems. The goal is to have a common source database for all facets of airline operations (dispatch, flight operations, maintenance, inventory/parts control, etc.).

Information updates to the airborne system and communications between the ground-based and airborne systems are accomplished through the emerging Gate-link concept and other existing and planned communication channels. In the long term, the very-high band-width Gate-link interface will allow the aircraft to park at the gate and "log in" as a node on the airline's computer network. Bidirectional Gate-link information transfers between the aircraft and airline ground-based operations centers will ensure accurate and up-to-date information on the aircraft while significantly simplifying the update process.

Figure 10: Concept



System

The evaluation system consisted of a monochromatic active-matrix liquid crystal display (LCD), an avionics-quality optical disk drive, a prototype ARINC 744A printer, and a workstation platform. The user input device to the liquid crystal display consisted of a capacitive touch screen overlay on the display surface. Flight crews accessed desired information by simply touching the display screen in the appropriate areas. The system did not include a keyboard for user input. Direct text entry for airport directory or word searches was implemented with a "soft" keyboard function displayed on the screen. Integrating the input device directly with the display also helped conserve the space necessary for installing the display on the flight deck. This is particularly important for fleet-wide ELS installations that may include flight decks with limited space.

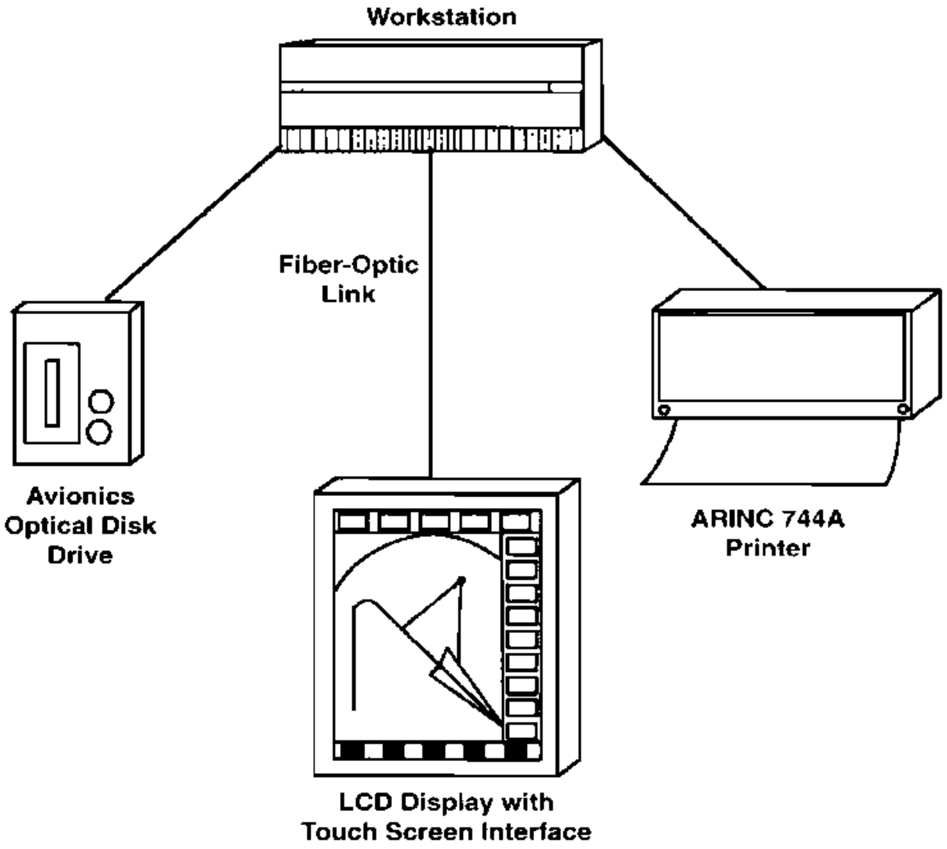
The integrated touch screen input device and a fibre-optic interface to the display simplifies the wiring installation.

Software provides an accurate and complete functional representation of the envisioned final product. The system included simple "page turning" functions as well as more advanced retrieval techniques such as text and graphical hyperlinking. Great care was taken in the design of the graphical user interface (GUI) to ensure intuitive and consistent operation.

A subset of all manuals and navigation charts carried in flight crew kit bags are stored digitally on the optical disk. Digital data was delivered and stored in multiple formats, including compressed bitmap, text, and vector graphic formats. This data set included sections from the Flight Crew Operating Manual, Aircraft Flight Manual, Airport Analysis Manual, Aircraft Maintenance Manual, Aircraft Schematic Manual, Illustrated Parts Catalogue and Minimum Equipment List (MEL). Digitized versions of airport terminal chards were provided by Jeppesen, Inc.

The electronic system would not only eliminate the bulky weight carried on the aircraft (up to 90 kilograms carried by international flight crews) but, more importantly, significantly reduce the cost of producing, updating, distributing, and maintaining the existing paper information. Furthermore, users recognized the potential benefit from task-oriented organization of information and that an ELS would allow this potential to be realized.

Figure 11: Electronic Library System



Airborne Printer

General

The printer comprises the following functional sub- assemblies:

- a front panel with pushbuttons and indicators,
- an electronic part consisting of a Central Processing Unit, printer controller and power supply boards,
- a mechanical block.

The printer allows to printout of the Central Maintenance System reports and additional printouts from:

- the Aircraft Condition Monitoring System (ADAS, AIDS or ACMS),
- the Aircraft Communication Addressing and Reporting System (ACARS),
- the Flight Management, Guidance and Envelope System (FMGES),
- the Engine Interface Vibration Monitoring Unit (EIVMU or EVMU).

