SHA-SHIB GROUP OF INSTITUTIONS

Training Notes

Module 13- Aircraft Aerodynamics, Structures and Systems

SHA-SHIB GROUP

EMPOWERING KNOWLEDGE THROUGH VISION

FOREWORD

UNCONTROLLED COPY

- The information in this book is for study/ training purposes only and no revision service will be provided to the holder.

- While carrying out a procedure/ work on aircraft/ aircraft equipment you must always refer to the relevant Aircraft Maintenance Manual or Equipment Manufacturer's Handbook.

- For health and safety in the workplace you should follow the regulations/ Guidelines as specified by the Equipment Manufacturer, your company, National Safety Authorities and National Governments.

Knowledge Levels – Category A, B1, B2, B3 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1, B2 and B3 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each application subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.
The knowledge level indicators are defined as follows:

LEVEL 1

- A familiarization with the principal elements of the subject.

Objectives: The applicant should be familiar with the basic elements of the subject.

- The applicant should be able to give a simple description of the whole subject, using common words and examples.
- The applicant should be able to use typical terms.

LEVEL 2

- A general knowledge of the theoretical and practical aspects of the subject.
- An ability to apply that knowledge.

Objectives: The applicant should be able to understand the theoretical fundamentals of the subject.

- The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

- A detailed knowledge of the theoretical and practical aspects of the subject.
- A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives: The applicant should know the theory of the subject and interrelationships with other subjects.

- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- The applicant should understand and be able to use mathematical formulae related to the subject.
- The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
- The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

: DGCA MODULARISATION :-

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CAR – 66 ISSUE II R 2

(LICENSING OF AIRCRAFT MAINTENANCE ENGINEERS)

DIRECTORATE GENERAL OF CIVIL AVIATION

TECHNICAL CENTRE, OPP SAFDURJUNG AIRPORT, NEW DELHI

Modules	Subject	A or B1 Aero plane with		A or B1 Helicopter with		B2
		Turbine Engine (s)	Piston Engine (s)	Turbine Engine (s)	Piston Engine (s)	Avionics
1	Not Applicable					
2	Not Applicable					
3	ELECTRICAL FUNDAMENTALS	X	X	X	X	X
4	ELECTRONIC FUNDAMENTALS	X	X	X	X	X
5	DIGITAL TECHNIQUES ELECTRONIC INSTRUMENT SYSTEMS	X	X	X	X	X
6	MATERIALS AND HARDWARE	X	X	X	X	X
7A	MAINTENANCE PRACTICES	X	X	X	X	X
7B	MAINTENANCE PRACTICES					
8	BASIC AERODYNAMICS	X	X	X	X	X
9A	HUMAN FACTORS	X	X	X	X	X
9B	HUMAN FACTORS					
10	AVIATION LEGISLATION	X	X	X	X	X
11A	TURBINE AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS	X				
11B	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS		X			
11C	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS					
12	HELICOPTER AERODYNAMICS, STRUCTURES AND SYSTEMS			X	X	
13	AIRCRAFT AERODYNAMICS, STRUCTURES AND SYSTEMS					X
14	PROPULSION					X
15	GAS TURBINE ENGINE	X		X		
16	PISTON ENGINE		X		X	
17A	PROPELLER	X	X			
17B	PROPELLER					

MODULE 13. Aircraft Aerodynamics, Structures and Systems		LEVEL	
		B1.1	B2
13.1	**13.1 Theory of Flight 1** (a) Aeroplane Aerodynamics and Flight Controls Operation and effect of: — roll control: ailerons and spoilers, — pitch control: elevators, stabilators, variable incidence stabilisers and canards, — yaw control, rudder limiters; Control using elevons, ruddervators; High lift devices: slots, slats, flaps; Drag inducing devices: spoilers, lift dumpers, speed brakes; Operation and effect of trim tabs, servo tabs, control surface bias; (b) High Speed Flight Speed of sound, subsonic flight, transonic flight, supersonic flight; Mach number, critical Mach number; (c) Rotary Wing Aerodynamics Terminology; Operation and effect of cyclic, collective and anti-torque controls.	-	1
13.2	**13.2 Structures — General Concepts** (a) Fundamentals of structural systems; 1 (b) Zonal and station identification systems; Electrical bonding; Lightning strike protection provision.	-	2
13.3	**13.3 Autoflight (ATA 22) 3** Fundamentals of automatic flight control including working principles and current terminology; Command signal processing; Modes of operation: roll, pitch and yaw channels; Yaw dampers; Stability Augmentation System in helicopters; Automatic trim control; Autopilot navigation aids interface; Autothrottle systems; Automatic Landing Systems: principles and categories, modes of operation, approach, glideslope, land, go-around, system monitors and failure conditions.	-	3
13.4	**13.4 Communication/Navigation (ATA 23/34)** Fundamentals of radio wave propagation, antennas, transmission lines, communication, receiver and transmitter; Working principles of following systems: — Very High Frequency (VHF) communication, — High Frequency (HF) communication, — Audio, — Emergency Locator Transmitters, — Cockpit Voice Recorder,	-	3

	— Very High Frequency omnidirectional range (VOR), — Automatic Direction Finding (ADF), — Instrument Landing System (ILS), — Microwave Landing System (MLS), — Flight Director systems, Distance Measuring Equipment (DME), — Very Low Frequency and hyperbolic navigation (VLF/Omega), — Doppler navigation, — Area navigation, RNAV systems, — Flight Management Systems, — Global Positioning System (GPS), Global Navigation Satellite Systems (GNSS), — Inertial Navigation System, — Air Traffic Control transponder, secondary surveillance radar, — Traffic Alert and Collision Avoidance System (TCAS), — Weather avoidance radar, — Radio altimeter, — ARINC communication and reporting.		
13.5	**13.5 Electrical Power (ATA 24)** Batteries Installation and Operation; DC power generation; AC power generation; Emergency power generation; Voltage regulation; Power distribution; Inverters, transformers, rectifiers; Circuit protection; External/Ground power.	-	3
13.6	**13.6 Equipment and Furnishings (ATA 25)** Electronic emergency equipment requirements; Cabin entertainment equipment.	-	3
13.7	**13.7 Flight Controls (ATA 27)** (a) Primary controls: aileron, elevator, rudder, spoiler; Trim control; Active load control; High lift devices; Lift dump, speed brakes; System operation: manual, hydraulic, pneumatic; Artificial feel, Yaw damper, Mach trim, rudder limiter, gust locks. Stall protection systems; (b) System operation: electrical, fly-by-wire.	-	2
13.8	**13.8 Instruments (ATA 31)** Classification; Atmosphere; Terminology; Pressure measuring devices and systems; Pitot static systems; Altimeters; Vertical speed indicators; Airspeed indicators; Machmeters; Altitude reporting/alerting systems; Air data computers; Instrument pneumatic systems;	-	3

	Direct reading pressure and temperature gauges; Temperature indicating systems; Fuel quantity indicating systems; Gyroscopic principles; Artificial horizons; Slip indicators; Directional gyros; Ground Proximity Warning Systems; Compass systems; Flight Data Recording systems; Electronic Flight Instrument Systems; Instrument warning systems including master warning systems and centralised warning panels; Stall warning systems and angle of attack indicating systems; Vibration measurement and indication; Glass cockpit		
13.9	**13.9 Lights (ATA 33)** External: navigation, landing, taxiing, ice; Internal: cabin, cockpit, cargo; Emergency.	-	3
1310	**13.10 On Board Maintenance Systems (ATA 45)** Central maintenance computers; Data loading system; Electronic library system; Printing; Structure monitoring (damage tolerance monitoring).	-	3
13.11	**13.11 Air Conditioning and Cabin Pressurisation (ATA21)** 1) Air supply Sources of air supply including engine bleed, APU and ground cart; 2) Air Conditioning Air conditioning systems; Air cycle and vapour cycle machines; Distribution systems; Flow, temperature and humidity control system. 3) Pressurisation Pressurisation systems; Control and indication including control and safety valves; Cabin pressure controllers. 4) Safety and warning devices Protection and warning devices.	-	2
13.12	**13.12 Fire Protection (ATA 26)** (a) Fire and smoke detection and warning systems; Fire extinguishing systems; System tests; (b) Portable fire extinguisher	-	3
13.13	**13.13 Fuel Systems (ATA 28)** System lay-out; Fuel tanks; Supply systems; Dumping, venting and draining; Cross-feed and transfer;	-	3

	Indications and warnings; Refuelling and defuelling; Longitudinal balance fuel systems.		
13.14	**13.14 Hydraulic Power (ATA 29)** System lay-out; Hydraulic fluids; Hydraulic reservoirs and accumulators; Pressure generation: electrical, mechanical, pneumatic; Emergency pressure generation; Filters; Pressure control; Power distribution; Indication and warning systems; Interface with other systems.	-	3
13.15	**13.15 Ice and Rain Protection (ATA 30)** Ice formation, classification and detection; Anti-icing systems: electrical, hot air and chemical; De-icing systems: electrical, hot air, pneumatic, chemical; Rain repellent; Probe and drain heating; Wiper Systems.	-	3
13.16	**13.16 Landing Gear (ATA 32)** Construction, shock absorbing; 1 Extension and retraction systems: normal and emergency; 3 Indications and warnings; 3 Wheels, brakes, antiskid and autobraking; Tyres; 1 Steering; 3 Air-ground sensing.	-	3
13.17	**13.17 Oxygen (ATA 35)** System lay-out: cockpit, cabin; 3 Sources, storage, charging and distribution; 3 Supply regulation; 3 Indications and warnings.	-	3
13.18	**13.18 Pneumatic/Vacuum (ATA 36)** System lay-out; 2 Sources: engine/APU, compressors, reservoirs, ground supply; 2 Pressure control; 3 Distribution; 1 Indications and warnings; 3 Interfaces with other systems.	-	3
13.19	**13.19 Water/Waste (ATA 38) 2** Water system lay-out, supply, distribution, servicing and draining; Toilet system lay-out, flushing and servicing.	-	3
13.20.	**13.20 Integrated Modular Avionics (ATA42)** 3 Functions that may be typically integrated in the Integrated Modular Avionic (IMA) modules are, among others: Bleed Management, Air Pressure Control, Air Ventilation and Control, Avionics and Cockpit Ventilation Control, Temperature Control, Air Traffic Communication, Avionics Communication Router, Electrical Load Management, Circuit Breaker Monitoring, Electrical System BITE, Fuel Management, Braking Control, Steering Control, Landing Gear Extension and Retraction, Tyre Pressure Indication, Oleo	-	3

	Pressure Indication, Brake Temperature Monitoring, etc.; Core System; Network Components.		
13.21	**13.21 Cabin Systems (ATA44)** 3 The units and components which furnish a means of entertaining the passengers and providing communication within the aircraft (Cabin Intercommunication Data System) and between the aircraft cabin and ground stations (Cabin Network Service). Includes voice, data, music and video transmissions. The Cabin Intercommunication Data System provides an interface between cockpit/cabin crew and cabin systems. These systems support data exchange of the different related LRU's and they are typically operated via Flight Attendant Panels. The Cabin Network Service typically consists on a server, typically interfacing with, among others, the following systems: — Data/Radio Communication, In-Flight Entertainment System The Cabin Network Service may host functions such as: — Access to pre-departure/departure reports, — E-mail/intranet/Internet access, — Passenger database; Cabin Core System; In-flight Entertainment System; External Communication System; Cabin Mass Memory System; Cabin Monitoring System; Miscellaneous Cabin System.	-	3
13.22	**13.22 Information Systems (ATA46)** 3 The units and components which furnish a means of storing, updating and retrieving digital information traditionally provided on paper, microfilm or microfiche. Includes units that are dedicated to the information storage and retrieval function such as the electronic library mass storage and controller. Does not include units or components installed for other uses and shared with other systems, such as flight deck printer or general use display. Typical examples include Air Traffic and Information Management Systems and Network Server Systems. Aircraft General Information System; Flight Deck Information System; Maintenance Information System; Passenger Cabin Information System; Miscellaneous Information System.	-	3

Module 13: Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of DGCA, CAR – 66 (Appendix I) and the associated Knowledge Levels as specified.

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13.1 Theory of Flight

(a) Aeroplane Aerodynamics and Flight Controls Operation and effect of:
— roll control: ailerons and spoilers,
— pitch control: elevators, stabilators, variable incidence stabilisers and canards,
— yaw control, rudder limiters; Control using elevons, ruddervators; High lift devices: slots, slats, flaps; Drag inducing devices: spoilers, lift dumpers, speed brakes; Operation and effect of trim tabs, servo tabs, control surface bias;

(b) High Speed Flight
Speed of sound, subsonic flight, transonic flight, supersonic flight; Mach number, critical Mach number;

(c) Rotary Wing Aerodynamics Terminology;
Operation and effect of cyclic, collective and anti-torque controls.

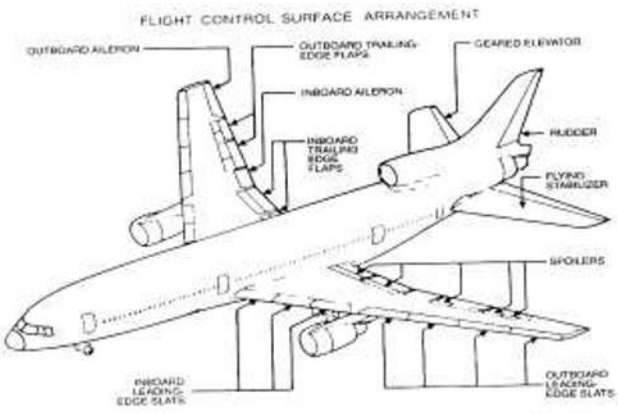
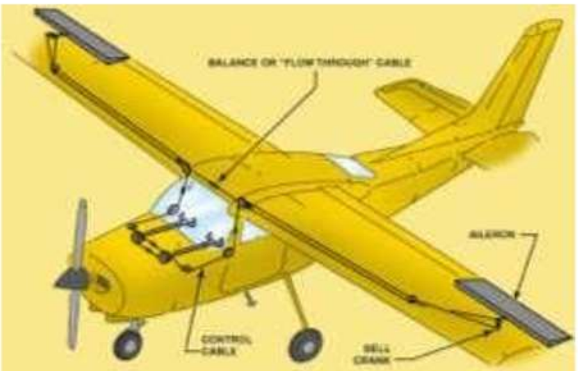


FIGURE 5–16 L-1011 flight controls. (Lockheed Corp.)

(a) Aeroplane Aerodynamics and Flight Controls

The purpose of flight controls is to allow the pilot to maneuver the airplane, and to control it from the time it starts the takeoff roll until it lands and safely comes to a halt. Flight controls are typically associated with the wing and the vertical and horizontal stabilizers, because these are the parts of the airplane that flight controls most often attach to.
In flight, and to some extent on the ground, flight controls provide the airplane with the ability to move around one or more of the three axes. Flight controls function by changing the shape or aerodynamic characteristics of the surface they are attached to. Aircraft flight control systems consist of primary and secondary systems. The ailerons, elevator, and rudder constitute the primary control system and are required to control an aircraft safely during flight.



Operation and effect of:
CONTROLS ABOUT THE LONGITUDINAL AXIS

Roll control: ailerons

Ailerons control roll about the longitudinal axis. The ailerons are attached to the outboard trailing edge of each wing and move in
the opposite direction from each other. Ailerons are connected by cables, bell cranks, pulleys and/or push-pull tubes to a control wheel or control stick. The corresponding downward deflection of the left aileron increases the camber resulting in increased lift on the left wing. Thus, the increased lift on the left wing and the decreased lift on the right wing cause the airplane to roll to the right.
Moving the control wheel or control stick to the right causes the right aileron to deflect upward and the left aileron to deflect downward. The upward deflection of the right aileron decreases the camber resulting in decreased lift on the right wing.

ADVERSE YAW

Downward deflected aileron produces more lift, it
also produces more drag. This added drag causes the wing to slow down slightly. This results in the aircraft yawing toward the wing

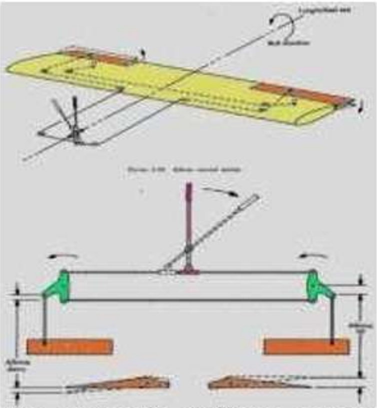
which had experienced an increase in lift (and drag). The adverse yaw is a result of differential drag and the slight difference in the velocity of the left and right wings.
Adverse yaw is caused by higher drag on the outside wing, which is producing more lift.
To reduce the effects of adverse yaw, following systems are used:

Differential ailerons, Fraise-type ailerons,
Coupled ailerons and rudder, and Flaperons.

DIFFERENTIAL AILERONS

With differential ailerons, one aileron is raised a greater distance than the other aileron is lowered for a given movement of the control wheel or control stick.

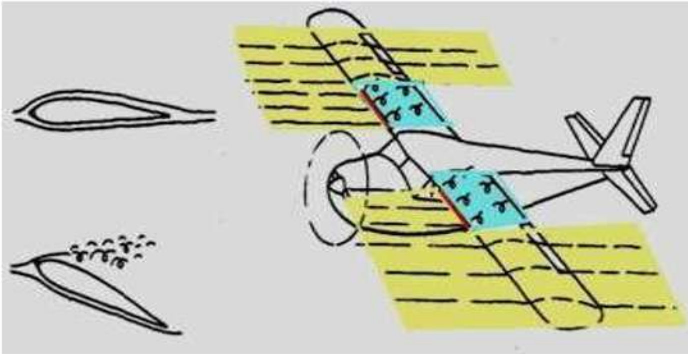
SPOILERS



The purpose of spoilers is to disturb the smooth airflow across the top of the airfoil there by creating an increased amount of drag and a decreased amount of lift. Some spoilers are automatic in

operation in that they come into operation only at high angle of attack. This arrangement keeps them out of

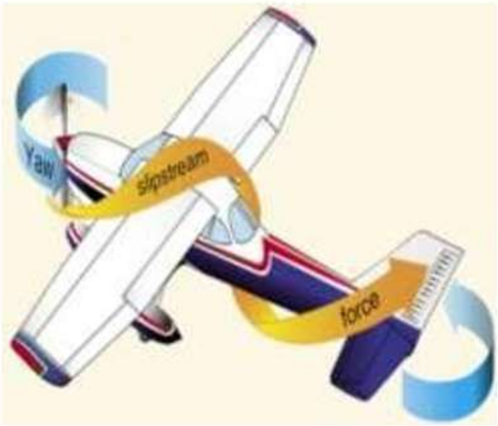
the slipstream at cruise and high speeds.
FIXED SPOILER - Fixed spoiler are a small wedge affixed to the leading edge of the airfoil as shown. This type spoiler causes the inboard portion of the wing to stall ahead of the outboard portion which results in aileron control fight up to the occurrence of complete wing stall.



CONTROLS AROUND VERTICAL AXIS

Yaw control, rudder limiters

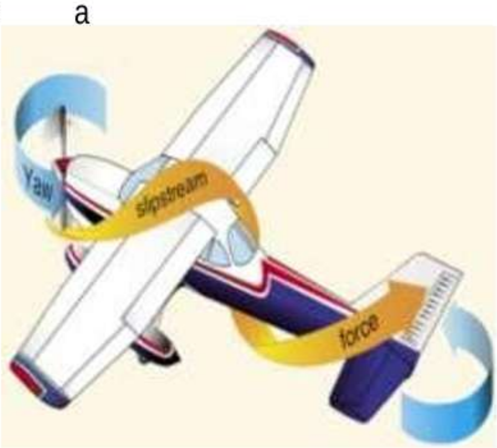
The rudder controls movement of the aircraft about its vertical axis. This motion is called yaw. Like the other primary control surfaces, the rudder is a movable surface hinged to a fixed surface, in this case to the vertical stabilizer, or fin. Moving the left or right rudder pedal controls the rudder.



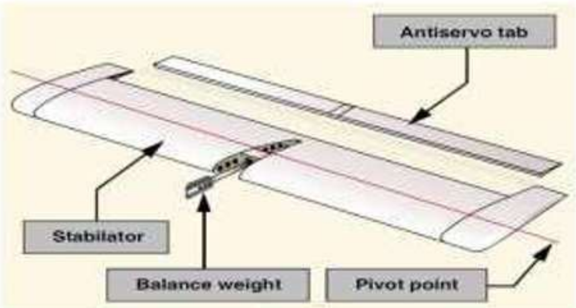
When the rudder is deflected into the airflow, a horizontal force is exerted in the opposite direction. By pushing the left pedal, the rudder moves left. This alters the airflow around the vertical stabilizer/rudder, and creates a sideward lift that moves the tail to the right and yaws the nose of the airplane to the left.
Rudder effectiveness increases with speed; therefore, large deflections at low speeds and small deflections at high speeds may be required to provide the
desired reaction. In propeller-driven aircraft, any slipstream flowing over the rudder increases its effectiveness.
The main function of rudder is to turn the a/c in flight. This turn is maintained by the side
pressure of the air moving past the vertical surface. When an a/c being to slip or skid, rudder pressure is applied to keep the a/c headed to its desired direction (balanced).
Slip or side slipping refers to any motion of the a/c to the side and downward toward the inside of a turn. Skid or skidding refers to any movement upward and outward away from the center of a turn.
V-TAIL - The V-tail design utilizes two slanted tail surfaces to perform the same functions as the surfaces of a conventional elevator and rudder configuration. The fixed surfaces act as both horizontal and vertical stabilizers.

RUDDERVATORS - The movable surfaces, which are usually called ruddervators, are connected through a special linkage that allows the control wheel to move both surfaces simultaneously. On the other hand, displacement of the rudder pedals moves the surfaces differentially, thereby providing directional control.

When both rudder and elevator controls are moved by the pilot, a control mixing mechanism moves each surface the appropriate amount. The control system for the V- tail is more complex than that required for a



conventional tail. In addition, the V-tail design is more susceptible to Dutch roll tendencies than a conventional tail, and total reduction in drag is minimal.

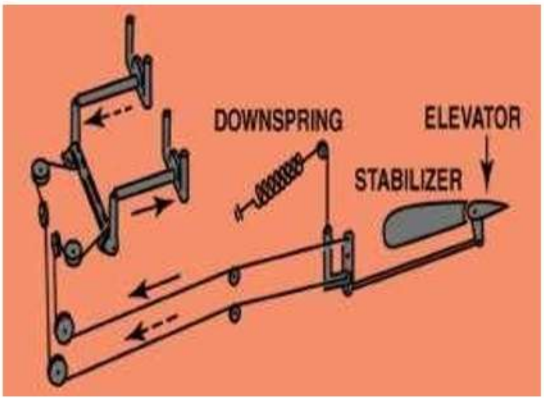


CONTROLS AROUND LATERAL AXIS — pitch control: elevators, stabilators, variable incidence stabilisers and canards The elevator controls pitch about the lateral axis. The elevator is connected to the control column in the flight deck by a series of mechanical linkages. Aft movement of the control column deflects the trailing edge of the elevator surface up.

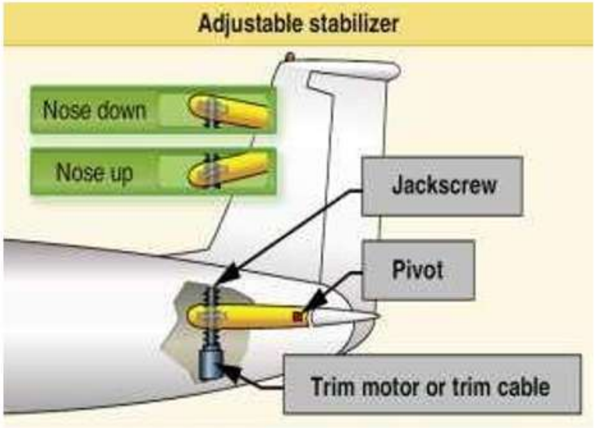
The up- elevator position decreases the camber of the elevator and creates a downward aerodynamic force, which is greater than the normal tail-down force that exists in straight-and-level flight. The overall effect causes the tail of the aircraft to

move down and the nose to pitch up. The pitching moment occurs about the center of gravity (CG). The strength of the pitching moment is
determined by the distance between the CG and the horizontal tail surface, as well as by the aerodynamic effectiveness of the horizontal tail surface. The elevator is the primary control for changing the pitch attitude of an airplane
T-Tail - The horizontal tail surfaces may be attached near the lower part of the vertical stabilizer, at the midpoint, or at the high point, as in the T-tail design. In a T-tail configuration, the elevator is above most of

the effects of downwash from the propeller as well as airflow around the fuselage and/or wings during normal flight conditions. Operation of the elevators in this undisturbed air allows control movements that are consistent throughout most flight regimes.
When flying at a very high AOA with a low airspeed and an aft CG, the T-tail aircraft may be susceptible to a deep stall. In a deep stall, the
airflow over the horizontal tail is blanketed by the disturbed airflow from the wings and fuselage. In



these circumstances, elevator or stabilator control could be diminished, making it difficult to recover from the stall.
ELEVATOR DOWN SPRING - An elevator down spring assists in lowering the nose of the aircraft to prevent a stall caused by the aft CG position. The elevator down spring produces a mechanical load on the elevator, causing it to move toward the nose-down position if not otherwise balanced. The elevator trim tab balances the elevator down spring to position the elevator in a trimmed position. When the trim tab becomes ineffective, the down spring drives the elevator to a nose-down position. The nose of the aircraft lowers, speed builds up, and a stall is prevented. When the



aerodynamic efficiency of the horizontal tail surface is inadequate due to an aft center of gravity condition, an elevator down spring may be used to supply a mechanical load to lower the nose.
STABILATOR - A stabilator is essentially a one-piece horizontal stabilizer that pivots from a central hinge point. When the control column is pulled back, it raises the stabilator‘s trailing edge, pulling the airplane‘s nose up. Pushing the control column forward lowers the trailing edge of the stabilator and pitches the nose of the airplane down.

Because stabilators pivot around a central hinge point, they are extremely sensitive to control inputs and aerodynamic loads. Antiservo tabs are incorporated on the trailing edge to decrease sensitivity. They deflect in the same direction as the stabilator. This result in an increase in the force required to move the stabilator, thus making it less prone to pilot- induced over controlling. One piece horizontal tail surface that pivots up and down about a central hinge point.

ADJUSTABLE STABILIZER

Rather than using a movable tab on the trailing edge of the elevator, some aircraft have an adjustable stabilizer or variable incidence stabilizer. With this arrangement, linkages pivot the horizontal stabilizer about its rear spar. This is accomplished by use of a jackscrew mounted on the leading edge of

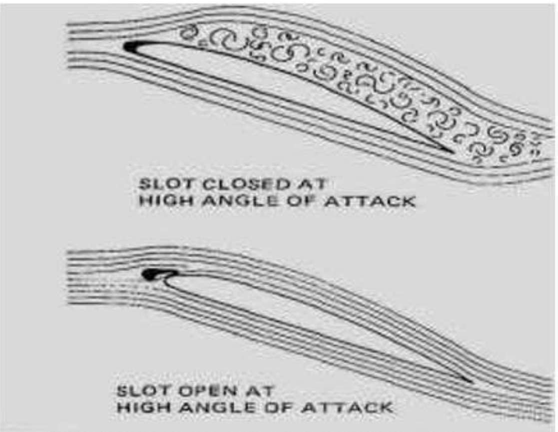
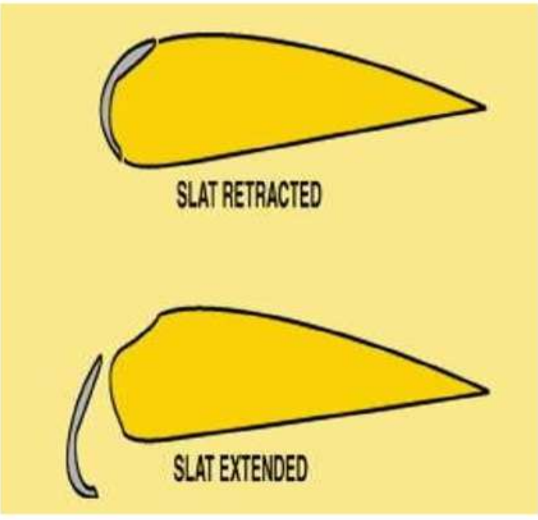


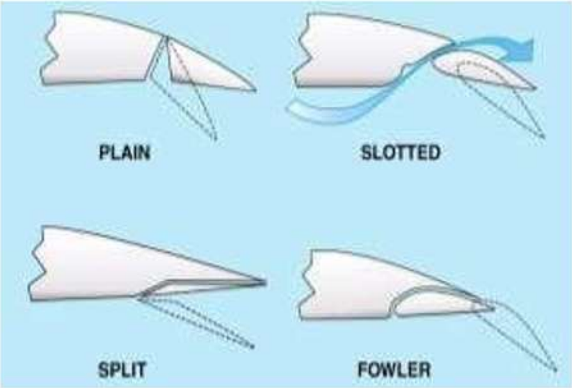
FIGURE 4–34 Effect of a slot on wing performance.

the stabilator. Some airplanes, including most jet transports, use an adjustable stabilizer to provide the required pitch trim forces.
Dual purpose control surface Elevons (Aileron + Elevator) Flaperons (Flap + Aileron)
All moving tail plane (Stabilizer + elevator) Ruddervators (Rudder + Elevator)

High lift devices: slots, slats, flaps SLOTS
Fixed slots direct airflow to the upper wing surface and delay airflow separation at higher angles of attack. The slot does not increase the wing camber, but allows a higher maximum CL because the stall is delayed until the wing reaches a greater AOA.
SLATS

Movable slats consist of leading edge segments, which move on tracks. At low angles of attack, each slat is held flush against the wing's leading edge by the high pressure that forms at the wing's leading edge.





As the AOA increases, the high-pressure area moves aft below the lower surface of the wing, allowing the slats to move forward. Some slats, however, are pilot operated and can be deployed at any AOA. Opening a slat allows the air below the wing to flow over the wing's upper surface, delaying airflow separation.

FLAPS

Flaps are the most common high-lift devices used on aircraft. These surfaces, which are attached to the trailing edge of the wing, increase both lift and induced drag for any given AOA.

Flaps allow a compromise between high cruising speed and low landing speed, because they may be extended when needed, and retracted into the wing's structure when not needed. They reduce the landing speed, thereby shortening the length of landing rollout. Flaps used during takeoff reduce the take off run. As flaps are extended, the stalling speed of the aircraft is reduced, which means that the aircraft can fly safely at slower speeds (especially during take offs and landings). Flaps increase the camber of the wing airfoil, thus raising the lift coefficient. This increase in lift coefficient allows the aircraft to generate a given amount of lift with a slower speed. Therefore, extending the flaps will reduce the stalling speed of an aircraft.

They also increase drag, which helps to slow the aircraft. A useful side effect of flap deployment is a decrease in aircraft pitch angle resulting from the increase in angle of attack relative to the fuselage. This allows the pilot to lower the nose for better ground visibility.

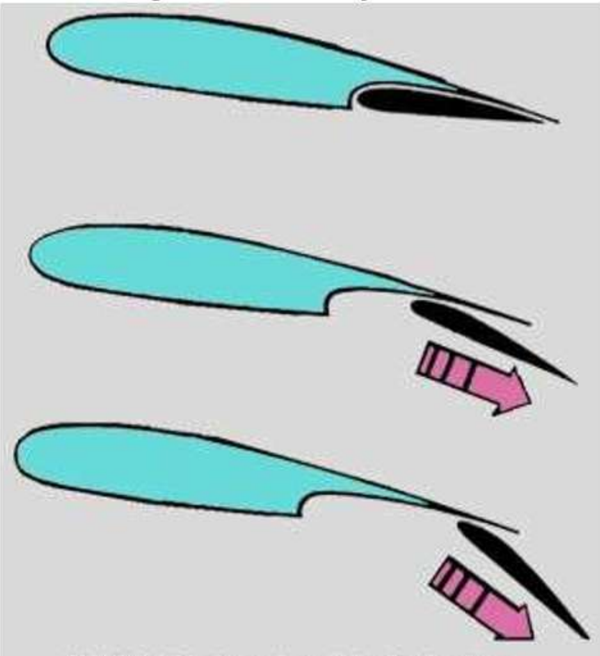
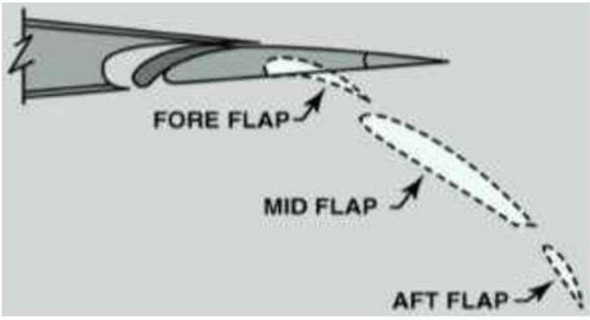


FIGURE 4-30 Operation of the Fowler flap.

Some trailing edge flap systems increase the plan form area of the wing in addition to changing the camber. In turn, the larger lifting surface will allow the aircraft to generate a given amount of lift with a slower speed, thus further reducing stalling speed. The Fowler flap is an example of a flap system that increases the plan form area of the wing in addition to increasing the camber.



The general airplane lift equation demonstrates these relationships where:
L is the lift,
ρ is the air density,

- V is the true airspeed of the airplane
- S is the plan form area of the wing and
- CL is the aircraft lift coefficient

Here, it can be seen that increasing the area (S) and lift coefficient (CL) will allow a similar amount of lift to be generated at a slower airspeed (V).

TYPES OF FLAPS - Most flaps are hinged to the lower trailing edges of the wings, inboard of the ailerons. These are common four types of flaps:

- Plain flaps.

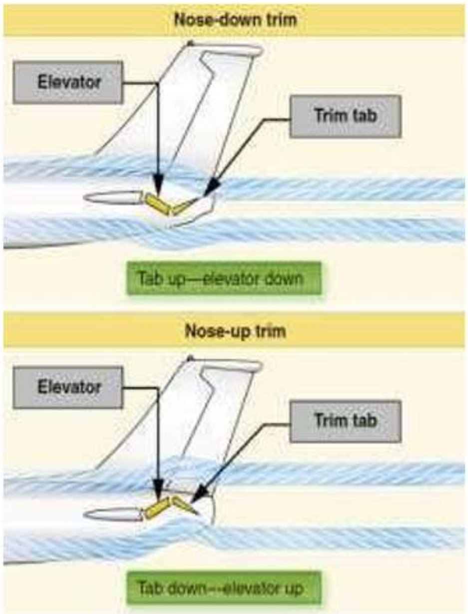
- Split flaps.

- Slotted flaps.

- Fowler flaps

When they are ―up‖ (or retracted) position, they fair in with the wings and serve as part of the wing trailing edge. When they are
―down‖ (or extended) position, the flaps pivot on the hinge points and drop to about 450 or 500 angle with wing chord line. This increases the wing camber and changes the airflow, providing greater lift.
Plain (simple and ordinary) Flap - The plain flap forms the trailing edge of the wing when the flap is in up (or retracted) position. 50% increase in lift. 12 degree angle of basic aerofoil at max lift. The complete rear section of the wing moves down. Increase camber and much drag when fully lowered. Nose-down pitching moment.
Split Flap - The plain split flap is remain flush with the undersurface of the wing. Plain split flap also called split edge flap. 60% increase in lift. 14 degree angle of basic aerofoil at max lift. The complete rear section

of the wing moves down. Increase camber and even much more drag than plain flap. Nose-down moment.
Slotted Flap - 65% increase in lift. 16 degree angle of basic aerofoil at max lift. The flap moves down and forms a slot between it and the wing. This allows some air through the slot from the bottom of the wing to the top of the flap keeping the top side clean from eddy currents and making the flap more efficient. Control of



boundary layer. Increase camber, stalling delayed and not so much drag.
Double-slotted Flap - 70% increase in lift. 18 degree angle of basic aerofoil at max lift. Same as single slotted flap only more doubled slots sometimes used.

Fowler flaps - In Fowler flaps – flaps flush under the wings much as does the plain split flap system. But, instead of the flaps hinging straight down from a stationary hinge line, worm-gear drives moves the flaps leading edge rearward as the flaps droop. This action provides
normal flap effect and at the same time wing areas is increased when the flaps are extended. 90% increase in lift. 15 degree angle of basic aerofoil at max lift. The flap move down and back to

effectively increase the wing area while producing a more cambered mean camber line. Increase camber and wing area. Best flap for lift and complicated mechanism. Nose-down pitching moment.
Double Slotted Fowler Flap - 100 increase in lift with an increase of stalling angle of 20 degree. The double slot allows air from under the flap to sweep the top surface clear of any turbulence.

FIGURE 5–18 Slipstream.

Zap Flap -
90% increase in lift. 13 degree angle of basic aerofoil at max lift. Increase camber and wing area. Much drag and Nose-down pitching moment.

TRIPLE SLOTTED TRAILING EDGE FLAPS - It is used in
large turbine a/c. This type of trailing flap system provides high lift for both takeoff and landing. Each flap consists of four-flap, a mid- flap, and an aft-flap. The chord length of each flap expands as the flap is extended, providing greatly increased flap area.
Drag inducing devices: spoilers, lift dumpers, speed brakes;
In aeronautics a spoiler (sometimes called a lift dumper) is a device intended to reduce lift in an aircraft.
Spoilers are plates on the top surface of a wing which can be extended upward into the airflow and spoil it. By doing so, the spoiler creates a carefully controlled stall over the portion of the wing behind it, greatly reducing the lift of that wing section. Spoilers differ from airbrakes in that airbrakes are designed to increase drag while making little change to lift, while spoilers greatly reduce lift while making only a moderate increase in drag.
Found on many gliders and some aircraft, high drag devices called spoilers are deployed from the wings to spoil the smooth airflow, reducing lift and increasing drag. On gliders, spoilers are most often used to control rate of descent for accurate landings. On other aircraft, spoilers are often used for roll control, an advantage of which is the elimination of adverse yaw.
To turn right, for example, the spoiler on the right wing is raised, destroying some of the lift and creating more drag on the right. The right-wing drops, and the aircraft banks and yaws to the right. Deploying spoilers on both wings at the same time allows the aircraft to descend without gaining speed. Spoilers are also deployed to help reduce ground roll after landing. By destroying lift, they transfer weight to the wheels, improving braking effectiveness.

SPOILERS AS CONTROL SURFACES - Some aircraft use spoilers in combination with or in lieu of ailerons for roll control, primarily to reduce adverse yaw when rudder input is limited by higher speeds. For such spoilers the term spoileron has been coined. In the case of a spoileron, in order for it to be used as a control surface, it is raised on one wing, thus decreasing lift and increasing drag, causing roll and yaw.

Operation and effect of trim tabs, servo tabs, control surface bias

Common types of trim systems include
- Trim tabs
- Balance tabs
- Anti servo tabs
- Ground adjustable tabs
- Adjustable stabilizer.

TRIM TABS

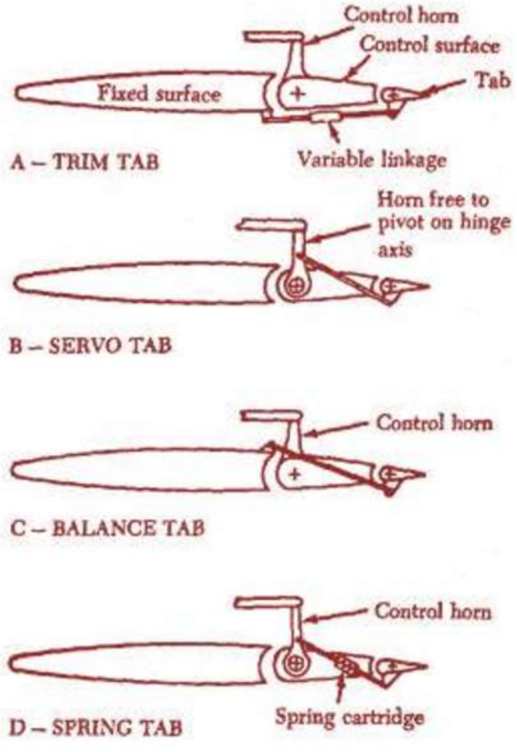
The most common installation on small aircraft is a single trim tab attached to the trailing edge of the elevator. The flight deck control includes a trim tab position indicator. Placing the trim control in the full nose-down position moves the trim tab to its full up position.
With the trim tab up and into the airstream, the airflow over the horizontal tail surface tends to force the trailing edge of the elevator down. This causes the tail of the airplane to move up, and the nose to move down. If the trim tab is set to the full nose-up position, the tab moves to its full down position. In this case, the air flowing under the horizontal tail surface hits the tab and forces the trailing edge of the elevator up, reducing the elevator‘s AOA. This causes the tail of the airplane to move down, and the nose to move up.

The movement of the elevator is opposite to the direction of movement of the elevator trim tab.
In spite of the opposing directional movement of the trim tab and the elevator, control of trim is natural to a pilot. If the pilot needs to exert constant back pressure on a control column, the need for nose-up trim is indicated. The normal trim procedure is to continue
trimming until the aircraft is balanced and the nose-heavy condition is no longer apparent.
Pilots normally establish the desired power, pitch attitude and configuration first, and then trim the aircraft to relieve control pressures that may exist for that flight condition. Any time power, pitch attitude, or configuration is

changed; expect that retrimming will be necessary to relieve the control pressures for the new flight condition.

TABS

Even though an a/c has inherent stability, it does not always tend to fly straight and level. The weight of the load and its distribution affect stability. Various speeds also affect its flight characteristics.
If the fuel in one wing tanks is used before that in the other wing tank, the a/c tends to roll toward the full tank.
All of these variations require constant exertion of pressure on the controls for correction. To offset the forces that tend to unbalance an a/c in flight, aileron, elevator & rudders are provided with auxiliary controls known as tabs. These are small, hinged control surfaces attached to the trailing edge of the primary control surface. Tabs can be moved up or down by means of a



crank or moved electrically from the cockpit.

SERVO TABS - Servo tabs, sometimes referred as flight tabs, are used primarily on the large main control surface. They aid in moving the control surface and holding it in desired position. Only the servo tab moves in response to the movement of the cockpit control.

The servo tab horn is free to pivot to the main control surface hinge axis. The force of the airflow on the servo tab then moves the primary control surface. With the use of a servo tab less force is needed to move the main control surface.

SPRING TABS - spring tabs are similar in appearance to trim tab, but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators; that is, to aid in moving a primary control surface. There are various spring arrangements used in the linkage of the spring tabs.
On some a/c, a spring tabs is hinged to the trailing edge of each aileron and is actuated by a spring loaded push pull rod assembly which is also linked to the other aileron control linkage. The linkage is connected in such a way that movement of the aileron in one direction causes the spring tab to be deflected in the opposite direction. This provides a balanced condition, thus reducing the amount of force required to move the ailerons.
The deflection of the spring tabs is directly proportional to the aerodynamic load imposed upon the aileron; there for, at low speeds the spring tabs remains in a neutral position and the aileron is a direct manually controlled surface. At high speeds however, where the aerodynamic load is greater, the tab functions as an aid in moving the primary control surface.