Paper

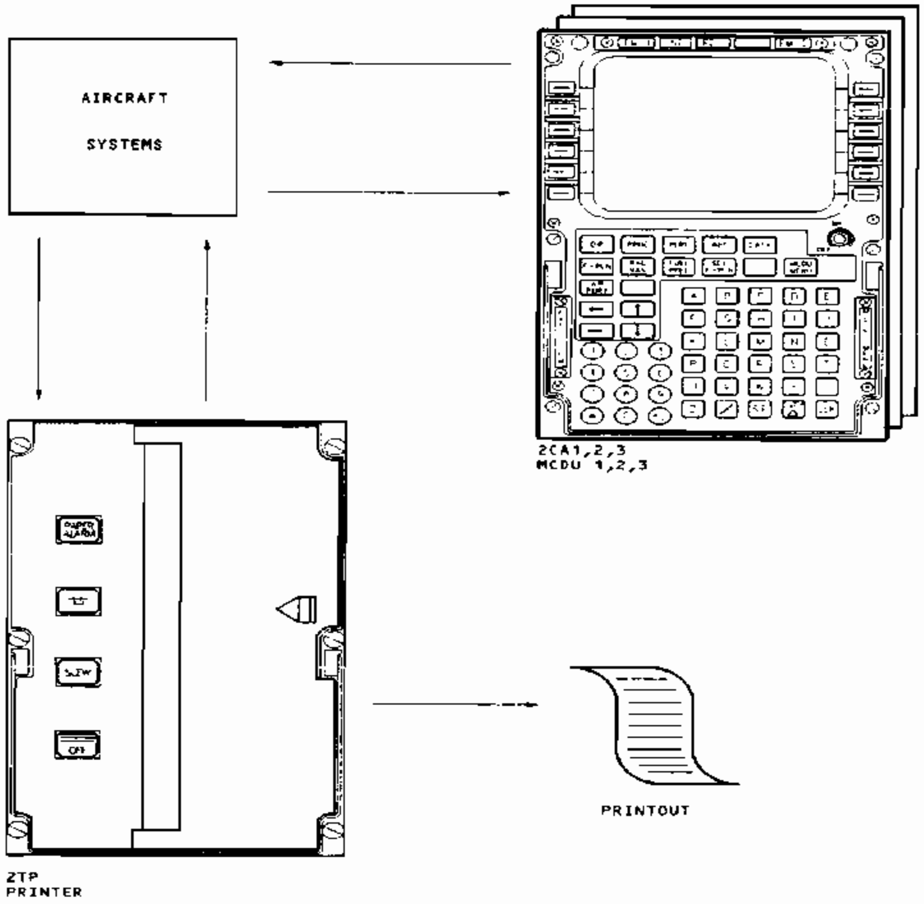
The printer works as a non-impact thermal printer which only works on special heat sensitive paper The paper can be inserted via an access door incorporated in the front panel. The printer is loaded with a correct size of paper roll. (108 or 216 mm)

Controls

The printer face features pushbutton switches and annunciator lights, i.e.

- TEST switch is used to perform a functional test.
- SLEW switch is used to exit paper.
- "PAPER ALARM" pushbutton switch includes an AMBER caution light.
- "OFF" pushbutton switch includes a status indicator light.

Figure 12: Printer Interface



Printer

This model shown below is often used as a versatile cockpit printer. Different controls located on the front panel:

PRINTER INHIBIT button and light: Turning printer on/off.

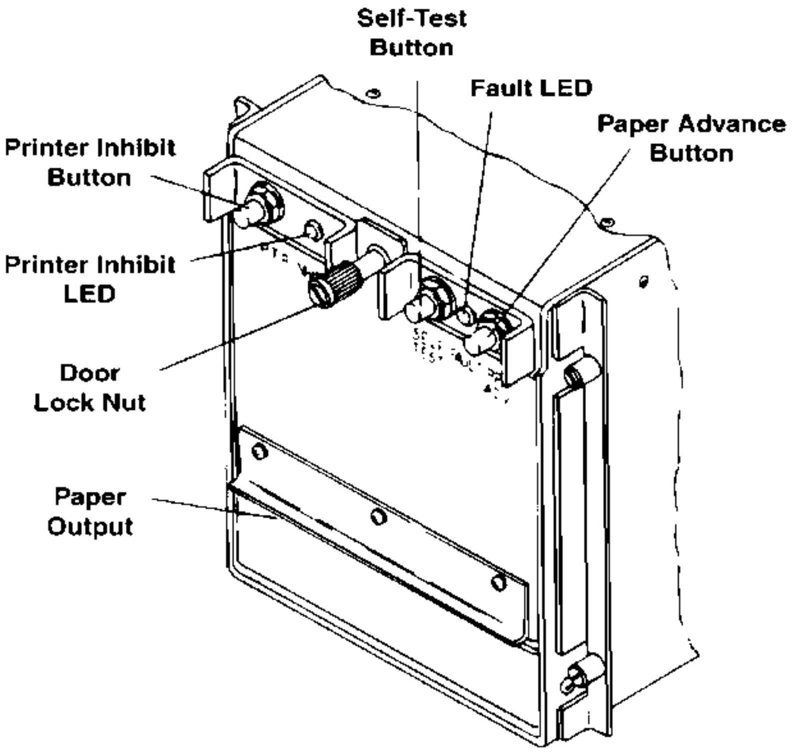
DOOR LOCK to open the printer for paper replacement.

SELF TEST button to start a self test and to print a test pattern.

FAULT LED illuminates with internal failure or overheat.

PAPER ADVANCE or SLEW button advances paper without printing.