BALANCEING THE CONTROL SURFACE

To lessen the force required to operate the control surfaces they are usually balanced statically and aerodynamically. Aerodynamic balance is usually achieved by extending a portion of the control surfaces ahead of the hinge line. This utilizes the air flow about the a/c to aid in moving the surface.
STATIC BALANCE - Static balance is accomplished by adding weight to the section forwarded of the hinge line until it weighs the same as the section aft of it. An unbalanced surface has a tendency to flutter as air passes over it. Flutter – sustained oscillation, usually on wing, fin or tail caused by interaction of aerodynamic force, elastic reactions and inertia, which may rapidly break structure.
BALANCE TABS - The control forces may be excessively high in some aircraft, and, in order to decrease them, the manufacturer may use balance tabs. They look like trim tabs and are hinged in

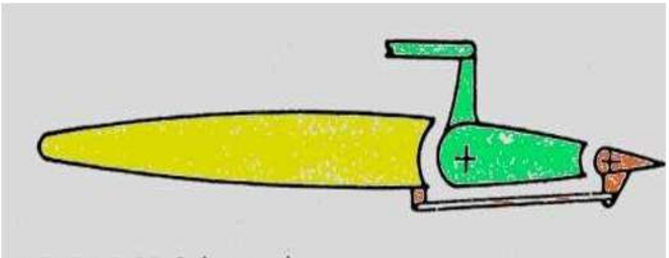
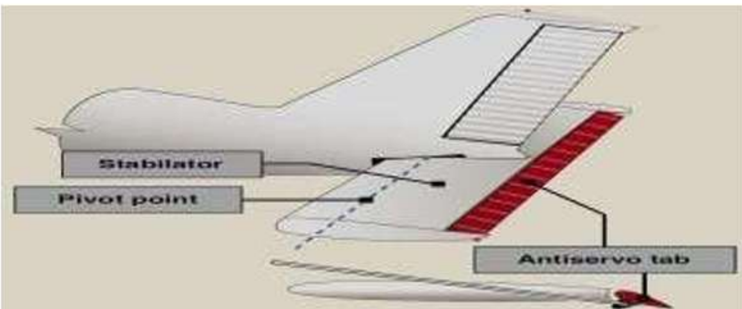


FIGURE 5–29 Balance tab.

approximately the same places as trim tabs. The essential difference between the two is that the balancing tab is coupled to



the control surface rod so that when the primary control surface is moved in any direction, the tab automatically moves in the opposite direction. The airflow striking the tab countercall ances some of the air pressure against the primary control surface, and enables the pilot to move more easily and hold the control surface in position. If the linkage between the balance tab and the fixed surface is adjustable from the flight deck, the tab acts as a combination trim and balance tab that can be adjusted to any desired deflection.

ANTISERVO TABS - Antiservo tabs work in the same manner as balance tabs except, instead of moving in the opposite direction, they move in the same direction as the trailing edge of the stabilator (Stabilizer + elevator). In addition to decreasing the sensitivity of the stabilator, an Antiservo tab also functions as a trim device to relieve control pressure and maintain the stabilator in the desired position. An Antiservo tab attempts to streamline the control surface and is used to make the stabilator less sensitive by opposing the force exerted by the pilot.

The fixed end of the linkage is on the opposite side of the surface from the horn on the tab; when the trailing edge of the stabilator moves up, the linkage forces the trailing edge of the tab up. When

the stabilator moves down, the tab also moves down. Conversely, trim tabs on elevators move opposite of the control surface.

GROUND ADJUSTABLE TABS - Many small aircraft have a non-movable metal trim tab on the rudder. This tab is bent in one direction or the other while on the ground to apply a trim force to the rudder.

The correct displacement is determined by trial and error. Usually, small adjustments are necessary until the aircraft no longer skids left or right during normal cruising flight. A ground adjustable tab is used on the rudder of many small airplanes to correct for a tendency to fly with the fuselage slightly misaligned with the relative wind.

(b) High Speed Flight THE SPEED OF SOUND

Sound, in reference to airplanes and their movement through the air, is nothing more than

pressure disturbances in the air. It is like dropping a rock in the water and watching the waves flow out from the center. As an airplane flies through the air, every point on the airplane that causes a disturbance creates

sound energy in the form of pressure waves. Sound is a vibration that travels through an elastic medium as a wave. The speed of sound describes how far this wave travels in a given amount of time. In dry air at 20 °C (68 °F), the speed of sound is 343 meters per second (1,125 ft/s). This equates to 1,236 kilometers per hour (768 mph), or about one mile in five seconds. This figure for air increases with gas temperature but is nearly independent of pressure or density for a given gas.
Although "the speed of sound" is commonly used to refer specifically to the speed of sound waves in air, the speed of sound can be measured in virtually any substance. Sound travels faster in liquids and non-porous solids (5,120 m/s in iron) than it does in air, traveling about 4.3 times faster in water (1,484 m/s) than in air at 20 degrees Celsius.
In the Earth's atmosphere, the most important factor affecting the speed of sound is the temperature. Since temperature and thus the speed of sound normally decrease with increasing altitude, sound is refracted upward, away from listeners on the ground, creating an acoustic shadow at some distance from the source.

SPEED RANGES

In high-speed flight and/or high-altitude flight, the measurement of speed is expressed in terms of a ―Mach number‖—the ratio of the true airspeed of the aircraft to the speed of sound in the

same atmospheric conditions. An aircraft traveling at the speed of sound is traveling at Mach 1.0.
Aircraft speed regimes are defined approximately as follows:

- Subsonic—Mach numbers below 0.75
- Transonic—Mach numbers from 0.75 to 1.20
- Supersonic—Mach numbers from 1.20 to 5.00
- Hypersonic—Mach numbers above 5.00

The speed of an aircraft in which airflow over any part of the aircraft or structure under consideration first reaches (but does not exceed) Mach 1.0 is termed ―critical Mach number‖ or ―Mach Crit.‖ Thus, critical Mach number is the boundary between subsonic and transonic flight and is largely dependent on the wing and airfoil design. Critical Mach number is an important point in transonic flight. When shock waves form on the aircraft, airflow separation followed by buffet and aircraft control difficulties can occur.
Shock waves, buffet, and airflow separation take place above critical Mach number. At speeds 5
- 10 percent above the critical Mach number, compressibility effects begin. Drag begins to rise sharply.

SUBSONIC FLIGHT

When an airplane is flying at subsonic speed, all of the air flowing around the airplane is at a velocity of less than the speed

of sound (known as Mach 1). Keep in mind that the air accelerates when it flows over certain parts of the airplane, like the top of the wing, so an airplane flying at 500 mph could have air over the top of the wing reach a speed of 600 mph. How fast an airplane can fly and still be considered in subsonic flight varies with the design of the wing, but as a Mach number, it will typically be just over Mach 0.8.

TRANSONIC FLIGHT

When an airplane is flying at transonic speed, part of the airplane is experiencing subsonic airflow and part is experiencing supersonic airflow. Over the top of the wing, probably about halfway back, the velocity of the air will reach Mach 1 and a shock wave will form. The shock wave forms 90 degrees to the airflow and is known as a normal shock wave.

Stability problems can be encountered during transonic flight, because the shock wave can cause the airflow to separate from the wing. The shock wave also causes the center of lift to shift aft, causing the nose to pitch down. The speed at which the shock wave forms is known as the critical Mach number. Transonic speed is typically between Mach
0.80 and 1.20.

U.S. Navy F/A-18 breaking the sound barrier. The white halo is formed by condensed water droplets which are thought to result from a drop in air pressure around the aircraft. A United States Navy F/A-18E/F Super Hornet

in transonic flight. Rapid condensation of water vapor due to a sonic shock produced at sub-sonic speed creates a vapor cone (known as a Prandtl–Glauert singularity), which can be seen with the naked eye.

SUPERSONIC FLIGHT

When an airplane is flying at supersonic speed, the entire airplane is experiencing supersonic airflow. At this speed, the shock wave which formed on top of the wing during transonic flight has moved all the way aft and has attached itself to the wing trailing edge. Supersonic speed is from
Mach 1.20 to 5.0. If an airplane flies faster than Mach 5, it is said to be in hypersonic flight. An F-22 Raptor executes a supersonic fly.

(c) RotaryWing Aerodynamics

Once a helicopter leaves the ground, it is acted upon by four aerodynamic forces;
thrust, drag, lift and weight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight. [Figure 2-1] They are defined as follows:

Thrust—the forward force produced by the power plant/propeller or rotor. It opposes or overcomes the force of drag. As a general rule, it acts parallel to the longitudinal axis. However, this is not always the case, as explained later.

Drag—a rearward, retarding force caused by disruption of airflow by the wing, rotor, fuselage, and other protruding objects. Drag opposes thrust and acts rearward parallel to the relative wind.

Weight—the combined load of the aircraft itself, the crew, the fuel, and the cargo or baggage. Weight pulls the aircraft downward because of the force of gravity. It opposes lift and acts vertically downward through the aircraft‘s center of gravity (CG) Lift—opposes the downward force of weight, is produced by the dynamic effect of the air acting on the airfoil, and acts perpendicular to the flightpath through the center of lift.

Airfoil Terminology and Definitions

- Blade span—the length of the rotor blade from center of rotation to tip of the blade.
- Chord line—a straight line intersecting leading and trailing edges of the airfoil.
- Chord—the length of the chord line from leading edge to trailing edge; it is the characteristic longitudinal dimension of the airfoil section.

- Mean camber line—a line drawn halfway between the upper and lower surfaces of the airfoil.

The chord line connects the ends of the mean camber line. Camber refers to curvature of the airfoil and may be considered curvature of the mean camber line. The shape of the mean camber is important for determining aerodynamic characteristics of an airfoil section. Maximum camber (displacement of the mean camber line from the chord line) and its location help to define the shape of the mean camber line. The location of maximum camber and its displacement from the chord line are expressed as fractions or percentages of the basic chord length. By varying the point of maximum camber, the manufacturer can tailor an airfoil for a specific purpose. The profile thickness and thickness distribution are important properties of an airfoil section.

- Leading edge—the front edge of an airfoil.
- Flightpath velocity—the speed and direction of the airfoil passing through the air. For airfoils on an airplane, the flightpath velocity is equal to true airspeed (TAS). For helicopter rotor blades, flightpath velocity is equal to rotational velocity, plus or minus a component of directional airspeed. The rotational velocity of the rotor blade is lowest closer to the hub and increases outward towards the tip of the blade during rotation.
- Relative wind—defined as the airflow relative to an airfoil and is created by movement of an airfoil through the air. This is rotational relative wind for rotary-wing aircraft and is covered in detail later. As an induced airflow may modify flightpath velocity, relative wind experienced by the airfoil may not be exactly opposite its direction of travel.
- Trailing edge—the rearmost edge of an airfoil.
- Induced flow—the downward flow of air through the rotor disk.
- Resultant relative wind—relative wind modified by induced flow.
- Angle of attack (AOA)—the angle measured between the resultant relative wind and chord line.
- Angle of incidence (AOI)—the angle between the chord line of a blade and rotor hub. It is usually referred to as blade pitch angle. For fixed airfoils, such as vertical fins or elevators, angle of incidence is the angle between the chord line of the airfoil and a selected reference plane of the helicopter.
- Center of pressure—the point along the chord line of an airfoil through which all aerodynamic forces are considered to act. Since pressures vary on the surface of an airfoil, an average location of pressure variation is needed. As the AOA changes, these pressures change and center of pressure moves along the chord line.

Operation and effect of cyclic, collective and anti-torque controls.

Cyclic

The cyclic control, commonly called the cyclic stick or just cyclic,
is similar in appearance on most helicopters to a joystick from a conventional aircraft. It is usually located between the pilot's legs, but on some helicopters, such as the Robinson R22, it is a central pillar that either pilot can manipulate.

The control is called the cyclic because it changes the pitch angle of the rotor blades cyclically. That is, the pitch, or feathering angle, of the rotor blades changes depending upon their position as they rotate around the hub, so that all blades have the same incidence at the same point in the cycle. The change in cyclic pitch has the effect of changing the angle of attack, and thus the lift generated by a single blade as it moves around the rotor disk. This in turn causes the blades to fly up or down in sequence, depending on the changes in lift affecting each individual blade.
The result is to tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction. If the pilot pushes the cyclic forward, the rotor disk tilts forward, and the rotor produces a thrust vector in the forward direction. If the pilot pushes the cyclic

to the right, the rotor disk tilts to the right and produces thrust in that direction, causing the helicopter to move sideways in a hover or to roll into a right turn during forward flight, much as in a fixed wing aircraft.
Any rotor system has a delay between the point in rotation where the controls introduce a change in pitch and the point where the desired change in the rotor blade's flight occurs. This difference is caused by phase lag, often confused with gyroscopic precession. A rotor is an oscillatory system that obeys the laws that govern vibration—which, depending on the rotor system, may resemble the behaviour of a gyroscope.

1.1.1 COLLECTIVE

The collective pitch control, or collective lever, is normally located on the left side of the pilot's seat with an adjustable friction control to prevent inadvertent movement. The collective changes the pitch angle of all the main rotor blades
collectively (i.e., all at the same time) and independent of their position.
Therefore, if a collective input is made, all the blades change equally, and as a result, the helicopter increases or decreases its total lift derived from the rotor. In level flight this would cause a climb or descent, while with the helicopter pitched forward an increase in total lift would produce an acceleration together with a given amount of ascent.

The collective pitch control in a Boeing CH-47 Chinook is called a thrust control, but serves the same purpose, except that it controls two rotor systems, applying differential collective pitch.

1.1.2 ANTI-TORQUE PEDALS

The anti-torque pedals are located in the same place as the rudder pedals in an airplane, and serve a similar purpose—they control the direction that the nose of the aircraft points. Applying the pedal in a given direction changes the tail rotor blade pitch, increasing or reducing tail rotor thrust and making the nose yaw in the direction of the applied pedal.

1.1.3 THROTTLE

Helicopter rotors are designed to operate at a specific rotational speed. The throttle controls the power of the engine, which is connected to the rotor by a transmission. The throttle setting must maintain enough engine power to keep the rotor speed within the limits where the rotor produces enough lift for flight. In many

helicopters, the throttle control is a single or dual motorcycle- style twist grip mounted on the collective control (rotation is opposite of a motorcycle throttle), while some multi-engine helicopters have power levers.
In many piston engine-powered helicopters, the pilot manipulates the throttle to maintain rotor speed. Turbine engine helicopters, and some piston helicopters, use governors or other electro- mechanical control systems to maintain rotor speed and relieve the pilot of routine responsibility for that task. (There is

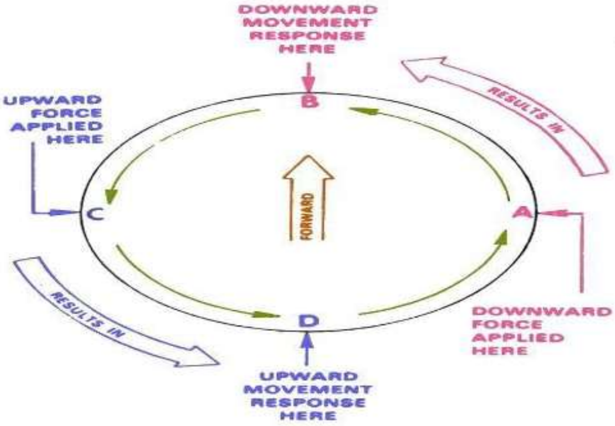


FIGURE 2-55. GYROSCOPIC PRECESSION.

normally also a manual reversion available in the event of a governor failure.)
Gyroscopic Precession:

The spinning main rotor of a helicopter acts like a gyroscope. As such, it has the properties of gyroscopic action, one of which is precession. Gyroscopic precession is the resultant action or deflection of a spinning object when a force is applied to this object. This action occurs approximately 90° in the direction of rotation from the point where the force is applied (or 90° later in the rotation cycle). [Figure 2-28] Examine a two-bladed rotor system to see how gyroscopic precession affects the movement of the tip-path plane. Moving the cyclic pitch control increases the angle of incidence of one rotor blade with the result of a greater lifting force being applied at that point in the plane of rotation. This same control movement simultaneously decreases the angle of incidence of the other blade the same amount, thus decreasing the lifting force applied at that point in the plane of rotation. The blade with the increased angle of incidence tends to flap up; the blade with the decreased angle of incidence tends to flap down. Because the rotor disk acts like a gyro, the blades reach maximum deflection at a point approximately 90° later in the plane of rotation. The retreating blade angle of incidence is increased and the advancing blade angle of incidence is decreased resulting in a tipping forward of the tip-path plane, since maximum deflection takes place 90°.

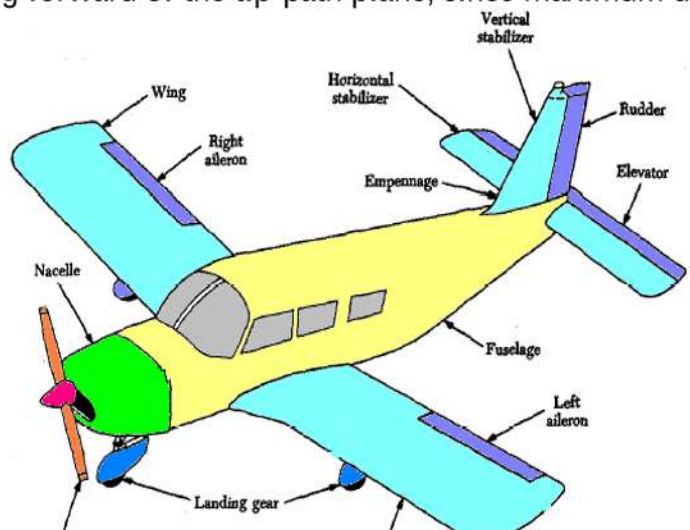


Figure 1-2. Aircraft structural components.

13.2 Structures — General Concepts

AIRCRAFT STRUCTURES

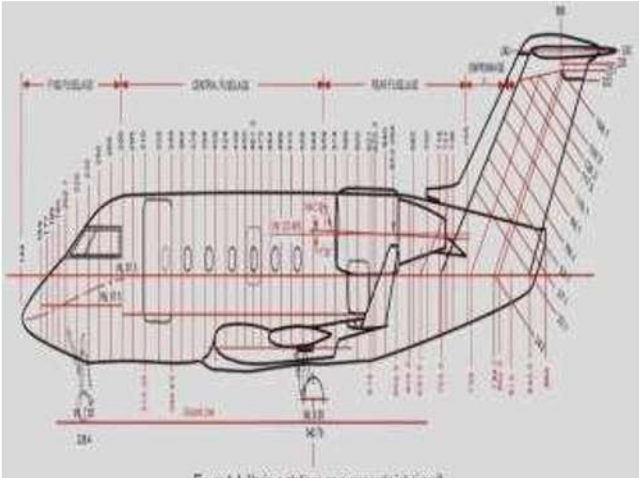
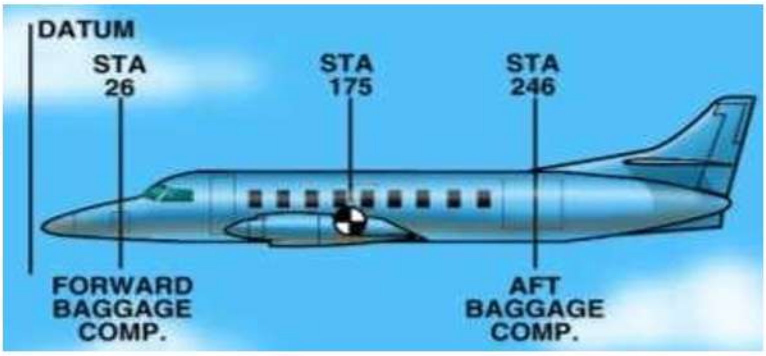


Figure 1.4 Various stations on a corporate jet aircraft

The airframe of a fixed wing aircraft is generally considered to consist of five principal units.

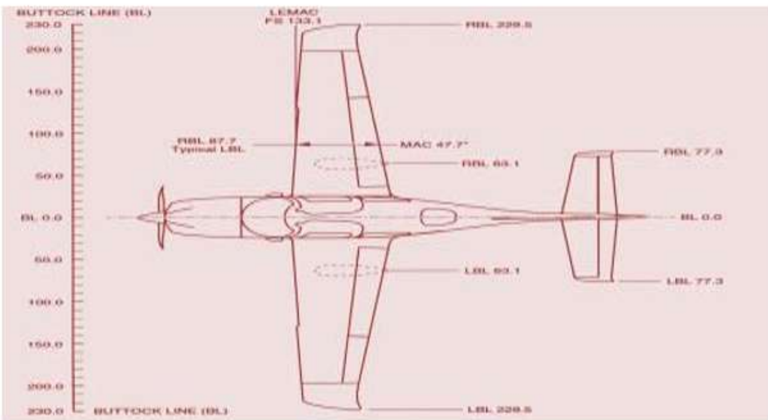
- Fuselage
- Wings
- Horizontal & vertical Stabilizers
- Flight control surface
- Landing gear (undercarriage)



(b) Zonal and station identification systems

STATION NUMBER - A method of locating components on the a/c must be established in order that maintenance and repair can be

carried out. This is achieved by identifying reference lines and station numbers for fuselage,
Fuselage station lines are determined by reference to zero datum line (Fuselage station 0.00) at or near the forwarded portion of the a/c as defined by the manufacturer.
DATUM - The datum is an imaginary vertical plane from which all horizontal
measurements are taken for balance purposes, with the aircraft in level flight attitude. If the datum was viewed on a drawing or photograph of an aircraft, it would appear as a vertical line which is perpendicular (90 degrees) to the aircraft's horizontal axis.
For



each aircraft make and model, the location of all items is identified in reference to the datum. For example, the fuel in a tank might be 60‖ behind the datum, and a radio on the flight deck might be 90" forward of the datum.

Station numbers are given in inches forward (negative and given a ‗- ‗sign) or aft (positive and given a ‗+ ‗sign) of the zero datum. Wing stations are measured from the center line of the a/c and are also given in inches left or right of the centre line. Vertical position from a ground line or horizontal datum can be known as a Water Line (WL) or Buttock Line, given as a dimension in inches from the horizontal datum. If a blueprint reads —fuselage frame station 137‖– that frame of fuselage is located 137 inches behind the nose of the a/c. Forward and aft locations on aircraft are made by reference to the datum. Locations left and right of the aircraft‘s longitudinal axis are made by reference to the buttock line and are called butt stations. Vertical locations on an airplane are made in reference to the waterline.

Aileron Station (A. S.) – is measured outboard from, and parallel to, the inboard edge of the aileron, perpendicular to the rear beam(spar) of the wing.
Flap Station (F.S.) - is measured perpendicular to the rear beam(spar) of the wing and parallel to, and outboard from, the inboard edge of the flap.
Nacelle Station (N.C. or Nac. Sta.) - is measured either forward of or behind the front spar of the wing and perpendicular to a designated water line.
(H.S.S.) Horizontal Stabilizer Station (V.S.S.) Vertical Stabilizer Station (P.P.S.) Power Plant Station
STATIONS DESCRIPTION AND OPERATION - The aircraft is divided into reference points along three axes. The reference points are measured in inches. These reference points provide a means of quickly identifying the location of a bulkhead, component, etc. The measurements used in manual are rounded to the nearest inch. All reference points may be converted to metric measurement (centimeters) by multiplying the reference point tin inches) to 2.54.

The following terms are used for reference points.

Fuselage station (FS) - It is a horizontal reference designation starting at the nose of the aircraft.
Water line (WL) - It is a vertical reference designation measured parallel to the ground.
Buttock line (BL) - it is a horizontal reference designation starting at the aircraft centerline. Right or left is added to indicate the direction from aircraft centerline (RBL/LBL).
Wing station (WS) - it is a horizontal reference designation starting at the wing centerline, and measured perpendicular along wing datum.

LIGHTNING PROTECTION ILLUSTRATIONS

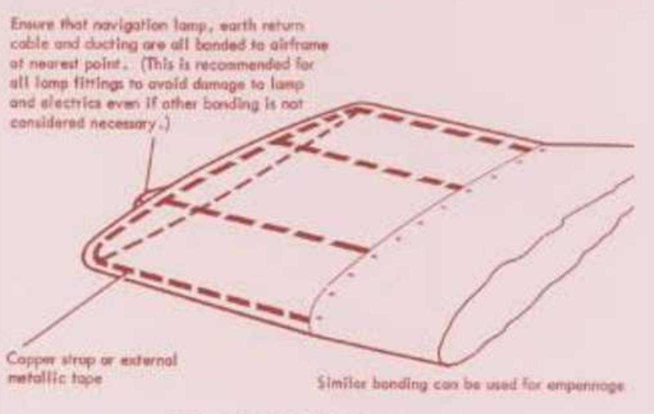
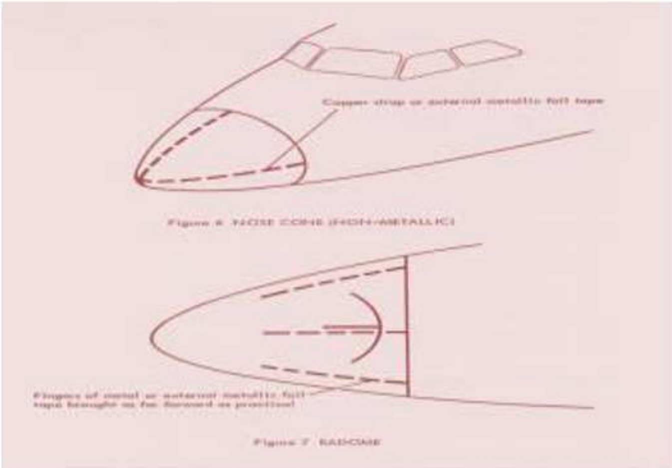


Figure 1 WING TIP (NON-METALLIC)

Electrical Bonding

Bonding is the electrical connecting of two or more conducting objects not otherwise adequately connected. The following bonding requirements must be considered:
Equipment bonding

Low-impedance paths to aircraft structure are normally required for electronic equipment to provide radio frequency return circuits and for most electrical equipment to facilitate reduction in EMI. The cases of



components that produce electromagnetic energy should be grounded to structure. To ensure proper operation of electronic equipment, it is particularly important to conform the system‘s installation specification when interconnections, bonding, and grounding are being accomplished.
Metallic surface bonding

All conducting objects on the exterior of the airframe must be electrically connected to the airframe through mechanical joints, conductive hinges, or bond straps capable of conducting static charges and lightning strikes. Exceptions may be necessary for some objects, such as antenna elements, whose function requires them to be electrically isolated from the airframe. Such items should be provided with an alternative means to conduct static charges and/or lightning currents, as appropriate.
Static bonds all isolated conducting parts inside and outside the aircraft, having an area greater than 3 square inches and a linear dimension over 3 inches, that are subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion, should have a mechanically secure electrical connection to the aircraft structure of sufficient conductivity to dissipate possible static charges. A resistance of less than 1 ohm when clean and dry generally ensures such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.
Lightning strike Protection provisions

When an aeroplane is struck the discharge will most probably enter and leave by the wing tips, nose or empennage and it is therefore these components that require special protection. All should be adequately bonded to each other through the aircraft's metallic structure or, in the case of non-metallic aircraft, by bonding links throughout the complete structure.

Wing and empennage tips can be protected by fitting copper straps either solid or a woven sheath of at least an equivalent to 1" x 26 SWG cross sectional area attached to the component to form a complete cage, and bonded to the structure at the nearest joint.
However, this is not always practical on existing parts and as an alternative metallic foil tapes can be glued on the exterior, but again should be bonded to the airframe, and routine inspections should be carried out to check against damage by erosion. It should also be noted that should the tape be struck it will burn away

probably without damage to the airframe.

Wing tip fuel tanks made from non-metallic materials (see Figures 2, 4 and 5) should be given special attention and only external bonding may be used. This may be similar to that used on wing tips but in addition it is vital to ensure that the navigation lamp plus its earth return cable and associated duct is bonded to the airframe as near the wing tip as possible. Where the tanks are of all metal construction (see Figure 3) it is necessary to ensure that the nose and tail are not less than 0.080" thick in order to reduce the danger of being punctured by the lightning strike. The safest tank design is one with an air space at either end thus eliminating any fuel vapours from the most dangerous areas.

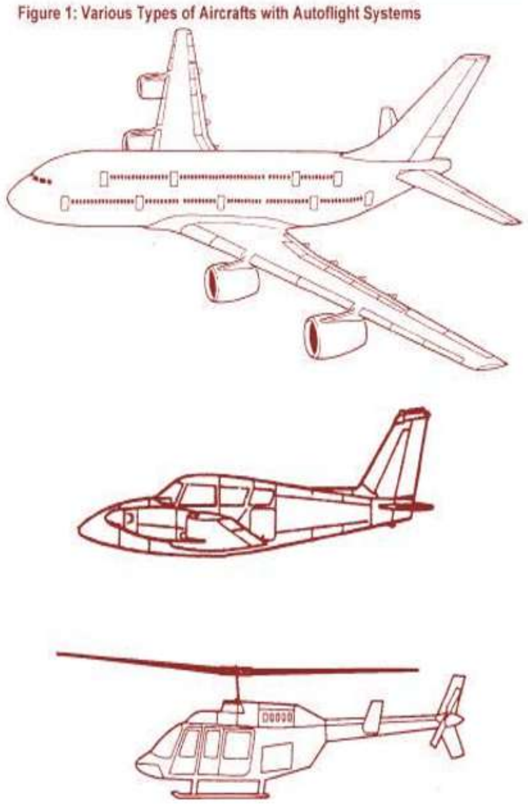
Where loss of or damage to a non-metallic nose cone can hazard the aeroplane it can be protected by a suitable cage (see Figure 6) in the shape of a cruciform fitted either inside or outside and made from similar materials as the wing tip protection. If radar is fitted (see Figure 7)
fingers should be brought as far forward as possible without affecting the radar efficiency.

13.3 Auto flight (ATA 22)

Automatic f light 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 let 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

Figure 1: Various Types of Aircrafts with Autoflight Systems



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 smatter 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 mum 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.

Feedback Controls

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

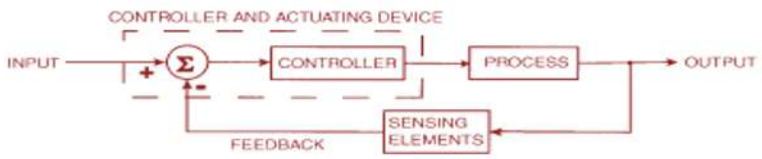
1. input
2. process being controlled output

sensing elements

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

Figure 3: Control Loop



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 an 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.

Synchronisation Autopilot not engaged

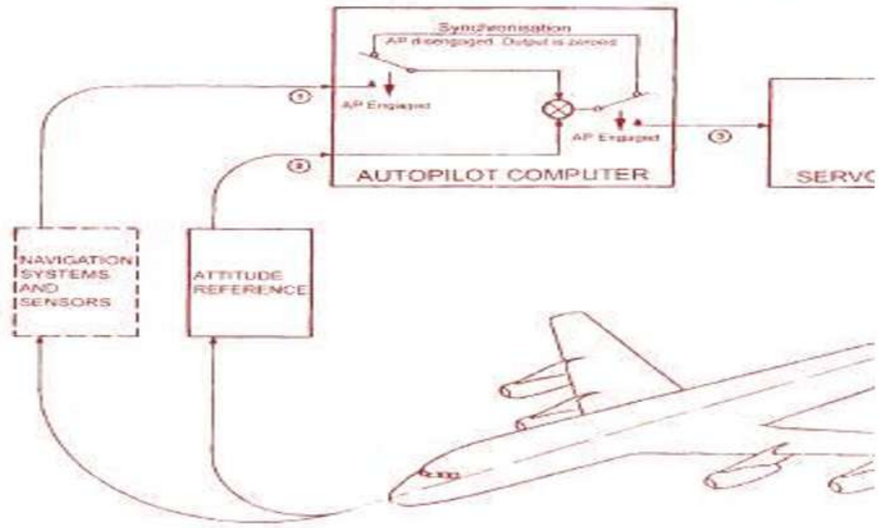
During the time, when the human pilot steers manually the aircraft, the attitude reference provides the actual attitude information (2) to the autopilot computer. The output of the internal summing point is feeded back instead of input (1) to wash out any builded up signal to the servo.

- 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 4: 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 term 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 tailor 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
Depending of the environment conditions (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 gets 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
- L a n d
- Go Around

•All other modes are non redundant

Fail Safe System

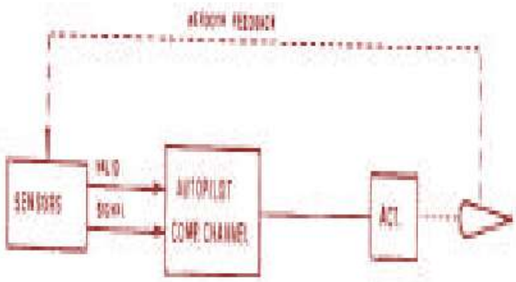
The crew is part of the monitoring.
When only one sensor of one kind is available (one RA. one ILS)

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 5: Single Channel System



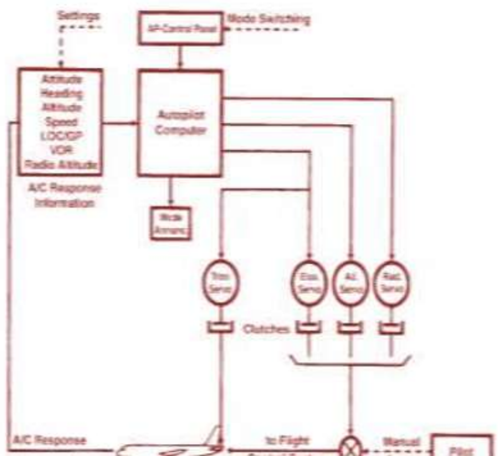
Fail Operational System

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 auto-flight system becomes a fail operational status. This is used in critical modes like Take-off, Land and Go-around.

Autopilot General

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

Figure 13: Autopilot operational loop

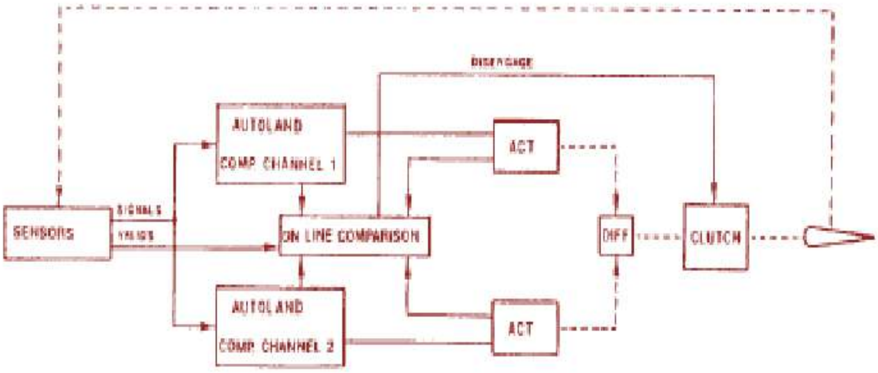


If the autopilot is not engaged, clutches are open so the pilot has to control the plane. Then the autopilot is synchronizing during this time the output of the servos to zero, so the autopilot can be engaged at any time with no jerking aircraft movements.
The aircraft response is sensed by different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

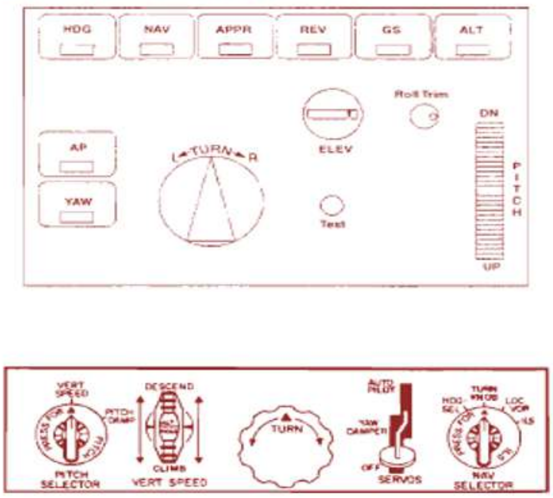
Control panel

Figure 6: Dual Channel System

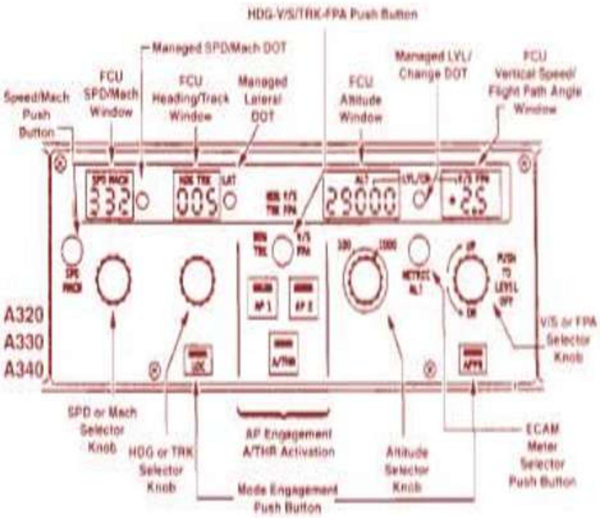


Are used to engage the autopilot presetting the parameters and mode selection.

6: Various Autopilot Control Panels 1/2

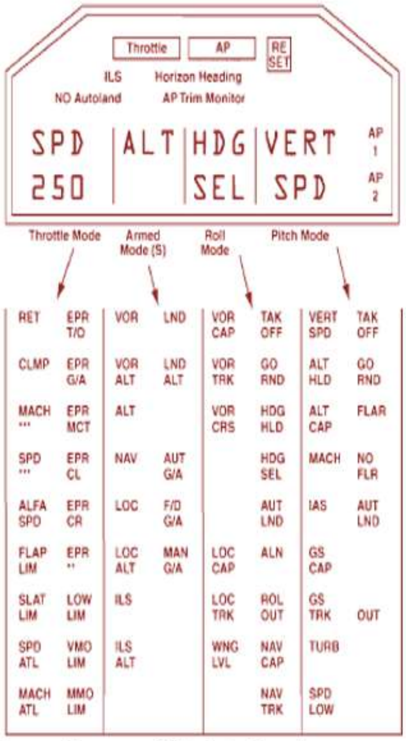


Flight Mode Annunciation



The autothrottle/autothrust, autopilot and flight director operational modes are displayed at the specified

Figure 28: Flight Mode Anunciator



flight mode annunciator or integrated in the primary flight display.

Command Signal Processing

The signals produced by error signal sensors, in whatever form the sensors may take, cannot be applied directly to their associated servo-actuators for the principal reasons that further computation of signals is necessary particularly when outer loop control is

adopted, and in terms of power capability they are not strong enough to cope with the aerodynamic loads acting on the control surfaces. Therefore, in any one flight control system it is necessary to incorporate within the corresponding servo control loops a signal processing system having some, or all, of the following functions:

(i) Differentiating, e.g. deriving simulated rate information from a vertical-axis gyroscope controlled signal sensor.

(ii) Demodulating, i.e. converting a.c. error signals into d.c. control signals which have the same phase

relationship.
(iii) Integrating to obtain simulated attitude information or to correct any sustained attitude errors.
(iv) Amplifying to increase sensor signals to a level high enough to operate the servomotors.
(v) Limiting to ensure that certain parameter changes are kept within prescribed limits.

Figure 30: Vacuum driven servo

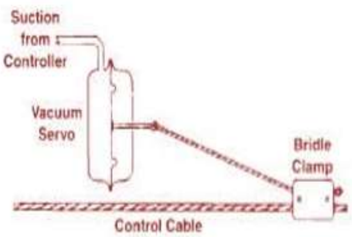
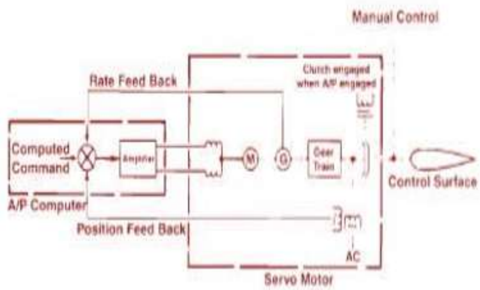


Figure 31: Electric motor driven servo



(vi) Gain adjustments that may be pre-set and/or automatically programmed to adapt system response to suit the handling qualities or flight path of an aircraft.
(vii) Programming to produce a precise manoeuvre, e.g. when selecting a particular outer loop control mode
(viii) Applying feedback signals to ensure that corrective control is proportional to command signal inputs.

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 the 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.

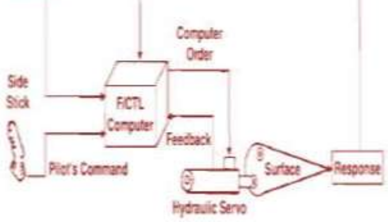
Control Wheel Steering
Force sensors are installed in the mechanical steering links or directly inside the control wheel hub. If the pilot is manually steering, sensors takes the applied force from the control wheel to the autopilot computer. The output is electrically send to the servo actuator. The 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.
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.
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.
Take off
The autopilot can be engaged after lift off

Figure 43: System Layout



The pitch attitude is controlled to reach and maintain take off reference speed V2 +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 modem solution is the automatic determination of the automated computation of the alfa speed 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 0+ a safe margin of 10 kts is applied. The roll control is identical of take off.

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/ CATS 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 sub mode is engaged at touchdown 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.

- CAPTURE PHASE - This phase is when the aircraft captures the localizer or glideslope beams for guidance during an automatic landing. The localize, 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 4C nautical miles from the runway threshold and at airspeeds up to 1.5 Vs (Minimum steady-flight speed). The localizes 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 attitude 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 's 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 node 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

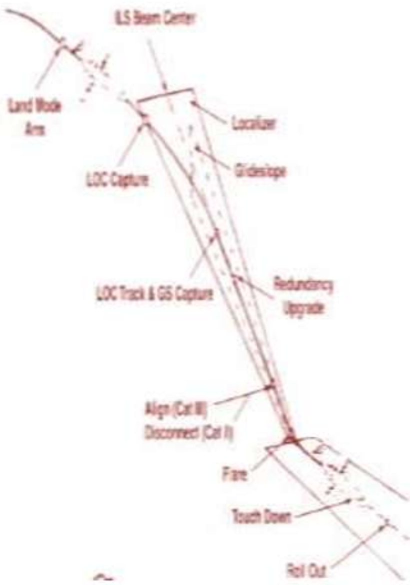
pitch rate of two degrees per second. After the nose gear has touched down the autopilot continuously sends a nose down command (to make sure there is always firm contact with the runway) during the landing rollout phase

• ROLLOUT - The AFS supplies a ground rollout mode which controls the aircraft to stay on the runway centerline

Automatic Landing

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

Figure 51: Automatic Landing Sequence



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.
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 se-lection 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 posi-tion. 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.
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.

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.

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 Ax IA = S x Is

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).

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 three-phase electric motor. Shown is a DC electric motor.

There are always at least two stabilizer motors, and usually, both

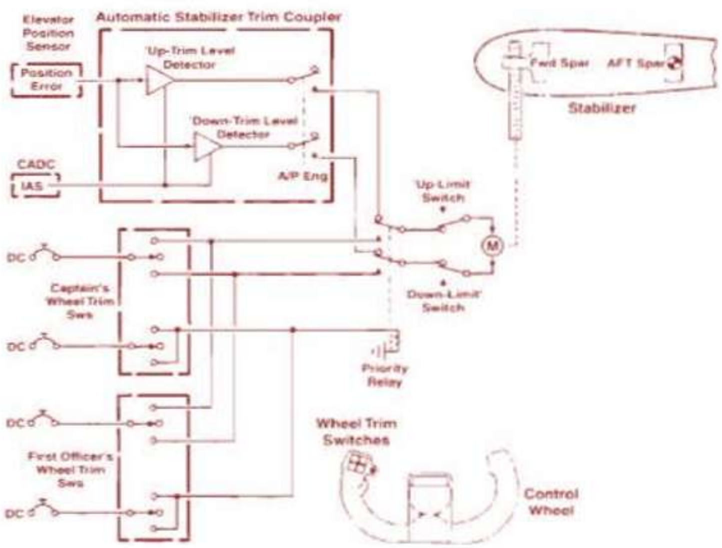
captain's or first officers wheel trim switches operates a priority relay which disconnects from the motor any signals that might be generated by the automatic stabilizer trim coupler. The trim coupler is part of the automatic fight guidance system.

The basic control signal for automatic stabilizer trim is the elevator position. If the level detectors see an elevator too far away from the fared 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 114 away from the faired position. The stabilizer trim system operates. At approach or takeoff speeds, automatic 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 slew 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 mm the stabilizer, the autopilot is not doing its job correctly. Operation of either the not Stabilizer trimming is 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 auto trim 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.

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.

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 air- craft 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.

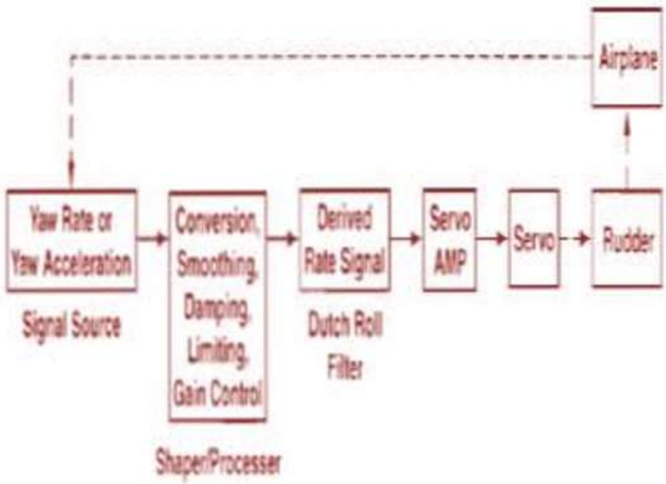
The yaw damper system provides the following functions: Dutch roll damping Turn coordination in low speed manual flight to reduce the sideslip induced by the turn.
Engine failure compensation- A command is generated to the rudder to counteract sideslip during the transient induced by an engine failure.

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.

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.
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.

Figure 71: Block Diagramm



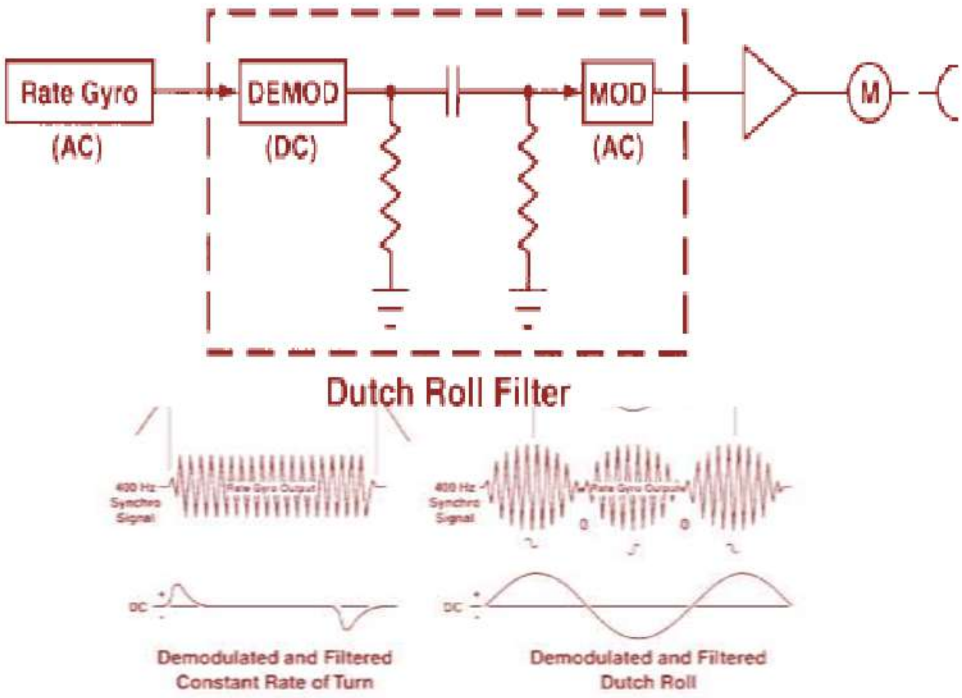
The rate gyro output represents the 400 Hertz synchro signal developed by the rate gyro during this flight path. When the airplane is flying straight ahead there is no output from the synchro. During the time it is

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 tum 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 115 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 75: Yaw Damper Dutch Roll dampening Function



Stability Augmentation 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 natu- rally unstable. The deficiencies in the helicopters stability and control characteristics have become an acceptable part of the vehicle over the years providing that a good Automatic Stabilization Equipment (ASE) or Stability Augmen- tation 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 longitudinal 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 un augmented helicopter will not meet the handling quality specifications,

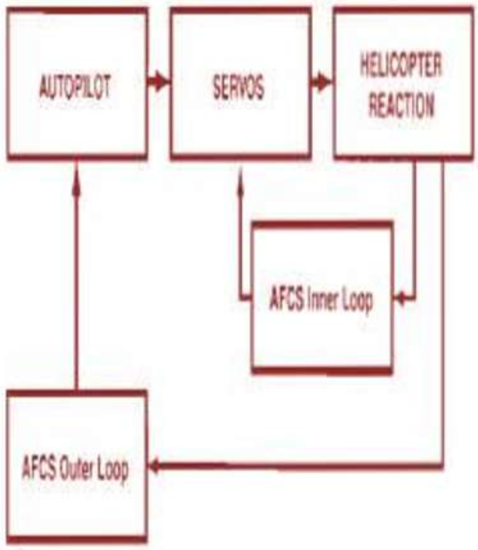
Stability Augmentation System (SAS) is necessary to improve handling qualities so that safe operation close to the ground in poor weather conditions and/ or at night is possible.
The correction movements are mostly relative fast and small (constant regulation). There is no correction movement feedback 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 an 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 gover- nor 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. 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.
Level Description
The inner most level called SAS (Stability Augmentation System) provides rate damping for the helicopter.

Figure 76: Relationships between inner and outer loops of AFCS



This makes the helicopter stable in fight. 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 ACS 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 altitude 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 "gob point (x.y.z)"

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.

Airworthiness Criteria for Helicopter Instrument Flight Stability Augmentation System (SAS)

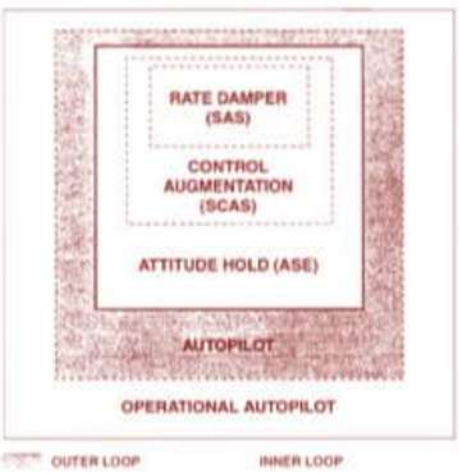
1. If a SAS is used, the reliability of the SAS must be related to the effects of its failure. The occurrence of any failure condition which would prevent continued safe flight and landing must be extremely improbable. For any failure condition of the SAS which is not shown to be extremely improbable:

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 oper- ation 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.

Figure 77: Architecture of Automatic Flight Control System

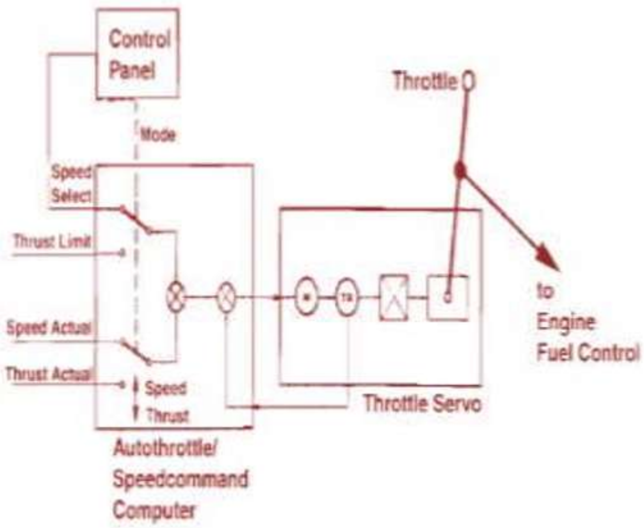


AUTO THROTTLE/THRUST

Introduction

The auto throttle system controls the power setting of the engines to reach and maintain a preselected speed or thrust limit. A servo

Figure 81: Auto Throttle Principle



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 holed 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 knit/target
RETARD Provides control of throttles to reduce thrust at the appropriate radio altitude during the landing bare 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 evadable during both manual and automatic throttle operation. It is engaged any time when two or more engines are operating above an EPR/T41 threshold. The engine thrust trim system will maintain the engines at a common thrust setting to eliminate the need for throttle adjustments Au- tomatic engine trim is independent of air/ground operations.

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 N1 Limit depending of the engine model. The limit is shown at a dedicated indicator: Thrust rating indicator,
EPR indicator.

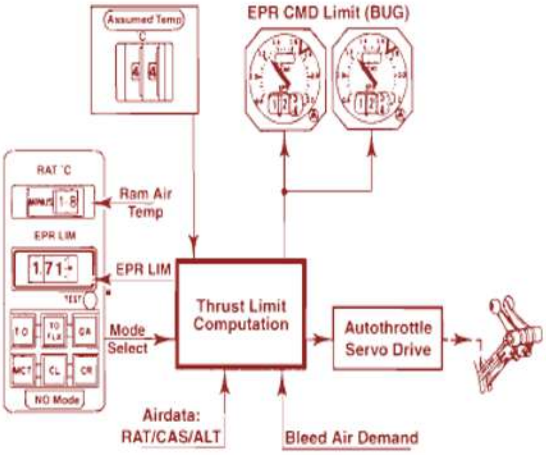
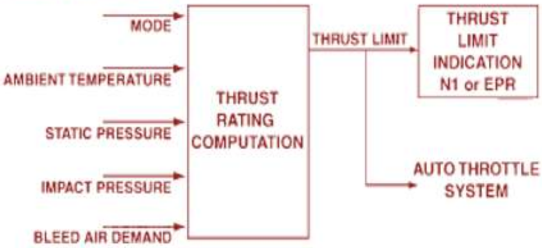


Figure 86: Thrust Rating Computation



engine protection.

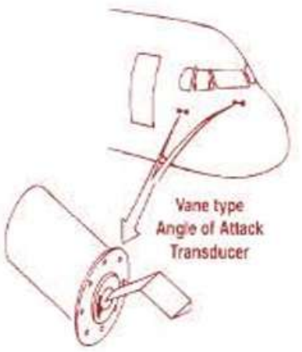
Thrust Rate Limit Computation

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

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.
Warnings Overview
Different warnings are covered in a modern flight guidance system
S t a l l Altitude alert W i nd s h ea r Flight envelope protection Autopilot failure/disengage
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.

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 91: Vane Type Sensor



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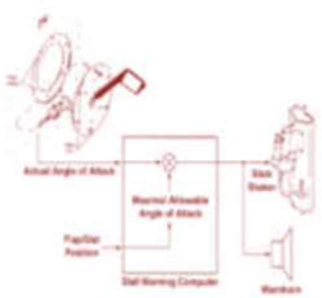
As angle of attack Increases tie coefficient of lift also
increases this continues to a point where CL peaks. The point of maximum lift is caned C1, If the maximum lift angle is exceeded lift decreases rapidly and the wing stalls.

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.

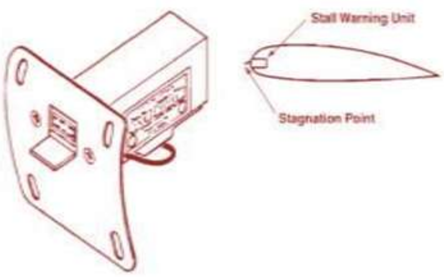
Angle of Attack Sensor AOA

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 correctio n, stall warning/protection and other avionics system.



Stall Warning

Figure 90: Stall Warn Switch



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 copilots 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 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. 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.

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.

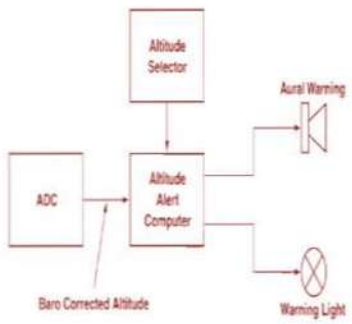
The altitude exit alert is visual and aural. The exit alert resets when the aircraft is back within the alert area or when the crew selects a new altitude.

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

Figure 94: Altitude Alert System



Are triggered below 200 ft in LAND and FLARE mode if an automatic landing (e- lated failure occur.

Master warning lights Illuminates red if autopilot disengages due of system failure or manual disengage- ment Cavalry charge sound is broadcasted. (Level 3)

Master caution lights

Illuminates amber if an auto flight related failure occurs that causes not a complete disengagement.

Single chime sound is broadcasted. (Level 2)

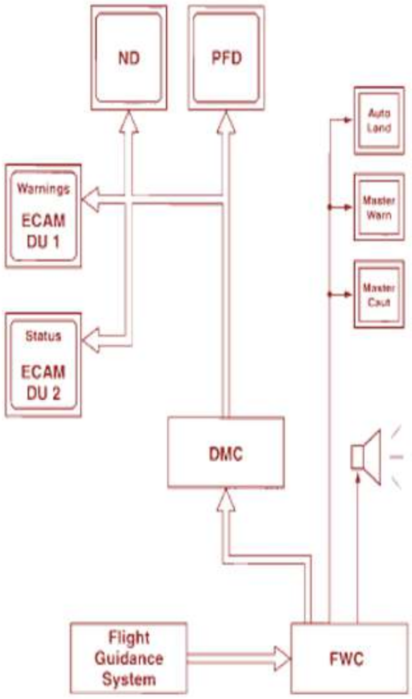
Cockpit speakers

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.

Figure 101: Failure Warning Block Diagram



different flight envelope speeds.
Navigation display ND
Presenting the horizontal flight situation No specific auto flight messages are shown Fault Isolation and Test Build In Test

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 winds hear warning 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 operations.

Flight Fault Review

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

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 al failure detentions 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.
Fault isolation Detection System

Figure 102: DFGC's and Maintenance Panel

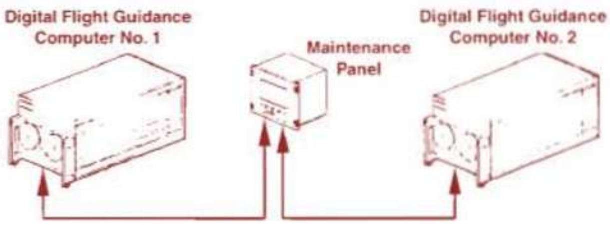
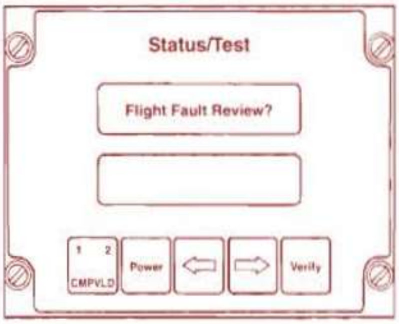


Figure 103: Maintenance Status/Test Panel



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 ADS 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.
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

13.4 Communication/Navigation (ATA 23/24)

Fundamentals of radio wave propagation, antennas, transmission lines, communication, receiver and transmitter;
Working principles of following systems:

Radio wave propagation
Basic Principle of Radio
If a wire is fed with an alternating current, some of the power will be
radiated into space. A similar wire parallel to and remote from the first will intercept some of the radiated power and as a consequence an alternating current will be induced, so that using an appropriate detector, the characteristics of the original current may be measured. This is the basis of all radio systems.
Electromagnetic (e.m.) Waves

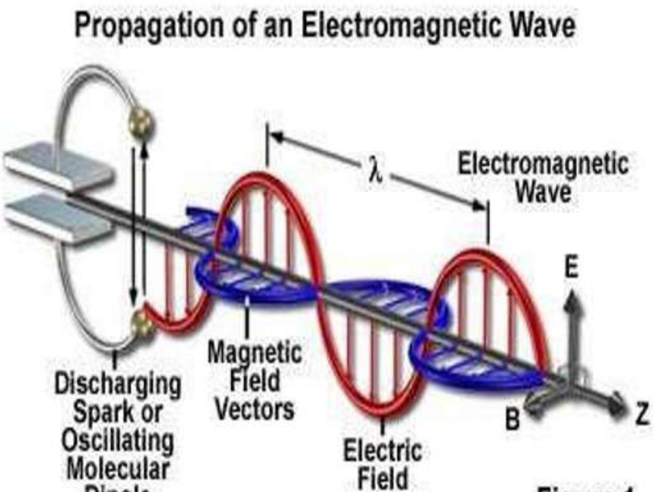


Figure 1

A wave produced by the acceleration of an electric charge through wire and propagated by the periodic variation of intensities of electric and magnetic fields usually perpendicular to each other.

Radiation of Electromagnetic (e.m.) Waves

This involves a transfer of energy from one point to another by means of an e.m. wave. The wave consists of two oscillating fields

mutually perpendicular t o each other and to the direction of propagation.
The electric field (E) will be parallel to the wire from which the wave was transmitted, while the magnetic field (H) will be at right angles.
The velocity and wavelength of an e.m. wave are directly related through the frequency of the alternating current generating the wave. The Formula is:
$C = \lambda f$
Or $\lambda = C / f$ ……(1) Where :
C is the speed of light (3 X 108 m/s). λ is the wavelength in metres.
f is the frequency in Hertz (cycles/s).

Antennas

An antenna is an electrical device which converts electric power into radio waves, and vice versa. In transmission a radio transmitter supplies an electric current oscillating at radio frequency (i.e. an alternating current) to the antenna's terminals, and the antenna radiates the energy in the form of electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, that is applied to a receiver to be amplified.
A radiating wire (antenna) is most efficient when its length is equal to half a wavelength.
i.e. $L = 1/2 \lambda$ ……… (Dipo

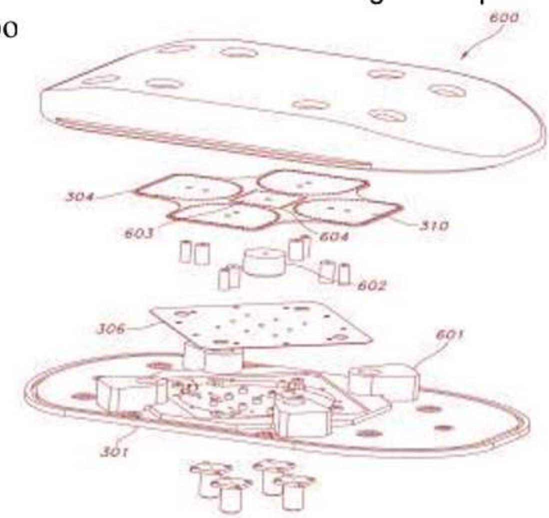


FIG. 6

In practice many airborne radio systems do not make use of dipole antennas since their size is prohibitively large, except at very high frequencies, and the radiation pattern is not suited to applications where energy needs to be transmitted or received from a certain directions.
The notch/airframe load must be `tuned' to the correct frequency for efficient transmission. Without tuning, little energy would be radiated and a large standing wave would be set up on the connector feeding the notch. This is due to the interaction of incident and reflected energy to and from the antenna. An alternative type of antenna for this band of frequencies is a long length of wire similarly tuned, i.e. with variable reactive components

- Capacitive Antenna:-

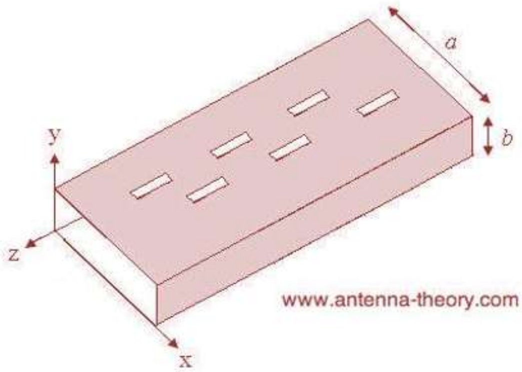
Frequencies within the range 10-100 kHz the maximum dimension of even large aircraft is only a small fraction of a wavelength. At these frequencies capacitive type antennas are being used.
One plate of the capacitor is the airframe; the other a horizontal tube, vertical blade or a mesh (sometimes a solid plate).
The aircraft causes the field to become intensified over a limited region near its surface. The resulting comparatively strong oscillating E field between the capacitor's plates causes a current to flow in twin feeder or coaxial cable connected across the antenna.

- The airborne systems operating in the relevant frequency band are the receive-only systems

Loop Antenna :-

An alternative to the capacitance antenna is the loop antenna which
is basically a loop of wire which cuts the H field component of the e.m. wave. The field is intensified by use of a ferrite core on which several turns are wound. Use of two loops mounted at right angles provides a means of ascertaining the direction of arrival (ambiguous) of an e.m. wave. Such antennas are used for ADF (loop) and may also be used for Omega.

TRANSMISSION LINES



Transmission Lines Transmitters and receivers must be connected to their antenna(s) via conductive wire. These transmission lines are coaxial cable, also known as coax. Coax consists of a center wire conductor surrounded by a semirigid insulator. Surrounding the wire and insulator material is a conductive, braided cover that runs the length of the cable. Finally, a waterproof covering is set around the braided shield to protect the entire assembly from the elements. The braided cover in the coax shields the inner conductor from any external fields. It also prevents the fields generated by the internal conductor from radiating. For optimum performance, the impedance of the transmission line should be equal to the impedance of the antenna. In aviation antenna applications, this is often approximately 50 ohms. Special connectors are used for coaxial cable. The technician should follow all manufacturer‘s instructions when installing transmission lines and antenna. Correct installation is critical to radio and antenna performance.
Waveguide :-

At frequencies above, say, 3000 MHz the properties of waveguides may be used. A waveguide is a hollow metal tube, usually of rectangular cross - section, along which an e.m. wave can
propagate. If the end of a waveguide is left open some energy will be radiated. To improve the efficiency, the walls of the waveguide are flared out, so providing matching to free space and hence little or no reflected energy back down the guide. Such an antenna is called a horn and may be used for radio altimeters. Associated with the wave propagated along a waveguide are wall currents which flow in specific directions. A slot, about
1 cm in length, cut in the waveguide so as to interrupt the current flow will act as a radiator. If several slots are cut the energy from them will combine several wavelengths from the antenna to form a directional beam.

The direction depends on the spacing of the slots. Such antennas may be used for Doppler radar and weather radar.

Mode of Propagation

a) Ground Wave Propagation:- The ground wave follows the surface of the earth partly because of diffraction, a phenomenon associated with all wave motion which causes the wave to bend around any obstacle it passes. In addition, the wave H field cuts the earth's surface, so causing currents to flow. The required power for these currents must come from the wave, thus a flow of energy

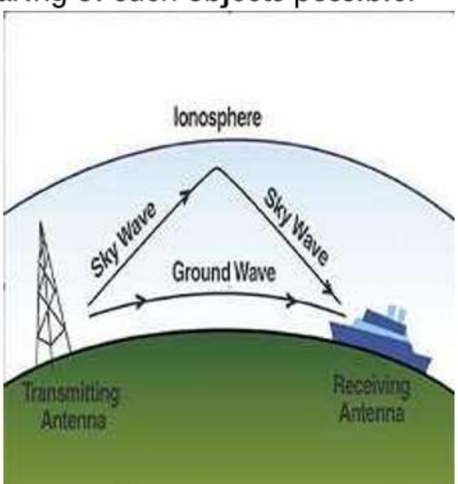
Flat Plate Radiator – photo courtesy of Helicopter Specialties

from wave to earth takes place causing bending and attenuation. Ground waves are used for v.l.f. and l.f.

b) Sky wave propagation:- Radio waves striking the ionosphere (lying between 50 and 500 km above the earth's surface) are refracted by an amount depending on the frequency of the incident wave. Under favourable circumstances the wave will return to the earth. The distance between the transmitter and point of return (one hop) is known as the skip distance. Multiple hops may occur giving a very long range.

Sky wave propagation is useful for h.f. comm. but can cause problems with l.f. and m.f. navigation aids since the sky wave and ground wave may combine at the receiver in such a way as to cause fading, false direction of arrival or false propagation time measurements. At v.l.f. the ionosphere reflects, rather than refracts, with little loss; thus v.l.f. navigation aids of extremely long range may be used.

c) Space Wave propagation:-Above 30 MHz, space waves, sometimes called line of sight waves, are utilized. From about 100 MHz to 3 GHz the transmission path is highly predictable and reliable, and little atmospheric attenuation occurs. Above 3 GHz attenuation and scattering occur, which become limiting factors above about 10 GHz. The fact that space waves travel in a straight line at a known speed and, furthermore, are reflected from certain objects (including thunderstorms and aircraft) makes the detection and determination of range and bearing of such objects possible.



Related Terminology:-

Attenuation:-Attenuation refers to any reduction in the strength of a signal while transmission over long distances. The attenuation is a limiting factor on the range of frequencies which can be used. The higher the frequency the greater the rate of change of field strength, so more attenuation is experienced in maintaining the higher currents.

Modulation:-Modulation is the process of varying one or more properties of a periodic waveform (i.e. carrier signal) by superimposing a modulating signal that typically contains information to be transmitted.

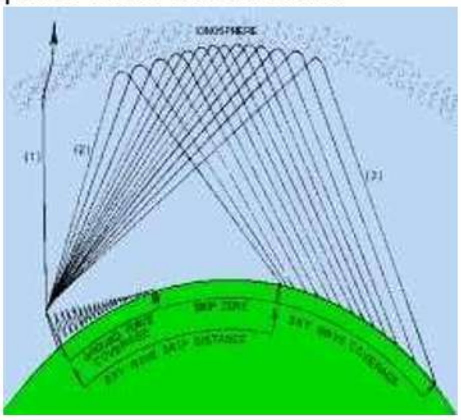
Multiplexing:-

Allocation of non-overlapping bands of frequencies centred on specified discrete carriers to obtain required number of channel is known as frequency multiplexing.

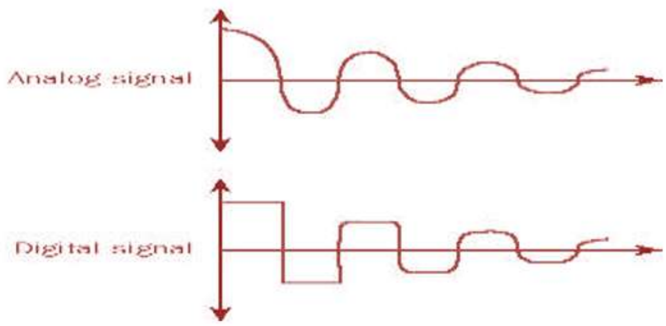
Shannon's sampling theory This theory shows that a sine wave of frequency fm can be completely specified by a series of samples spaced at less than 1/2 fm second (s). To transmit speech where the highest frequency component is 3000 Hz we need only transmit a sample of the instantaneous amplitude at every

1/6000 = 0-000 166 7 s (= 166.7 ps)

The number of signals we can time multiplex on one carrier link depends on the duration and frequency of each sample. The shorter the sample duration the greater the bandwidth required, confirming the statement made earlier that more information requires wider bandwidths.

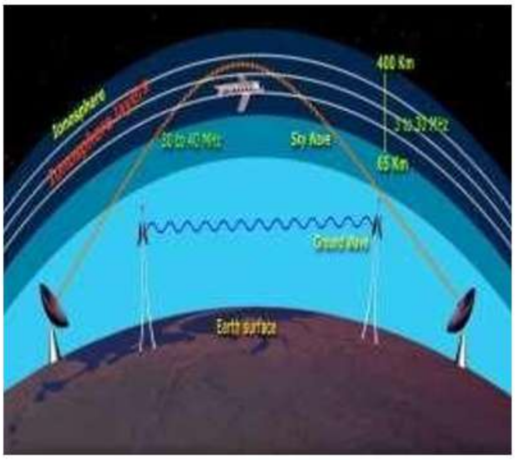


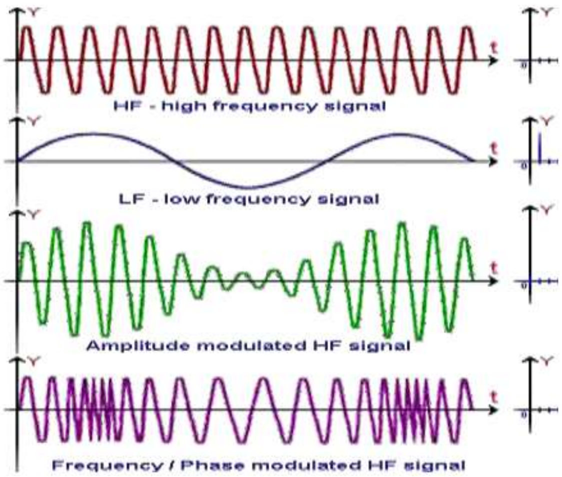
Radio Communication



Much of aviation communication and navigation is accomplished through the use of radio waves. Communication by radio was the first use of radio frequency transmissions in aviation. In aviation, a variety of radio waves are used for communication. Figure 11-75 illustrates the radio spectrum that includes the range of common aviation radio frequencies and their applications.

NOTE: A wide range of frequencies are used from low frequency (LF) at 100 kHz (100,000 cycles per second) to super high frequency (SHF) at nearly 10 gHz (10,000,000,000 cycles per second). The Federal Communications Commission (FCC) controls the assignment of frequency usage. AC power of a particular frequency has a characteristic length of conductor that is resonant at that frequency. This length is the wavelength of the frequency that can be seen on an oscilloscope. Fractions of the wavelength also resonate, especially half of a wavelength, which is the same as half of the AC sign wave or cycle. The frequency of an AC signal is the number of times the AC cycles every second. AC applied to the center of a radio antenna, a conductor half the wavelength of the AC frequency, travels the length of the antenna, collapses, and travels the length of the antenna in the opposite direction. The number of times it does this every second is known as the radio wave signal frequency or radio frequency. As the current flows through the antenna, corresponding electromagnetic and electric fields build, collapse, build in the opposite direction, and collapse again. To transmit radio waves, an AC generator is placed at the midpoint of an antenna. As AC current builds and collapses in the antenna, a magnetic field also builds and collapses around it. An electric field also builds and subsides as the voltage shifts from one end of the antenna to the other. Both fields, the magnetic and the electric, fluctuate around the antenna at the same time. The antenna is half the wavelength of the AC signal received from the generator. At
any one point along the antenna, voltage and current vary inversely to each other.





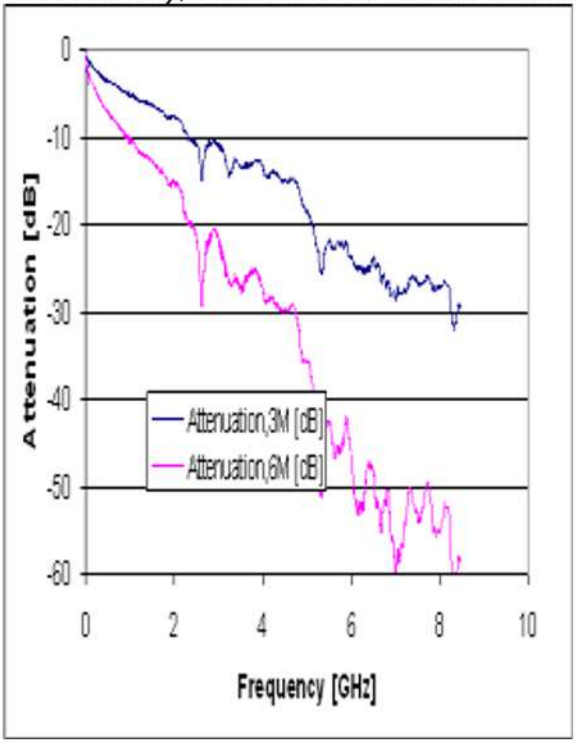
Basic radio transmitter block diagram

Basic Receivers and Transmitters

- Low-level a.m. Transmitter:- If any amplification of the carrier before modulation.
- High-level a.m. transmitter:- if any amplification of the carrier after modulation.
- s.s.b. Transmitter:- Introduce a band pass filter after the modulator.

– F M Transmitter:- Introduce a frequency multiplier after the modulator.

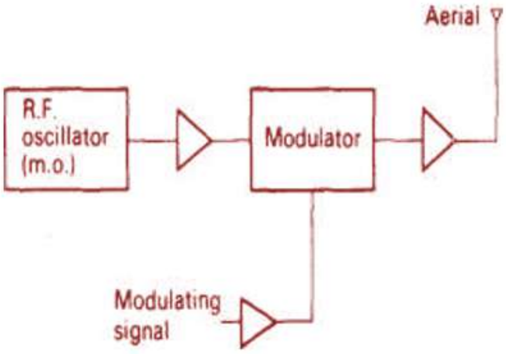
– In both the transmitter and the receiver, r.f. oscillators have to b e tuned to different frequencies. In the transmitter it is the m.o. (master oscillator), while in the receiver it is the LO(Local Oscillator).



Basic superhetrodyne receiver block diagram.

WORKING PRINCIPLE OF FOLLOWING SYSTEMS:

VHF Communication System

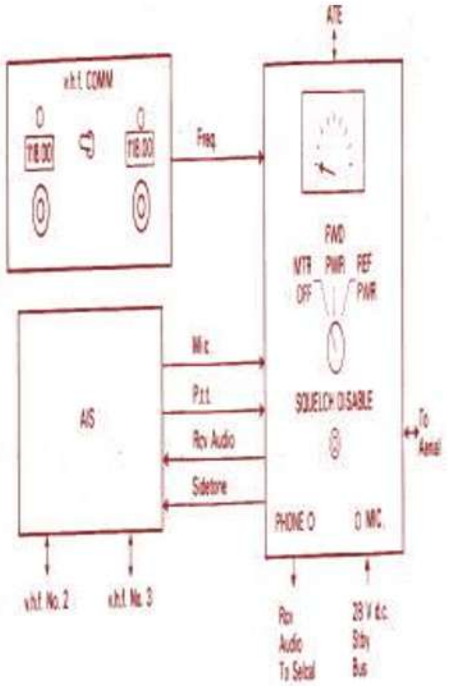


Operating Frequency:- 118 MHz - 136 MHz.
Number of Channels:-
720 channels at 25 kHz spacing Or 360 channels at 50 kHz spacing Basic Principle:-
An aircraft VHF communication transceiver comprised of either a single or double conversion superhet receiver and an a.m. transmitter.
The mode of operation is Single channel simplex (s,c.s.), i.e. one frequency and one antenna for both receiver and transmitter. If provision for satellite communication is included then in addition to a.m. s.c.s. we will have f.m double channels simplex (d.c.s.), i.e. different frequencies for transmitting and receiving. Communication by v.h.f. is essentially 'line of sight_by direct (space) wave. The range available can be Calculated by

1.23 $(\sqrt{ht} + \sqrt{hr})$ nm where:-ht is height of Transmitter above sea Level; hr is height of Receiver above sea Level

Problem:-
Calculate the range of the VHF Trans receiver (Tx Rx) having Ground Station at Sea Level and aircraft height at 1000 ft & 10000 ft.
*Hint:- convert the unit(i.e. ft in to miters)

Installation:-
A single v.h.f. installation consists of three parts_ namely control unit, transceiver and antenna. In addition crew phones are



connected to the VHF via selection switches in the AIS (Audio Integrated System).
Figure Given below shows one of a triple v.h.f. comms installation as might be fitted to a large passenger transport aircraft: VHF2 and VHF3 are similar to VHFI but are supplied from a different 28 V d.c. bus bar and feed different selection switches in the AIS.
The transceiver which is rack-mounted, contains all the electronic circuitry and has provision for the maintenance technician to connect mic. and tels direct, disable the squelch, and measure VSWR. These provisions for testing are by no means universal but if the system conforms to ARINC 566 a plug is provided to which automatic test equipment (ATE) can be connected. A protective cover for the ATE plug is fitted when the unit is not in the workshop.
The antenna can take various forms: whip, blade or suppressed in a triple v.h.f. comms installation these may be two top-mounted blade antennas and one bottom-mounted: an alternative would be two blade and one suppressed within the fincap dielectric. The whip antenna is to be found on smaller aircraft.
All antennas are mounted so as to receive and transmit vertically polarized waves. The blade antenna may be quite complex. It will be self-resonant near the centre of the bandwidth. Bandwidth

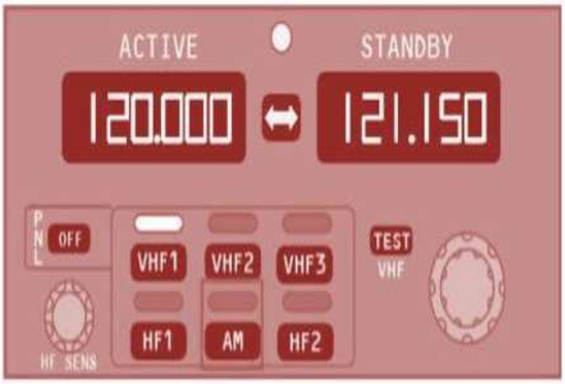
improvement provided by a short circuited stub across the feed terminal or a more complicated reactive network built in which will permit height and hence drag reduction.
Controls And Operation
Frequency Control:-Frequency control is achieved b y concentric knobs, the outer one of which varies the tens and units while the inner one varies the tenths and hundredths. An alternative is where there is one frequency control and two displays' On rotating the frequencyk nobsc lockwiseo r anticlock wise the standby frequency only will increases or decreases respectively. Standby may then become in-use by

operation of the transfer switch.
Volume control:-A potentiometer, which allows variable attenuation of audio, prior to feeding the AIS may be fitted as a separate control or as a concentric knob on the frequency selector(s). Such a volume control may have side-tone coupled through it on transmit.
Squelch Control:-A squelch circuit disables the receiver output when no signals are being received so preventing noise being fed to the crew headsets between ground transmissions.
The squelch control is a potentiometer which allows the pilot to set the level at which the squelch opens, so allowing audio output from the receiver.
When the control is set to minimum squelch (fully clockwise) the Hi and Lo squelch-disable leads, brought to the control unit from the transceiver, should be shorted, so giving a definite squelch disable.
Mode Selector Control :- This Provides selection of normal a.m. extended range a.m., or Satcom. If the Satcom antenna has switchable lobes such switching may be included in the mode switch, or could be separate.
On-Off Switch:-
This Energizes master power relay in transceiver.
The switch may be separate, incorporated in mode selector switch as an extra switch position, or ganged with the volume or squelch control.
Receiver Selectivity Switch:-This provides Normal or sharp selectivity. When Satcom is selected sharp selectivity automatically applies.
Block Diagram Operation VHF Transmitter:-
Ramp Testing:-After checking for condition and assembly and making available the appropriate power supplies the following (typical)'checks should be made at each station using each v.h.f.

1. Disable squelch, check background noise and operation of volume control.

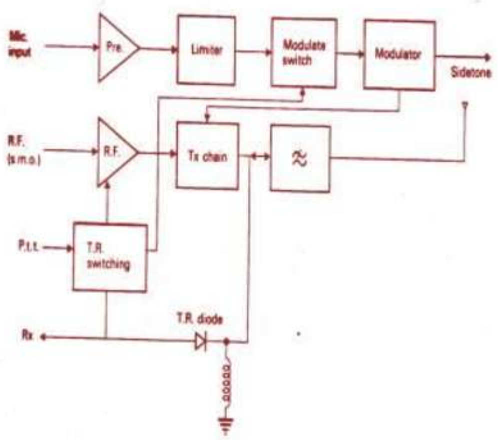
2. On an unused channel rotate squelch control until squelch just closes(no noise). Press p.t.t. button, speak into mic. and check sidetone.
3. Establish two-way communication with a remote station using both sets of frequency control knobs, in conjunction with transfer switch, if appropriate. Check strength and quality of signal.

Note :- Do not transmit on I 2l '5 MHz (Emergency). Do not transmit if refuelling in progress.
Do not interrupt ATC-aircraft communications
HF Communication System



Operating Frequency:- 2 MHz - 30 MHz.
The use of h.f. (2-30 MHz) carriers for communication purposes greatly extends the range of channel at which aircrew can establish contact with Aeronautical Mobile Service stations.
This being so, we find that h.f. comm. Systems are fitted to aircraft flying routes which are, for some part of the flight, out of range of
v.h.f. Service.
Basic Principle:-

The long range is achieved by use of sky waves which are refracted by the ionosphere to such an extent that they are bent sufficiently to return to earth.



The h.f. ground wave suffers quite rapid attenuation with distance from the transmitter. Ionospheric attenuation also takes place, being greatest at the lower h.f. Frequencies.
A significant feature of long-range h .f. Transmission is that it is subjected to selective fading over narrow bandwidths (tens of cycles)
The current and future norm is to use single sideband(s.s.b.) mode of operation for h.f. communications, although sets in service may have provision for compatible or normal a.m., i.e. carrier and one or two sidebands being transmitted respectively. A feature of aircraft h.f. systems is that coverage of a wide band of r.f. and use of a resonant antenna requires efficient antenna tuning arrangement which must operate automatically on changing channel in order to reduce the VSWR to an acceptable level.
Installation :-
A typical large aircraft h.f. installation consists of two systems each of which comprises a
1. Transceiver
2. Controller
3. Antenna tuning unit (ATU) and
4. Antenna

Each of the transceivers are connected to the AIS for mic. tel. and
p.t.t. provision. In addition outputs to Selcal decoders are provided. The transceivers contain the receiver transmitter, power amplifier and power supply circuitry. They are mounted on the radio rack and provided with a flow of cooling air, possibly augmented by a fan.
Telephone and microphone jacks may be provided on the front panel, as might a meter and associated switch which will provide a means of monitoring various voltages and currents.
Coupling to the antenna is achieved via the antenna tuning unit (ATU). Some systems may employ an antenna coupler and a separate antenna coupler control unit. The ATU provides, automatically, a match from the antenna to the 50 ohm transmission line. Closed-loop control of matching elements reduces the standing wave ratio to 1.3: 1 or less.
Since the match must be achieved between line and antenna the ATU is invariably mounted adjacent to the antenna lead-in, in an unpressurized part of the airframe. For high-flying aircraft (most jets) the ATU is pressurized possibly with nitrogen. Some units may contain a pressure switch which will be closed whenever the pressurization within the tuner is adequate. The pressures which may be used for ohmmeter checks or, may be connected in series with the key line thus preventing transmission in the event of a leak. Alternatively an attenuator may be switched in to reduce power.
Light aircraft h.f. systems in service are likely to have a fixed antenna coupler. Such a system operates on a

restricted number of channels (say twenty). As a particular channel is selected, appropriate switching takes place in the coupler to ensure the r.f. feed to the antenna is via previously adjusted, reactive components, which make the effective antenna length equal to a quarter of a wavelength thus presenting an impedance of approximately 50 Ohm. The required final manual adjustment must be carried out by maintenance personnel on the aircraft.

Antenna :-

The use of antenna will depending on the type of aircraft. For low- speed aircraft a long wire antenna is popular although whip antennas may be found on some light aircraft employing low- powered h.f. systems. The aerodynamic problems of wire antennas on aircraft which fly faster than, say, 400 knots, have led to the use of notch and probe antennas which effectively excites the airframe so that it becomes a radiating element.

Modern wire antennas are constructed of copper-clad steel or phosphor bronze, giving a reduced r.f. resistance compared with earlier stainless steel wires. A covering of polythene reduces the effects of precipitation static.

Positioning is normally a single span between forward fuselage and vertical stabilizer. Larger aircraft will have twin antennas while a single installation, possibly in a 'V' configuration, is more common for smaller aircraft. The r.f. feed is usually at the forward attachment via an antenna mast. The rear tethering is by means of a tensioning unit.