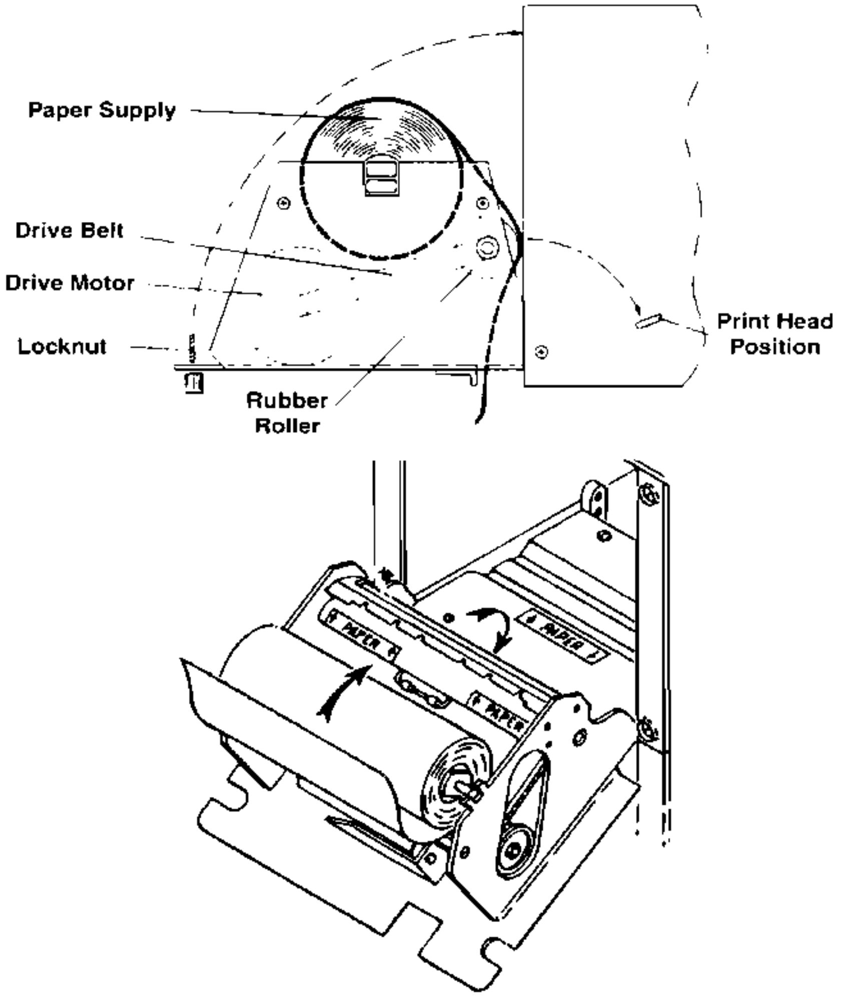
Figure 13: Front face



Paper Loading

A red line marked on the paper indicates that the supply roll must be replaced. Open the printer and insert a new roll. Verify that the heat sensitive side is facing against the print head. Close the printer and initiate a test print.

Figure 14: Paper transport

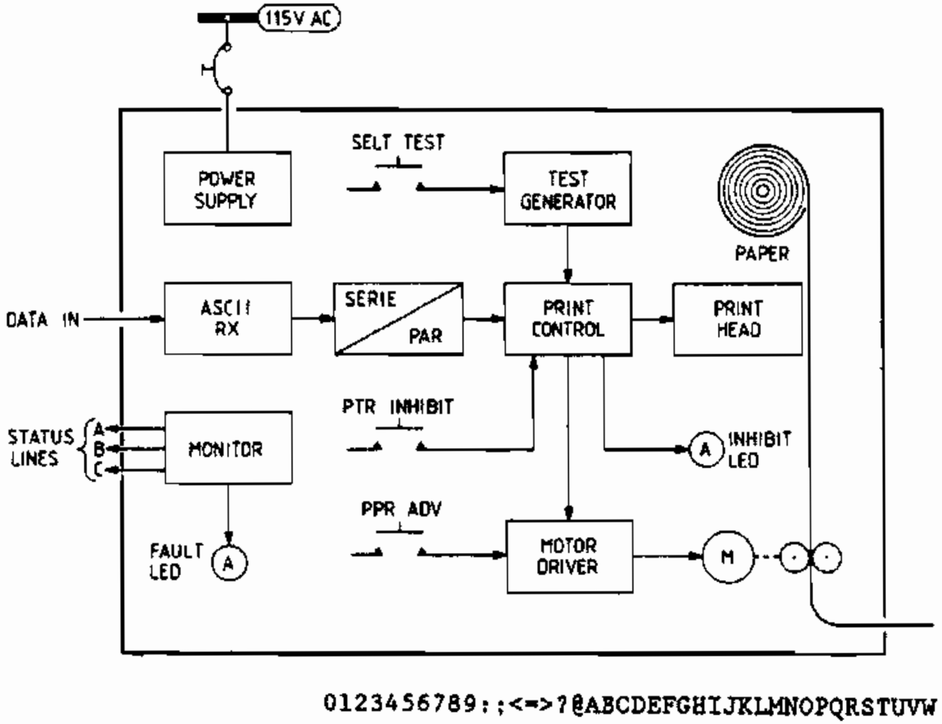


Dot Matrix Printing Technology

This printer has an 64 ASCII character set and prints this in a 10x16 dot matrix, with a speed of 160 lines per minute. The printer receives the data as serial ASCII or ARINC code from one ore more different aircraft systems.

Status lines ABC, or ARINC 429 signals feeding back the printer status to the sender, so called Handshake.

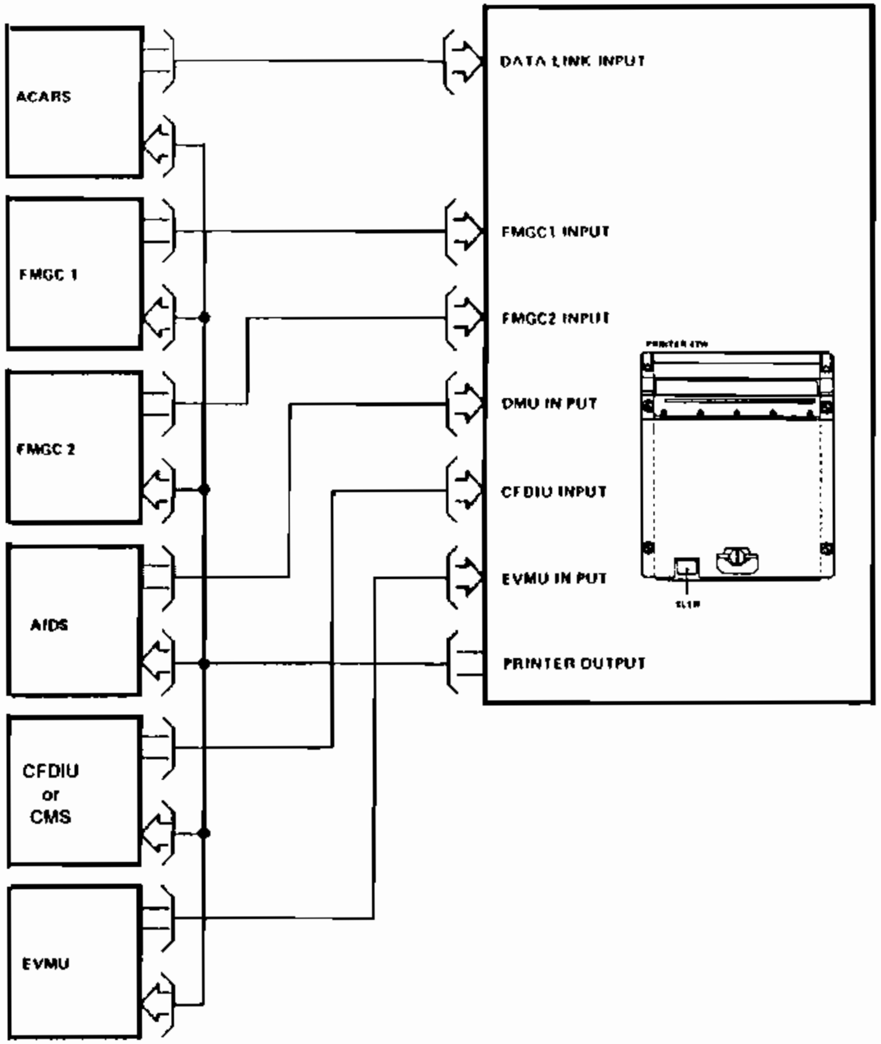
Figure 15: Block Diagram



Interface

The printer is connected with different aircraft system.

Figure 16: Printer with 6 different signal sources



Study Questions

13.1 Theory of Flight

1 Name the primary and secondary flight control surfaces of an aeroplane.
Answer:

2 On which axis act the following control surfaces?

a) Rudder: ____________

b) Elevator: ____________

c) Aileron: ____________

3. What are Flight control trim systems used for?
Answer:

4. What kind of high lift devices are used on modern jet airliner aircraft?
Answer:

5. What kind of boundary layer control devices are used on modern jet airliner? And Why?
Answer:

6. Explain the function of:

a) Servo tab:

b) Trim tab:

7. The speed of sound is only affected by the ____________ of the air

8. What is the Mach number?
Answer:

9. Make a list of the flight speed ranges with its desired speed values.
Answer:

10. Explain the definition rotor blade angle and rotor angle of attack (AOA)
Answer:

11. Explain the principle Helicopters are controled to move in the different directions.
Answer:

12. What is collective and cyclic pitch?
Answer:

13.2 Airframe Structures - General Concepts

13. What is the difference between primary and secondary structure?
Answer:

14. Explain the different station system described in this sub module.
Answer:

15. What is all included in the major zone 300

Answer:

16. Describe the difference between a monocoque and semimonocoque structure.

Answer:

13.3 Autoflight (ATA22)

Fundamentals

17. Name the aircraft axes, the rotatation around them and the movement along

18. Differentiation of roll-attitude results in: (2 answers)

19. Integration of pitch-acceleration results in: (2 answers)

20. Name the primary flight controls

21 Name the secondary flight controls

22. To change the attitude, how long a flight control tap must be extended ?

23. Describe a simple control loop

24. The task of inner loop of autopilot is:

25. The task of the outer loop of autopilot is:

26. Synchronisation of autopilot; when is it active and the reason for this

27. What means Fail Passive ?

28. What means Fail Operational ?

29. What means Fail Safe ?

Autopilot

30. Its task is:

31. Which autopilot related functions can be selected on a control panel ?

32. Where are the operation modes displayed ?

33. What is the pilots input when the autopilot is activated ?

34. Name some navigation inputs an autopilot computer will use

Actuators

35. Name the 3 power sources for actuators

36. The clutch inside an electric actuator opens if:

37. The actuator provides following feedback signals:

38. The purpose of the transfer valve inside a hydraulic actuator is:

39. How a hydraulic actuator will be engaged/disengaged for autopilot function ?

40. The Autopilot LVDT provides the . . . . .signal

41 The Control Surface or Ram LVDT provides the . . . . .signal

42. What means Serie Mode ?

43. What means Parallel Mode ?

44. The advantages of Control Wheel Steering function are

45. How CWS sensors are build up, where are they installed ?

46. The advantages of Fly By Wire over a regular flight control system is:

Flight Director

47 What is the task of a FD ?

48. The difference between an Autopilot and a Flight Director controlled flight is.

49. Name the advantages of the FD operation

50. Where the FD commands are shown, name all command bars

51. The FD bars are centered, this means:

52. Where the FD mode is shown

53. What means a Flight Path Vector

54. In which flight phases the FPV is used instead of FD

Operational Modes

55. In which flight phase there is no autopilot possible or allowed ?

56. The aircraft is in take off climb, how pitch attitude is controlled ?

57. The aircraft is in take off climb, how roll attitude is controlled ?

58. The aircraft is in take off climb, yaw axis is controlled ?

59. Name the phases of approach and landing

60. Name the ILS categories and their minimum visual ranges

61. Define Align and the input signal therefore

62. Define Flare and the input signal therefore

63. Define Roll Out and the input signal therefore

64. Go around, how the autopilot steers the plane

65. Heading Hold or Heading Select, explain the difference

66. Altitude Hold or Altitude Select, explain the difference

67. Explain Level Change

68. Vertical Speed Select or Flight Path Angle Select, explain the difference

69. Which input source is used for Lateral and Vertical Navigation

Auto Throttle / Thrust

70. What is the task of this system ?

71. Name the two basic mode for thrust control

72. Name different way to apply the thrust command to the engine (3 solutions)

73. What means Thrust Limit computation, in which unit is the limit expressed ?

74. Which input parameters are used to compute the Thrust Limit

Pitch Trim

75. Which flight control surface is used for pitch trim

76. Name the diffent actuator used for trim

77. The stabilizer trim is dependant of:

78. Following trim functions can be incorperated

Yaw Damping

79. What is the purpose of this function ?

80. What means Dutch Rolling

81. Name the signal source to counteract the dutch rolling

82. Following YD / Rudder functions can be incorperate

Warnings

83. What means STALL

84. How the Stall situation is alerted

85. Some aircrafts are equipped with stall prevention system, how they work ?

86. Altitude Alert distinguishes between two conditions

87 Windshear means:

88. How to counteract a windshear, how the pilot is alerted

89. Flight Envelope protection comprises

90. Name some autoflight related warning annunciators

91. The AUTOLAND light illuminates, that means

Fault Isolation / Test

92. What can be tested ?

93. What can be readed out ?

94. Where are AFS maintenance panels located ?

95. This panels are today substituted by:

96. Where are autoflight failures stored ?

97. Which test must be performed, to verfy the AP is ready for CAT III operation ?

13.4 Communication / Navigation (ATA23/34)

Communications ATA-23

Fundamentals

98. What means AVIONICS ?

99 Name the components of a radio transmitter

100. Name the components of a radio receiver

101. Name the advantage of a superheterodyne receiver

102. Local oscillator and mixer, why

103. Squelch, what is it ?

104. Automatic gain control, what is the purpose ?

105. The basic components of an oscillator are:

106. Name the characteristics of a quarz oscillator

107. Today most transmitter and receivers are using a PLL, why ?

108. Name the characteristics of amplitude modulation AM

109. Name the characteristics of frequency modulation FM

110. Single Side Band, what does this mean ?

111. Name the advantages and disadvantages of SSB

112. Pulse Code Modulation PCM, explain this:

113. Multiplexing means:

114. Following modulations are used in (one example each)
CW: AM: FM:

115. Name the two components of radio waves:

116. An antenna is works like .

117. Name the 3 basic type of antennas

118. An antenna is vertically polarized, that means:

119. Wavelength means:

120. The radiation speed of radiowaves is:

121. Name different types of tranmission lines:

122. A radio transmission line is comparable with:

123. The power in a matched radio transmission line is dissipated by .

124. In a mismatched transmission line there is . .

125. A standing wave means:

126. Name the frequencies (Abbreviation) of the radio frequency band

127. Name some common characteristics of radio wave propagation

128. The ionosphere will:

129. The propagation and coverage of VHF, UHF and SHF is:

130. The propagation and coverage of HF is:

131. The propagation and coverage of MF is:

132. The propagation and coverage of LF is:

133. Feading means:

134. Reception noise is coming from:

135. Name the antennas which are used by communication systems.

136. Name the antennas which are used by navigation systems.

137. The purpose of the static dischargers is:

138. How ist the static discharger build up ?

139. Where are the static dischargers located ?

VHF Communication

140. The purpose of this system is:

141. Following components are belonging to this system:

142. The frequency range of the VHF COMM is:

143. The channel spacing is:

144. Is it possible to communicate in duplex mode ? (Tx/Rx simultanously)

145. How to change from the receive-mode to the transmit-mode ?

146. How is this signal named ?

147. How the operation frequency can be tuned ?

148. The VSWR shows more than 2.0, that means:

149. On some frequencies you should never transmit, why ?

HF Communication

150. The purpose of this system is:

151. Following components are belonging to this system:

152. The frequency range of the HF COMM is:

153. The HF system will work in following modulation-modes:

154. The channel spacing is:

155. What is the task of the antenna coupler, where is it located?

156. Some antenna systems are using a lightning arrestor other none, why ?

157. In receive mode, is it necessary to tune the antenna cirquit ?

158. Explain the antenna tuning sequence

159. How is the antenna tuning mode indicated to the pilots ?

SELCAL

160. The SELCAL is used to:

161. Following input signals the decoder will process:

162. How a call is processed ?

163. Two conditions must be meet to get a call.

164. How a call is indicated in the cockpit ?

165. How and where, a SELCAL code can be selected ?

SATCOM

166. The purpose of this system is:

167. A phone call between airplane and office. How the signal is routed ?

168. How many satellites are used by inmarsat ?

169. How many ground stations are working with this satellites ?

170. Name all components of an airborne ground station.

171. Which of all the units does the control over the system ?

172. The SATCOM system uses position and attitude signals, why ?

173. Does the communication operate in simplex or duplex mode ?

174. The uplink/downlink frequencies between AES to satellite are:

175. The uplink/downlink frequencies between GES to satellite are:

ACARS

176. The purpose of this system is:

177. Which aircraft communication system will broadcast ACARS messages ?

178. Name the 4 ACARS provider and their operation aera

179. The VHF ACARS frequency in Zurich is:

180. An ACARS message is send from an airplane placed in Zurich to the maintenance control (MCC) in Zurich. How are the data routed?