The antenna mast is subject to pitting and erosion at the leading edge in spite of regular inspection; a neoprene covering will provide some protection.

Protection against condensation within the mast may be provided by containers of silica gel which should be periodically inspected for a change in colour from blue to pink, indicating saturation.

Hollow masts are usually provided with a water-drain path which should be kept free from obstruction.

The two most important features of the rear tethering point are that the wire is kept under tension and that a weak link is provided so as to ensure that any break occurs at the rear, so preventing the wire wrapping itself around the vertical stabilizer and rudder.

On light aircraft a very simple arrangement of a spring, or rubber bungee, and hook may be used. The spring maintains the tension but if this becomes excessive the hook will open and the wire will be free at the rear end.

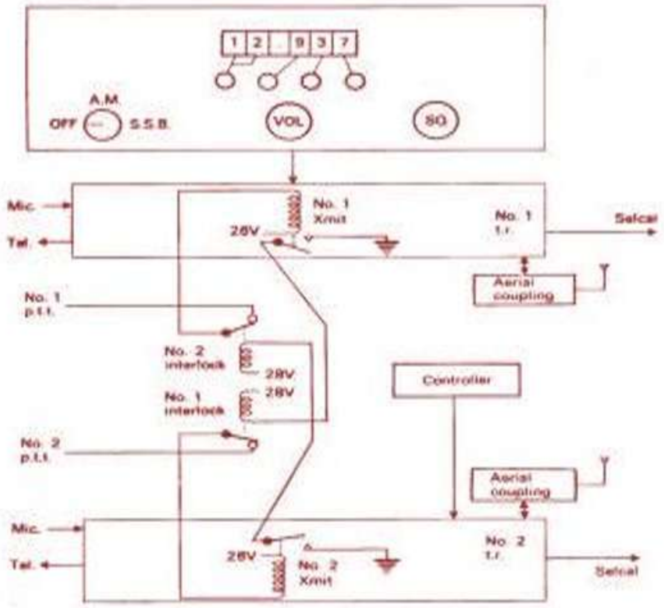
On larger aircraft a spring-tensioning unit will be used to cope with the more severe conditions encountered due to higher speeds and fuselage flexing. The unit loads the wire by means of a metal spring, usually enclosed in a barrel housing. A serrated tail rod is attached to the tethering point on the aircraft and inserted into the barrel where it is secured by a spring collet, the grip of which increases with tension. The wire is attached to a chuck unit which incorporates a copper pin serving as a weak link designed to shear when the tension exceeds about 180 lbf.

Some units incorporate two-stage protection against overload. Two pins of different strengths are used; should the first shear, a small extension(3/ 16 in.) of overall length results, thus reducing tension and exposing a yellow warning band on the unit.

A probe antenna, which is aerodynamically acceptable, may be fitted at either of the wing-tips or on top of the vertical stabilizer. Again series tuning provides the necessary driving force for radiation.

The probe antenna, as well as the wire antenna, is liable to suffer lightning strikes, so protection in the form of a lightning arrester (spark gap) is fitted. Any voltage in excess of approximately l 6 kV on the antenna will cause an arc across the electrodes of the hydrogen-filled spark gap, thus preventing discharge through the h.f. equipment.

Build-up of precipitation static on antennas, particularly probes, is dealt with by providing a high resistance static drain (about 6 M Ohm) path to earth connected between the antenna feed point and the ATU.



Interlock

Circuit Diagram Operation

It is important in dual installations that only one h.f. system can transmit at any one time; this is achieved by means of an interlock circuit.

It can be seen that the No. 1 p.t.t. line is routed via a contact of the No. 2 interlock relay, similarly with No. 2 p.t.t. The interl ock relays will be exter nal to the transc eivers often fitted in an h.f. accessory box.

While one of the h.f. systems is transmitting the other system must be protected against induced voltages from the keyed system. In addition with some installations we may have a probe used as a transmitting antenna for both systems and as a receiving antenna for, say, No.1 system. The No. 2 receiving antenna might be a notch.

It follows that on keying either system we will have a sequence of events which might proceed as follows:-

_ HF I keyed:

I. HF 2 keyline broken by a contact of HF Iinterlock relay;

2. HF 2 antenna grounded;

3. HF 2ATU input and output feeds grounded and feed to receiver broken.

‾ HF 2 keyed:

I. HF I keyline broken by a contact of HF 2 interlock relay;

2. HF I probe antenna transferred from HF I; ATU to HF 2 ATU;

3. HF 2 notch antenna feed grounded;

4. HF I ATU input and output feeds grounded and feed to receiver broken.

Controls And Operation

Separate controllers are employed in dual installations, each having 'in-use_ frequency selection only.

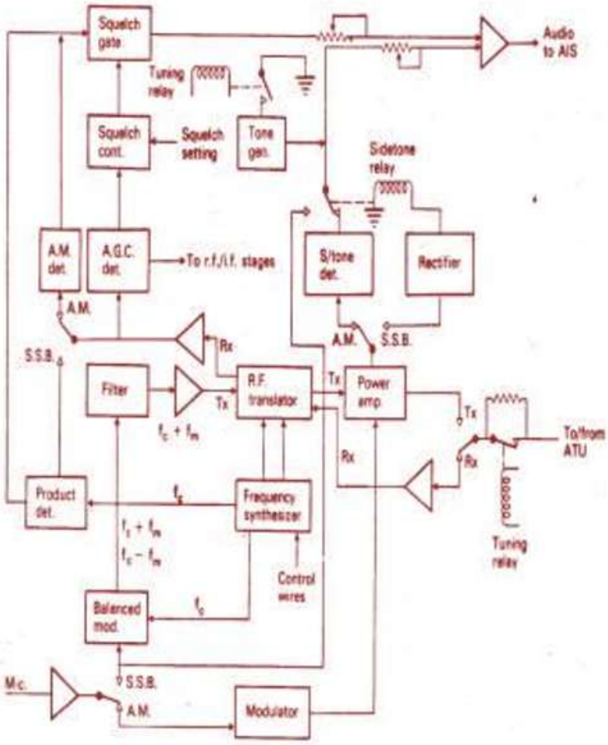
Mode Selector Switch:- (OFF-AM-SSB)

Switching on and off being achieved with the master radio switch. The 'AM_ position may be designated_ AME_(AM equivalent or compatible) and is selected whenever transmission and reception is required using a.m. or s.s.b. plus full carrier (a.m.e.). The 'SSB' position provides for transmission and reception of upper sideband only.

In addition 'DATA_ and 'CW_ modes may be available. The former is for possible future use of data links by h.f. using the upper sideband- the receiver is operated at maximum gain. The latter is for c.w.

transmission and reception, morse code, by 'key bashing', being the information-carrying medium.

Frequency Selector:-



Frequency selectors

consist of, typically, four controls which allow selection of frequencies between 2.8 and 24MHz with 1 kHz spacing. Military requirements are for frequency coverage of 2 to 30 MHz in0.1 kHz steps.

When a new frequency is selected the ATU must adjust itself since the antenna characteristics will change. For this purpose the transmitter is keyed momentarily in order that SWR and phase can be measured and used to drive the ATU servos.

Squelch Control:-

Normal control of squelch threshold may be provided. As an alternative an r.f. sensitivity control may be used, but where Selcal is utilized it is important that the receiver operates at full sensitivity at all times with a squelch circuit being employed only for aural monitoring and not affecting the output to the Selcal decoder.

Audio Volume control:-

It provides for adjustment of audio level. Such a control may be located elsewhere, such as on an audio selector panel, part of the AIS.

Clarifier:-

With s.s.b. signals while the phase of the re-inserted carrier is of little consequence its frequency should be accurate. Should the frequency be incorrect by, say, in excess of +/- 20 Hz deterioration of the quality of speech will result.

A clarifier allows for manual adjustment of the re-inserted carrier frequency. Use of highly accurate and stable frequency synthesizers make the provision of such a control unnecessary.

Indicator:-

A meter mounted on the front panel of the controller may be provided in order to give an indication of radiated power.

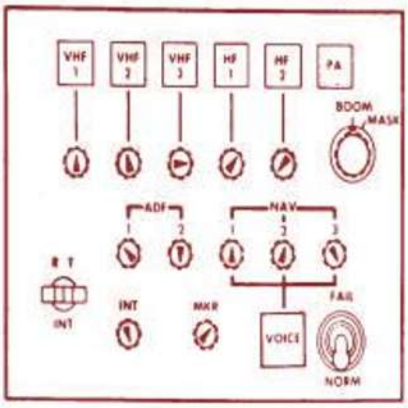
Block Diagram Operation HF Transceiver:-

Ramp Testing:-

Any maintenance schedule should require frequent inspection of antenna tensioning units and tethering points in the case of wire antennas, while for both probe and wire antennas the spark gap should be inspected for signs of lightning strikes (cracking and/or discolouring).

A functional test is similar to that for vh.f. in that two-way communication should be established with a remote station: all controls should be checked for satisfactory operation and meter indications, if any, should be within limits. Safety precautions are particularly important since very high voltages are present on the antenna system with the resulting danger of electric shock or arcing. No personnel should be in the vicinity of the antenna when transmitting, nor should fuelling operations be in progress.

Remember with many h.f. systems a change of frequency could result in transmission to allow automatic antenna tuning.



Audio Integrated System AIS

The function of the Audio Integrated system is to provide an interface between the pilot's mic. & tel. and the selected receiver &
transmitter.

Or

It provides provision for selection of radio system audio outputs and inputs and crew intercommunications.

Audio Integrated System comprises of following services:-

1. Flight Interphone
2. Cabin Interphone
3. Service Interphone
4. Passenger Addressing (PA)
5. Passenger Entertainment System (IFES)
6. Ground Crew Call System
7. Cockpit Voice Recorder

1. Flight interphone: It allows flight deck crew to communicate with each other or with ground stations.
2. Cabin interphone: It allows flight deck and cabin crew to communicate.
3. Service interphone: It allows ground staff to communicate with each other and also with the flight crew.
4. Passenger Address (PA): It allows announcements to be made by the crew to the passengers.
5. Passenger Entertainment system (IFES): It allows the showing of movies and the piping of music.
6. Ground crew call system: allows flight and ground crew to attract each other's attention.
7. Cockpit voice recorder: It meets regulatory requirements for the recording of flight crew audio for subsequent accident investigation if necessary.

Flight Interphone

This is really the basic and most essential part of the audio system. All radio equipments having mic. inputs or tel. outputs, as well as virtually all other audio systems, interface with the flight interphone which may, in itself, be termed the AIS.

A large number of units and components make up the total system as in Table 2.1 and with abbreviated terms as listed in Table 2.2

Audio Selection Panel (ASP)

Table 2.1 Flight interphone facilities

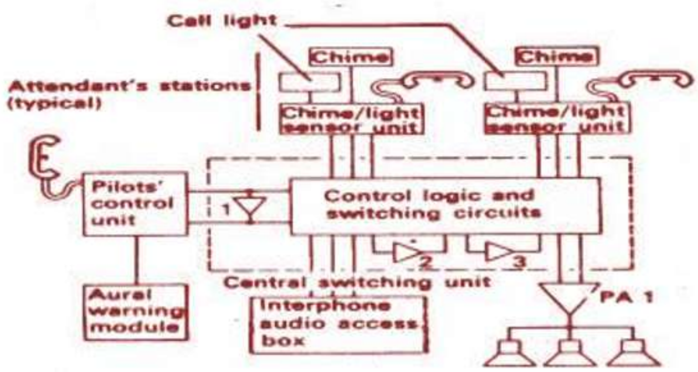
	CAPT	F/O	F/E	OBS1	OBS2	M.E.
ASP	×	×	×	×	×	×
Jack panel	×	×	×	×	×	—
Int — R-T p.t.t.	×	×	×	×	×	×
Handheld mic.	×	×	Jack	Jack	Jack	Jack
Headset	Jack	Jack	Jack	Jack	Jack	Jack
Boom mic. headset	×	×	×	×	×	—
Oxygen mask mic.	Jack	Jack	Jack	Jack	Jack	—
Interphone speaker	×	×	—	—	—	—

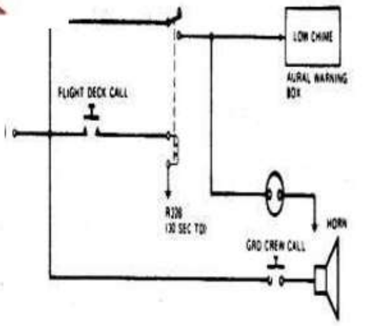
A '×' indicates the particular unit or component is fitted at that station (column).
'Jack' indicates a jack plug is fitted to enable use of the appropriate mic. and/or tel.

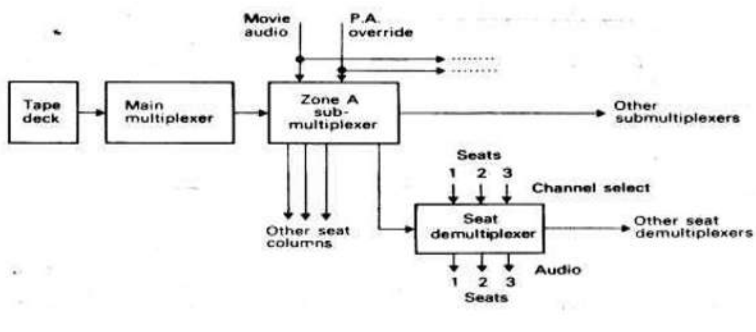
Table 2.2 Abbreviations

CAPT – Captain	a.s.p. – Audio Selector Panel
F/O – First Officer	int. – Interphone
OBS – Observer	r/t – Radiotelephone
m.e. – Main Equipment Centre	p.t.t. – Press to Transmit
mic. – Microphone	tel. – Telephone

Block Diagram of Flight Interphone







A crew member selects the tel. and mic. Signals required by the use of the appropria te controls/s witches on an ASP. The various audio signals entering an ASP are selected by combined push select and volume controls. Each ASP has an audio bus feeding a built-in isolation amplifier. The v.h.f. and h.f. comm. ADF, interphone and marker audio signals are fed to the bus via the appropriate select buttons and -volume controls. The v.h.f. nav. and DME audio is fed to the bus when voice and range are selected with the Voice pushbutton; with voice only selected the DME audio is disconnected while the v.h.f. nav.
Audio is passed through a sharp 1020 Hz bandstop filter (FLI) before feeding the bus. With the fail-normal switch in the fail position only one audio channel can be selected (bypassing the amplifier) and the PA audio is fed direct to the audio out lines. Radio altimeter audio is fed direct to the audio-out lines.

Cabin Interphone

The cabin interphone is a miniature automatic telephone exchange servicing several subscribers: the cabin attendants and the captain. In addition the system interfaces with the PA to allow announcement to be made.
Numbers are dialled by pushbuttons on the telephone type handsets or on the pilot's control unit. Eleven two-figure numbers are allocated to the subscribers plus additional numbers for PA in various or all compartments an 'all-attendants' call and an 'all-call'. Two dialling codes consist of letters: P-P is used by an attendant to alert the pilot (call light flashes on control unit and chime sounds once) while PA-PA is used by the pilot to gain absolute priority over all other users of the PA system. The directory is listed on the push-to-talks witch incorporated in each handset to minimize ambient noise.
All dialling code decoding and the necessary trunk switching is carried out in the central switching unit, CSU (automatic exchange). The CSU also contains three amplifiers, one of which is perma nently allocat ed to the pilot on what is effecti vely a private trunk. Of the five other available trunks, two are allocated to the attendants, two to the PA system and-one for dialling. (Note a trunk is simply a circuit which can connect two subscribers.)

Block Diagram of Cabin Interphone

The cabin interphone and service interphone systems may be combined into a common network by appropriate selection on the flight engineer's interphone switch panel, captain's ASP and cabin interphone control unit. Any handset may then be lifted and connected in to the network (dial —all-call'). In a similar way the flight interphone circuits may be used to make specific calls over the cabin interphone.

Service Interphone

A total of twenty-two handset jacks are located in various parts of the airframe in order that ground crew can communicate with one another using the service interphone system. The system is rather simpler than those considered above. Mic. audio from all handsets with 'press to talk' depressed are combined in and amplified by the service interphone amplifier in the interphone audio accessory box. The amplified signal is fed to all handset tels. Volume control adjustment is provided by a preset potentiometer.

Block Diagram of Service Interphone

With the flight engineer's interphones witch selected to ON the input summing networks for both service and flight interphone system recombined. All mic.inputs from either system are amplified and fed to both systems.

Passenger Address (PA)

The system comprises three PA amplifiers, tape deck, annunciator panel, attendant's panel, PA accessory box, control assemblies, speaker switch panel and fifty-three loudspeakers. The various PA messages have an order of priority assigned to them: pilot's announcements, attendant's announcements, pre-recorded announcements and finally boarding music. All PA audio is broadcast over the speaker system and also, except for boarding music, overrides entertainment audio fed to the passenger stethoscope headsets. A pre-recorded emergency announcement may be initiated by the pilot or an attendant, or automatically in the event of cabin decompression'. A chime is generated when the pilot turns on 'fasten seat-belt' or 'no smoking' lights.
The passenger address amplifiers are fed via the flight or cabin interphone systems for pilot or attendant

announcements respectively. Distribution of audio from the amplifiers to the

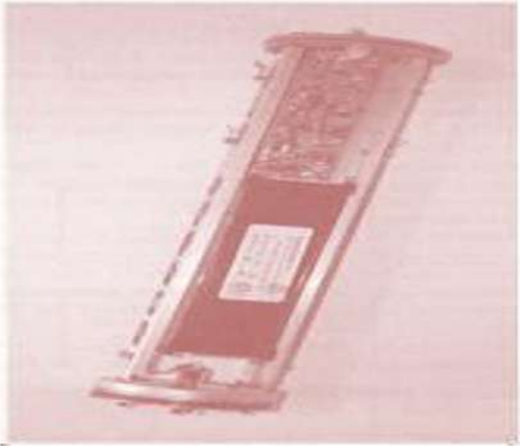


Figure 8: Interior view of the Class W ELT. Note how the battery occupies 50% of the space

speakers in various zones depends on the class configuration, since some announcement may be intended for only a certain class of passengers.

The necessary distribution is achieved by means of switches on the speakers witching panel. Audio is also fed to the flight interphone system for sidetone purposes.

Number 2 and number 3 amplifiers are slaved to number 1 for all class announcements. Should separate class

announcements be required the parallel control relay is energized, so separating the number 1 audio from that of number 2 and 3. The

control assemblies in the PA accessory box contain potentiometers used to set the gain of the PA amplifiers. When the aircraft is on the ground with landing gear locked down and ground power applied the level of speaker audio is reduced by 6 dB.

Passenger Entertainment System

The passenger entertainment system of the Boeing 747 and any other modern large airliner is perhaps the most complex of all airborne systems. It is also the system likely to cause most trouble and, fortunately, least likely to affect the safety of the aircraft unless bad servicing leads to a fire or loose-article hazard. Even on the same type of aircraft a variety of services will be available since different operators will offer different entertainment in a bid to capture more customers.

Block Diagram of Passenger Address

Ground Crew Call System

Ground crew call is hardly worthy of the title 'system', as can be seen from the schematic diagram in Figure. The horn and flight-deck call button are located in the nose wheel bay while the ground-crew call (with illumination) and aural warning box are on the flight deck. Operation is self-explanatory from the diagram. Should horn or chime sound, the ground crew, or flight crew respectively, will contact each other using one of the interphone systems.

Emergency Locator Transmitter (ELT)

Purpose

The emergency locator transmitters (ELT) are required for most general aviation aircraft for the purpose of helping search & rescue (SAR) team to locate the aircraft and facilitate the timely rescue of survivor.

Working Frequency

The ELT designed to operate on the VHF and UHF band.

VHF ELT generates an RF career that is amplitude modulated by distinctive siren-like sound. This weeps downward at the repetition rate of typically between 2 & 4 Hz. This signal will be transmitted radically on the career frequency of 121.5 MHz (For Civil Aviation) & 243 MHz (For Military).

* Note:- 121.5 MHz ELT can be easily converted in 243 MHz ELT by adding a frequency doubler in the primary Ckt.

UHF ELT operates on the frequency of 460.025 MHz. This device is much more sophisticated and operates on higher power (5 w instead of 150mW commonly used at VHF). Unlike the simple amplitude modulation used with their VHF counterparts, 460 MHz ELT transmit digitally encoded data which incorporate a code that is unique to the aircraft.

Types of ELT

1. Automatic ejectable or Automatic Deployable (A or AD)
2. Fixed (non-ejectable) or Automatic Fixed (F or AF)
3. Automatic Portable (AP)
4. Personal Activated (P)
5. Water Activated or Survival (W or S)

1. Automatic ejectable or Automatic Deployable (A or AD)

This type of ELT automatically eject from the aircraft and is set in operation by inertia sensors when the aircraft is subjected to a crash de-acceleration force acting through the aircraft flight axis. This type is expensive and seldom used in aviation.

2. Fixed (non-ejectable) or Automatic Fixed (F or AF)

This type of ELT is fixed to the aircraft and is automatically set in operation by inertia switch when the aircraft is subjected to a crash de-acceleration force acting through the aircraft flight axis. The transmitter can be manually activated deactivated and in some cases may be remotely controlled from the cockpit. Provision may be made for recharging the ELT battery from the aircraft electrical supply. Most general aviation aircraft uses this type ELT, which must have the function switch placed to the armed position for the unit to function automatically in a crash.

3. Automatic Portable (AP)

This type of ELT is similar to Type-F / Type-AF except that the antenna is integral to the unit for portable operation.

4. Personal Activated (P)

This type of ELT has no fixed mounting and does not transmit automatically. Instead, a switch must be manually operated in order to activate or de-activate ELT transmitter.

5. Water Activated or Survival (W or S)

This type of ELT transmits automatically when immerged in water. It is waterproof, float and operates on the surface of the water. It has no fixed mounting and should be tethered to survivors or life rafts by means of the supplied cord.

Maintenance of ELT

Provided they have been properly maintained the ELT are capable of continuous operation for up to 50 hours. ELT performance may seriously impaired when the batteries are out of date. Therefore routine maintenance is essential to check the ELT battery date and y ELT is found with outdate battery then it will be considered manufacturer‘s instruction when testing.

Two station air testing (in conjunction with a nearby ground station) is usually preferred because , due to the proximity of transmitting and receiving antenna, a transmitting before activating the unit and the checking the radiated signal.

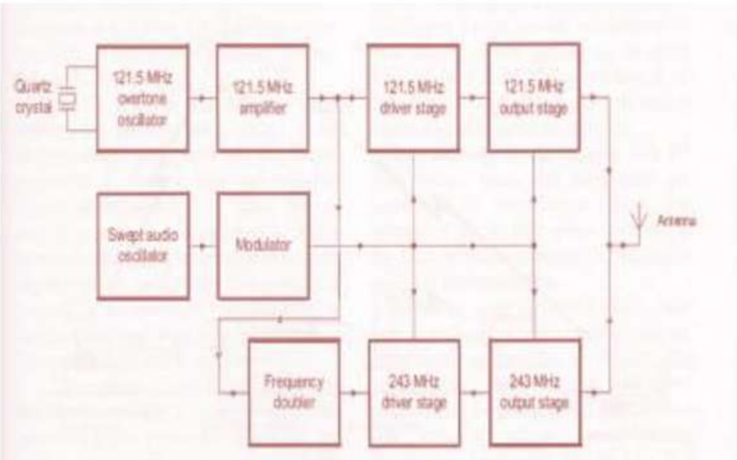
Simple air test between an aircraft and ground station (or between two aircrafts) can some time be sufficient to ensure that the ELT is functional.
However it is important to follow unserviceable.
The ELT should be checked to ensure that it is secure, free from external corrosion, and that antenna connection are secured.
Testing of ELT
Air testing normally involved first listening on the beacon‘s output frequency (i.e. 121.5 MHz), checking that the ELT is not test carried out with the aircraft‘s own VHF receiver may not reveal a fault condition in which the ELT‘s RF output has become reduced.
To avoid unnecessary SAR mission, all accidental activation of ELT must be reported to appropriate authority.
Installation Requirement of ELT

1. When installing in fixed wing aircraft, ELT should be mounted with its sensitive axis pointing in the direction of flight.
2. When installing in rotorcraft, ELT should be mounted with its sensitive axis pointing approximately 45 degree downward from the normal forward direction of the aircraft.
3. ELT should be installed to withstand ultimate inertia force of 10 G upward, 22.5 G downward, 45 G forward and 7.5 G sidewise.
4. The location chosen for ELT should be free from vibration to prevent involuntary activation of the transmitter.
5. ELT should be located in the area so as to minimize the probability of damage to the unit and antenna in the case of fire and crash.
6. ELT should be accessible for manual activation and de- activation. If it is equipped with the antenna for portable operation, the ELT should be easily detachable from inside the aircraft.
7. The External Surface of the aircraft should be marked to indicate the location of ELT.
8. When an ELT has provision or remote operation, it is important to ensure that appropriate notices are displayed.

The Antenna used by fixed type of ELT should confirm to the following :-

a) ELT should not use the antenna of another avionics system.
b) ELT antenna should be mounted as far away as possible from the other VHF antenna.
c) The position of antenna should be as to ensure essentially omni- directional radiation characteristic.
d) The antenna should be mounted as far aft as possible.
e) ELT antenna should not foul or make contact with any other antennas during flight.

Block Diagram of ELT

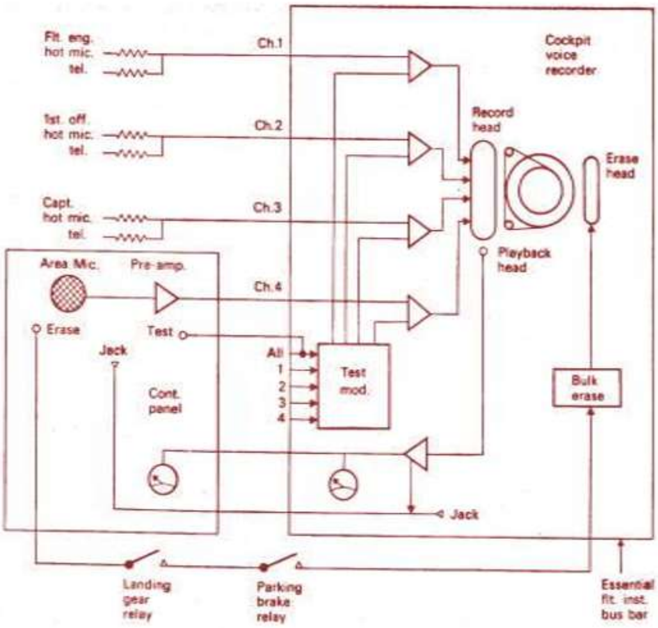


Cockpit Voice Recorder (CVR)

A recorder which records the Audio environment of flight deck.An endless tape provides 30 min recording time for audio signals in- put on four separate channels.

The channel inputs are:-

1. captain's
2. first officer's
3. flight engineer's transmitted and received audio
4. Cockpit area conversation.



Note:- Passenger address audio may be substituted for the flight engineer's audio in an aircraft certified to fly with two crew members.

The microphone inputs should be from so-called hot mics, (i.e. microphones which are permanently live regardless of the setting of ASP or control column switches.)

The area microphone (which may be separate from the control panel) is strategically situated so that it can pick up night crew speech and general cockpit sounds.

While the control panel is situated in the cockpit, the recorder unit (CVR) is located at the other end of the aircraft where it is least likely to suffer damage in the event of an accident. The CVR is constructed so as to withstand shock and fire damage, and additionally is painted in a fire-resistant orange paint to assist in Recovery from a wreck.

Block Diagram of CVR contacts are closed. As a further safeguard against accidental erasure a delay is incorporated in the bulk erase circuit which requires the operator to depress the 'erase_ switch for two second before erasure commences.

Test facilities are provided for all four channels, separately or all together. A playback head and monitor amplifier allows a satisfactory test to be observed on meters or heard over a headset via jack plug sockets. Pressing the test button on the control panel or the all-test button on the CVR causes the channels to be monitored sequentially.

The power supply for the system should be from a source which provides maximum reliability. Since the tape is subject to wear and thus has a limited life, the CVR should be switched off when not in use. A suitable method would be to remove power to the CVR whenever external ground power is connected.

VHF Omnidirectional Range (VOR)

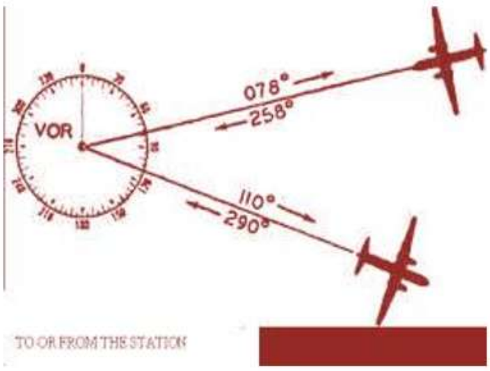
Introduction

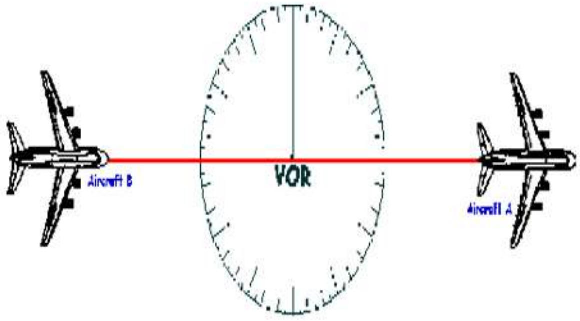
The recorded
audio may
be erased providing the landing gear and parking brake interlock
relay

VOR provide a short / medium range navigation system. The wave propagate in line of sight and essentially a space wave.

- Operating Frequency :- 108 MHz – 118 MHz
- Channel spacing :- 50 KHz
- Total Number of channel :- 200 (out of which 160 channel are allotted to VOR)

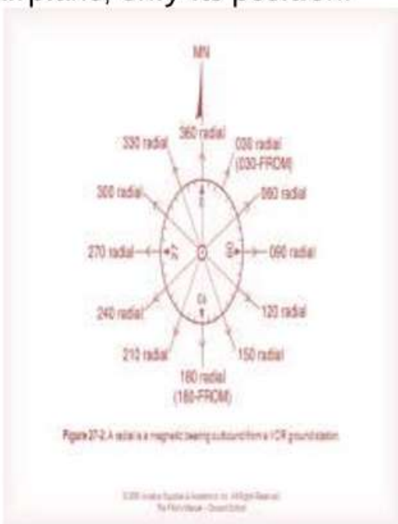
En-route VOR - Out of these160 channels 12O are allocated to en- route VOR stations. The output power of an en-route station will be about 200 W providing service up to 49 nautical miles. Its frequency will be within the band 112 MHz - 118 MHz.
Terminal VOR (TVOR) :- out of 160 channels, 40 are allotted to TVOR. it will have the output power of about 50 W providing service up to 25 nautical miles. Its frequency will be within the band 108 MHz - 112 MHz. This being the part of the total band shared with ILS localizer.
To obtain a position fix from VOR one needs bearings to two separate stations : when used in this way VOR can be considered a theta-theta system. If a VOR station is co-located with a DME station an aircraft can obtain a fix using the pair as a rho-theta system.
Important Terminology
1. Radial: - these radials are assigned number which pertains to their situation around the magnetic compass card. They are considered as being drawn away from the VOR station to a particular magnetic direction.
For example the given figure illustrates for 90 degree course. This 90 degree course consists for 90 degree radial
and / the 270 degree radial, with an intended direction of travel of 90 degree. The lower illustration for a 270 degree course consisting of a 90 degree radial and / the 270 degree radial, with an intended direction of travel of 90 degree.





2. Bearings:- Given figure indicates that the bearing refers to the direction from a certain place toward VOR station.
If the airplane is north of the station, the bearing of the VOR is 180 degrees.
If the airplane is east of the station, the bearing of the VOR is 270 degrees.
Radials are shown to be being pointed in the direction.
4. Course: -

reciprocal of the bearing or vice a versa.
This has nothing to do with heading of airplane, only its position.



3. Heading:-
Below given figure illustrate the heading which refers only to the direction in which aircraft is pointed. It has nothing to do with other than the compass heading which the aircraft has a result of

depends on the phase difference between reference and variable phases (time difference between light and beam).
Conventional VOR (CVOR)
The radiation from a conventional VOR (CVOR) station is a horizontally polarized v.h.f. wave modulated as follows:-

1. 30Hz AM :- The variable phase

9960Hz am:- this is sub career frequency modulated at 30 Hz with a deviation of + 480 Hz. The 30 Hz signal is reference phase.

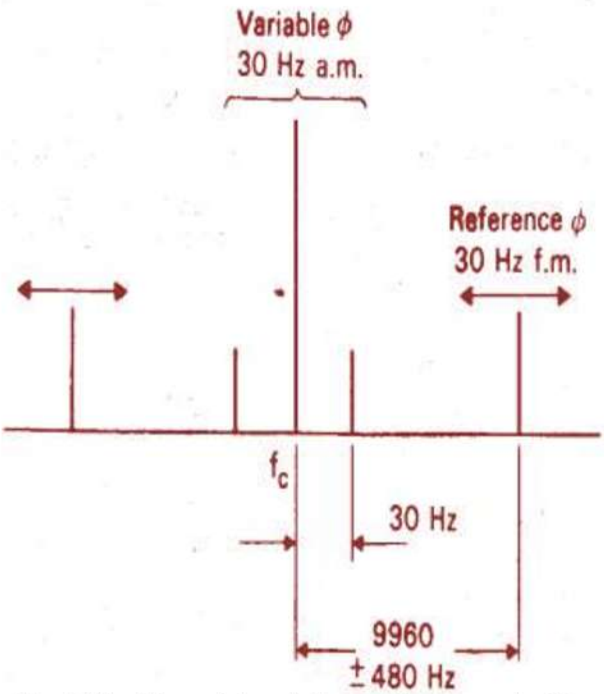
1020 Hz am :- identification signal

It is an intended flight path or direction of travel with respect to north.

Basic Principle

A simple analogy to VOR is given by imagining a lighthouse which emits an Omni-directional pulse of light every time the beam is pointing due north. If the speed of rotation of the beam is known, a distant observer could record the time interval between seeing the Omni-directional flash and seeing the beam, and hence calculate the bearing of the lighthouse.

In reality a VOR station radiates v.h.f. energy modulated with a reference phase signal (the Omni-directional light) and a variable phase signal (the rotating beam). The bearing of the aircraft

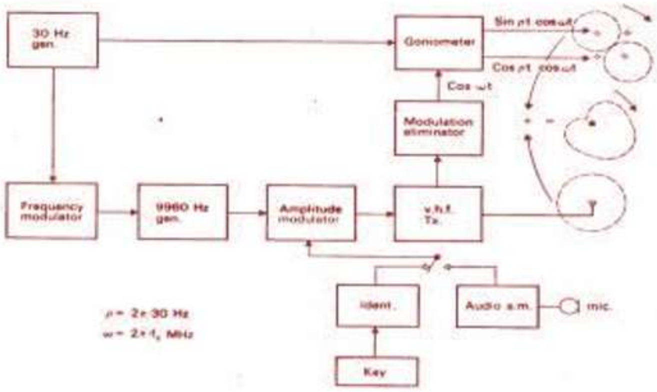


keyed to provide morse code identification at least three times each 30 s. Where a VOR & DME are collocated the identification transmission are synchronised.

4. Voice am:- the VOR system can be used as a ground to air communication channel as long as this does not interfere its basic navigational function. The frequency range of the voice modulation is limited to 300 – 3000 Hz.

The 30 Hz variable phase is space modulated in that the necessary amplitude variation in the received signal at the aircraft is achieved by radiating a cardioid pattern rotating at 1800 r.p.m. The frequency modulated 9960 Hz sub-carrier amplitude modulates the r.f. at source before radiation. It is arranged that an aircraft due north of the beacon will receive variable and reference signals in phase, for an aircraft at X Degree magnetic bearing from the station variable phase will lag the reference phase by X degree.

Frequency Spectrum CVOR Space Signal



VOR Ground Station Block Diagram

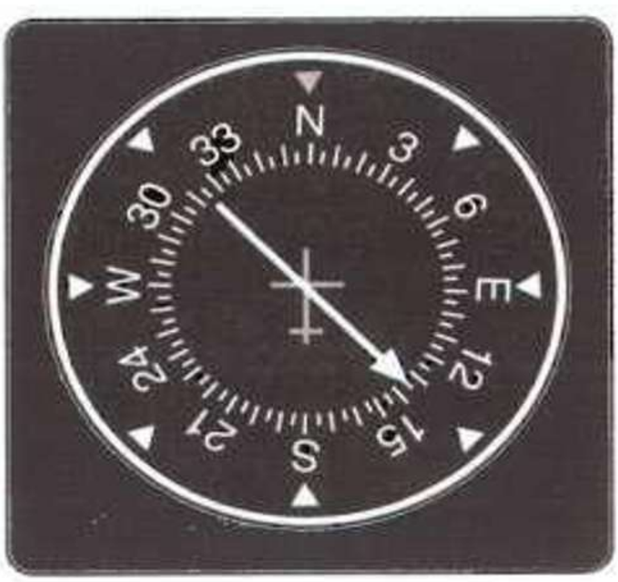
The airborne equipment receives the composite signal radiated by the station to which receiver are tuned. After detection the various modulating signals are separated by filters. The 30 Hz reference signal is phase compared with the variable signal, the difference in phase gives the bearing from the station.

The actual reading presented to the pilot is the bearing to the station rather than from the station so if he difference in phase between variable & reference signal is 135 degree the —to‖ bearing would be 135+180 =315 degree.

Automatic Direction Finder (ADF)

- The Automatic Direction Finder (ADF) consists of:
  - AM receiver
  - Sense Antenna
  - Loop Antenna (directional antenna)
  - Indicator (fixed or movable card)

The Auto mati c in ADF
come
s from the fact that the direc tio
l



antenna is rotated electronically rather than manually by rotating the antenna or turning the aircraft to make signal strength determinations.

the station)

Fixed card

With a fixed card there are two ways to determine magnetic bearing to the station:

Turn the aircraft toward the station and note heading MH + RB = MB (to the station)

MH = aircraft magnetic heading

RB = Relative bearing

MB = Magnetic Bearing (to

ADF Operation

There is a switch on the receiver marked: OFF/ADF/ANT/BFO

ANT- gives maximum receiver sensitivity and should be used for tuning and identifying (3 letter coded I.D. except for LOM's which have 2 letter I.D.'s)

BFO- (Continuous Wave) position is used for better identifying unmodulated signals which are used in other parts of the world.

After identifying station be sure to place selector switch in the

—ADF‖ mode as the indicator will not display any bearing information in the ANT mode

Leave volume up continuously when using the ADF as NDB frequencies can shift

Most units have a —Test‖ function which swings the needle; don't use if the needle doesn't swing. This verifies proper signal reception.

ADF indicators

– (If the result is more than 360 then subtract 360

Movable Card Indicators:

– Set aircraft heading at top of the indicator and read the relative bearing to the station.
– Sense Antenna is 840-1750kHz.

ADF Analog Controls and Indicator

The ADF pointer is pointed to the NDB that is tuned.

The Band Selector selects which band is tuned; the First band is 190-430kHz, the Second is 420-850kHz, the Third

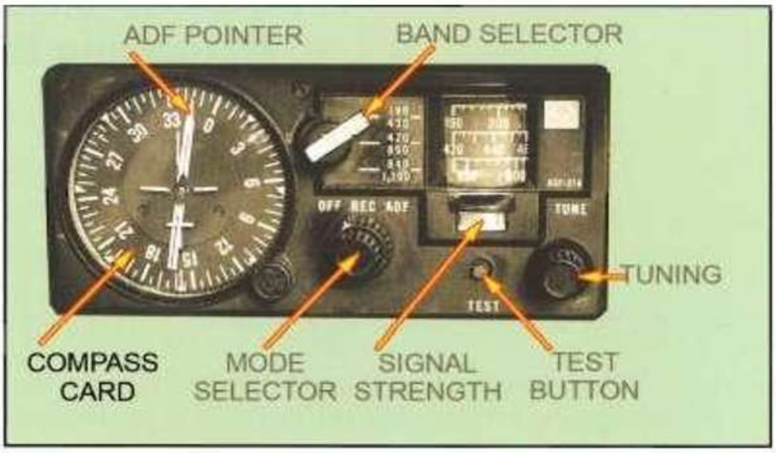
ADF Controls

The second band is also AM broadcast stations.
The Mode Selector allows selection between ADF to receive both loop and sense signals (ADF) or just the sense antenna (REC) to listen to AM radio.
TEST will cause the needles to swing 90° to insure the needles are not stuck.
Digital ADF Controls

Here is a digital controller for ADF used in General Aviation.
The BFO is used for audio station identification in Morse Code.

The ADF display has 2 sides: one for active and the other for stored frequencies.
The indicator light shows which frequency is active.
The transfer switch, TFR, allows selection of which frequency is active.
The TONE switch is the same as the BFO (Beat Frequency Oscillator) to make an audio
ID of the station for stations that don‘t broadcast audio. ANT is equivalent to the REC mode in the analog system.

ADF Block Diagram
The goniometer computes angle information which is fed to the ADF receiver.
The loop and sense antenna pick up directional signals from the station.

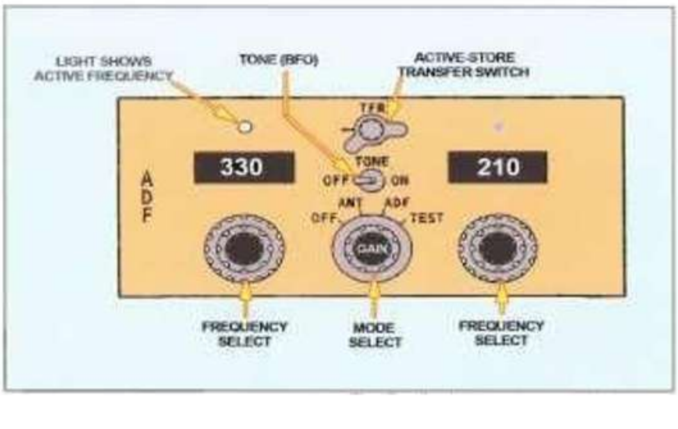


ID is sent to the aircraft‘s audio control panel.
NDB Navigation Techniques
• Homing:
The receiver
computes bearing information to the station and sends it to the

RMI.
The Morse code station

– Note the angle of deflection, double it, and use that as your intercept heading. When that angle of deflection is then noted on the indicator (from the nose or tail) the aircraft is back on course
– Establish an initial track by taking half of that intercept angle out
• Example:
– You want to track inbound on the 360 bearing to the station. There is a wind from the west.
– While tracking (heading north) unaware of the wind you note a left needle deflection of 10 degrees.
– Double that to 20 degrees for your intercept heading and turn the aircraft left to 340 degrees.

– Turing the aircraft such that the needle always points directly toward the station- easy but inefficient as it does not compensate for crosswinds
– Results in a curved path to the station in a crosswind situation
• Tracking:
– Establishing a wind correction angle that negates the drift caused by the crosswind
Principle: WHEN THE ANGLE OF DEFLECTION = THE ANGLE OF INTERCEPTION YOU'RE ON COURSE
– Or: when the angle formed by the aircraft heading and the desired course is the same as the angle between either the 0 or 180 mark on the indicator and the pointer, the aircraft is on course.
• Tracking tip- When tracking inbound on an NDB bearing and you note you‘re off course:
• As you turn to 340 you notice the needle move toward the top of the indicator.
• As you continue on 340 the needle will drift toward the right. When it indicates 20 degrees, the aircraft is back on course.
• Take half your calculated intercept heading and use that as your initial track heading (350 degrees). This results in a 010 degree indication on the indicator.
• Repeat the process until track correction and needle deflection are equal.
NDB/ADF Limitations Night Effect-
– NDB‘s emit three signals, among these are the ground wave and the sky wave. Normally the ground wave is the strongest which is the one use for navigation.