181. Name the ACARS components installed in the aircraft.

182. OOOI stands for:

183. Name some applications of ACARS

Audio Integrating

184. Name the two technologies used for audio integrating

185. The VOICE/IDENT switch will:

186. The filter inside an analog ACP is buildup with following components:

187. The only active component in an analog ACP is:

188. In newer technology, which function is digital controlled ?

189. What is the function of the RADIO/INT switch located located on audio control panel, control wheel or side stick ?

190. List all microphones used in cockpit

191. List all listening devices used in cockpit

192. Is it possible to listen several audio sources simultaneously from one ACP ?

193. Is it possible to select more than one microphone selector at one time ?

Interphone

194. The Flight Interphone is used to communicate between:

195. The Cabine Interphone is used to communicate between:

196. The Service or Maintenance Interphone is used to communicate between:

197 The main component of each interphone system is:

198. To communicate inside cabin, the attendant has to use . .

199. How the ground engineer will be called from cockpit to communicate ?

200. Is it possible to communicate between Flight-, Cabin- and Service Interphone

201. The horn in the aircraft nose aera is sounding, that means.

Passenger Address

202. The system is used to:

203. Name the audio sources which will be broadcasted:

204. Name the chime-sounds distributed over speakers

205. Is there any priority, if so, list them.

206. Which unit makes the amplification ?

207. Under which circumstances the volume is automatically increased

208. The PRAM provides following audio signals

209. The difference between an emergency- and a prerecorded announement is:

210. How an emergency announcement will be started ?

211. How a prerecorded announcement will be started ?

Passenger Entertainment and Service

212. How the passengers can be entertained during flight ?

213. On how many channels ?

214. The signal source for video is:

215. The signal source for audio is:

216. How the data are distributed in the cabin ?

217. Which system provides the flight map on screens

218. A Cabin Intercommunication Data System is capable handle following tasks:

219. The center piece (unit) of the CIDS is:

220. For passenger related functions, the . . . . is responsible.

221. For attendant related functions, the is responsible.

CVR

222. The purpose of the Cockpit Voice Recorder is:

223. The recording capacity is:

224. How many tracks will be recorded name their sources ?

225. The recording media is:

226. When is the CVR operative (powered) ?

227. Under which conditions the pilots can erase the recorded conversation ?

228.Where is the CVR installed ?

229.The Underwater Locator Beacon is provided to:

230.What kind of signal the ULB is radiating and how long ?

231.In which time period the ULB battery must be replaced ?

ELT

232.The purpose of an Emergency Location Transmitter is:

233.How the ELT will be activated ?

234.The time allowed for testing the ELT is:

235.The operation frequency of the ELT is:

236.The powersouce of the ELT is:

237.The operation time of the ELT is:

Navigation ATA34

Airdata

Name the inputs, the flight environment system computes altitude and velocity

238.The standard air pressure and temperature at sealevel is:

239.Name all airdata probes around the aircraft.

240.Which pressure components are sensed by a pitot tube ?

241.Name all airdata readings which are possible in the cockpit.

242.Explain the components of a pressure altimeter

243.The barosetting is QNH. At landing the altimeter shows:

244 The barosetting is QFE. At landing the altimeter shows:

245.During cruise flight the altimeter setting is . . . . .and shows the . . .

246.The pneumatic vertical speed indicator uses . . . . . .pressure.

247. The airspeed indicator uses pitot and static pressure. Why?

248. What means IAS and CAS and what is the difference between them ?

249. What means TAS and what is the difference between CAS ?

250. What means GS and what is the difference between TAS ?

251. The Mach number is a relation betweeen :

252. The speed of sound in air depends on:

253. What means Vmo and Mmo and for what they are used ?

254. Name all inputs airdata computer is using.

255. How the airdata computer converts pneumatic pressures to electric data ?

256. Name all outputs of airdata computer

257. The airdata module in a modern aircraft senses:

Gyros

258. Name the two behaviours of a rotating mass

259. A rotating gyro is distorted, in which direction it will deflect ?

260. Gyro-wheels are driven by:

261. Name different types of gyros

262. A vertical gyro is used for:

263. At which place on earth a vertical gyro will have maximum apparent drift ?
How much is this drift rate ?

264. The vertical gyro is vertically erected by:

265. Name the angles they are outputed from a VG

266. A directional gyro is used for:

267. At which place on earth a directional gyro will have maximum apparent drift ? How much is this drift rate ?

268. How the directional gyro can be slaved?

269. A rate gyro is used to:

270. The bank angle of a correct flown courve depends on:

271. In which direction the ball of the inclinometer deflects, when the aircraft is flying to fast in to right turn ?

272. What is sensed by laser gyros and where they are used ?

Compass

273. Where is the magnetic north pole of the earth located ?

274. What is Variation and the reason for this ?

275. What is Inclination and the reason for this ?

276. Under which conditions the readings of a magnet compass is correct ?

277. How to eliminate the deviation of a magnet compass ?

278. Where is the flux valve installed and for what it is used ?

279. The advantage of a gyro stabilized compass system over a compass is:

280. A DG is running free (not slaved), the apparent drift in Zurich (47°N) is

281. What contains a fluxvalve ?

282. Name some indicators showing the magnetic heading

283. Some compasses are equiped with a synchronizing knob, why ?

284. Name the errors existing in a magnet compass

285. Newer compass systems will not use flux valves anymore.
How they determine the magnetic heading ?

Inertial Navigation

286. What means latitude and longitude?

287. Express the coordinates of Zurich airport.

288. Name the components inside the system

289. The basic value used for inertial navigation is:

290. Why the instruments are fixed on a plattform ?

291. Newer systems are using strap down technology, what does this mean ?

292. A ringlaser gyro senses:

293. How the accelerometers are linearized, to have a high sensitivity ?

294. Alignemt of the system, what does this mean ?

295. For alignment the system needs from pilots following inputs:

296. The system is using airdata altitude and airspeed, why ?

297. Name the navigation parameter computed by inertial navigation system.

ADF

298. The ADF shows the direction toward a . . . .

299. Name the two antennas used for ADF.

300. Descibe construction and the purpose of the loop antenna

301. How many "nulls" are there , when a loop antenna is rotated in a radio field ?

302. Describe the construction and purpose of the sense antenna

303. The frequency range is from . . . . .to . . . .

304. Which indicator shows the ADF direction and how is this direction named ?

305. What is the difference between relative and absolute bearing ?

VHF NAV

306. VHF NAVIGATION comprises following functions

307. Name the frequency bands VHF NAV is working

ILS

308. The ILS comprises following functions:

309. What is the purpose of the Localizer

310. Name the LOC frequency band

311. What is the purpose of the Glidepath

312. Name the GP frequency band

313. How the ILS receiver will be tuned

314. Beside the frequency selection, on other selection is necessary. Name it

315. Where are the localizer and glidepath transmitters located ?

316. How the receiver in the aircraft is detecting LOC or GP deviation ?

317. One Dot localizer deviation represents:

318. The LOC deviation pointer is deflecting toward rh. side.
The aircraft position is on the .side from runway centerline.

319. The GP deviation pointer is deflecting toward up.
The aircraft position is on the . . . . .side of the glidepath beam.

320.One Dot glidepath deviation represents:

321.Name the mode sequences of an ILS approach

322.Name the landing categories and their minimum visual range

VOR

323.Where are VOR ground stations located, in which range they are useable ?

324.Describe the signal VOR transmitters are radiating

325.The operation principle of Doppler-VOR is:

326.In which frequency band VOR is operating ?

327 The needed selections in the cockpit for VOR operation is:

328.Name all possible VOR indications and their indicator in the cockpit

329.How the VOR-receiver is detecting the bearing ?

330.The deviaton bar is deflecting one dot toward left that means.

331.What means TO/FROM, how will this be presented to the users ?

332.The correct VOR reception is monitored by:

Marker

333.Where are Marker Beacons located ?

334.Name all the different Markers

335.What means Z- or Fan- Marker, where they are located ?

336.The Marker carrier frequency is:

337.How the receiver distinguishes different markers, the aircraft is overflying ?

338.How a passing of marker is represented in the cockpit

Radio Altimeter

339. The RA detects:

340. The functional principle of a radio altimeter is:

341. The operation range of the RA is:

342. The operation frequency of a RA is:

343. How the results of the RA is represented ?

344. What means DH

345. How many antennas are used for one system and name their function

346. Name some aircraft systems using radio altitude

347. How to verfy that the RA is correct operating ?

GPWS

348. The purpose of a GPWS is

349. Name all possible alert situation of the ground proximity warning system.

350. How the pilots are alerted ?

351. The most important inputs of a GPWS are:

352. The GPWS is using discrete inputs Gear and Flap position, why

353. What means call out ?

354. Additionally the EGPW alerts the pilots in following cases:

355. How the EGPWS is determining a dangerous terrain clearance alert

356. Name the possible related switches located in the cockpit

357. Stall and Windshear alert are inputed to the GPWS, why

Wx Radar

358. Name the purpose of the weather radar

359. The operation principle of a weather radar is:

360. The different colours on the display means:

361. Name the possible operation modes and selections

362. The turbulence and windshear detection is based on following principle:

363. In which frequency band Wx radar is working

364. The radiated rf power is:

365. The rf connection line between antenna an transceiver is called:

366. The antenna is stabilized by the attitude signal, why ?

367. To operate the weather radar, observe following safety precautions:

DME

368. The purpose of this system is:

369. Name different types of DME ground stations

370. The operation principle of DME is:

371. In which frequency range DME is operating and how the system is tuned ?

372. How each interrogator recognizes its corresponding answerpulses ?

373. The aircraft overflies a DME ground station. The DME read-out shows:

374. Transmission- receive-frequency, is it equal or how much is the difference

375. A modern interrogator is able to scan simultanously following DME stations:

376. The audio signal, what is their purpose ?

377. Supression, what does this mean ?

ATC

378. Name the two groups of surveillance radars

379. In which modes the ATC transponder will operate ?

380. The selectable code ranges from . . . . . . to . . . .

381. What is the purpose of the IDENT button ?

382. In which interrogation mode the altitude reporting is active ?

383. Name the advantages of mode S over the mode A

384. How many databit a mode A/C and mode S transponder is able to send ?

385. Fleet identification is used to:

386. The Rx/Tx frequency of the transponder is:

387. To which systems the suppression line is connected ?

TCAS

388. What is the purpose of the system ?

389. What means TCAS I, II or III ?

390. Name the components of TCAS

391. The TCAS computer communicates with the . . . of the intruding aircraft

392. The TCAS computer is able to determine following data for each intruder:

393. To coordinate evasive maneuvres, both planes must be equipped with:

394. TCAS transmits on: . . . . . . MHz and receives on: . . . MHz

395. Describe the antennas, where are they located ?

396. What means TA and RA ?

397. How a resolution advisory is indicated ?

GPS

398.The GPS receiver determines following informations:

399.Is the GPS an independant or a dependant navigation system ?