– The skip zone is the difference or gap between the ground wave and the reflected sky wave.
– Light passing through the ionosphere causes height fluctuations within it varying the angle of the reflected sky wave and possibly causing signal confusion during this time between the two signals. The needle may wander. Resolves shortly after sunrise or sunset.

Fading

- Usually occurs at night when ground wave and sky wave interact going in and out of ―phase‖ causing the signals to be either canceled or reinforced as the atmosphere changes.
- Pilots will notice a rythmic swinging of the needle and a volume fluctuation of the identifier.
- Average the fluctuations and note the bearing when the signal seems strong.

Shoreline Effect

Ground waves change direction as they pass from land to water and visa versa; they are bent slightly. Pilots should note potential bearing indication errors when flying in the vicinity of coastal areas. NDB‘s used primarily for oceanic navigation have been designed to minimize this error.

Other sources of Error

- Terrain- mountains, areas with high concentrations of iron
- Interference- between two stations may cause the ADF to oscillate between one station and the other- indicated by receiving two simultaneous I.D. codes. Usually resolves itself with proximity
- Thunderstorms
- Lightening can create signal disturbances causing the needle to momentarily swing in the direction of the storm. As such ADF is sometimes referred to as a ―Poor man‘s Storm Scope.‖
- Pilots should not rely on ADF indications in the vicinity of thunderstorms.

ADF Accuracy

Variable - not possible to determine. As such, back up ADF indications whenever possible.

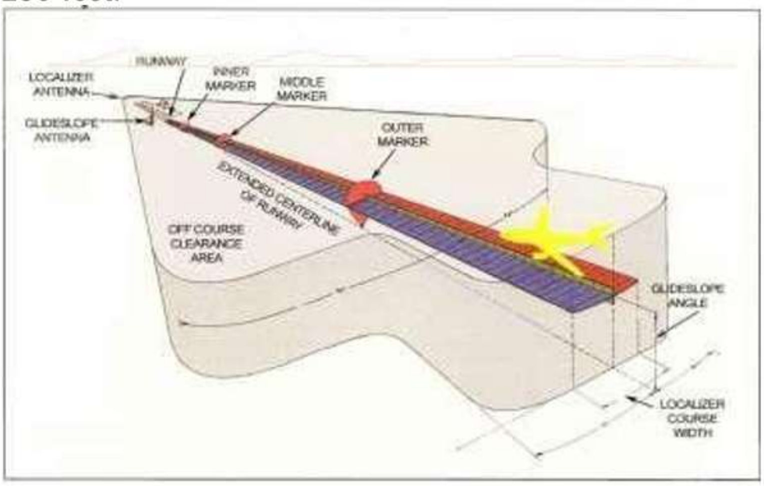
INSTRUMENT LANDING SYSTEM

The ILS system uses VHF radio (at the airport) to transmit signals that are received by the VOR receiver (in the airplane) and display guidance information on the flight director or send information to the autopilot.
The radio signal that lines up the airplane with the runway is called the Localizer.
The radio signal that keeps the aircraft descending at a safe angle is called the Glideslope.

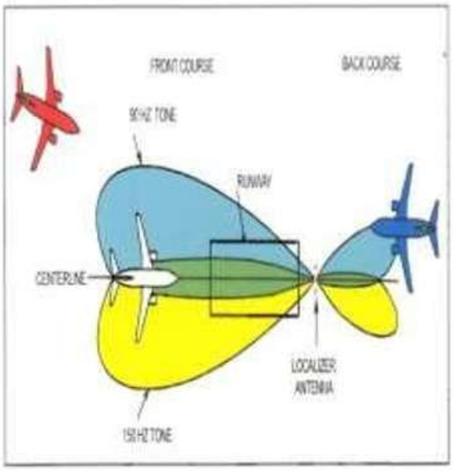
The Marker Beacon is 3 radio beacons positioned along the extended centerline of the runway that alert the pilot for glideslope intercept, decision height and when to go around.

ILS Categories

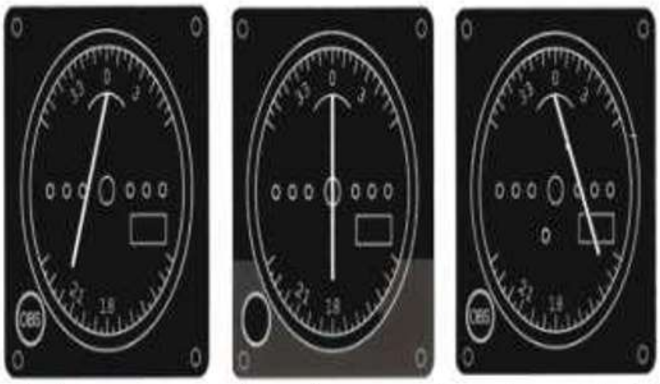
There are several categories of ILS, each pertaining to how low the visibility can be in order for the aircraft to land safely.
The categories are based on ceiling and visibility at the airport when the airplane arrives.
Decision Height (DH) Runway Visual Range (RVR). Category I is a DH of 200 feet and an RVR of 2400 feet. Category II is a DH of 100 feet and an RVR of 1200 feet
Catego ry IIIA is a DH of 100 feet and an RVR of 700 feet.
Catego ry IIIB is a DH of
100 feet and an RVR of 150 feet.



Category IIIC is ―0/0‖, no visibility, and currently there are no Cat IIIC airports in the US.
The airplane must be equipped and maintained for the various categories and the pilots must also be trained and qualified to land in low visibility conditions.
The ILS components consist of a Localizer, Glideslope and Marker Beacon System.
These systems have airborne and ground systems.
The compass locator is a low power station picked up by an ADF receiver to guide the airplane arriving from any direction to the outer marker.

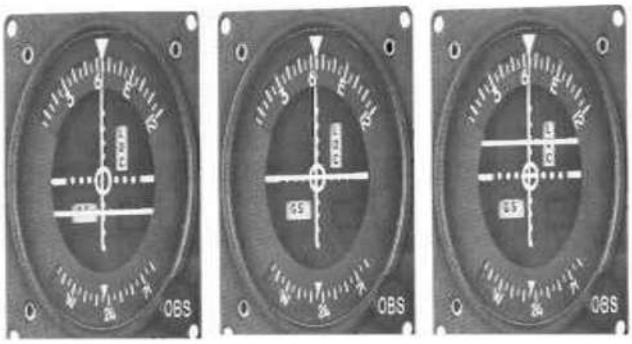


Localizer
From the ground, a localizer transmitter projects radio beams aligned with the centerline of the runway.
It operates in the VHF band from 108.1-111.95 MHZ.
The localizer transmits 2 tones: 150Hz and 90Hz,



and one tone is on one side of the runway, the other on the other side The ILS receiver measures the difference of strength of the 2 tones to compute whether or not the aircraft is centered or off course.
Localizer is displayed where VOR is displayed but it is 4x more sensitive.

LOCALIZER ANTENNA

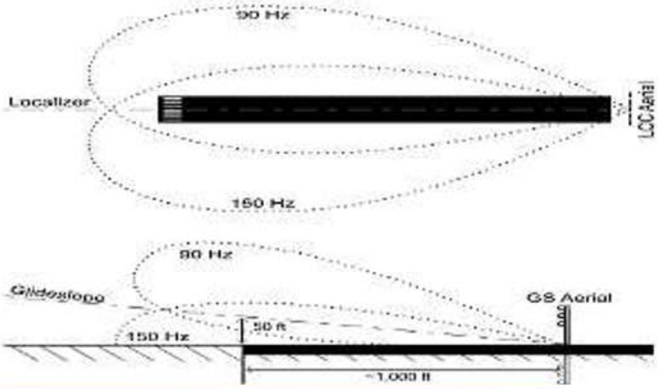


Glideslope
The glideslope signal provides
vertical guidance.
There are no controls for the
pilot to tune the glideslope, it is automatically tuned when he tunes the localizer.
The glideslope operates on the UHF band from 329.15 MHz to 335 MHz.
Just like with the localizer, it transmits 2 tones: 150 or 90Hz to indicate whether the airplane is above or below the glide path.

The standard beacon is the fan-shaped beam, which is rectangular in shape and radiating vertically, so that signals will only be received during the short period of time that the aircraft is passing through the beam. Z-markers are dumbbell or bone-shaped, signals being received from the narrow portion of the pattern. The latter type of marker is generally used where —timed‖ approaches are in operation. The Polar diagram of the transmitted signal is a vertical fan or funnel-shaped lobe. Quite opposite to the NDB, the marker beacon can only be received when directly overhead.
There are three types of marker beacons that may be installed as part of their most common application, an Instrument Landing System:

1.1.4 OUTER MARKER

Outer Marker indicator
Marker Beacon



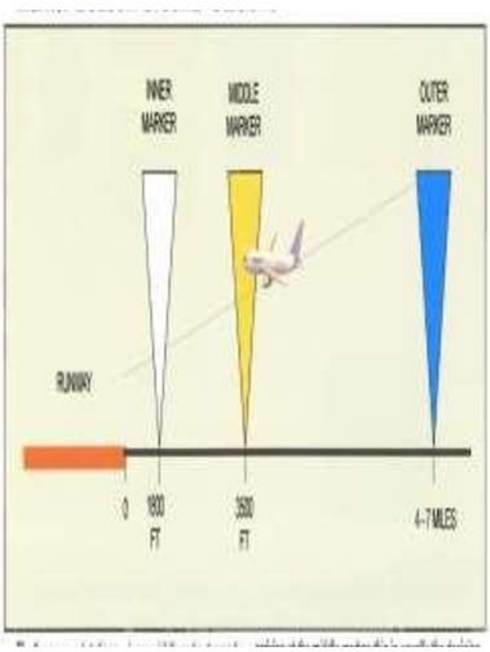
GLIDESLOPE ANTENNA

The Outer Marker, which normally identifies the final approach fix (FAF), is situated on the same course/track as the localizer and the runway center-line, four to seven nautical miles before the runway threshold. It is typically located about 1 NM (1.85 km)

The Marker Beacon receiver is fixed-tuned to 75MHz.
There is a 3-light indicator in the flight deck which will light up the respective light for each marker as the aircraft passes over the marker.
There is also an audio tone which sounds, and the pitch increases and sounds faster as the beacon is approached.
Z-markers and Fan Markers

inside the point where the glideslope intercepts the intermediate altitude and transmits a 400 Hz tone signal on a low-powered (3 watts), 75 MHz carrier signal. Its antenna is highly directional, and is pointed straight up. The valid signal area is a 2,400 ft (730 m) × 4,200 ft (1,280 m) ellipse (as measured 1,000 ft (300 m) above the antenna.) When the aircraft passes over the outer marker antenna, its marker beacon receiver detects the signal. The system gives the pilot a visual (blinking blue outer marker light) and aural

(continuous series of audio tone morse code-like 'dashes') indication.



1.1.4.1A locator outer marker
In the United States, the outer marker has often been combined with a non-directional beacon (NDB) to make a Locator Outer Marker (LOM). An LOM is a navigation aid used as part of an instrument landing system (ILS) instrument approach for aircraft. Aircraft can navigate directly to the location using the NDB as well as be alerted when they fly over it by the beacon.
The LOM is becoming less important now that GPS navigation is well established in the aviation community. Some countries, such as Canada, have abandoned marker beacons completely, replacing the outer marker with a non-directional beacon (NDB); and, more recently, with GPS fixes.
In the U.S., LOMs are identified by two-letter Morse code modulated at 1020 Hz. LOMs use the first two

letters of the parent ILS's identification. For example, at New York's JFK runway 31R the ILS identifier is I-RTH and the LOM identity is RT. If this facility were a locator middle marker (LMM) its identifier would be the last two letters, TH.

1.1.5 MIDDLE MARKER

A middle marker works on the same principle as an outer marker. It is normally positioned 0.5 to 0.8 nautical miles (1 km) before the runway threshold. When the aircraft is above the middle marker, the receiver's amber middle marker light starts blinking, and a repeating pattern of audible morse code-like dot-dashes at a frequency of 1,300 Hz in the headset. This alerts the pilot that the CAT I missed approach point (typically 200 feet (60 m) above the ground level on the glideslope) has been passed and should have already initiated the missed approach if one of several visual cues has not been spotted.

1.1.6 INNER MARKER

Inner Marker indicator

Similar to the outer and middle markers; located at the beginning (threshold) of the runway on some ILS approach systems (usually Category II and III) having decision heights of less than 200 feet (60 m) AGL. Triggers a flashing white light on the same marker beacon receiver used for the outer and middle markers; also a series of audio tone 'dots' at a frequency of 3,000 Hz in the headset.

On some older marker beacon receivers, instead of the "O", "M" and "I" indicators (outer, middle, inner), the indicators are labeled "A" (or FM/Z), "O" and "M" (airway or Fan and Z marker, outer, middle). The airway marker was used to indicate reporting points

along the centerline of now obsolete "Red" airways; this was sometimes a "fan" marker, whose radiated pattern was elongated at right angles across the airway course so an aircraft slightly off course would still receive it. A "Z" marker was sometimes located at low/medium frequency range sites to accurately denote station passage. As airway beacons used the same 3,000 Hz audio frequency as the inner marker, the "A" indicator on older receivers can be used to detect the inner marker.

MICROWAVE LANDNG SYSTEM

ILS Limitations

ILS has limitations.

It only has 40 channels.

It only can serve one runway, causing congestion in bad weather. It is subject to interference by powerful

FM broadcasts.
It can be blocked by terrain.

Advantages of MLS
Can be used to land aircraft on aircraft carriers. Has 200 channels, instead of just 40.
Can handle curved and stepped approaches.
The glideslope is selectable, which can handle steeper approaches that helicopters use.
Is not subject to interference from FM radio stations. Is not subject to blockage from terrain.
MLS is at very few airports, however. This is because it is anticipated to be replaced by GPS.

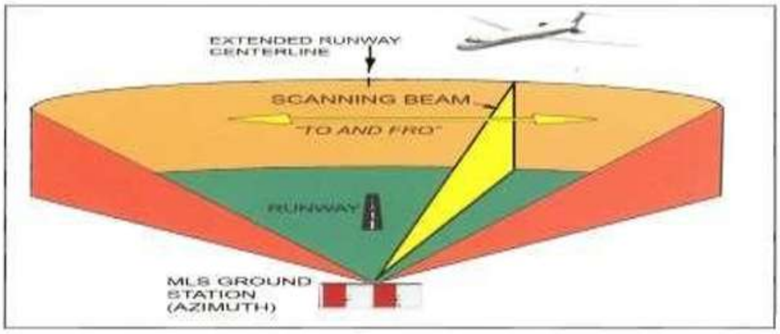
- MLS (Microwave Landing System) was developed to improve the uses of ILS system, however only few Airports have MLS installations.
- MLS is an advanced precision approach and landing system.

- MLS provides position information in a wide coverage sector and is determined by:
  - Azimuth angle measurement (horizontal)
  - Elevation measurement(vertical)
  - Range measurement

An MLS azimuth (horizontal) guidance station
MLS operates in the Super High Frequency (SHF) between 5031 – 5090 MHZ (5.031-5.090GHz).

- MLS use passive electronically scanned arrays to send scanning beams towards approaching aircraft.
- An aircraft that enters the scanned volume uses a special receiver that calculates its position by measuring the arrival times of the beams.
- MLS provide large coverage signals even in very poor visibility.
- As MLS signals have large coverage, this will increase runway utilization.

MLS also has more channels which can avoid the signal interferences.
MLS Azimuth Beam
A narrow scanning beam from the MLS sweeps back and forth beyond either side of the runway.
A new receiver was made to receive MLS, called a Multi-Mode receiver and can handle ILS, MLS and GPS.

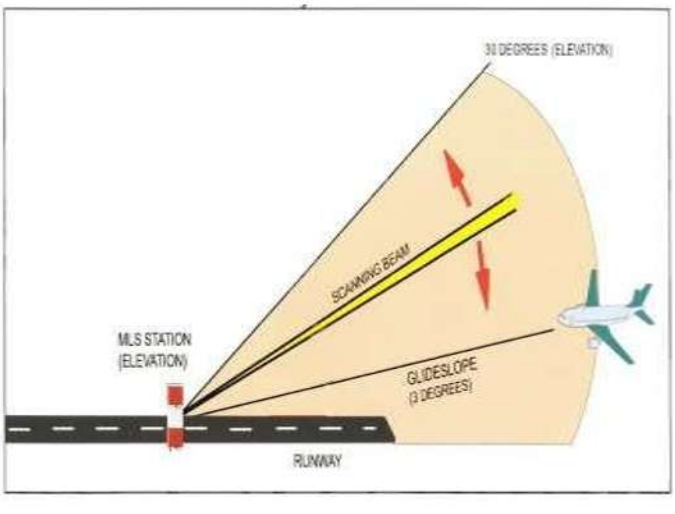


An arriving aircraft picks up the sweeps called —TO‖ and —FRO‖.
A time difference between the TO and FRO beams is used to compute where the runway centerline is.
A curved approach can be computed if the aircraft is equipped with a Flight Management System (FMS).
Azimuth Transmitter
One of the 2 major components of an MLS system is the azimuth transmitter.
The azimuth signal is similar to the localizer signal in ILS.
The azimuth signal sweeps a wide area beyond the left and right sides of the runway allowing for many inbound courses.
The station is located about 400 feet beyond the end of the runway as seen by an arriving aircraft.

Wilcox

MLS Elevation Beam
Just like with the azimuth beam, the elevation beam scans To and Fro.
However, the beam goes up and down instead of side to side.

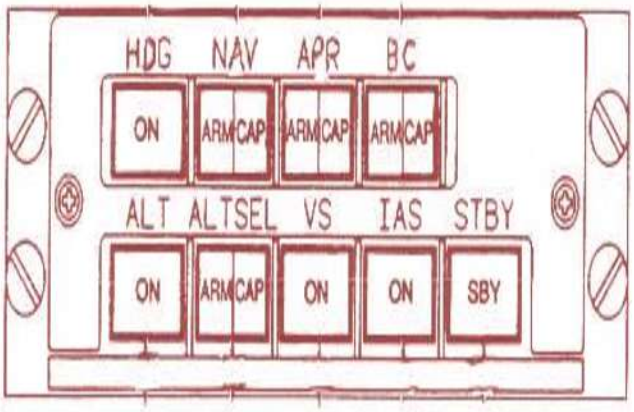
The aircraft again uses the time difference to compute glidepath.
Steeper glidepaths can be computed for helicopter use.
MLS signals
arriving at the airplane produce 2 peaks as the beam sweeps back and forth over the receiver antenna. The airborne equipment computes the time difference between the peaks to determine the centerline (AZ) or glidepath (EL).
The airborne equipment can tell the difference between the 2 signals by a short identifier known as a —preamble‖.
The AZ signal sweeps at 13.5 scans a second and the EL signal scans at 40.5 scans a second.
The EL signal has a higher frequency due the necessity of a more accurate signal for glidepath.



The FD is generally used in direct connection with the autopilot, where the FD commands the AP to put the aircraft in the attitude necessary to follow a trajectory. The FD/AP combination is typically used in autopilot coupled instrument approaches such as CAT II and CAT III ILS instrument approaches.

FLIGHT DIRECTOR SYSTEM/DISTANCE MEASURING EQUIPMENT

FLIGHT DIRECTOR SYSTEM



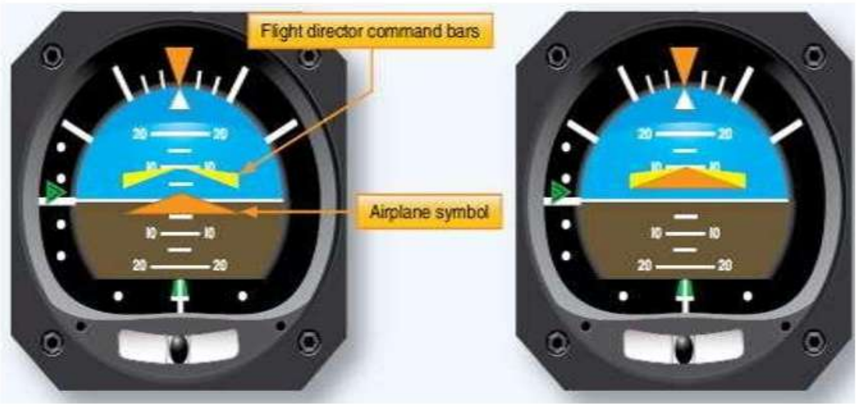
A flight director (FD) is a flight instrument that is overlaid on the attitude indicator that shows the pilot of an aircraft the attitude required to follow a certain trajectory to which the flight is to be conducted.
The flight director computes and displays the proper pitch and bank angles required in order for the aircraft to follow a selected path. Flight director guidance can be used in both manual flight and with the Autopilot engaged.

The exact form of the flight director's display varies with the instrument type.

A flight director system is an instrument system consisting of electronic components that compute and indicate the aircraft attitude required to attain and maintain a preselected flight condition. A command bar on the aircraft's attitude indicator shows the pilot how much and in what direction the attitude of the aircraft must be changed to achieve the desired result. The computed command indications relieve the pilot of many of the mental calculations required for instrument flights, such as interception angles, wind drift correction, and rates of climb and descent.

Essentially, a flight director system is an autopilot system without the servos. All of the same sensing and computations are made, but the pilot controls the airplane and makes maneuvers by following the commands displayed on the instrument panel. Flight director systems can be part of an autopilot system or exist on aircraft that do not possess full autopilot systems. Many autopilot systems allow for the option of engaging or disengaging a flight director display.

Flight director information is displayed on the instrument that displays the aircraft's attitude. The process is accomplished with a visual reference technique. A symbol representing the aircraft is fit into a command bar positioned by the flight director in the proper location for a maneuver to be accomplished. The symbols used to represent the aircraft and the command bar vary by manufacturer. Regardless, the object is always to fly the aircraft symbol into the command bar symbol.



The instrument that displays the flight director commands is known as a flight director indicator (FDI), attitude director indicator (ADI), or electronic attitude director indicator (EADI). It may even be referred to as an artificial horizon with flight director. This display element combines with the other primary components of the flight director system. Like an autopilot, these consist of the sensing elements, a computer, and an interface panel.

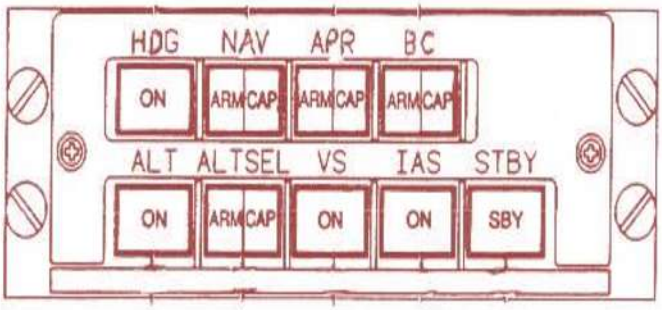
Integration of navigation features into the attitude indicator is highly useful. The flight director contributes to this usefulness by indicating to the pilot how to maneuver the airplane to navigate a desired course. Selection of the VOR function on the flight director control panel links the computer to the omni-range receiver. The pilot selects a desired course and the flight director displays the bank attitude necessary to intercept and maintain this course. Allocations for wind drift and calculation of the intercept angle is performed automatically.

Flight director systems vary in complexity and features. Many have altitude hold, altitude select, pitch hold, and other features. But flight director systems are designed to offer the greatest assistance during the instrument approach phase of flight. ILS localizer and glideslope signals are transmitted through the receivers to the computer and are presented as command indications. This allows the pilot to fly the airplane down the optimum approach path to the runway using the flight director system.

With the altitude hold function engaged, level flight can be maintained during the maneuvering and procedure turn phase of an approach. Altitude hold automatically disengages when the glideslope is intercepted. Once inbound on the localizer, the command signals of the flight director are maintained in a centered or zero condition. Interception of the glideslope causes a downward indication of the command pitch indicator. Any deviation from the proper glideslope path causes a fly-up or fly- down command indication. The pilot needs only to keep the airplane symbol fit into the command bar.

Flight director/mode selector

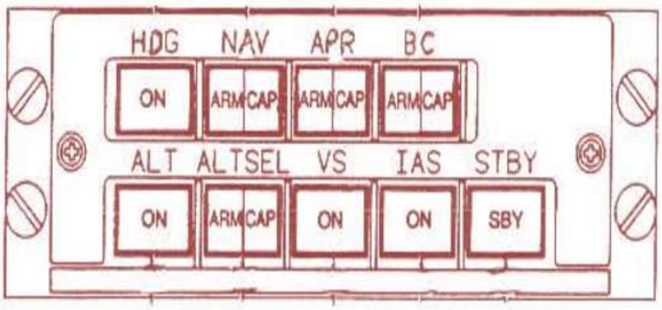
This provides all mode selections except go-around for the flight director. The top row of light annunciated pushbuttons contains.
The lateral modes and the bottom row contains the vertical modes.
The split light pushbuttons illuminate amber for armed and green for capture. When more than one lateral or vertical mode is selected,
The flight director system automatically arms and captures the sub- mode. The mode annunciations are repeated on the EADI.



HEADING SELECT MODE (HDG)
In the HDG mode the flight Director computer provides inputs to the command cue to command a turn to the heading indicated by the heading Bug on the EHSI. The heading select signal is gain programmed as a function of airspeed. When HDG is selected, it overrides the NAV, BC, APR and VOR APR modes.

NAVIGATION MODE (NAV)
The navigation mode represents a family of modes for various navigation systems including VOR, LOCALIZER, TACAN or VLF as selected by the EHSI selector switches.

VOR MODE (NAV)
VOR mode is selected by Depressing NAV and a VOR frequency tuned with DME greater than 20 miles from the station. Prior to capture, the command cue receives a heading select command from HDG mode. Upon VOR capture the system automatically switches to the VOR mode, HDG and NAV arm annunciators extinguish and NAV cap annunciator illuminates on the mode selector. VOR gain programmed as a function of distance. This programming corrects for beam convergence thus optimizing the gain through the useful VOR range. To utilize this feature, DME must be tuned to the same VOR as navigation source selected.
VOR MODE (CONT)
Cross-wind washout is included which maintains the aircraft on beam center in the presence of crosswind. The intercept angle and
DME distance are used in determining the capture point to ensure smooth and comfortable performance during bracketing. When passing over a station, an over station sensor detects station passage removing the VOR deviation signal from the command until it is no longer erratic. While over station, course changes may be made by selecting a new course on the EHSI.



Distance Measuring Equipment (DME)
Many VOR stations are co-located with the military version of the VOR station, which is known as TACAN. When this occurs, the navigation station is known as a VORTAC station. Civilian aircraft

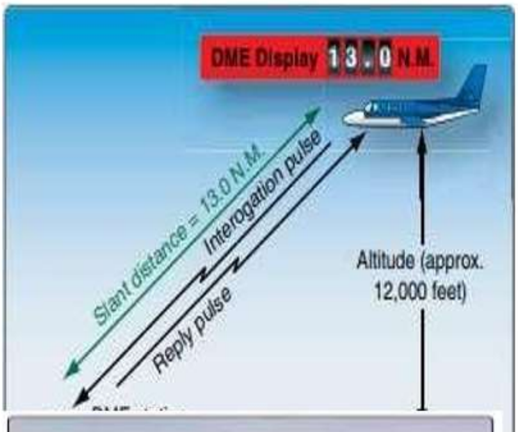


Figure 11-119. A VOR with DME ground station.

Figure 11-120. Distance information from the DME can be displayed on a dedicated DME instrument or integrated into any of the electronic navigational displays found on modern aircraft. A dual display DME is shown with its remote mounted receiver.

make use of one of the TACAN features not originally installed at civilian VOR stations–distance measuring equipment (DME). A DME system calculates the distance from the aircraft to the DME unit at the VORTAC ground station and displays it on the flight deck. It can also display calculated aircraft speed and elapsed time for arrival when the aircraft is traveling to the station.

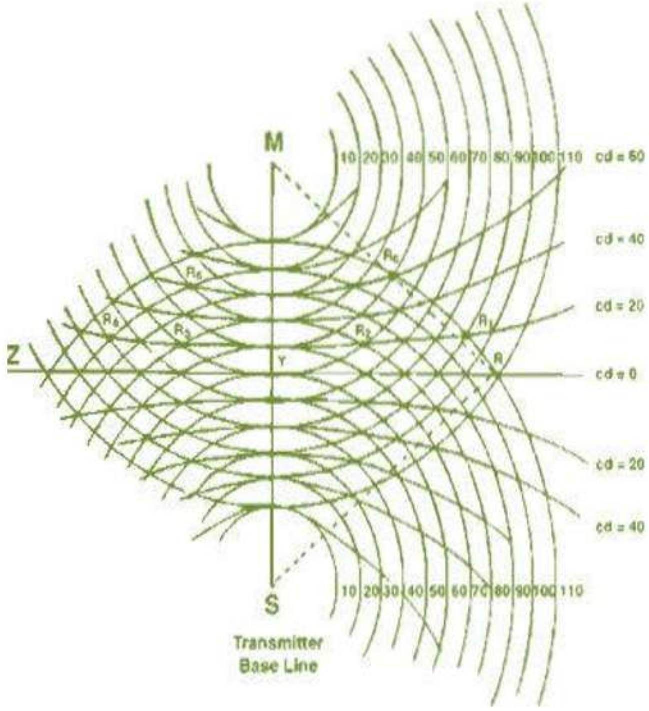
DME ground stations have subsequently been installed at civilian VORs, as well as in conjunction with ILS localizers. These are known as VOR/DME and ILS/DME or LOC/DME. The latter aid in approach to the runway during landings. The DME system consists of an airborne DME transceiver, display, and antenna, as well as the ground based DME unit and its antenna. [Figure 11-119] The DME is useful because with the bearing (from the VOR) and the distance to a known point (the DME antenna at the VOR), a pilot can positively identify the location of the aircraft. DME operates in the UHF frequency range from 962 MHz to 1213 MHz. A carrier signal transmitted from the aircraft is modulated with a string of integration pulses. The ground unit receives the pulses and returns a signal to the aircraft. The time that transpires for the signal to be sent and returned is calculated and converted into nautical miles for display. Time to station and speed are also calculated and displayed. DME readout can be on a dedicated DME display or it can be part of an EHSI, EADI, EFIS, or on the primary flight display in a glass cockpit. The DME frequency is paired to the co-located VOR or VORTAC frequency. When the correct frequency is tuned for the VOR signal, the DME is tuned automatically. Tones are broadcast for the VOR station identification and then for the DME. The hold selector on a DME panel keeps the DME tuned in while the VOR selector is tuned to a different VOR. In most cases, the UHF of the DME is transmitted and received via a small blade-type antenna mounted to the underside of the fuselage centerline.

A traditional DME displays the distance from the DME transmitter antenna to the aircraft. This is called the slant distance. It is very accurate. However, since the aircraft is at altitude, the distance to the DME ground antenna from a point directly beneath the aircraft is shorter. Some modern DMEs are equipped to calculate this ground distance and display it.

VERY LOW FREQUENCY AND HYPERBOLIC NAVIGATION (VLF/OMEGA)

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 kms or 6 18 its per NM). The ground

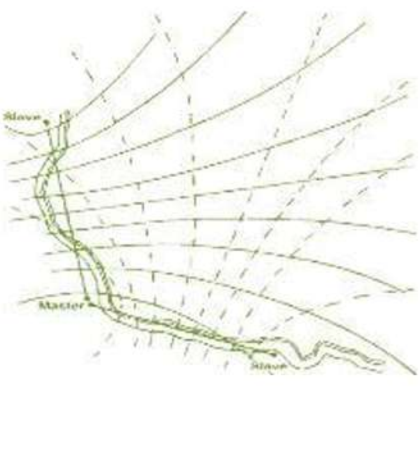


LORAN Long Range Navigation System O M E G A

installations consist o(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:

world The MASTER Station transmits pulses of radio energy which are received at the SLAVE Station after a certain time depending on the distance be Wean the 2 stations, e. g. if the 2 stations are 200 NM apart the MASTER Signal will take 200 x
6.18 us = 1'236 p s 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 denotes the SLAVE Station. The concentric lines surrounding the 2 stations represent time in microseconds. Cd lines are - lines of constant time difference.
R1 lies on the 90 us line of the MASTER and the 110 us line of the SLAVE Station. The time difference at this position is 20 us. At positions R2.R3 and R4 we also have a time difference of20 us. This allows to draw a hyperbolic position line having a constant time difference value of 20 us.
In early systems the navigator in the cockpit had to read the time difference with an oscilloscope twice and comparing it with a



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

specific loran chart with compote's 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 toe 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

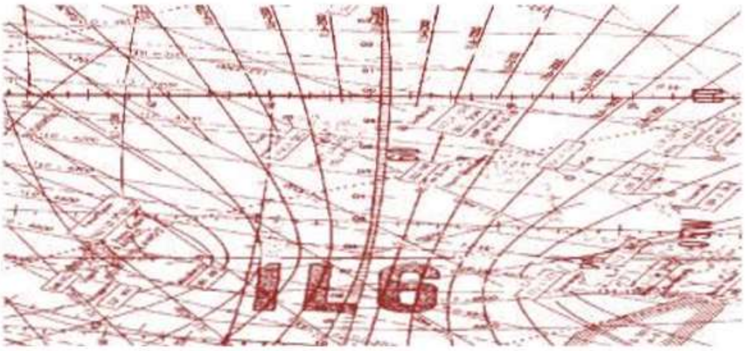


Figure 361: LORAN Chart used by Navigators DOPPLER NAVIGATION
The Doppler Radar is an airborne self-contained long-range navigation aid requiring no ground installation
The Doppler works with great accuracy and provides the plot with the following information:
- Ground Speed.
-Drift angle.

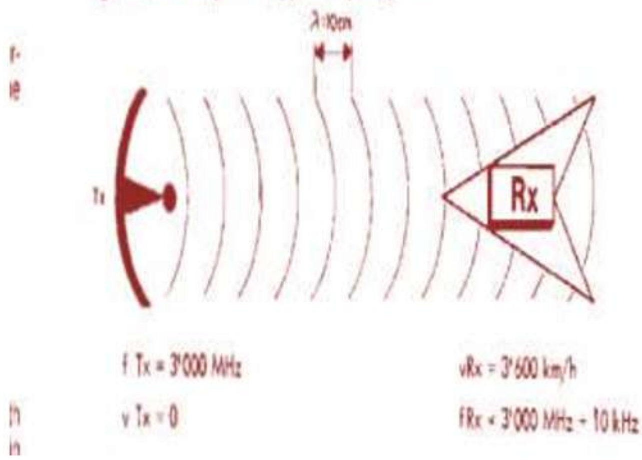
-Miles-to-go (to a preselected Position),

-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, he 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 cue 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:
$fd = lc \cdot v/c$

where v is the rate of change in path length between the transmit and receive antenna, c is the speed of light, fc is the carrier frequency of the signal, and fd is the Doppler frequency shift. The carrier frequency is stilted from fe to fc+fd.

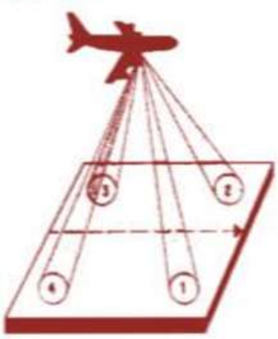
Figure 362: Example of Doppler frequency shift



Example
In the example shown, the stationary transmitter transmitting on 3'000 MHz.The wave length (X = c/f) of 3'000 MHz (300'000 KHz) is 0 1 m

The moving speed of the receiver is 3'60C 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 knots
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.

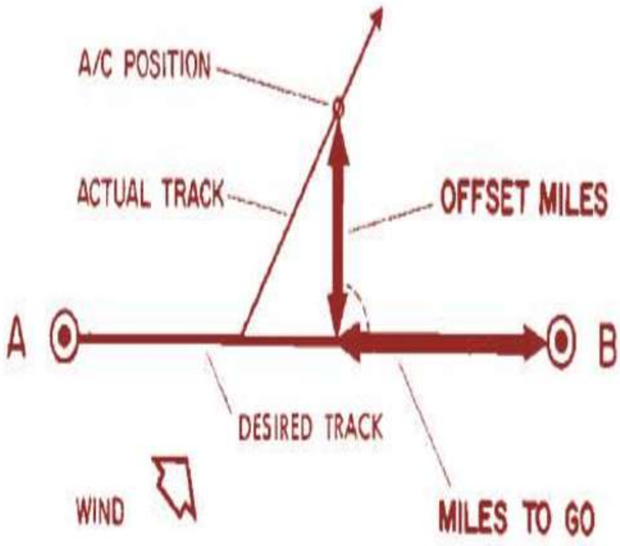
Figure 363: Four Beam Antenna



Doppler Sensor

The aircraft equipment consists of a transceiver unit and an antenna system emit- ting 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)



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 P o s i t i o n

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 +/- 112 degree

Ground Speed error +/• 0.5% plus 1 knot

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 independent of any provider and ground installations.

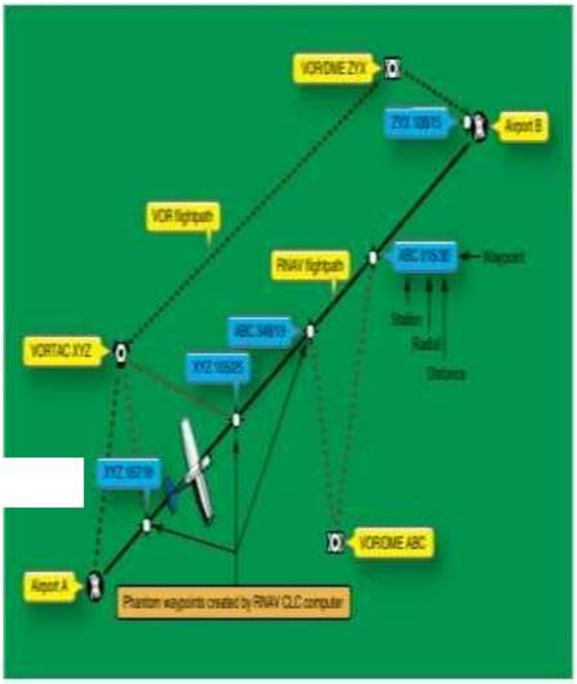
Area Navigation (RNAV)

Area navigation (RNAV) is a general term used to describe the navigation from point A to point B without direct over flight of navigational aids, such as VOR stations or ADF non-directional beacons. It includes VORTAC and VOR/DME based systems, as well as systems of RNAV based around LORAN, GPS, INS, and the FMS of transport category aircraft. However, until recently, the term RNAV was most commonly used to describe the area navigation or the process of direct flight from point A to point B using VORTAC and VOR/DME based references which are discussed in this section. All RNAV systems make use of waypoints. A waypoint is a designated geographical location or point used for route definition or progress-reporting purposes. It can be defined or described by using latitude/longitude grid coordinates or, in the case of VOR based RNAV, described as a point on a VOR radial followed by that point‘s distance from the VOR station (i.e., 200/25 means a point 25 nautical miles from the VOR station on the 200° radial). Figure 11-123 illustrates an RNAV route of flight from airport A to airport B. The VOR/DME and VORTAC stations shown are used to create phantom waypoints that are over flown rather than the actual stations. This allows a more direct route to be taken. The phantom waypoints are entered into the RNAV course-line computer (CLC) as a radial and distance number pair. The computer creates the waypoints and causes the aircraft‘s CDI to operate as though they are actual VOR

stations. A mode switch allows the choice between standard VOR navigation and RNAV. VOR based

RNAV uses the VOR receiver, antenna, and VOR display equipment, such as the CDI. The computer in the RNAV unit uses basic geometry and trigonometry calculations to produce heading, speed, and time readouts for each waypoint. VOR stations need to be within line-of sight and operational range from the aircraft for RNAV use. [Figure 11-124] RNAV has increased in flexibility with the development of GPS. Integration of GPS data into a planned VOR RNAV flight plan is possible as is GPS route planning without the use of any VOR stations.

Flight Management Systems



Flight Management Systems (FMS) are able to compute all relevant aspects of an entire flight using navigation and performance databases stored in the unit as well as pilot entered data. Pilots interact with the system by using one to three identical Multipurpose Control and Display Units (MCDU).

Navigation functions of the FMS Modern aircraft are still able to navigate using the techniques developed in the early days of instrument flying. By tuning ground based navigation aids (VORs and NDBs) according to airways depicted on maps, radials to or from a station are indicated on the pilot's navigation display and can be followed using autopilot basic modes – heading-mode in lateral and vertical speed in vertical direction. Today, this kind of flying is used in case of technical failures only. As constant re-tuning of navigation aids as well as manual corrections for wind influence are required, a high workload for the pilots results.

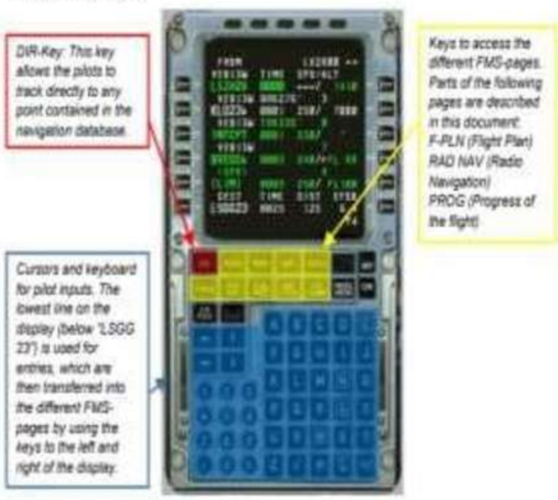


Fig. 1: Overview of the Multipurpose Control and Display Unit (MCDU) used in the Airbus A320.

Pilot's tasks are significantly reduced by the FMS: Its database contains all airports, navigation aids and waypoints (points set at arbitrary coordinates) and is able to calculate an entire route from a departure airport via waypoints to the destination.
Departure and arrival procedures often contain altitude and speed constraints at certain points, which are either programmed in the FMS database or can be entered manually by the pilots. Considering all constraints, the FMS then computes a three dimensional flight path and automatically adjusts the target speed if required. These

F-PLN page: This page contains the entire flightplan from the departure to the landing runway, in this example Zurich's runway 28 (LSZH28) to Geneva's runway 23 (LSGG23). At each waypoint, an estimated time of overflight, the expected speed, the estimated altitude and the estimated remaining fuel on board is calculated, considering navigational as well as performance and weather data. Pilots can adapt the flightplan by entering e.g. a new waypoint in the bottom display line and then entering it into the existing flightplan by using the keys to the left of the display.

INIT page 1: Used for initialization of the system before the flight, this page contains basic data like departure and destination airport, flight number, cost index to be used, planned cruising flight level, wind and weather data.

INIT page 2: Zero fuel weight and the corresponding center of gravity position as well as fuel figures (block fuel, taxi fuel, reserve fuel) are inserted here.

Fig. 2: FMS flightplan and initialization pages

signals are sent to the flight director and to the speed indication/autothrottle system and are followed by the autopilot.
Furthermore, flight management systems are able to perform four dimensional navigation. Pilots can enter a target time at a specific waypoint (e.g. the point where they start their final descent and approach), leaving the task of adjusting the speed to the FMS (within the aerodynamic capabilities of the aircraft). This method could help to reduce delays and holding times, however, it is seldom used in the current air traffic control environment. Performance functions of the FMS Due to economic and ecologic reasons, fuel saving is of utmost importance in today's airline business. Optimum speeds during all phases of a flight depend on aircraft mass and wind conditions as well as on the relationship between fixed costs (e.g. crew or maintenance costs, depreciation of the aircraft) and fuel costs, which is modelled using a so called Cost Index in modern aircraft. Final approach speeds depend on mass and actual winds and need to be calculated for each approach. All of these computations could be performed manually, using the performance tables provided by the manufacturer. However, to relieve the pilots from such time consuming routine tasks, the FMS contains the aircraft's performance data, enabling it to optimize the flight profile. Speeds are computed as well as the optimum altitude (again depending on aircraft mass and wind) and the top of descent (point at which to start the descent to allow for an economic approach) and subsequent descent profile.

The PROG page (progress of the flight) shows the actual (CRZ), the most economic (OPT) and the maximum (REC MAX) cruising altitude. These values are continuously updated.

In order to allow an efficient descent and approach, the FMS computes a top of descent (white flash at waypoint "VEBIT") and from there on an altitude profile to the landing runway.

Fig. 3: Examples of FMS optimization functions

General considerations Contrary to the paragraphs above, the distinction between navigation and performance functions of the FMS is not entirely precise and visible to the pilots, they handle the system as one unit. If traffic permits, air traffic control often allows pilots to fly shortcuts, dropping a few waypoints from the flight plan. Even though such ―direct to‖ commands are obviously navigational tasks, there might be an impact on the performance as well (e.g. different wind component due to heading change leading to an adjusted cruise speed). Vice versa, a change in cruising altitude will affect speed and therefore flight time to all subsequent waypoints. One of the most important tasks performed by the FMS is the continuous calculation of the fuel remaining on board at every waypoint and at the destination airport. Both performance values and the programmed flight route contribute to these figures.

Despite all advantages of modern flight management systems, there are a few drawbacks:

- Programming of the system takes some time, most of it needs to be completed before departure.
- Data inserted need to be precise. Wrong input e.g. of winds on the route lead to inaccurate predictions of time and fuel consumption.
- Inputs to the FMS are made using the MCDU.

This unit is positioned on the central pedestal of the flight deck and requires the pilot to look down and to his side, loosing continuous watch on the primary flight displays and/or outside reference. Each input on the MCDU consists of several key strokes, making it error prone when under time pressure. The FMS is well suited for strategic and long term inputs and calculations. However, it is hard or even impossible to perform (unexpected) short term actions or air traffic control orders like heading changes or speed reductions with immediate effect using the FMS. To handle this type of instructions, pilots use the Flight Control Unit (FCU) which
directly influences
the Autopilot and Flight Director System (AFDS),
disabling the FMS
from its navigatio nal duties. It is important to highlight that in any aircraft at any time the FMS may be overruled using FCU and AFDS or by flying the aircraft manually using the pilot controls.

The FMS is well suited for long term planning and inputs. In case of sudden changes or technical malfunction it can always be overruled by taking over command through the Flight Control Unit (FCU) or by disengaging the autopilot. Using the FCU, inputs to speed, heading, altitude and vertical speed can be done with immediate effect.

Fig. 6: Flight Control Unit (FCU) vs. FMS

Global Positioning System (GPS)

Global positioning system navigation (GPS) is the fastest growing type of navigation in aviation. It is accomplished through the use of NAVSTAR satellites set and maintained in orbit around the earth by the U.S. Government. Continuous coded transmissions from the satellites facilitate locating the position of an aircraft equipped with a GPS receiver with extreme accuracy. GPS can be utilized on its own for en route navigation, or it can be integrated into other navigation systems, such as VOR/RNAV, inertial reference, or flight management systems. There are three segments of GPS: the space segment, the control segment, and the user

segment. Aircraft technicians are only involvedwith user segment equipment such as GPS receivers, displays, and antennas. Twenty-four satellites (21 active, 3 spares) in six separate plains of orbit 12, 625 feet above the planet comprise what is known as the space segment of the
GPS system. The satellites are positioned such that in any place on earth at anyone time, at least four will be a minimum of 15° above the horizon. Typically, between 5 and 8 satellites are in view.
Two signals loaded with digitally coded information are transmitted from each satellite. The L1 channel transmission on a1575.42 MHz carrier frequency is used in civilian aviation. Satellite identification, position, and time are conveyed to the aircraft GPS receiver on this digitally modulated signal along with status and other information. An L2 channel 1227.60MHz transmission is used by the military. The amount of time it takes for signals to reach the aircraft GPS receiver from transmitting satellites is combined with each satellite's exact location to calculate the position of an aircraft. The control segment of the GPS monitors each satellite to ensure its location and time are precise. This control is accomplished with five ground-based receiving stations, a master control station, and three transmitting antenna. The receiving stations forward status information received from the satellites to the master control station.

Calculations are made and corrective instructions are sent to the satellites via the transmitters. The user segment of the GPS is comprised of the thousands
of receivers installed in aircraft as well as every other receiver that uses the GPS transmissions. Specifically, for the aircraft technician, the user section consists of a control panel/display, the GPS receiver circuitry, and an antenna.

The control, display and receiver are usually located in a single unit which also may include VOR/ILS circuitry and a VHF communications
transceiver. GPS
intelligence is integrated into the multifunctional displays of glass cockpit aircraft.
The GPS receiver measures the time it takes for a signal to arrive from three transmitting satellites. Since radio waves travel at 186,000
miles per second, the distance to each satellite can be calculated. The intersection of these ranges provides a two dimensional position of the aircraft. It is expressed in latitude/longitude coordinates. By incorporating the distance to a fourth satellite, the altitude above the surface of the earth can be calculated as well. This results in a three dimensional fix. Additional satellite inputs refine the accuracy of the position.

Having deciphered the position of the aircraft, the GPS unit processes many useful navigational outputs such as speed, direction, bearing to a waypoint, distance traveled, time of arrival, and more. These can be selected to display for use. Waypoints can be entered and stored in the unit's memory. Terrain features, airport data, VOR/RNAV and approach information, communication frequencies, and more can also be loaded into a GPS unit. Most modern units come with moving map display capability. A main benefit of GPS use is immunity from service disruption due to weather. Errors are introduced while the carrier waves travel through the ionosphere; however, these are corrected and kept to a minimum. GPS is also relatively inexpensive. GPS receivers for IFR navigation in aircraft must be built to TSO-129A. This raises the price above that of handheld units used for hiking or in an automobile. But the overall cost of GPS is low due to its small infrastructure. Most of the inherent accuracy is built into the space and control segments permitting reliable positioning with inexpensive user equipment. The
accuracy of current GPS is within 20 meters horizontally and a bit more vertically. This is sufficient for en-route navigation with greater accuracy than required. However, departures and approaches require more stringent accuracy.

Global Navigation Satellite Systems (GNSS)

The GNSS systems operate by using a network of satellites that cover an area to give position information. Each satellite knows its own position and time in relation to earth. The unit then sends a signal to multiple satellites interrogating it receiving both the satellite position and information to calculate the distance from it. Once the unit has at least 3 satellites it can work out its position. In order to get actually height above the ground, the unit requires at least 4 satellites. The more satellites the unit is in contact with the more accurate the position. With more than 5 satellite, the some devices have the function to determine the accuracy of the

satellite and know if any are not functioning (this however, does have limitation because it works on the theory majority rules).
Once the unit has their position it can be used in multiple ways. One point to note is that the devices are always giving past information. It takes time to calculate and display the information. The position will be different depending on the speed of the device. The accuracy can decrease with an increase in speed. To overcome this problem the unit will need to know the time in which the signals were sent. The position information can also come from _ground satellites', which are unit on the ground that act as a satellite, which helps reduce error time or in other words not enough satellites. These ground satellite are used in aviation to help increase reliability of the service in order for aircraft to use them for landing in very low visibility conditions.
There are many different systems that use the GNSS to help people or organizations with their day to day lives. The most commonly known is navigation. With the ability determine location it is possible to use that information against maps to work out were you are. These devices can be found in aircraft, boats and ships, equipment, personal use and even spacecraft. There are also devices for the visually impaired.

The devices though are used for other scenarios than navigation. For example this information is useful for search and rescue to located people. It can be used for surveying. Anytime that position information is useful the GNSS can more often than not offer the solution.

INERTIAL NAVIGATION SYSTEM

Figure 11-155. *An interface panel for three air data and inertial reference systems on an Airbus. The keyboard is used to initialize the system. Latitude and longitude position is displayed at the top.*

Inertial Navigation System (INS)/Inertial Reference System (IRS)

An inertial navigation system (INS) is used on some large aircraft for long range navigation. This may also be identified as an inertial reference system (IRS), although the IRS designation is generally reserved for more modern systems. An INS/IRS is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. The system derives attitude, velocity, and direction information from measurement of the aircraft's accelerations given

a known starting point. The location of the aircraft is continuously updated through calculations based on the forces experienced by INS accelerometers. A minimum of two accelerometers is used, one referenced to north, and the other referenced to east. In older units, they are mounted on a gyro-stabilized platform. This averts the introduction of errors that may result from acceleration due to gravity.
An INS uses complex calculation made by an INS computer to convert applied forces into location information. An interface control head is used to enter starting location position data while the aircraft is stationary on the ground. This is called initializing. [Figure 11-155] From then on, all motion of the aircraft

is sensed by the built-in accelerometers and run through the computer. Feedback and correction loops are used to correct for accumulated error as flight time progresses. The amount an INS is off in one hour of flight time is a reference point for determining performance. Accumulated error of less than one mile after one
hour of flight is possible. Continuous accurate adjustment to the gyro-stabilized platform to keep it parallel to the Earth's surface is a key requirement to reduce accumulated error. A latitude/longitude coordinate system is used when giving the location output.
INS is integrated into an airliner's flight management system and automatic flight control system. Waypoints can be entered for a predetermined flightpath and the
INS will guide the aircraft to each waypoint in succession.

Integration with other NAV aids is also possible to ensure continuous correction and improved accuracy but is not required.
Modern INS systems are known as IRS. They are completely solid-state units with no moving parts. Three-ring, laser gyros replace the mechanical gyros in the older INS platform systems. This eliminates precession and other mechanical gyro shortcomings. The use of three solid-state accelerometers, one for each plane of movement, also increases accuracy. The accelerometer and gyro output are input to the computer for continuous calculation of the aircraft's position.
The most modern IRS integrate is the satellite GPS. The GPS is extremely accurate in itself. When combined with IRS, it creates one of the most accurate navigation systems available. The GPS is used to initialize the IRS so the pilot no longer needs to do so. GPS also feeds data into the IRS computer to be used for error correction.
Occasional service
interruptions and altitude inaccuracies of the GPS system pose no problem for IRS/GPS. The IRS functions continuously and is completely self-contained within the IRS unit. Should the GPS falter, the IRS portion of the system continues without it. The latest electronic technology has reduced the size and weight of INS/IRS avionics units significantly. Figure 11-156 shows a modern micro-IRS unit that measures approximately 6-inches on each side.

ATC CONTROL TRANSPONDER/ SECONDARY SURVEILLENCE RADAR

A radar beacon transponder, or simply, a transponder, provides positive identification and location of an aircraft on the radar screens of ATC. For each aircraft equipped with an altitude encoder, the transponder also provides the pressure altitude of the
aircraft to be displayed adjacent to the on-screen blip that represents the aircraft.
Radar capabilities at airports vary. Generally, two types of radar are used by air traffic control (ATC). The primary radar transmits directional UHF or SHF radio waves sequentially in all directions. When the radio waves encounter an aircraft, part of those waves reflect back to a ground antenna. Calculations are
made in a receiver to determine the direction and distance of the aircraft from the transmitter. A blip or target representing the aircraft is displayed on a radar screen also known as a plan position indicator (PPI). The azimuth direction and scaled distance from the tower are presented giving controllers a two dimensional fix on the aircraft.

Figure 11-156. *A modern micro-IRS with built-in GPS.*

A secondary surveillance radar (SSR) is used by ATC to verify the aircraft's position and to add the third dimension of altitude to its location. SSD radar transmits coded pulse trains that are received by the transponder on board the aircraft. Mode 3/A pulses, as they are known, aid in confirming the location of the aircraft. When verbal communication is established with ATC, a pilot is instructed to select one of 4,096 discrete codes on the transponder. These are digital octal codes. The ground station transmits a pulse of energy at 1030 MHz and the transponder transmits a reply with the assigned code attached at 1090 MHz. This confirms the aircraft's location typically by altering its target symbol on the radar screen. As the screen may be filled with many confirmed aircraft, ATC can also ask the pilot to identify. By pressing the IDENT button on the transponder, it transmits in such a way that the aircraft's target symbol is highlighted on the PPI to be distinguishable.

To gain altitude clarification, the transponder control must be placed in the ALT or Mode C position. The signal transmitted back to ATC in response to pulse interrogation is then modified with a code that places the pressure altitude of the aircraft next to the target symbol on the radar screen. The transponder gets the pressure altitude of the aircraft from an altitude encoder that is electrically connected to the transponder.

The ATC/aircraft transponder system described is known as Air Traffic Control Radar Beacon System (ATCRBS). To increase safety, Mode S altitude response has been developed. With Mode S, each aircraft is pre-assigned a unique identity code that displays along with its pressure altitude on ATC radar when the transponder responds to SSR interrogation. Since no other aircraft respond with this code, the chance of two pilots selecting the same response code on the transponder is eliminated. A modern flight data processor computer (FDP) assigns the beacon code and searches flight plan data for useful information to be displayed on screen next to the target in a data block for each aircraft.
Mode S is sometimes referred to as mode select. It is a data packet protocol that is also used in onboard collision avoidance systems. When used by ATC, Mode S interrogates one aircraft at a time. Transponder workload is reduced by not having to respond to all interrogations in an airspace. Additionally, location information is more accurate with Mode S. A single reply in which the phase of the transponder reply is used to calculate position, called monopoles, is sufficient to locate the aircraft. Mode S also contains

Figure 11-125. A traditional transponder control head (A), a lightweight digital transponder (B), and a remote altitude encoder (C) that connects to a transponder to provide ATC with an aircraft's altitude displayed on a PPI radar screen next to the target that represents the aircraft.

capacity for a wider variety of information exchange that is untapped potential for the future. At the same time, compatibility with older radar and transponder technology has been maintained.

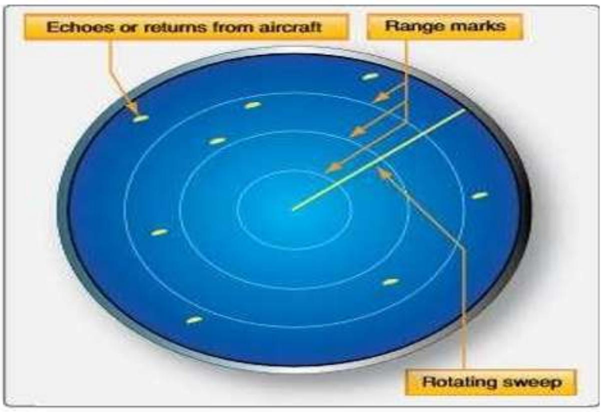


Figure 11-126. *A plan position indicator (PPI) for ATC primary radar locates target aircraft on a scaled field.*

Figure 11-127. *Aircraft radar beacon transponder antennas transmit and receive UHF and SHF radio waves.*

Figure 11-128. *Air traffic control radar technology and an onboard radar beacon transponder work together to convey and display air traffic information on a PPI radar screen. A modern approach ATC PPI is shown. Targets representing aircraft are shown as little aircraft on the screen. The nose of the aircraft indicates the direction of travel. Most targets shown above are airliners. The data block for each target includes the following information either transmitted by the transponder or matched and loaded from flight plans by a flight data processor computer: call sign, altitude/speed, origination/destination, and aircraft type/ETA (ZULU time). A "C" after the altitude indicates the information came from a Mode C equipped transponder. The absence of a C indicates Mode S is in use. An arrow up indicates the aircraft is climbing. An arrow down indicates a descent. White targets are arrivals, light blue targets are departures, all other colors are for arrivals and departures to different airports in the area.*

Figure 11-129. *A handheld transponder test unit.*

Transponder Tests and Inspections Title 14 of the Code of Federal Regulations (CFR) part 91, section 91.413 states that all transponders on aircraft flown into controlled airspace are required to be inspected and tested in accordance with 14 CFR part 43, Appendix F, every 24 calendar months. Installation or maintenance that may introduce a transponder error is also cause for inspection and test in accordance with Appendix F. Only an appropriately rated repair station, the aircraft manufacturer (if it installed transponder), and holders of a continuous airworthy program are approved to conduct the procedures. As with many radio electronic devices, test equipment exists to test airworthy operation of a transponder.
Operating a transponder in a hangar or on the ramp does not immunize it from interrogation and reply. Transmission of certain codes reserved for emergencies or military activity must be avoided. The procedure to select a code during ground operation is to do so with the transponder in the OFF or STANDBY mode to avoid inadvertent transmission. Code 0000 is reserved for military use and is a transmittable code. Code 7500 is used in a hijack situation and 7600 and 7700 are also reserved for emergency use. Even the inadvertent transmission of code 1200 reserved for VFR flight not under ATC direction could result in evasion action. All signals received from a radar beacon transponder are taken seriously by ATC.

SECONDARY SURVEILLENCE RADAR

Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft i.e. bearing, but also requests additional information from the aircraft itself such as its identity and altitude. Unlike primary radar systems that measure the bearing of targets using the detected reflections of radio signals, SSR relies on targets equipped with a radar transponder, that replies to each interrogation signal by transmitting a response containing encoded data. SSR is based on the military identification friend or foe (IFF) technology originally developed during World War II, therefore the two systems are still compatible. Monopulse secondary surveillance radar (MSSR), Mode S, TCAS and ADS-B are similar modern methods of secondary surveillance.

1.1.7 PRIMARY RADAR

The rapid wartime development of radar had obvious applications for air traffic control (ATC) as a means of providing continuous surveillance of air traffic disposition. Precise knowledge of the positions of aircraft would permit a reduction in the normal procedural separation standards, which in turn promised considerable increases in the efficiency of the airways system. This type of radar (now called a primary radar) can detect and report the position of anything that reflects its transmitted radio signals including, depending on its design, aircraft, birds, weather and land features. For air traffic control purposes this is both an advantage and a disadvantage. Its targets do not have to co-operate, they only have to be within its coverage and be able to reflect radio waves,

but it only indicates the position of the targets, it does not identify them. When primary radar was the only type of radar available, the correlation of individual radar returns with specific aircraft typically was achieved by the controller observing a directed turn by the aircraft. Primary radar is still used by ATC today as a backup/complementary system to secondary radar, although its coverage and information is more limited.

1.1.8 SECONDARY RADAR

The need to be able to identify aircraft more easily and reliably led to another wartime radar development, the Identification Friend or Foe(IFF) system, which had been created as a means of positively identifying friendly aircraft from unknowns. This system, which became known in civil use as secondary surveillance radar (SSR), or in the USA as the air traffic control radar beacon system (ATCRBS), relies on a piece of equipment aboard the aircraft known as a "transponder." The transponder is a radio receiver and transmitter pair which receives on 1030 MHz and transmits on 1090 MHz. The target aircraft transponder replies to signals from an interrogator (usually, but not necessarily, a ground station co-located with a primary radar) by transmitting a coded reply signal containing the requested information.

Both the civilian SSR and the military IFF have become much more complex than their war-time ancestors, but remain compatible with each other, not least to allow military aircraft to operate in civil airspace. Today's SSR can provide much more detailed information, for example, the aircraft altitude, as well as enabling the direct exchange of data between aircraft for collision avoidance. Most SSR systems rely on Mode C transponders, which report the aircraft pressure altitude. The pressure altitude is independent from the pilot's altimeter setting, thus preventing false altitude transmissions if altimeter is adjusted incorrectly. Air traffic control systems recalculate reported pressure altitudes to true altitudes based on their own pressure references, if necessary.

Given its primary military role of reliably identifying friends, IFF has much more secure (encrypted) messages to prevent "spoofing" by the enemy, and is used on many types of military platforms including air, sea and land vehicles.

The purpose of SSR is to improve the ability to detect and identify aircraft while automatically providing the Flight Level (pressure altitude) of an aircraft. An SSR ground station transmits interrogation pulses on 1030 MHz (continuously in Modes A, C and selectively, in Mode S) as its antenna rotates, or is electronically scanned, in space. An aircraft transponder within line-of-sight range 'listens' for the SSR interrogation signal and transmits a reply on 1090 MHz that provides aircraft information. The reply sent depends on the interrogation mode. The aircraft is displayed as a tagged icon on the controller's radar screen at the measured bearing and range. An aircraft without an operating transponder still may be observed by primary radar, but would be displayed to the controller without the benefit of SSR derived data. It is typically a requirement to have a working transponder in order to fly in controlled air space and many aircraft have a back-up transponder to ensure that condition is met.

There are several modes of interrogation, each indicated by the difference in spacing between two transmitter pulses, known as P1 and P3.Each mode produces a different response from the aircraft. A third pulse, P2, is for side lobe suppression and is described later. Not included are additional military (or IFF) modes, which are described in Identification Friend or Foe.

Mode	P1–P3 Pulse spacing	Purpose
A	8 µs	Identity
B	17 µs	Identity
C	21 µs	Altitude
D	25 µs	undefined
S	3.5 µs	multipurpose

A mode-A interrogation elicits a 12-pulse reply, indicating an identity number associated with that aircraft. The 12 data pulses are bracketed by two framing pulses, F1 and F2. The X pulse is not used. A mode-C interrogation produces an 11-pulse response (pulse D1 is not used), indicating aircraft altitude as indicated by its altimeter in 100-foot increments. Mode B gave a similar response to mode A and was at one time used in Australia. Mode D has never been used operationally.

The new mode, Mode S, has different interrogation characteristics. It comprises pulses P1 and P2 from the antenna main beam to ensure that Mode-A and Mode-C transponders do not reply, followed by a long phase-modulated pulse.

The ground antenna is highly directional but cannot be designed without sidelobes. Aircraft could also detect interrogations coming from these sidelobes and reply appropriately. However these replies cannot be differentiated from the intended replies from the main beam and can give rise to a false aircraft indication at an erroneous bearing. To overcome this problem the ground antenna is provided with a second, mainly omni-directional, beam with a gain which exceeds that of the sidelobes but not that of the main beam. A third pulse, P2, is transmitted from this second beam 2 µs after P1. An aircraft detecting P2 stronger than P1 (therefore in the sidelobe and at the incorrect main lobe bearing), does not reply.

Traffic Collision Avoidance Systems (TCAS)

Traffic collision avoidance systems (TCAS) are transponder based air-to-air traffic monitoring and alerting systems. There are two classes of TCAS. TCAS I was developed to accommodate the general aviation community and regional airlines. This system identifies traffic in a 35–40 mile range of the aircraft and issues Traffic Advisories (TA) to assist pilots in visual acquisition of intruder aircraft. TCAS I is mandated on aircraft with 10 to 30 seats.

TCAS II is a more sophisticated system. It is required internationally in aircraft with more than 30 seats or weighing

more than 15,000 kg. TCAS II provides the information of TCAS I, but also analyzes the projected flight path of approaching aircraft. If a collision or near miss is imminent, the TCAS II computer issues a Resolution Advisory (RA). This is an aural command to the pilot
to take a specific evasive action (i.e., DESCEND). The computer is programmed such that the pilot in the encroaching aircraft receives an RA for evasive action in the opposite direction (if it is TCAS II equipped).

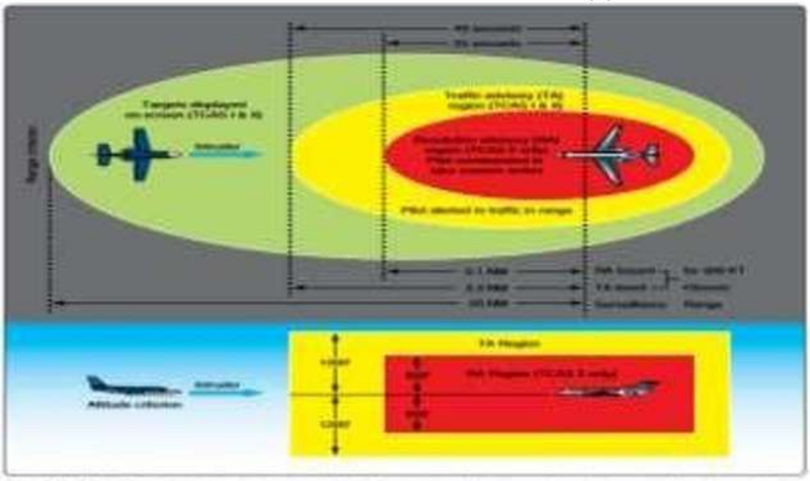


Figure 11-131. Traffic collision and avoidance system (TCAS) uses an aircraft's transponder to interrogate and receive replies from other aircraft in close proximity. The TCAS computer alerts the pilot as to the presence of an intruder aircraft and displays the aircraft on a screen in the cockpit. Additionally, TCAS II equipped aircraft receive evasive maneuver commands from the computer that calculates trajectories of the aircraft to predict potential collisions or near misses before they become unavoidable.

The transponder of an aircraft with TCAS is able to interrogate the transponders of other aircraft nearby using SSR technology (Mode C and Mode S). This is done with a 1030 MHz signal. Interrogated aircraft transponders reply with an encoded 1090 MHz signal that allows the TCAS computer to display the position and altitude of each aircraft. Should the aircraft come within the horizontal or vertical distances shown in Figure 11-131, an audible TA is announced. The pilot must decide whether to take action and what action to take. TCAS II equipped aircraft use continuous reply information to analyze the speed and trajectory of target aircraft in close proximity. If a collision is calculated to be imminent, an RA is issued.
TCAS target aircraft are displayed on a screen on the flight deck. Different colors and shapes are used to depict approaching aircraft depending on the imminent threat level. Since RAs are currently limited to vertical evasive maneuvers, some stand-alone TCAS displays are electronic
vertical speed indicators. Most aircraft use some version of an electronic HSI on a navigational screen or page to display TCAS information. [Figure 11-
132] A multifunction display may depict TCAS and weather radar information on the same screen. [Figure
11-133] A TCAS control panel [Figure 11-134] and computer are required to work with a compatible transponder and its antenna(s).

Figure 11-133. *TCAS information displayed on a multifunction display. An open diamond indicates a target; a solid diamond represents a target that is within 6 nautical miles of 1,2000 feet vertically. A yellow circle represents a target that generates a TA (25-48 seconds before contact). A red square indicates a target that generates an RA in TCAS II (contact within 35 seconds). A (+) indicates the target aircraft is above and a (-) indicates it is below. The arrows show if the target is climbing or descending.*

Interface with EFIS or other previously installed or selected display(s) is also required.
TCAS may be referred to as airborne collision avoidance system (ACAS), which is the international name for the same system. TCAS II with the latest revisions is known as Version7. The accuracy and reliability of this TCAS information is such that pilots are required to follow a TCAS RA over an ATC command.

WEATHER AVOIDANCE RADAR

There are three common types of weather aids used in an aircraft flight deck that are often referred to as weather radar:
1. Actual on-board radar for detecting and displaying weather activity;
2. Lightning detectors; and

3. Satellite or other source weather radar information that is uploaded to the aircraft from an outside source.

On-board weather radar systems can be found in aircraft of all sizes. They function similar to ATC primary radar except the radio waves bounce off of precipitation instead of aircraft. Dense precipitation creates a stronger return than light precipitation. The on-board weather radar receiver is set up to depict heavy returns as red, medium return as yellow and light returns as green on a display in the flight deck. Clouds do not create a return. Magenta is reserved to depict intense or extreme precipitation or turbulence. Some aircraft have a dedicated weather radar screen. Most modern aircraft integrate weather radar display into the navigation display(s). Figure 11-142 illustrates weather radar displays found on aircraft.
Radio waves used in weather radar systems are in the SHF range such as 5.44 GHz or 9.375 GHz. They are transmitted forward of the aircraft from a directional antenna usually located behind a non-metallic nose cone. Pulses of approximately 1 micro-second in length are transmitted. A duplexer in the radar transceiver switches the antenna to receive for about 2500 micro seconds after a pulse is transmitted to receive and process any returns. This cycle repeats and the receiver circuitry builds a two dimensional image of precipitation for display. Gain adjustments control the range of the

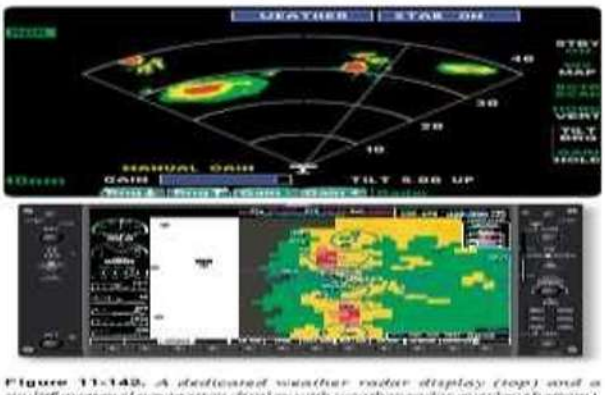


Figure 11-142. A dedicated weather radar display (top) and a multifunctional navigation display with weather radar overlay (bottom).

Figure 11-134. *This control panel from a Boeing 767 controls the transponder for ATC use and TCAS.*

radar. A control panel facilitates this and other adjustments. [Figure 11-143]

Severe turbulence, wind shear, and hail are of major concern to the pilot. While hail provides a return on weather radar, wind shear and turbulence must be interpreted from the movement of any precipitation that is detected. An alert is annunciated if this condition occurs on a weather radar system so equipped. Dry air turbulence is not detectable. Ground clutter must also be attenuated when the radar sweep includes any terrain features. The control panel facilitates this.

Special precautions must be followed by the technician during maintenance and operation of weather radar systems. The radome covering the antenna must only be painted with approved paint to allow the radio signals to pass unobstructed. Many radomes also contain grounding strips to conduct lightning strikes and static away from the dome.

When operating the radar, it is important to follow all manufacturer instructions. Physical harm is possible from the high energy radiation emitted, especially to the eyes and testes. Do not look into the antenna of a transmitting radar. Operation of the radar should not occur in hangars unless special radio wave absorption material is used. Additionally, operation of radar should not take place while the radar is pointed toward a building or when refueling takes place. Radar units should be maintained and operated only by qualified personnel.

Lightning detection is a second reliable means for identifying potentially dangerous weather. Lightning gives off its own electromagnetic signal. The azimuth of a lightning strike can be calculated by a receiver using a loop type antenna such as that used in ADF. [Figure 11-144] Some lightning detectors make use of the ADF antenna. The range of the lightning strike is closely associated with its intensity. Intense strikes are plotted as being close to the aircraft.

Stormscope is a proprietary name often associated with lightning detectors. There are others that work in a similar manner. A dedicated display plots the location of each strike within a 200 mile range with a small mark on the screen. As time progresses, the marks may change color to indicate their age. Nonetheless, a number of lightning strikes in a small area indicates a storm cell, and the pilot can navigate around it. Lightning strikes can also be plotted on a multifunctional navigation display.

Figure 11-140. *A digital display radio altimeter (top), and the two antennas and transceiver for a radio/radar altimeter (bottom).*

A third type of weather radar is becoming more common in all classes of aircraft. Through the use of orbiting satellite systems and/or ground up-links, such as described with ADS-B IN, weather information can be sent to an aircraft in flight virtually anywhere in the world. This includes text data as well as real-time radar information for overlay on an aircraft's navigational display(s). Weather radar data produced remotely and sent to the aircraft is refined through consolidation of various radar views from different angles and satellite imagery. This produces more accurate depictions of actual weather conditions. Terrain databases are integrated to eliminate ground clutter. Supplemental data includes the entire range of intelligence available from the National Weather Service (NWS) and the National Oceanographic and Atmospheric Administration

Figure 11-145. A dedicated stormscope lightning detector display (left), and an electronic navigational display with lightning strikes overlaid in the form of green "plus" signs (right).

(NOAA).

RADIO ALTIMETER

A radio altimeter, or radar altimeter, is used to measure the distance from the aircraft to the terrain directly beneath it. It

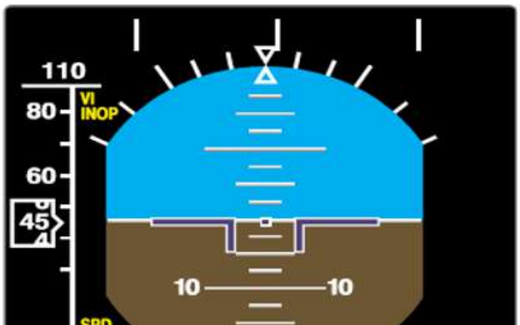
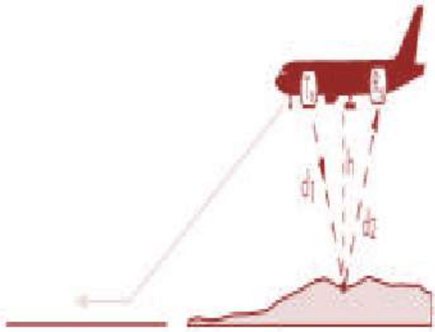


Figure 11-141. *The decision height, DH200, in the lower right corner of this EADI display uses the radar altimeter as the source of altitude information.*

is used primarily during instrument approach and low level or night flight below 2500 feet. The radio altimeter supplies the primary altitude information for landing decision height. It incorporates an adjustable altitude bug that creates a visual or aural warning to the pilot when the aircraft reaches that altitude.

Typically, the pilot will abort a landing if the decision height is reached and the runway is not visible.
Using a transceiver and a directional antenna, a radio altimeter broadcasts a carrier wave at 4.3 GHz from the aircraft directly toward the ground. The wave is frequency modulated at 50 MHz and travels at a known speed. It strikes surface features and bounces back toward the aircraft where a second antenna receives the return signal. The
transceiver processes the signal by measuring the elapsed time the signal traveled and the frequency modulation that occurred. The display indicates height above the terrain also known as above ground level (AGL).
A radar altimeter is more accurate and responsive than an air pressure altimeter for AGL information at low altitudes. The transceiver is usually located remotely from the indicator. Multifunctional and glass cockpit displays typically integrate decision height awareness from the radar altimeter as a digital number displayed on the screen with a bug, light, or color change used to indicate when that altitude is reached. Large aircraft may incorporate radio altimeter information into a ground proximity warning system (GPWS) which aurally alerts the crew of potentially dangerous proximity to the terrain below the aircraft. A decision height window (DH) displays
the radar
altitude on the EADI.
The purpose of the Radio Altimeter (RA) is to measure the absolute height of the aircraft above the terrain. This
is accomplished by transmitting a signal to the ground, and processing the received
signal into analog voltage proportional to the height. This analog voltage is used to position a pointer on an indicator for a visual indication of altitude.



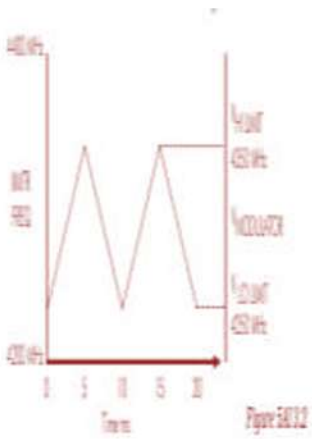
$d_1 + d_1 > 2 \times h$

Figure: 5AI 3.1

Using Frequency Modulated Continuous Wave techniques (FMCW), radio altimeters provide a continuous indication of height above the surface immediately below the aircraft, up to a maximum of 5,000 ft, with 2500 ft as the most common range. They are particularly suited to low altitude terrain clearance measurement and for provision of height data to GPWS and Autoland (ILS) equipment. Although the antenna of the RA sits at the bottom of the fuselage, an electronic compensation is made so on most larger aircraft the height (h) is calculated from the lowest wheel.
The radio altimeter is instantaneous and accurate, but gives no indication of high ground ahead. It is not possible, within the frequency allocation (4200-4400 MHz), to change the frequency (FM) indefinitely. On one popular brand of RA the modulation sweeps 100 MHz between the base frequency 4,250 MHz and the upper limit 4,350 MHz - the variation, or modulation, is made.
Because the height measurement is absolute, flight over undulating terrain will result in sympathetic variations in the indications of aircraft height on the radio altimeter display.
Principle of Operation

A radio altimeter will consist of a transmitter/receiver and integral timing device, a transmitter antenna, a receiver antenna and a display of some type. The elapsed time, from transmission of an electromagnetic signal to reception back at the aircraft after ground reflection, is measured. As long as the path followed by the wave is vertical, down and up, then the elapsed time is a function of aircraft height.

By the time the transmitted signal has been reflected from the terrain and back to the receive antenna the transmitter has shifted to a new frequency; therefore, when the instantaneous transmitted signal is mixed with the delayed received signal, an Intermediate Frequency (IF) is produced. This IF is directly proportional to the time delay for the round trip.
This variable IF is applied to the receiver where it is amplified and processed to a DC voltage proportional to the incoming IF frequency. The DC analog voltage representative of altitude is used to drive the Indicator and other flight control systems requiring accurate above ground level altitude information.
Throughout the cycle there will be two very short periods when the modulation changes from VHI to VLO and vice-versa; apart from during these short periods, which can be excluded from height calculation, the instantaneous frequency difference is proportional to aircraft height. Sweep-rates are normally in the order of 500 times per second.
It is possible for an aircraft to be at a height such that the returning wave arrives after a complete frequency sweep, and this would give an erroneous height solution. To overcome this



ambiguity, the sweep rate is made low, i.e. the time for a sweep is made longer, so that all normal heights within the range of the radio altimeter are covered.
Display

At two types of radio altimeter display are shown. The displayed maximum altitude (2,500 or 5,000 ft) is obvious from the conventional dial display, but not so apparent from the moving vertical scale presentation. The circular displays are linear up to 500 feet and logarithmic from 500 - 2,500 (or 5,000) feet, making the lower range of heights easier to read more accurately. All radio altimeter displays have a setting control for a decision height, at which point a warning will be given. The height can be set by positioning an outside cursor against the required height on the scale. The setting control will normally double as a PTT (press-to-test) facility which, when engaged, drives the display to a predetermined value - normally 100 feet.
With reference to the left display, an OFF or FAIL flag will be visible when:
a. The equipment is switched off;
b. There is a power failure;
c. A Tx, Rx, or display fault occurs.
d. The returning signal is too weak;
e. Signals are reflected from the airframe.

The height pointer is hidden from view behind the mask when:

a. The equipment is switched off;

b. A Tx, Rx, or display fault occurs;

c. The aircraft climbs beyond the equipment height limit

Other Warnings

Both light and/or audio warnings are given for departure from the height limit indicator. Visual warnings may be:

AMBER - above selected height GREEN - ± 15 feet of selected height RED - 15 feet below selected height

Where only a single light is fitted, the DH light will flash continuously when the aircraft goes below the set height until the aircraft climbs or until the DH value is set lower.

Performance Accuracy

The accuracy of the radio altimeter is expected to be:

0 - 500 feet: ±2 feet or 2% of height, whichever is the greater. Above 500 feet: 5 % of height

Errors

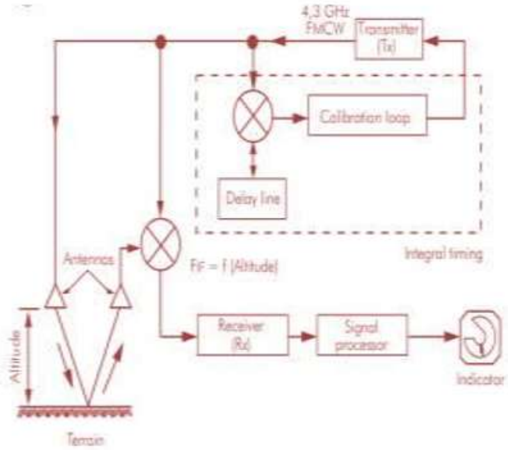


Figure: 5AI 3.3

Given that the sweep rate is compatible with the height performance of the installation, the only two errors that might occur are:

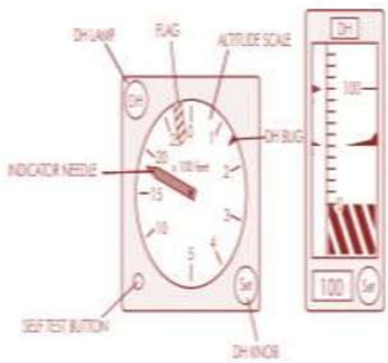


Figure: 5AI 3.5

a) Leakage - It is necessary to separate the Tx and the Rx antenna on the underside of the aircraft to avoid leakage, i.e. spilling through of side-lobes directly into Rx antenna. Placing the antenna a distance apart is generally adequate screening.

b) Mushing - Because the antenna are apart, the closer the aircraft is to the ground, then the Tx antenna, reflection point and Rx antenna form a triangle. It follows that the path travelled by the wave is greater than twice the vertical height between surface and aircraft, as illustrated in figure 5AI 3.1. This causes inaccuracies very close to the ground and is known as —mushing error‖.

However, this error is normally remedied by a fixed correction for the particular aircraft, so the height indicated corresponds to the vertical distance from the lower wheels to the ground. When carrying out automatic approach and landing, an important factor is that zero height indication coincedes with touch-down.

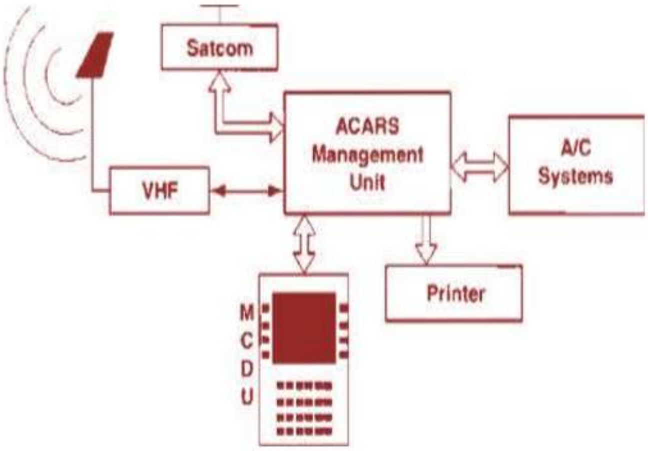
Advantages of Radio Altimeters

- Indication of actual (absolute) height is given
- Provides an easy crosscheck with barometric altimeter for terrain clearance
- Provides a warning signal at DH (decision height).

Outputs

Outputs from the Radio Altimeter can be fed directly or via a data bus to:

- AFCS (for ILS coupling)
- GPNS
- Flight Director
- EFIS
- FMC



ARINC COMMUNICATION AND REPORTING SYSTEM: 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 AGARS 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 AGARS 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

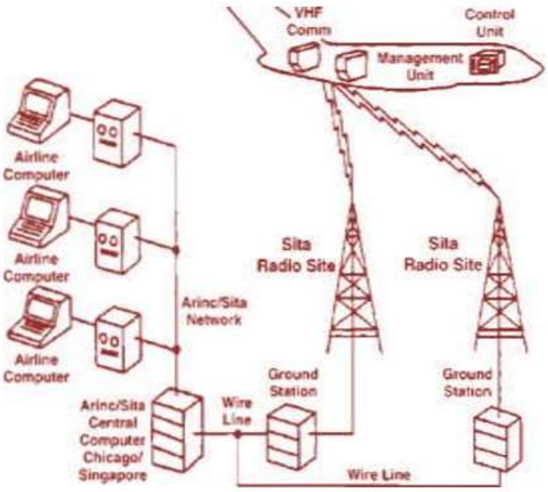
not available.
The transmitted information is received via the ground stations to a central computer (Singapore for SITA or Chicago for ARINC) where data is converted into airline messages
A ground network (SITA for EUROPE, ARINC for the USA).transmits the data from the ground receiver to the airline main base
Ground Network with Aircraft

ARINC Aeronautical Radio Incorporated operates ACARS. SITA Society International de Telecommunication Aerienere 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 Air Canada at 131.475 MHz.
Japan uses AVICOM at 131.450 MHz.

If there is too much communication traffic at a certain frequency channel, the ground station initiates an automate frequency change to another channel (Remote Tuning). At uncovered areas of the world, if there is no link to a ground station the ACARS uses the Satellite Communication.