400.The GPS receiver determines its position in the following manner:

401.How many satellites must be in minimum "visible" for correct navigation ?

402.Are the satellites in a geosynchronous orbit ? They are in which height ?

403.In which frequency the receiver works ?

404.How the satellites determines the accurate time ?

405.How the receiver determines the accurate time ?

406.The control segment of GPS comprises the following stations

407.How to increase the accurancy of GPS i.e. approaches and landings

FMS

408.What is the purpose of a flight management system?

409.What means lateral navigation ?

410.Name some data sources used for lateral navigation

411.What means profile navigation ?

412.In which modes and aspects the profile mode is operating

413.The FMS is using input signals from:

414.The FMS provides outputs to:

415.Name the databases of the FMS

416.The navigation data base stores following data

How often the FMS database must be updated?

13.5 Electrical Power (ATA 24)

417. How a brush less generator works?

418. How the voltage regulator works?

419. How a CSD works?

420. For which purpose the disconnect mechanism is provided?

421. How can the disconnected generator be reconnected?

422. What means IDG?

423. The output voltage, current and power of a IDG is:

424. How the IDG is cooled?

425. The emergency generator is provided for following cases:

426. How the emergency generator is driven?

427. Name their electrical output parameters

428. How their frequency is controlled?

429. A transformer/rectifier unit contains:

430. The output voltage and current of a T/R-unit is:

431. The T/R is protected against:

432. What is the purpose of a static inverter?

433. The power source of static inverter is:

434. The output voltage and power of the inverter is:

435. Name the battery voltage and capacity

436. What is the meaning of differential current protection?

437. Name two different types of power distribution systems

438. The Bus Tie Breaker closes in following conditions

439. The advantage of the parallel power system is:

440. Under which condition the generators can be paralleled?

441. Name the AC voltages of the power distribution system

442. Name the DC voltages of the power distribution system

443. Is the aircraft structure used to conduct electrical current

444. The aircraft is parked on ground. From where electrical power is provided?

445. Name all protections in the power distribution system.

446. If the aircraft is under electrical power, verify that:

13.6 Equipment and Furnishing (ATA 25)

13.7 Flight Controls (ATA 27)

13.8 Instrument Systems (ATA 31)

Fundamentals

447. Name position sensing systems

448. Which of them operates with DC

449. The difference between a potentiometer and a rheostat is:

450. What is a control transormer ?

451. How many voltage null and maximum occures when the rotor is rotated 360°

452. How a synchro is build up ?

453. Explain in brief words a direct torquer system

454. Synchros with servo loop are used if:

455. How the Rx synchro rotor is positioned in a nulled servo loop ?

456. What is a differential synchro ?

457. What is a resolver ?

458. Name two possible applcations for the resolver

459. How a LVDT is build up

460. What is the difference between LVDT and RVDT ?

461. Which kind demodulation is necessary for position reading with LVDT/RVDT ?

462. How a DC servo loop is build up ?

463. How to drive an AC motor in a DC servo loop ?

464. Desribe the possible phase angles in the windings of a two phase ac motor

465. What is the purpose of a tacho generator in a servo loop ?

466. The tacho generator output can have following phase angles and frequencies:

467. Name some pressure sensing devices.

468. Which of them are working electrically ?

469 Which of them has the highest accurancy ?

470. Name some quantity sensing systems

471. Which technology is used for fuel quantity indication in a car or light aircraft ?

472. The meter of this system has two coils, why ?

473. Which technology is used for a accurate fuel quantity indication system ?

474. The capacitance of a capacitor depends on:

475. The capacitance current, is it proportional of the capacitance

476. Name the dielectric constant of air and fuel

477. What is the purpose of the compensator in the fuel tank ?

478. How the capacitance bridge reads the fuel quantity ?

479. In which units the fuel quantity indication is represented

480. Are there aditional technologies to increase the accurancy ?

481. Name all known temperature sensing systems

482. Name the two types of temperature dependant resistors

483. List the different instrument types used with temperature dependant resistors

484. A thermo couple consits of following material:

485. The wires between thermo couple and instrument must consist of:

486. Where thermo couples are used ?

487. The advantage of thermo couple temperature indicating system is:

Flight Data Recording

488. The purpose of the flight data recorder is:

489. List the different construction technologies of FDR's

490. The FDR records the following parameter:

491. The recording capacity is how many hours ?

492. What is the purpose of the Flight Data Acquisition Unit ?

493. Where is the FDR located ?

494. When is the FDR recording ?

495. The EVENT button will:

496. Can the recordings be ereased after a successfull landing ?

497. The under water locator beacon (ULB) is used to:

498. The ULB is capable to operate for how many hours and which range ?

499. Where is the 3 axis accelerometer located

500. Name its data and in which format is the output signal ?

Aircraft Data Acquisition System

(See also condition monitoring ata-45)

501. What is the purpose of this system

502. Where are the data stored ?

503. How to read the stored data ?

504. Name the recording media of the associated recorder

505. How the data comes from aircraft to the airline host-computer ?

506. On ground, the recorded data is used for:

507. Where are all the data stored on ground

13.9 Lights (ATA 33)

13.10 On Board Maintenance Systems (ATA 45)