SYSTEM ARCHITECTURE



An established 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 mows 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 Chicago via separate telex connections

Airborne Components and Subsystems

The AGARS 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 (0001) 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

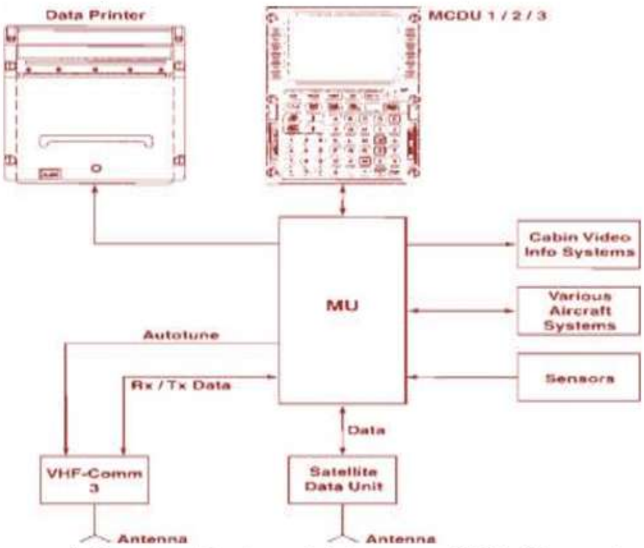
The multifunction printer is the output device for data.
Furthermore, there is an Cabin Video Information System (Long Haul) providing the display of actual data from ground to all passengers for example:
Connecting flights
Information about passenger terminals Weather at destination
Sport results
Operations, 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) v:a 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 initialization (must be done before the flight Flt Nr. and From-To) Mission Status (0001, Block Time and Flight Time. UTC)
Out Aircraft out gate (Doors closed, Engines Running. Park brake 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) Fight 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 Flight plan
Diversion (New Destination, Comment and ETA) Parking Position Request

Passenger Connection Request

Data Format
The data is transmitted via VI IF with frequency shift keying it analog format 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 Protocol Message 220 Characters of data
Trailer 7 Characters Parity and Verification

13.5 Electrical Power (ATA 24)

Batteries Installation and Operation

Aircraft Batteries

Aircraft batteries are used for many functions (e.g., ground power, emergency power, improving DC bus stability, and fault clearing). Most small private aircraft use lead acid batteries. Most commercial and corporate aircraft use nickel-cadmium (Ni-Cd) batteries. However, other lead acid types of batteries are becoming available, such as the valve-regulated lead-acid (VRLA) batteries. The battery best suited for a particular application depends on the relative importance of several characteristics, such as weight, cost, volume, service or shelf life, discharge rate, maintenance, and charging rate. Any change of battery type may be.

Simple Storage cells

The basic function of any electrical cell is the conversion of chemical energy into electrical energy. The cells can be considered as a chemical means of storing electrical energy. Electrons are removed from the (positive) cathode and deposited on the (negative) anode. The electrolyte is the physical means of migration between the cathode/anode. The attraction of electrons between cathode/anode creates a potential difference across the cell; the cathode/anode is attached to external terminals for connection to the equipment or system. Material types used for the cathode/anode and electrolyte will determine the cell voltage.

Cells are categorized as either primary (where they can only be used once) or secondary (where they can be recharged). It can be dangerous to attempt charging a primary cell. In the secondary cell, the chemical activity is reversible.

Type of Batteries

Aircraft batteries are usually identified by the material used for the plates. The two most common types of battery used are lead-acid and Ni-Cd batteries.

Lead-Acid Batteries

Dry Charged Cell Lead Acid Batteries

Dry charged cell lead-acid batteries, also known as flooded or wet batteries, are assembled with electrodes (plates) that have been fully charged and dried. The electrolyte is added to the battery when it is placed in service, and battery life begins when the electrolyte is added. An aircraft storage battery consists of 6 or 12 lead-acid cells connected in series. The open circuit voltage of the 6 cell battery is approximately 12 volts, and the open circuit voltage of the 12-cell battery is approximately 24 volts. Open circuit voltage is the voltage of the battery when it is not connected to a load. When flooded (vented) batteries are on charge, the oxygen generated at the positive plates escapes from the cell. Concurrently, at the negative plates, hydrogen is generated from water and escapes from the cell. The overall result is the gassing of the cells and water loss. Therefore, flooded cells require periodic water replenishment.

Valve-Regulated Lead-Acid Batteries (VRLA)

VRLA batteries contain all electrolyte absorbed in glass-mat separators with no free electrolyte and are sometimes referred to as sealed batteries.The electrochemical reactions for VRLA batteries are the same as flooded batteries, except for the gas recombination mechanism that is predominant in VRLA batteries. These types of battery are used in general aviation and turbine powered aircraft and are sometimes authorized replacements for NiCd batteries.

When VRLA batteries are on charge, oxygen combines chemically with the lead at the negative plates in the presence of H2SO4 to form lead sulphate and water. This oxygen recombination suppresses the generation of hydrogen at the negative plates. Overall, there is no water loss during charging. A very small quantity of water may be lost as a result of self-discharge reactions; however, such loss is so small that no provisions are made for water replenishment. The battery cells have a pressure relief safety valve that may vent if the battery is overcharged.

Chemical action or operation

$$\text{Positive electrode: } PbO_2 + H_2SO_4 + 2H^+ + 2e^- \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} PbsO_4 + 2H_2O \qquad (1)$$

$$\text{Negative electrode: } Pb + H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} PbSO_4 + 2H^+ + 2e^- \qquad (2)$$

$$\text{Overall cell reaction: } PbO_2 + pb + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} 2PbSO_4 + 2H_2O \qquad (3)$$

The chemical reactions that occur in a lead-acid battery are represented by the above equations:

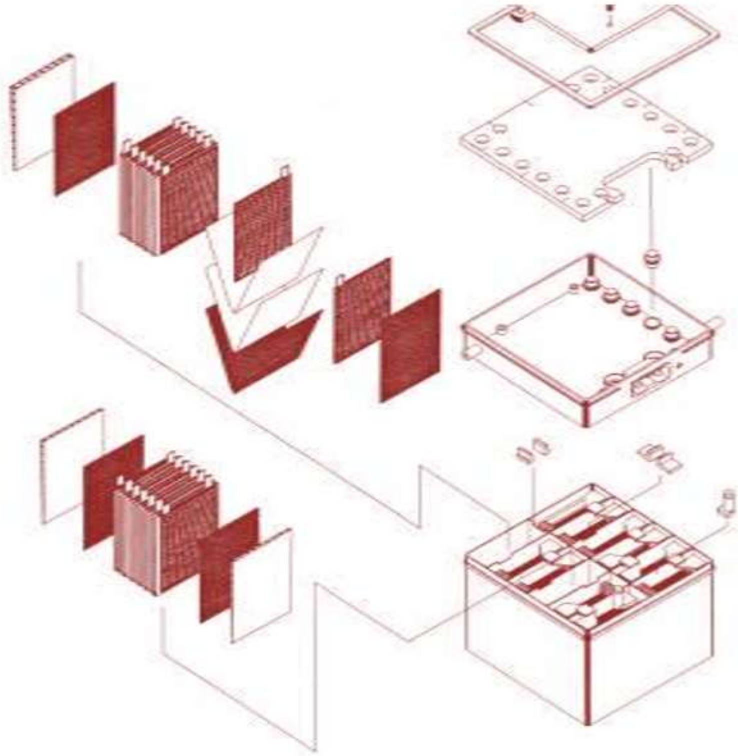
As the cell is charged, the sulphuric acid (H2SO4) concentration increases and becomes highest when the cell is fully charged. Likewise, when the cell is discharged, the acid concentration decreases and becomes most dilute when the cell is fully discharged. The acid concentration generally is expressed in terms of specific gravity, which is weight of the electrolyte compared to the weight of an equal volume of pure water.

The cell‘s specific gravity can be estimated from its open circuit voltage using the following equation:
Specific Gravity (SG)=Open Circuit Voltage (OCV)-0.84

There are two basic cell types: vented and recombinant. Vented cells have a flooded electrolyte, and the hydrogen and oxygen
gases generated during charging are vented from the cell container. Recombinant cells have a starved or gelled electrolyte, and the oxygen generated from the positive electrode during charging diffuses to the negative electrode where it recombines to form water by the following reaction:
$Pb + H2SO4 + 1/2O2 \rightarrow PbSO4 + H2O$

The recombination reaction suppresses hydrogen evolution at the negative electrode, thereby allowing the cell to be sealed. In practice, the recombination efficiency is not 100% and a resalable valve regulates the internal pressure at
a relatively low value, generally below 10 psig. For this reason, sealed lead- acidcells are often called —valve- regulated lead-acid‖ (VRLA) cells.

Battery Construction



Lead-acid aircraft batteries are constructed using injection-molded, plastic monoblocs that contain a group of cells connected in series. Monoblocs typically are made of polypropylene, but ABS is used by at least one manufacturer. Normally, the monobloc serves as the battery case, similar to a conventional automotive battery.

For more robust designs, monoblocs are assembled into a separate outer container made of steel, aluminum, or fiberglass-reinforced epoxy. Cases usually incorporate an electrical receptacle for connecting to the external circuit with a quick connect/disconnect plug. Two generic styles of receptacles are common: the ―Elcon style‖ and the ―Cannon style.‖ The Elcon style is equivalent to military type MS3509. The Cannon style has no military equivalent, but is produced by Cannon and other connector manufacturers. Batteries sometimes incorporate thermostatically controlled heaters to improve low temperature performance. The heater is powered by the aircraft's AC or DC bus. Figure shows an assembly drawing of a typical lead-acid aircraft battery; this particular example does not incorporate a heater.

Temperature Effects and Limitations

Lead-acid batteries generally are rated at 25°C (77°F) and operate best around this temperature. Exposure to low ambient temperatures results in performance decline, whereas exposure to high ambient temperatures results in shortened life.

The lower temperature limit is dictated by the freezing point of the electrolyte. The electrolyte freezing point varies with acid concentration, as shown in Table 10.1. The minimum freezing point is a chilly 70°C (95°F) at a specific gravity (SG) of 1.30. Since fully charged batteries have SGs in the range of 1.28 to 1.33, they are not generally susceptible to freezing even under extreme cold conditions. However, when the battery is discharged, the SG drops and the freezing point rises. At low SG, the electrolyte first will turn to slush as the temperature drops. This is because the water content freezes first, gradually raising the SG of the remaining liquid so that it remains unfrozen. Solid freezing of the electrolyte in a discharged battery requires temperatures well below the slush point; a practical lower limit of 30°C is often specified.

Solid freezing can damage the battery permanently (i.e., by cracking cell containers), so precautions should

be taken to keep the battery charged or heated when exposed to temperatures below 30°C.
The upper temperature limit is generally in the range of 60 to 70°C. Capacity loss is accelerated greatly when charged above this temperature range due to vigorous gassing and/or rapid grid corrosion. The capacity loss generally is irreversible when the battery is cooled.

Service Life
The service life of a lead-acid aircraft battery depends on the type of use it experiences (e.g., rate, frequency, and depth of discharge), environmental conditions (e.g., temperature and vibration), charging method, and the care with which it is maintained. Service lives can range from 1 to 5 years, depending on the application. Table 10.2 shows representative life cycle data as a function of the depth of discharge. Manufacturers' data should be consulted for specific batteries of interest.

NiCd Batteries
A NiCd battery consists of a metallic box, usually stainless steel, plastic-coated steel, painted steel, or titanium containing a number of individual cells. These cells are connected in series to obtain 12 volts or 24 volts. The cells are connected by highly conductive nickel copper links. Inside the battery box, the cells are held in place by partitions, liners, spacers, and a cover assembly. The battery has a ventilation system to allow the escape of the gases produced during an overcharge condition and provide cooling during normal operation.

NiCd cells installed in an aircraft battery

are typical of the vented cell type. The vented cells have a vent or low pressure release valve that releases any generated oxygen and hydrogen gases when overcharged or discharged rapidly. This also means the battery is not normally damaged by excessive rates of overcharge, discharge, or even negative charge. The cells are rechargeable and deliver a voltage of 1.2 volts during discharge.

Aircraft that are outfitted with Ni-Cd batteries typically have a fault protection system that monitors the condition of the battery. The battery charger is the unit that monitors the condition of the battery and the following conditions are monitored.

1. Overheat condition
2. Low temperature condition (below –40 °F)
3. Cell imbalance
4. Open circuit
5. Shorted circuit

If the battery charger finds a fault, it turns off and sends a fault signal to the Electrical Load Management System (ELMS).

Theory of Operation

The chemical reactions that occur in a nickel-cadmium battery are represented by the following equations

$$\text{Positive electrode: } 2NiOOH + 2H_2O + 2e^- \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2Ni(OH)_2 + 2(OH)^-$$

$$\text{Negative electrode: } Cd + 2(OH)^- \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} Cd(OH)_2 + 2e^-$$

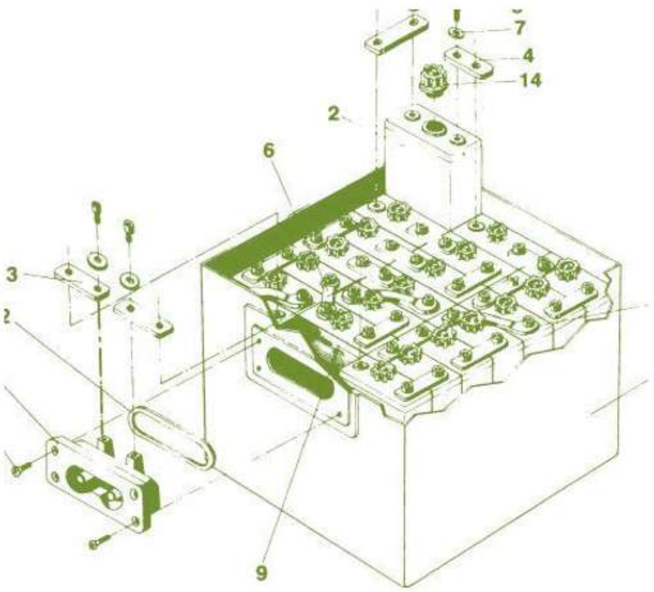
$$\text{Overall cell reaction: } 2NiOOH + Cd + 2H_2O \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2Ni(OH)_2 + Cd(OH)_2$$

There are two basic cell types: vented and recombinant. Vented cells have a flooded electrolyte, and the hydrogen and oxygen gases generated during charging are vented from the cell container. Recombinant cells have a starved electrolyte, and the oxygen generated from the positive electrode during charging

Diffuses to the negative electrode where it recombines to form cadmium hydroxide by the following reaction:

The recombination reaction suppresses hydrogen evolution at the negative electrode, thereby allowing the cell to be sealed. Unlike valve-regulated lead-acid cells, recombinant nickel-cadmium cells are sealed with a high-pressure vent that releases only during abusive conditions. Thus, these cells remain sealed under normal charging conditions. However, provisions for gas escape must still be provided when designing battery cases since abnormal conditions may be encountered periodically (e.g., in the event of a charger failure that causes an over current condition).

Cell Construction

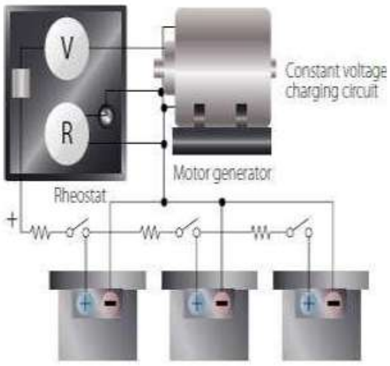


The construction of nickel-cadmium cells varies significantly, depending on the manufacturer. In general, cells feature alternating positive and negative plates with separator layers interleaved between them, a potassium hydroxide (KOH) electrolyte of approximately 30% concentration by weight (specific gravity 1.30), and a prismatic cell container with the cell terminals extending through the cover. The positive plate is impregnated with nickel hydroxide and the negative plate is impregnated with cadmium hydroxide.

The most common plate structure is made of nickel powder sintered onto a substrate of perforated nickel foil or woven screens. At least one manufacturer (ACME) uses nickel-coated polymeric fibers to form the plate structure. Cell containers typically are made of nylon, polyamide, or steel. One main difference between vented cells and sealed (recombinant) cells is the type of separator. Vented cells use a gas barrier layer to prevent gases from diffusing between adjacent plates. Recombinant cells feature a porous separator system that permits gas diffusion between plates.

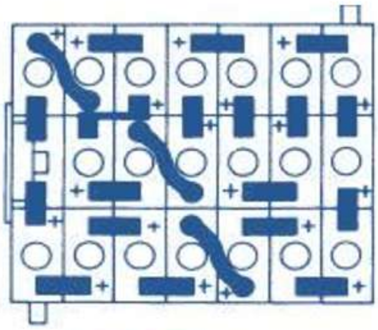
Battery Construction

Nickel-cadmium aircraft batteries generally consist of a steel case



containing identical, individual cells connected in series. The number of cells depends on the particular application, but generally 19 or 20 cells are used. The end cells of the series are connected to the battery receptacle located on the outside of the case. The receptacle is usually a two-pin, quick disconnect type; both Cannon and elcon styles commonly are used. Cases are vented by means of vent tubes or louvers to allow escape of gases produced during overcharge. Some battery designs have provisions for forced air cooling, particularly for engine start applications. Thermostatically controlled heating pads sometimes are employed on the inside or outside of the battery case to improve low temperature performance. Power for energizing the heaters normally is provided by the aircraft's AC or DC bus. Temperature sensors often are included inside the case to allow regulation of the charging voltage. In addition, many batteries are equipped with a thermal switch that protects the battery from overheating if a fault develops or if battery is exposed to excessively high temperatures. A typical aircraft battery assembly is shown in Figure.

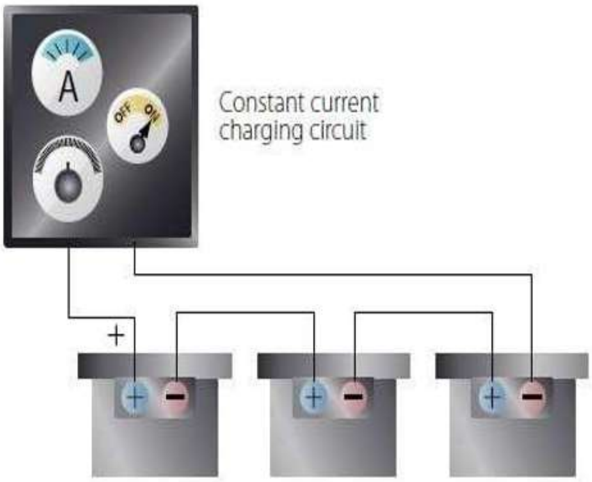
Battery Charging



20-Cell Connector Location and Polarity

Operation of aircraft batteries beyond their ambient temperature or charging voltage limits can result in excessive cell temperatures leading to electrolyte boiling, rapid deterioration of the cells, and battery failure. The relationship between maximum charging voltage and the number of cells in the battery is also significant. This determines (for a given ambient temperature and state of charge) the
rate at which energy is absorbed as heat within the battery. For lead-acid batteries, the voltage per cell must not exceed 2.35 volts. In the case of NiCd batteries, the charging voltage limit varies with design and construction. Values of 1.4 and 1.5 volts per cell are generally used. In all cases, follow the recommendations of the battery manufacturer.

Constant Voltage Charging (CP)
The battery charging system in an airplane is of the constant voltage type. An engine-driven generator, capable of supplying the required voltage, is connected through the aircraft electrical system directly to the battery. A battery switch is incorporated in the system so that the battery may be disconnected when the airplane is not in operation. The voltage of the generator is accurately controlled by means of a voltage regulator connected in the field circuit of the generator.
For a 12-volt system, the voltage of the generator is adjusted to approximately 14.25. On 24-volt systems, the adjustment should be between 28 and 28.5 volts. When these conditions exist, the initial charging current through the battery is high. As the state of



current flows into the battery.

charge increases, the battery voltage also increases, causing the current to taper down. When the battery is fully charged, its voltage is almost equal to the generator voltage, and
very little before it is passed through the rectifier. If a constant current charging system is used, multiple batteries may be connected in series, provided that the charging current is kept at such a level that the battery does not overheat or gas excessively.
The constant current charging method is the preferred method for charging Ni-Cd batteries. Typically, a Ni-Cd battery is constant current charged at a rate of 1CA until all the cells have reached at least 1.55V. Another charge cycle follows at 0.1CA, again until all cells have reached 1.55V. The charge is finished with an overcharge or top-up charge, typically for not less than 4 hours at a rate of 0.1CA. The purpose of the overcharge is to expel as much, if not all the gases collected on the electrodes, hydrogen on the anode, and oxygen on the cathode; some of these gases recombine to form water that, in turn, raises the electrolyte level to its highest level after which it is safe to adjust the electrolyte levels.

When the charging current is low, the battery may remain connected to the generator without damage. When using a constant-voltage system in a battery shop, a voltage regulator that automatically maintains a constant voltage is incorporated in the system. A higher capacity battery (e.g., 42 Ah) has a lower resistance than a lower capacity battery (e.g., 33 Ah). Hence, a high-capacity battery draws a higher charging current than a low- capacity battery when both are in the same state of charge and when the charging voltages are equal. The constant voltage method is the preferred charging method for lead-acid batteries.

Constant Current Charging

Constant current charging is the most convenient for charging batteries outside the airplane because several batteries of varying voltages may be charged at once on the same system. A constant current charging system usually consists of a rectifier to change the normal AC supply to DC. A transformer is used to reduce the available 110-volt or 220- volt AC supply to the desired level

During the overcharge or top-up charge, the cell voltages go beyond 1.6V and then slowly start to drop. No cell should rise above 1.71V (dry cell) or drop below 1.55V (gas barrier broken). Charging is done with vent caps loosened or open. A stuck vent might increase the pressure in the cell. It also allows for refilling of water to correct levels before the end of the top-up charge while the charge current is still on. However, cells should be closed again as soon as the vents have been cleaned and checked since carbon dioxide dissolved from outside air carbonates the cells and ages the battery.

Thermal runaway

Ni-Cd batteries are capable of performing to its rated capacity when the ambient temperature of the battery is in the range of approximately 60–90 °F. An increase or decrease in temperature from this range results in reduced capacity. Ni-Cd batteries have a ventilation system to control the temperature of the battery. A combination of high battery temperature (in excess of 160 °F) and overcharging can lead to a condition called thermal run away. The temperature of the battery has to be constantly monitored to ensure safe operation. Thermal runaway can result in a Ni-Cd chemical fire and/or explosion of the Ni--Cd battery under recharge by a constant-voltage source and is due to cyclical, ever-increasing temperature and charging current. One or more shorted cells or an existing high temperature and low charge can produce the following cyclical sequence of events:

1. Excessive current,
2. Increased temperature,
3. Decreased cell(s) resistance,
4. Further increased current, and
5. Further increased temperature

This does not become a self-sustaining thermal-chemical action if the constant voltage charging source is removed before the battery temperature is in excess of 160 °F.

Storage Characteristics

Nickel-cadmium batteries can be stored in any state of charge and over a broad temperature range (i.e., -65 to 60°C). For maximum shelf life, however, it is best to store batteries between 0 and 30°C. Vented cell batteries normally are stored with the terminals shorted together. Shorting of sealed-cell batteries during storage is not recommended, however, since it may cause cell venting and/or cell reversal.

When left on open circuit during periods of non-operation, nickel- cadmium batteries will self-discharge at a relatively fast rate. As a rule of thumb, the self discharge rate of sealed cells is approximately 1%/day at 20°C (when averaged over 30 days), and the rate increases by 1%/day for every 10°C rise in temperature (e.g., 2%/day at 30°C, 3%/day at 40°C, etc.). The self-discharge rate is somewhat less for vented cells. The capacity lost by self- discharge usually is recoverable when charged in the normal fashion.

Battery Maintenance Battery inspection and maintenance procedures vary with the type of chemical technology and the type of physical construction. Always follow The battery manufacturer‘s approved procedures. Battery performance at any time in a given application depends upon the battery‘s age, state of health, state of charge, and mechanical integrity, which you can determine according to the following:

- To determine the life and age of the battery, record the install date of the battery on the battery. During normal battery maintenance, battery age must be documented either in the aircraft maintenance log or in the shop maintenance log.
- Lead-acid battery state of health may be determined by duration of service interval (in the case of vented batteries), by environmental factors (such as excessive heat or cold), and by observed electrolyte leakage (as evidenced by corrosion of wiring and connectors or accumulation of powdered salts). If the battery needs to be refilled often, with no evidence of external leakage, this may indicate a poor state of the battery, the battery charging system, or an overcharge condition.

Use a hydrometer to determine the specific gravity of the lead-acid battery electrolyte, which is the weight of the electrolyte compared to the weight of pure water. Take care to ensure the electrolyte is returned to the cell from which it was extracted. When a specific gravity difference of 0.050 or more exists between cells of a battery, the battery is approaching the end of its useful life and replacement should be considered. Electrolyte level may be adjusted by the addition of distilled water. Do not add electrolyte.

- Battery state of charge is determined by the cumulative effect of charging and discharging the battery. In a normal electrical charging system, the aircraft generator or alternator restores a battery to full charge during a flight of 1 hour to 90 minutes.
- Proper mechanical integrity involves the absence of any physical damage, as well as assurance that hardware is correctly installed and the battery is properly connected. Battery and battery compartment venting system tubes, nipples, and attachments, when required, provide a means of avoiding the potential buildup of explosive gases, and should be checked periodically to ensure that they are securely connected and oriented in accordance with the maintenance manual‘s installation procedures. Always follow procedures approved for the specific aircraft and battery system to ensure that the battery system is capable of delivering specified performance.

Aircraft Battery Inspection

Aircraft battery inspection consists of the following items:

1. Inspect battery sump jar and lines for condition and security.

2. Inspect battery terminals and quickly disconnect plugs and pins for evidence of corrosion, pitting, arcing, and burns. Clean as required.

3. Inspect battery drain and vent lines for restriction, deterioration, and security.

4. Routine pre flight and post flight inspection procedures should include observation for evidence of physical damage, loose connections, and electrolyte loss.

Installation Practices

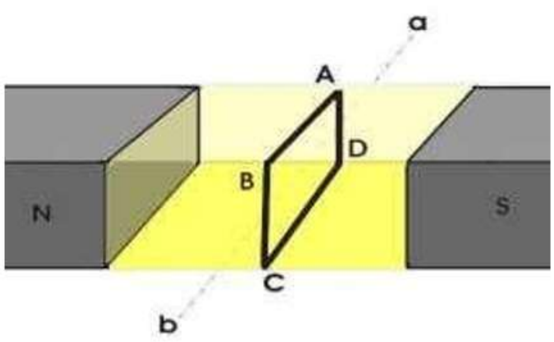
- External surface—Clean the external surface of the battery prior to installation in the aircraft.
- Replacing lead-acid batteries—When replacing lead-acid batteries with NiCd batteries, a battery temperature or current monitoring system must be installed. Neutralize the battery box or compartment and thoroughly flush with water and dry. A flight manual supplement must also be provided for the NiCd battery installation. Acid residue can be detrimental to the proper functioning of a NiCd battery, as alkaline is to a lead-acid battery.

- Battery venting—Battery fumes and gases may cause an explosive mixture or contaminated compartments and should be dispersed by adequate ventilation.

Venting systems often use ram pressure to flush fresh air through the battery case or enclosure to a safe overboard discharge point. The venting system pressure differential should always be positive and remain between recommended minimum and maximum values. Line runs should not permit battery overflow fluids or condensation to be trapped and prevent free airflow.

- Battery sump jars—A battery sump jar installation may be incorporated in the venting system to dispose of battery electrolyte overflow. The sump jar should be of adequate design and the proper neutralizing agent used. The sump jar must be located only on the discharge side of the battery venting system.
- Installing batteries—When installing batteries in an aircraft, exercise care to prevent inadvertent shorting of the battery terminals. Serious damage to the aircraft structure (frame, skin and other subsystems, avionics, wire, fuel, etc.) can be sustained by the resultant high discharge of electrical energy. This condition may normally be avoided by insulating the terminal posts during the installation process. Remove the grounding lead first for battery removal, then the positive lead. Connect the grounding lead of the battery last to minimize the risk of shorting the hot terminal of the battery during installation.

Quick-disconnect type battery—If a quick-disconnect type of battery connector that prohibits crossing the battery lead is not employed, ensure that the aircraft wiring is connected to the proper battery terminal. Reverse polarity in an electrical system can seriously damage a battery and other electrical components.



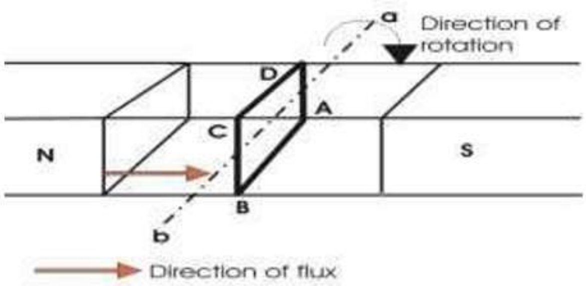
DC POWER GENERATION

There are two types of generators, one is ac generator and other is dc generator. Whatever may be the types of generators, it always converts mechanical power to electrical power. An ac generator produces alternating power. A DC generator produces direct power. Both of these generators produce electrical power, based on same fundamental principle of Faraday's law of electromagnetic induction. According to these laws, when an conductor moves in a magnetic field it cuts magnetic lines force, due to which an emf is induced in the conductor. The magnitude of this induced emf depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This emf will cause an current to flow if the conductor circuit is closed.

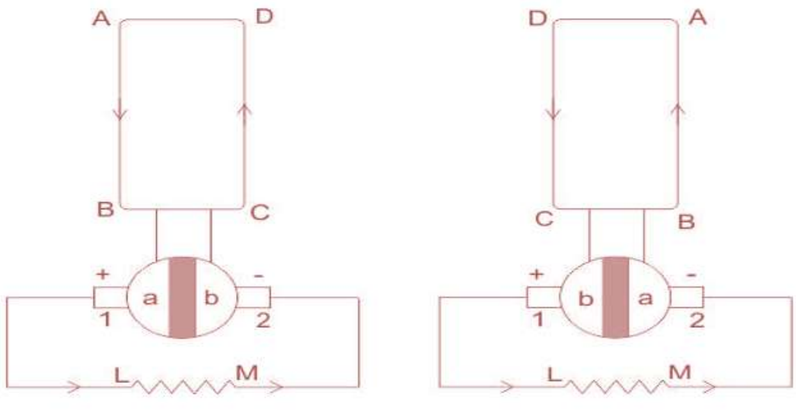
Hence the most basic two essential parts of a generator are
a) a magnetic field and
b) conductors which move inside that magnetic field.

Single Loop DC Generator
A single loop of conductor of rectangular shape is

placed between two opposite poles of magnet. Let's us consider, the rectangular loop of conductor is ABCD which rotates inside the magnetic field about its own axis ab. When the loop rotates from its vertical position to its horizontal position, it cuts the flux lines of the field. As during this movement two sides, i.e. AB and CD of the loop cut the flux lines there will be an emf induced in these both of the sides (AB & dC) of the loop.
As the loop is closed there will be a current circulating through the loop. The direction of the current can be determined by Fleming's right hand Rule. This rule says that is you stretch thumb, index finger and middle finger of your right hand perpendicular to each other, then thumbs indicates the direction of motion of the conductor, index finger indicates the direction of magnetic field i.e. N - pole to S - pole, and middle finger indicates the direction of flow of current through the conductor.



Now if we apply this right hand rule, we will see at this horizontal position of the loop, current will flow from point A to B and on the other side of the loop current will flow from point C to D.
Now if we allow the loop to move further, it will come again to its vertical position, but now upper side of the loop will be CD and lower side will be AB (just opposite of the previous vertical position). At this position the
tangential motion of the sides of the loop is parallel to the flux lines of the field. Hence there will be no question of flux cutting and consequently there will be no current in the loop.
If the loop rotates further, it comes to again in horizontal position. But now, said AB side of the loop comes in front of N pole and CD comes in front of S pole, i.e. just opposite to the previous horizontal position as shown in the figure beside.

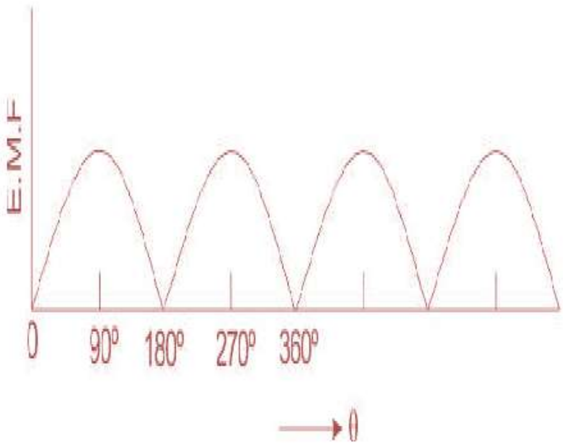


Here the tangential motion of the side of the loop is perpendicular to the flux lines, hence rate of flux cutting is maximum here and according to Flemming's right hand rule, at this position current flows from B to A and on other side from D to C.
Now if the loop is continued to rotate about its axis, every time the side AB comes in front of S pole, the current flows from A to B and when it comes in front of N pole, the current flows from B to
A. Similarly, every time the side CD comes in front of S pole the current flows from C to D and when it comes in front of N pole the current flows from D to C.

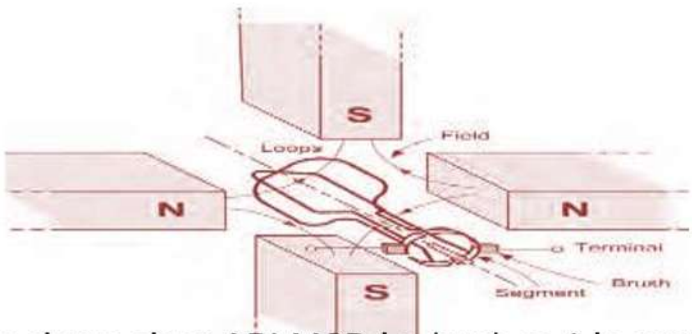
direction i.e. upwards from reference plane. From this, we will come to the topic of principle of dc generator.
Now the loop is opened and connected it with a split ring as shown in the figure below. Split rings are made out of a conducting cylinder which cuts into two halves or segments insulated from each other. The external load terminals are connected with two carbon brushes which are rest on these split slip ring segments.

If we observe this phenomena in different way, it can be concluded, that each side of the loop comes in front of N pole, the
current will flow through that side in same direction i.e. downward
to the reference plane and similarly each side of the loop comes in front of S pole, current through
it flows in same

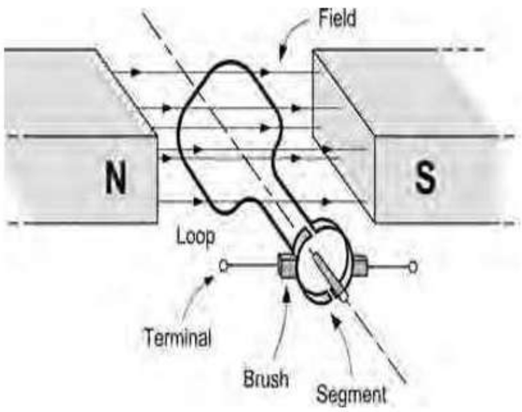
1.1.9



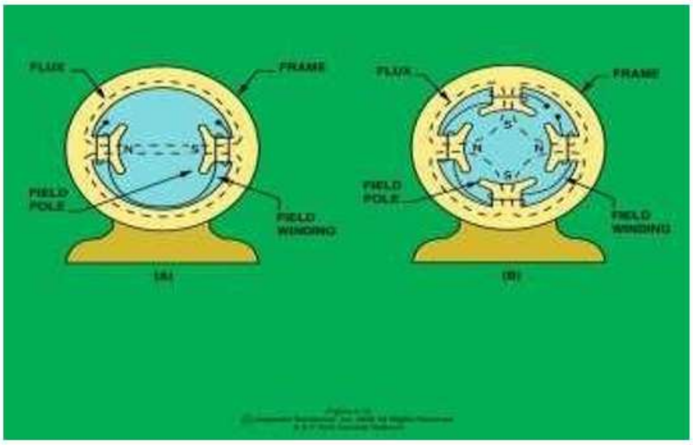
1.1.10 WORKING PRINCIPLE OF DC GENERATOR
It is seen that in the first half of the



revolution current flows always along ABLMCD i.e. brush no 1 in contact with segment a. In the next half revolution, in the figure the direction of the induced current in the coil is reversed. But at the same time the position of the segments a and b are also reversed which results that brush no 1 comes in touch with that segment b. Hence,
the current in the load resistance again flows from L to M. The wave from of



the current through the load circuit is as shown in the figure. This current is unidirectional.
This is basic working principle of DC generator, explained by single loop generator model.
The position of the brushes of DC generator is so arranged that the changeover of the segments a and b from one brush to other takes place when the plane of rotating coil is at right angle to the plane of the lines of force. It is so become in that position, the induced emf in the coil is zero.
Output after commutator action Commutator Arrangement By increasing no. of loop DC ripple reduces

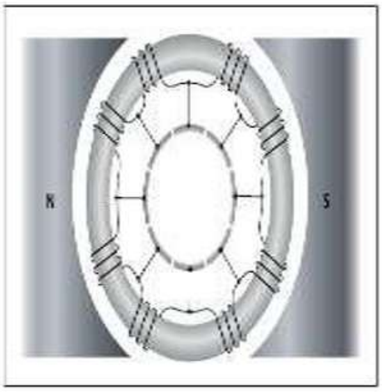


Parts of DC generator
A DC generator has the following parts
1) Yoke or Field frame
2) Pole of generator
3) field winding
4) Armature of DC generator
5) Commutator or split rings (collector rings) & slip rings in ac. Gen.
6) Brushes of generator
7) Bearing
8) End frame

Field Frame Assembly
Yoke of DC generator serves two purposes,
(i) It holds the magnetic pole cores of the generator and acts as cover of the generator.
(ii) It carries the magnetic field flux.

In small generator, yoke are made of cast iron. Cast iron is cheaper in cost but heavier than steel. But for large construction of DC generator, where weight of the machine is concerned, lighter cast steel or rolled steel is preferable for constructing yoke of DC generator. Normally larger yokes are formed by rounding a rectangular steel slab and the edges are welded together at the bottom. Then feet, terminal box and hangers are welded to the outer periphery of the yoke frame.

A practical DC generator uses electromagnets instead of permanent magnets. To produce a magnetic field of the necessary strength with permanent magnets would greatly increase the physical size of the generator. The field coils are made up of many turns of insulated wire and are usually wound on a form that fits over the iron



core of the pole to which it is securely fastened. The exciting current, which is used to produce the magnetic field and which flows through the field coils, is obtained from an external source or from the generated DC of the machine. No electrical connection exists between the windings of the field coils and the pole pieces. Most field coils are connected so that the poles show alternate polarity. Since there is always one north pole for each south pole, there must always be an even number of poles in any generator. Note that the pole pieces project from the frame. Because air offers a great amount of reluctance to the magnetic field, this design reduces the length of the air gap between the poles and the rotating armature and increases the efficiency of the generator. When the pole pieces are made to project as shown in, they are called salient poles Pole Cores and Pole Shoes of DC Generator

There are mainly two types of construction available.

One: Solid pole core, where it made of a solid single piece of cast iron or cast steel.

Two: Laminated pole core, where it made of numbers of thin, laminations of annealed steel which are riveted together.

The thickness of the lamination is in the range of 0.04" to 0.01". The pole core is fixed to the inner periphery of the yoke by means of bolts through the yoke and into the pole body.

The pole shoes are so typically shaped, that, they spread out the magnetic flux in the air gap and reduce the reluctance of the magneticpath.

Due to their larger cross - section they hold the pole coil at its position.

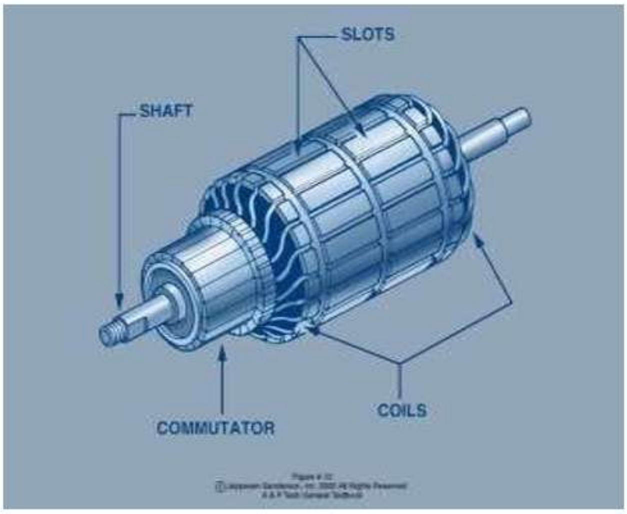
Pole Coils: The field coils or pole coils are wound around the pole core. These

are a simple coil of insulated copper wire or strip, which placed on the pole which placed between yoke and pole shoes.

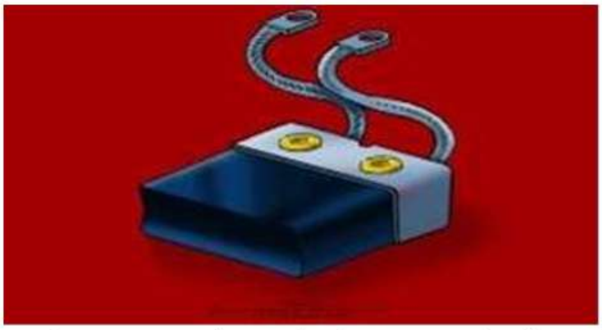
Armature

The armature assembly of a generator consists of many armature coils wound on an iron core,
a commutator and associated mechanical parts. These additional loops of wire are actually called windings and are evenly spaced around the armature so that the distance between each winding is the same. Mounted on a shaft, it rotates through the magnetic field produced by the field coils. The core of the armature acts as an iron

conductor in the magnetic field and, for this reason, is laminated to prevent the circulation of eddy currents.
Gramme-Ring Armature



There are two general kinds of armatures: the ring and the drum. a ring-type armature made up of an iron core, an eight-section winding, and an eight-segment commutator. The disadvantage of this arrangement is that the windings, located on the inner side of the iron ring, cut few lines of flux. As a result, they have very little voltage induced in them. For this reason, the Gramme-ring armature is not widely used.
A drum-type armature:
In Drum-type armature, armature core is in the shape of a drum and has slots cut into it where the armature windings are placed. The advantage is that each winding completely surrounds the core

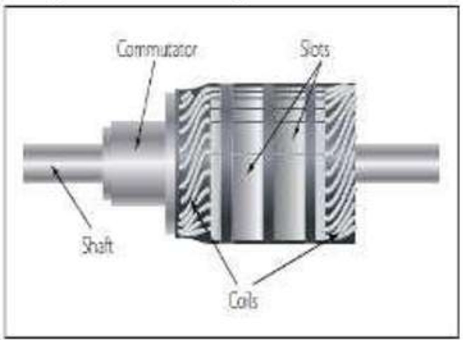


so that the entire length of the conductor cuts through the magnetic flux. The total induced voltage in this arrangement is far greater than that of the Gramme ring.
Drum-type armatures are usually constructed in one of two methods, each method having its own advantage .The two types of winding methods are the lap winding and the wave winding. Lap windings are in generators that are designed for high current outputs. The windings are connected in parallel paths and for this reason require several brushes. The wave winding is used in generators that are designed for high voltage outputs. The two ends of each coil are connected to commutator segments separated by the distance between poles. This results in a
series arrangement of the coils and is additive of all the induced voltages.
Commutator
Figure shows a cross-sectional view of a typical commutator. The commutator is located at the end of an armature and consists of wedge shaped segments of hard drawn copper, insulated from each other by thin sheets of mica. The segments are held in place by steel V-rings or clamping flanges fitted with bolts. Rings of mica insulate the segments from the flanges. The raised portion of each segment is called a riser, and the leads from the armature coils are soldered to the risers. When the segments have no risers, the leads are

soldered to short slits in the ends of the segments.

Brush

The brushes ride on the surface of the commutator, forming the electrical contact between the armature coils and the external circuit. A flexible, braided copper conductor, commonly called a pigtail, connects each brush to the external circuit. The brushes, usually made of high-grade carbon and held in place by brush holders insulated from the frame, are free to slide up and down in their holders in order to follow any irregularities in the surface of the commutator. The brushes are usually adjustable so that the pressure of the brushes on the commutator can be varied and the position of the brushes with respect to the segments can be adjusted. The constant making and breaking of connections to the coils in which a voltage is being induced necessitates the use of material for brushes, which has a definite contact resistance. Also, this material must be such that the friction between the commutator and the brush is low, to prevent excessive wear. For these reasons, the material commonly used for brushes is high-grade carbon. The carbon must be soft enough to prevent undue wear of the commutator and yet hard enough to provide reasonable brush life. Since the contact resistance of carbon is fairly high, the brush must be quite large to provide a large area of contact. The commutator surface is highly polished to reduce friction as much as possible. Oil or grease must never be used on a commutator, and extreme care must be used when cleaning it to avoid marring or scratching the surface



Generator Engine Coupling

Depending on the type, generators can be driven by gearbox or pulley and belt. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both.

A gear coupling is a mechanical device for transmitting torque between two shafts that are not collinear. It consists of a flexible joint fixed to each shaft. The two joints are connected by a third shaft, called the spindle.

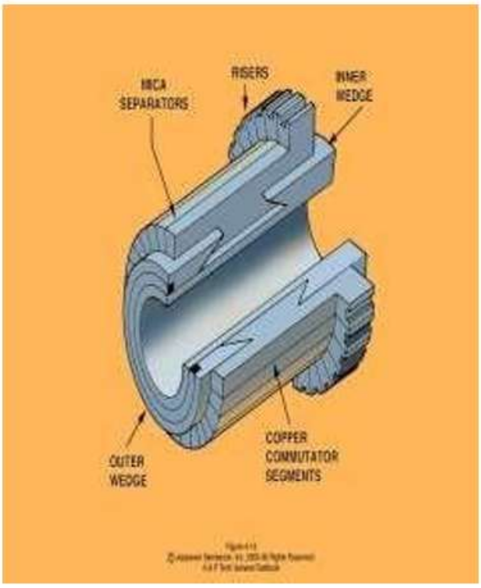
Bearing of DC Generator

For small machine, ball bearing is used and for heavy duty dc generator, roller bearing is used. The bearing must always be lubricated properly for smooth operation and long life of generator.

Types of DC Generators

Generally DC generators are classified according to the ways of excitation of their fields. There are three methods of excitation.

i. Field coils excited by permanent magnets – Permanent magnet DC generators



ii. Field coils excited by some external source – Separately excited DC generators
iii. Field coils excited by the generator itself – Self excited DC generators
ii.

1.1.11 PERMANENT MAGNET DC GENERATOR

When the flux in the magnetic circuit is established by the help of permanent magnets then it is known as Permanent

magnet dc generator. It consists of an armature and one or several permanent magnets situated around the armature. This type of dc generators generates very low power. So, they are rarely found in industrial applications. They are normally used in small applications like dynamos in motor cycles.

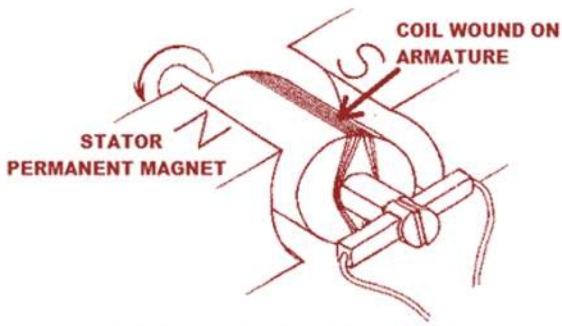
Separately Excited DC Generator

These are the generators whose field magnets are energized by some external dc source such as battery .

A circuit diagram of separately excited DC generator is shown in figure.

Ia = Armature current IL = Load current
V = Terminal voltage Eg = Generated emf

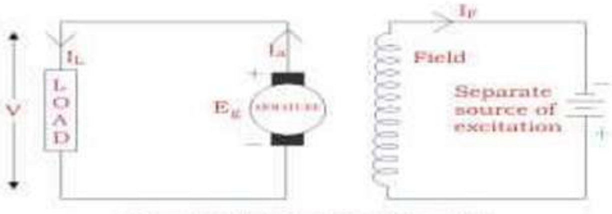
Voltage drop in the armature = Ia × Ra (R/sub>a is the armature resistance)
Let, Ia = IL = I (say)



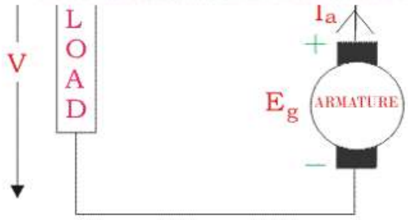
PERMANENT MAGNET DC GENERATOR

Then, voltage across the load, V = IRa

Power generated, Pg
= Eg×I
Power delivered to the external load, PL
= V×I.



Separately Excited DC Generator



Series Wound Generator

1.1.12 SELF-EXCITED DC GENERATORS

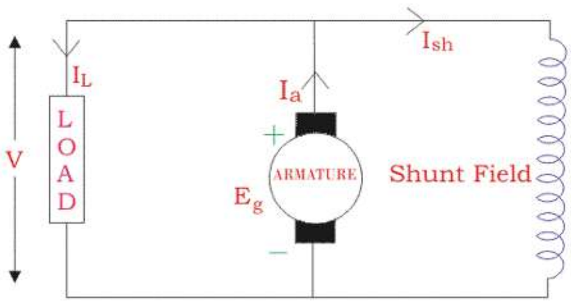
These are the generators whose field magnets are energized by the current supplied by themselves. In these type of machines field coils are internally connected with the armature. Due to residual magnetism some flux is always present in the poles. When the armature is rotated some emf is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux. As the pole flux strengthened, it will produce more armature emf, which cause further increase of current through the field. This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value.

According to the position of the field coils the Self-excited DC generators may be classified as…

A. Series wound generators
B. Shunt wound generators
C. Compound wound generators

1.1.12.1 Series Wound Generator

In these type of generators, the field windings are connected in series with armature conductors as shown in figure below. So, whole current flows through the field coils as well as the load. As series field winding carries full load current it is designed with relatively few turns of thick wire. The electrical resistance of series field winding is



Shunt Wound Generator

therefore very low (nearly 0.5Ω).

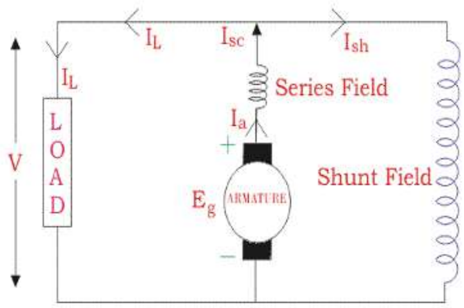
Let,
Rsc = Series winding resistance   Isc = Current flowing through the series field
Ra = Armature resistance   Ia = Armature current
IL = Load current   V = Terminal voltage Eg = Generated emf

Then, Ia = Isc = IL=I (say)

Voltage across the load, V = Eg I(Ia×Ra) Power generated, Pg = Eg×I
Power delivered to the load, PL = V×I

1.1.12.2 Shunt Wound DC Generators

In these type of DC generators the field windings are connected in parallel with armature conductors as shown in figure below. In
shunt wound generators the voltage in the field winding is same as the voltage across



Long Shunt Compound Wound Generator

the terminal. Let,
Rsh = Shunt winding resistance
Ish = Current flowing through the shunt field Ra = Armature resistance
Ia = Armature current IL = Load current
V = Terminal voltage Eg = Generated emf
Here armature current Ia is dividing in two parts, one is shunt field current Ish and another is load current IL.
So, Ia=Ish + IL
The effective power across the load will be maximum when IL will be maximum. So, it is required to keep shunt field current as small as possible. For this purpose the resistance of the shunt field winding generally kept high (100 Ω) and large no of turns are used for the desired emf.
Shunt field current, Ish = V/Rsh Voltage across the load, V = Eg-Ia Ra Power generated, Pg= Eg×Ia
Power delivered to the load, PL = V×IL

1.1.12.3

1.1.12.4 Compound Wound DC Generator

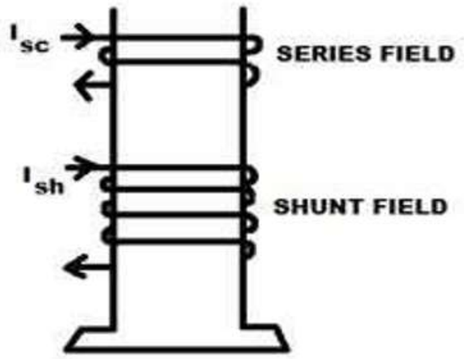
In series wound generators, the output voltage is directly proportional with load current. In shunt wound generators, output

voltage is inversely proportional with load current. A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called compound wound DC generator.
Compound wound generators have both series field winding and shunt field winding. One winding is placed

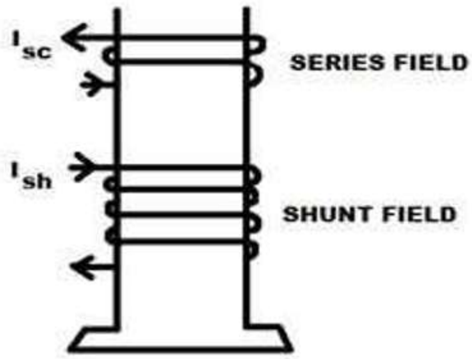
in series with the armature and the other is placed in parallel with the armature. This type of DC generators may be of two types- short shunt compound wound generator and long shunt compound wound generator.
In a compound wound generator, the shunt field is stronger than the series field. When the series field assists the shunt field, generator is said to be cumulative compound wound. On the other hand if series field opposes the shunt field, the generator is said to be differentially compound wound.

Mechanical losses
– Friction loss
– Windage loss

The above three categorizes various types of losses that occur in a dc generator or a dc motor. Each of these is explained in details below.



CUMULATIVE COMPOUNDING



DIFFERENTIAL COMPOUNDING

1.2 LOSSES IN A ROTATING DC MACHINE
1.3 COPPER LOSSES

– Armature Cu loss
– Field Cu loss

Loss due to brush contact resistance Iron Losses
– Hysteresis loss
– Eddy current loss

1.3.1 COPPER LOSSES

These losses occur in armature and field copper windings. Copper losses consist of Armature copper loss, Field copper loss and loss due to brush contact resistance.
Armature copper loss = Ia2Ra (where, Ia = Armature current and Ra = Armature resistance
This loss contributes about 30 to 40% to full load losses. The armature copper loss is variable and depends upon the amount of loading of the machine.
Field copper loss = I 2R (where, I = field current and Rf = field resistance)
In the case of a shunt wounded field, field copper loss is practically constant. It contributes about 20 to 30% to full load losses.
Brush contact resistance also contributes to the copper losses. Generally, this loss is included into armature copper loss.

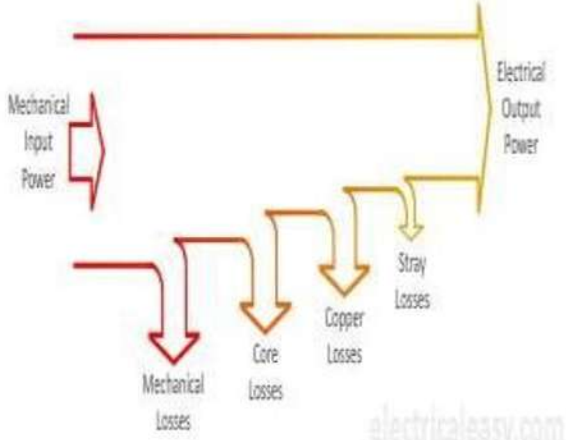
1.3.2 IRON LOSSES (CORE LOSSES)

As the armature core is made of iron and it rotates in a magnetic field, a small current gets induced in the core itself too. Due to this current, eddy current loss and hysteresis loss occur in the armature iron core. Iron losses are also called as Core losses or magnetic losses.
Hysteresis loss is due to the reversal of magnetization of the armature core. When the core passes under one pair of poles, it undergoes one complete cycle of magnetic reversal. The frequency of magnetic reversal if given by, f=P.N/120 (where, P
= no. of poles and N = Speed in rpm)
The loss depends upon the volume and grade of the iron, frequency of magnetic reversals and value of flux density. Hysteresis loss is given by, Steinmetz formula: Wh=ηB 1.6fV (watts)

current to flow in the body due to the low resistance of the core. This current is known as eddy current. The power loss due to this current is known as eddy current loss.
Mechanical Losses
Mechanical losses consist of the losses due to friction in bearings and commutator. Air friction loss of rotating armature also contributes to these. These losses are about 10 to 20% of full load losses.
Stray Losses- In addition to the losses stated above, there may be small losses present which are called as stray losses or miscellaneous losses. These losses are difficult to account. They
are usually due to inaccuracies in the designing and modeling of the machine. Most of the times, stray losses are assumed to be 1% of the full load.
Generator Ratings

max
where, η = Steinmetz hysteresis constant V = volume of the core in m3
Eddy current loss: When the armature core rotates in the magnetic field, an emf is also induced in the core (just like it induces in armature conductors), according to the Faraday'slaw of electromagnetic induction. Though this induced emf is small, it causes a large

A generator is rated in power
output. Since a generator is designed to operate at a specified voltage, the rating usually is given as the number of amperes the generator can safely supply at its rated voltage. Generator rating and performance data are stamped on the nameplate attached to the generator. When replacing a generator, it is important to choose
one of the proper rating. The rotation of generators is termed either clockwise or counterclockwise, as viewed from the driven end. Usually, the direction of rotation is stamped on the data plate. If no



Power flow diagram of a DC generator

direction is stamped on the plate, the rotation may be marked by an arrow on the cover plate on the brush housing. It is important that a generator with the correct direction of rotation be used; otherwise, the voltage will be reversed. The speed of an aircraft engine varies from idle rpm to takeoff rpm; however, during the major portion of a flight, it is at a constant cruising speed. The generator drive is usually geared to revolve the generator between 1-1/8 and 1-1/2 times the engine crankshaft speed. Most aircraft generators have a speed at which they begin to produce their normal voltage. Termed the ―coming in‖ speed, it is usually about 1,500 rpm.

Armature Reaction

Current flowing through the armature sets up electromagnetic fields in the windings. These new fields tend to distort or bend the magnetic flux between the poles of the generator from a straight- line path. Since armature current increases with load, the distortion becomes greater with an increase in load. This distortion of the magnetic field is called armature reaction. Armature windings of a generator are spaced so that, during rotation of the armature, there are certain positions when the brushes contact two adjacent segments, thereby shorting the armature windings to these segments. When the magnetic field is not distorted, there is usually no voltage being induced in the shorted windings, and therefore no harmful results occur from the shorting of the windings. However, when the field is distorted, a voltage is induced in these shorted windings, and sparking takes place between the brushes and the commutator segments. Consequently, the commutator becomes pitted, the wear on the brushes becomes excessive, and the output of the generator is reduced. To correct this condition, the brushes are set so that the plane of the coils, which are shorted by the brushes, is perpendicular to the distorted magnetic field, which is accomplished by moving the brushes forward in the direction of rotation. This operation is called shifting the brushes to the neutral

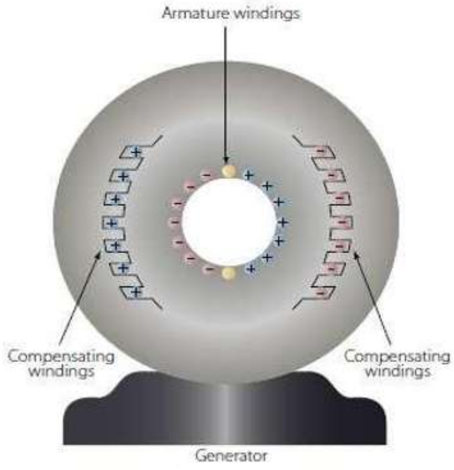
plane, or plane of commutation. The neutral plane is the position where the plane the two opposite coils is perpendicular to the magnetic field in the generator. On a few generators, the brushes can be shifted manually ahead of the normal neutral plane to the neutral plane caused by field distortion. On nonadjustable brush generators, the manufacturer sets the brushes for minimum sparking. Compensating windings or interpoles may be used to counteract some of the effects of field distortion, since shifting the brushes is inconvenient and unsatisfactory, especially when the speed and load of the generator are changing constantly.

Compensating Windings

The compensating windings consist of a series of coils embedded in slots in the pole faces. These coils are also connected in series with the armature. Consequently, this series connection with the armature produces a magnetic field in the compensating windings that varies directly with the armature current. The compensating windings are wound in such a manner that the magnetic field produced by them will counteract the magnetic field produced by the armature. As a result, the neutral plane will remain stationary any
magnitude of armature current. With this design, once the brushes are set correctly, they do not need to be moved again.

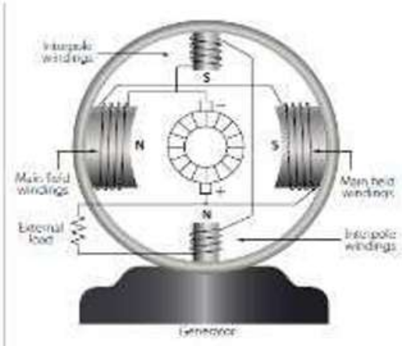
Interpoles

An interpole is a pole placed between the main poles of a generator. An example of interpole placement is shown in Figure. This is a simple two-pole generator with two interpoles. An interpole has the same polarity as the next main pole in the direction of rotation. The magnetic flux produced by an interpole



(A) Compensating

causes the current in the armature to change direction as an armature winding passes under it. This cancels the electromagnetic fields about the armature windings. The magnetic strength of the interpoles varies with the load on the generator; and since field distortion varies with the
load, the magnetic field of the interpoles counteracts the effects of the field set up around the armature windings and minimizes field distortion. Thus, the interpole tends to keep the neutral plane in the same position for all loads on the generator; therefore, field distortion is reduced by the interpoles, and the efficiency, output, and service life of the brushes are improved.



(B) Interpole

DC GENERATOR MAINTENANCE

Inspection

In general, the inspection of the generator installed in the aircraft should include the following items:

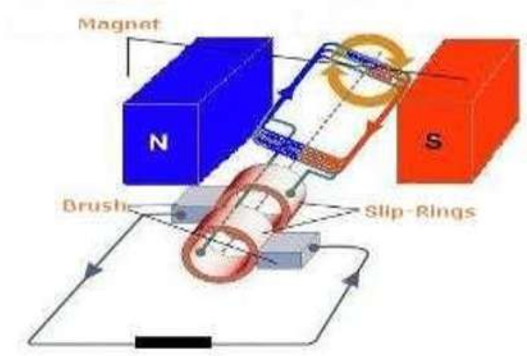
1. Security of generator mounting.
2. Condition of electrical connections.
3. Dirt and oil in the generator. If oil is present, check engine oil seal. Blow out dirt with compressed air.
4. Condition of generator brushes.
5. Generator operation.
6. Voltage regulator operation.

AC POWER GENERATION

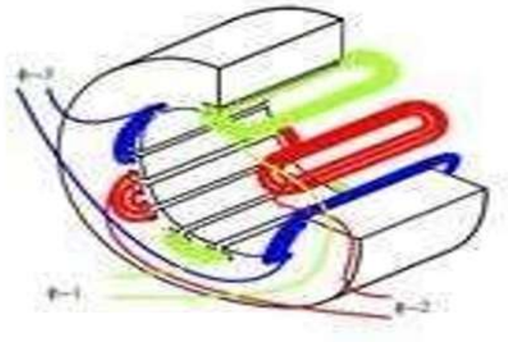
Alternating current (ac) generators supply the electrical energy for operating aircraft avionics equipment. A generator is a machine that converts mechanical energy into electrical energy by electromagnetic induction.

Ac power systems result in better design and use of equipment than older electronic equipment powered by direct current (dc), which have inverters for ac power and dynamotors for supplying higher voltage dc power. These components are very heavy compared to their relative power outputs. They are not reliable and increase maintenance costs and time. In today's aircraft, the same ac-powered equipment obtains various ac voltages and dc power by using simple transformers and transformer-rectifiers. These components are lightweight, simple, and reliable.

Modern naval aircraft use the three-phase, 120-/208-volt, 400-hertz (Hz) ac power system.



The number of magnetic poles and rotor revolutions per minute (rpm) determine the voltage frequency of the generator. With a fixed number of poles, constant frequency requires constant rotor rpm. An ac generator-rotating field has 12 poles with adjacent poles of opposite polarity. Each pair of poles produces one cycle per revolution; therefore, each revolution produces six cycles. The output frequency of the generator varies in direct proportion to the



engine drive speed. A generator operating at 6,000 rpm is operating at 100 revolutions per second or at 600 Hz. The 120-/208-volt, 400-Hz, three-phase ac power system has many advantages over the 28-volt dc system. It requires less current than the 28-volt dc system because of higher voltage and a ground neutral system. The current required is a fraction of that required for the same power in a 28-volt dc system. This permits the use of smaller aircraft wiring, saving weight. The ac generator and many of the system's control and protection components are lighter. Twelve kilowatts is the practical limit to the size of an aircraft dc generator. Aircraft now have ac generators with ratings up to 90 kilovolt-ampere (kVA).

Construction Of AC Generator (Alternator)

Main parts of the alternator, consists of stator and rotor. But, the unlike other machines, in most of the alternators, field exciters are rotating and the armature coil is stationary.

Stator: Unlike in DC machine stator of an alternator is not meant to serve path for magnetic flux. Instead, the stator is used for holding armature winding. The stator core is made up of lamination of steel alloys or magnetic iron, to minimize the eddy current losses.

1.3.2.1Why Armature Winding Is Stationary In An Alternator?

- At high voltages, it easier to insulate stationary armature winding, which may be as high as 30 kV or more.
- The high voltage output can be directly taken out from the stationary armature. Whereas, for a rotary armature, there will be large brush contact drop at higher voltages, also the sparking at the brush surface will occur.
- Field exciter winding is placed in rotor, and the low dc voltage can be transferred safely.
- The armature winding can be braced well, so as to prevent deformation caused by the high centrifugal force.

Rotor: There are two types of rotor used in an AC generator / alternator:

(i) Salient and (ii) Cylindrical type Salient pole type: Salient pole type rotor is used in low and medium speed alternators. This type of rotor consists of large number of projected poles (called salient poles), bolted on a
magnetic wheel. These poles are also laminated to minimize the eddy current losses. Alternators featuring this type of rotor are large in diameters and short in axial length.

Cylindrical type: Cylindrical type rotors are used in high speed alternators, especially in turbo alternators. This type of rotor consists of a smooth and solid steel cylinder having slots along its outer periphery. Field windings are placed in

these slots.

Types of Ac Generators

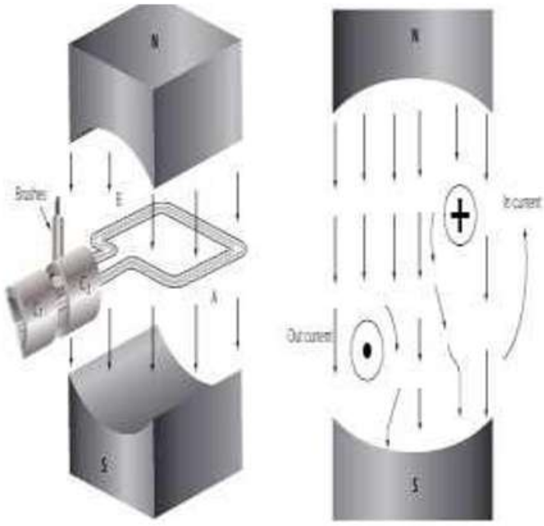
Aircraft ac generators range in size from the tachometer instrument generator up to the 90,000 volt-ampere generators. Generators are categorized as either brush-type or brushless. Regardless of weight, shape, or rating, practically all of these generators have
the following common characteristics:

- The stator (stationary armature winding) provides the ac output.
- The ac generator field (rotor) is a rotating magnetic field with fixed polarity.
- Regulating the rpm of the rotating magnetic field controls the voltage frequency.
- Controlling the strength of the magnetic field regulates the voltage.

A simple AC generator

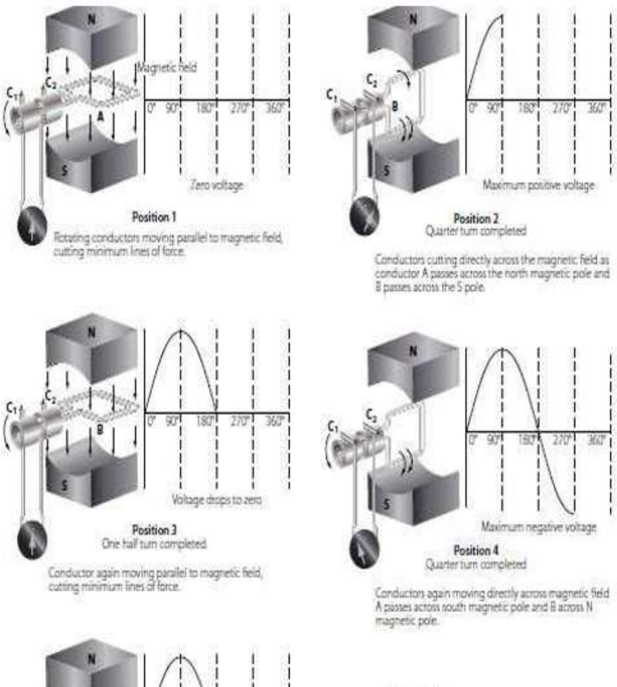
Generators used to produce an alternating current are called AC generators or alternators. The simple generator constitutes one method of generating an alternating voltage. It consists of a rotating loop, marked A and B, placed between two magnetic poles, N and S. The ends of the loop are connected to two metal slip rings (collector rings), C1 and C2. Current is taken from the collector rings by brushes. If the loop is considered as separate wires A and B, and the left-hand rule for generators is applied, then it can be observed that as wire A moves up across the field, a voltage is induced which causes the current to flow inward. As wire B moves down across the field, a

voltage is induced which causes the current to flow outward. When the wires are formed into a loop, the voltages induced in the two sides of the loop are combined. Therefore, for explanatory purposes, the action of either conductor, A or B, while rotating in the magnetic field is similar to the action of the loop
In a simple AC generator a loop of wire are inside the magnetic field produced by two opposite magnetic poles. Contact is made to the loop as it rotates by means of slip-rings and brushes.
Figure illustrates the generation of alternating current with a simple loop conductor rotating in a magnetic field. As it is rotated in a counter clockwise direction, varying values of voltages are induced in it.



Position 1
The conductor A moves parallel to the lines of force. Since it cuts no lines of force, the induced voltage is zero. As the conductor
advances from position 1 to position 2, the voltage induced gradually increases.

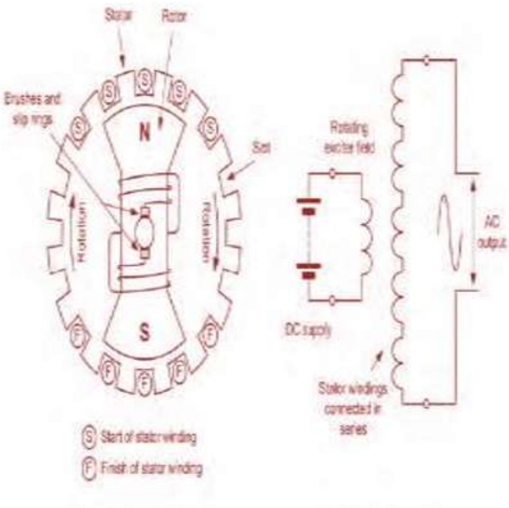
Position 2
The conductor is now moving perpendicular to the flux and cuts a maximum number of lines of force; therefore, a maximum voltage is induced. As the conductor
moves beyond position 2, it cuts a decreasing amount of flux at each instant, and the induced voltage decreases.



Position 3
At this point, the conductor has made one-half of a revolution and again moves parallel to the lines of force, and no voltage is induced in the conductor. As the A conductor passes position 3, the direction of induced voltage now reverses since the A conductor is moving downward, cutting flux in the opposite direction.
As the A conductor moves across the south pole, the induced voltage gradually increases in a negative direction, until it reaches position 4.

Position 4
Like position 2, the conductor is again moving perpendicular to the flux and generates a maximum negative voltage. From position 4 to 5, the induced voltage gradually decreases until the voltage is zero, and the conductor and wave are ready to start another cycle.

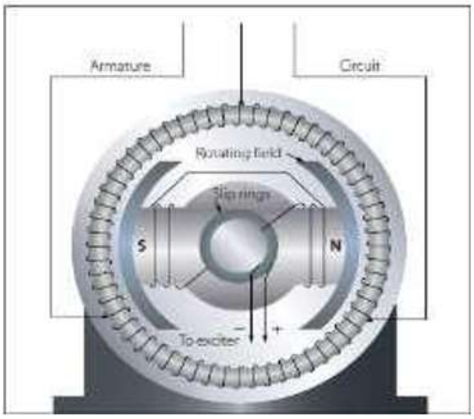
from which the output is taken. Furthermore, the magnetic field is usually produced by a rotating electromagnet (the rotor) rather than a permanent magnet. There are a number of reasons for this including:
(a) the conductors are generally lighter in weight than the magnetic field system and are thus more easily rotated
(b) the conductors are more easily insulated if they are stationary
(c) the currents which are required to produce the rotating magnetic field are very much smaller than those which are produced by the conductors.
Single-phase AC generator
The stator consists of five coils of



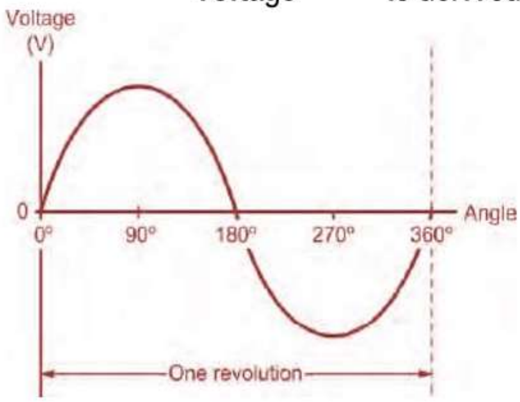
(a) Simplified construction (b) Electrical equivalent

Position 5
The curve shown at position 5 is called a sine wave. It represents the polarity and the magnitude of the instantaneous values of the
voltages generated. The horizontal base line is divided into degrees, or time, and the vertical distance above or below the base line represents the value of voltage at each particular point in the rotation of the loop.

ALTERNATOR
AC generators, or alternators, are based on the principles that relate to the simple AC generator. However, in a practical AC generator the magnetic field is rotated rather than the conductors



insulated heavy gauge wire located in slots in the high-permeability laminated core. These coils are connected in series to make a single stator winding from which the output voltage is derived. The two-pole



rotor comprises a field winding that is connected to a DC field supply via a set of slip rings and brushes. As the rotor moves through one complete revolution the output voltage will complete one full cycle of a sine wave. The major difference between an alternator and a DC
generator is the method of connection to the external circuit; that is, the alternator is connected to the external circuit by slip rings, but the DC generator is connected by a commutator.

By adding more pairs of poles to the arrangement it is possible to produce several
cycles of output voltage for one single revolution of the rotor. The frequency of the output voltage produced by an AC generator is given by:
$f = Pn/60$
wheref is the frequency of the induced e.m.f. (in Hz), p is the number of pole pairs, and N is the rotational speed (in rev/min).

Method of Excitation
One means of classification is by the type of excitation system used. In alternators used on aircraft, excitation can be affected by one of the following methods:
1. A direct connected, direct current generator. This system consists of a DC generator fixed on the same shaft with the AC generator. A variation of this system is a type of alternator which uses DC from the battery for excitation, after which the alternator is self-excited.

2. By transformation and rectification from the AC system. This method depends on residual magnetism for initial AC voltage buildup, after which the field is supplied with rectified voltage from the AC generator.
3. Integrated brushless type. This arrangement has a direct current generator on the same shaft withan

alternating current generator. The excitation alternator with circuit is completed through silicon rectifiers rather than a commutator and brushes. The rectifiers are mounted on the generator shaft and their output is fed directly to the alternating current generator's main rotating field

Two-phase AC generators

By adding a second stator winding to the single- phase AC generator shown in Fig. we can produce an alternator that produces two separate output voltages which will differ in phase by 90°. This arrangement is known as a two-phase AC generator. When compared with a single-phase AC generator of similar size, a two-phase AC generator can produce

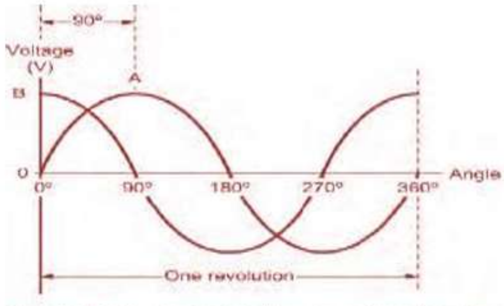


Figure 4.25 Output voltage produced by the two-phase AC generator shown in Fig. 4.24

more power. The reason for this is attributable to the fact that the two- phase AC

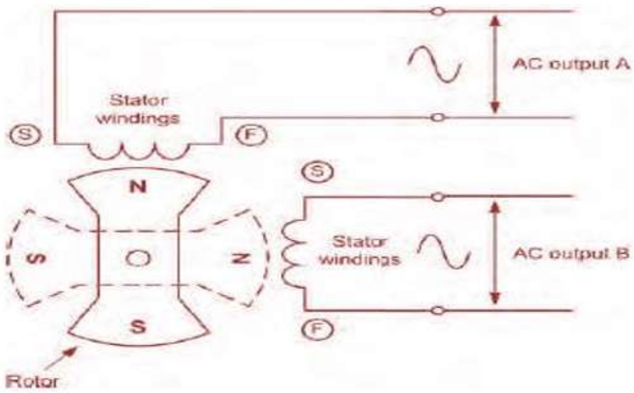


Figure 4.24 Simplified construction of a two-phase AC generator

generator will produce two positive and two negative pulses per cycle whereas the single-phase generator will only produce one positive and one negative pulse. Thus, over a period of time, a multi-phase supply will transmit a more evenly distributed power and this, in turn, results in a higher overall efficiency.

Three-phase AC generators are more efficient and produces more constant output than comparable single-phase AC generators.

Three-phase AC generators

The three-phase AC generator has three individual stator windings, as shown in Fig. 4.26 . The output voltages produced by the three-phase AC generator are spaced by 120° as

shown in Fig. 4.27 . Each phase can be used independently to supply a different load or the generator outputs can be used with a three phase distribution system .In a practical three-phase system the three output voltages are identified by the colours red, yellow, and blue or by letters A, B, and C respectively

Three-phase generation and distribution

When three-phase supplies are distributed there are two basic methods of connection:

- star (as shown in Fig. 4.28)
- delta (as shown in Fig. 4.29)

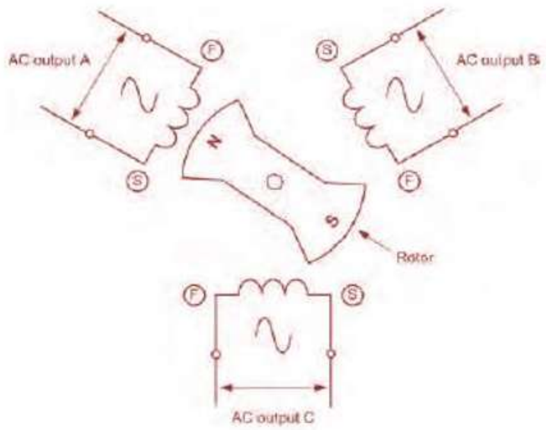


Figure 4.26 Simplified construction of a three-phase AC generator

A complete star-connected three-phase distribution system is shown in Fig. This shows a three-phase AC generator connected a three-phase load. Ideally, the load will be balanced in which case all three load resistances (or impedances) will be identical. The relationship between the line and phase voltages shown in Fig. 4.30 can be determined from the phasor diagram shown in Fig.4.3.This diagram shows the relative directions of the three alternating phase voltages (VP) and the voltages between the lines (VL). From this diagram it is important to note that three line voltages are 120° apart and that

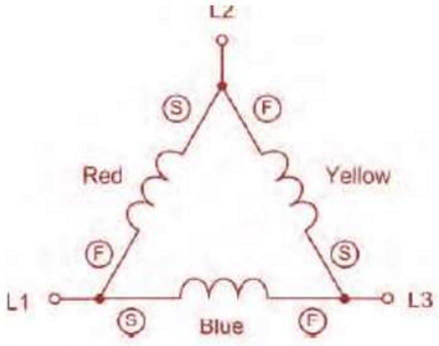


Figure 4.29 Delta connection

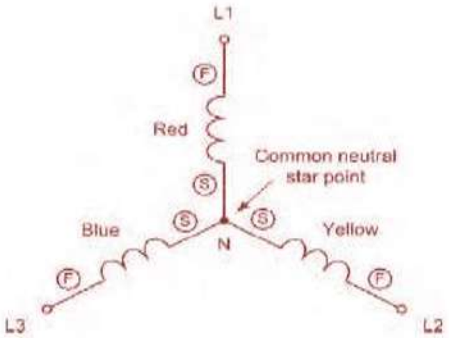


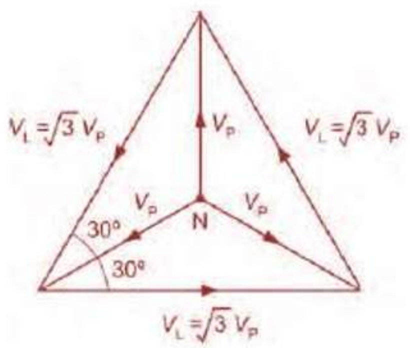
Figure 4.28 Star connection

resolve any one of the triangles, from which we find that: alternative, delta-connected three-phase distribution system is shown in Fig. 4.32 . Once again this shows a three-phase
AC generator connected a three-phase load. Here again, the load will ideally be balanced in which case all three load resistances (or impedances) will be identical. In this arrangement the three line currents are 120° apart and that the line currents lag the phase currents by 30°. Using a similar phasor diagram to that which we used earlier, we can show that: It should also be obvious that:

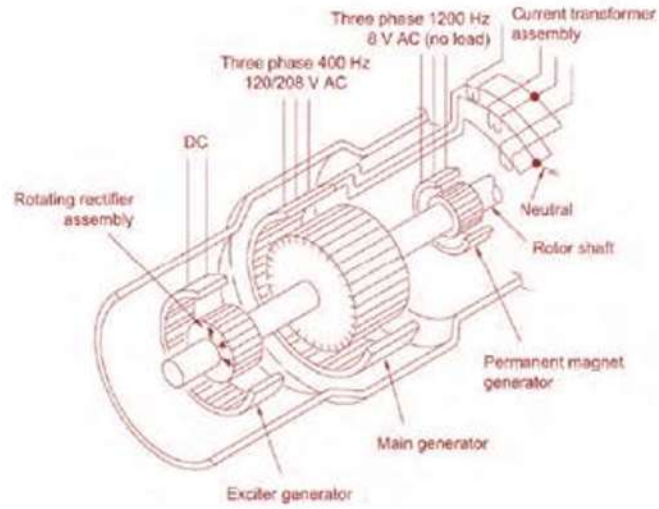
Brushless Alternator
This design is more efficient because there are no brushes to wear down or to arc at high altitudes. This generator consists of a pilot exciter, an exciter, and the main generator system. The need for brushes is eliminated by using an integral exciter with a rotating armature that has its AC output rectified for the main AC field, which is also of the rotating type.
The brushless generator is a more complex device but has significantly increased reliability coupled with reduced maintenance requirements. A schematic diagram for the brushless generator is shown in; the device can be divided into three main sections:
- permanent magnet generator
- rotating field
- three-phase output.

The AC generator uses a brushless arrangement based on a rotating rectifier and permanent magnet (PMG). The output of the PMG rectifier is fed to the voltage regulator which provides current for the primary exciter field winding. The primary exciter field induces current into a three-phase rotor winding. The output of this winding is fed to the shaft-mounted rectifier diodes which
produce a pulsating DC output which is

$$I_L = \sqrt{3}\, I_P$$



fed to the rotating field winding. It is important to note that the excitation system is an integral part of the rotor and that there is no direct electrical connection between the stator and rotor. The output of the main three-phase generator is supplied via current transformers (one for each phase) that monitor the load current in each line. An additional current transformer can also be present in the neutral line to detect an out-of-balance condition (when the load is unbalanced an appreciable current will flow in the generator‘s neutral connection).



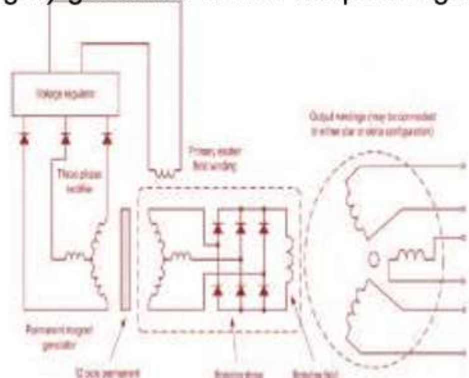
The generator output is fed to the various aircraft systems and a solid-state regulator. This rectifies the output and sends a regulated direct current to the stator exciter field of the PMG. The regulator maintains the output of the generator at 115 V AC and is normally contained within a generator control unit(GCU).

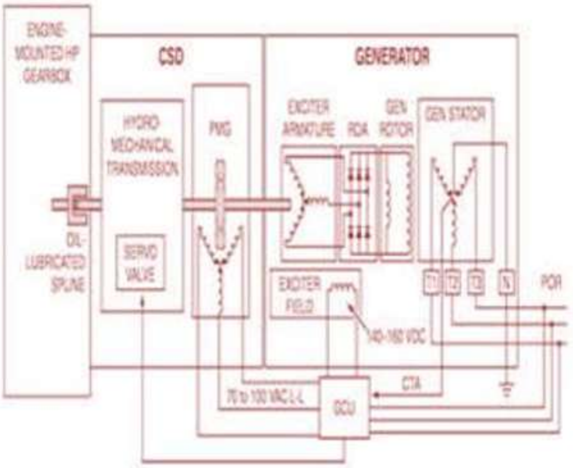
Alternator Constant Speed drive

Alternators are not always connected directly to theairplane engine like DC generators. Since the various electrical devices operating on AC supplied by alternatorsare designed to operate at a certain voltage and ata specified frequency, the speed of the alternators must be constant; however, the speed of an airplane enginevaries. Therefore, the engine, through a constant speed drive installed between the engine and the alternator,drives some alternators.. The discussion of a constant speed drive system will be based on such a drive, found onl arge multiengine aircraft.The constant speed drive is a hydraulic transmission,which may be controlled either electrically or mechanically.The constant speed drive assembly is designed to deliver an output of 6,000 rpm, provided the inputremains between 2,800 and 9,000 rpm. If the input,which is determined by engine speed, is below 6,000rpm, the drive increases the speed in order to furnishthe desired output. This stepping up of speed is known as over drive. In over drive, an automobile engine will operate at about the same rpm at 60 mph as it does in conventional drive at 49 mph. In aircraft, this principle is applied in the same manner. The constant speed drive enables the alternator to produce the same frequency at slightly above engine idle rpm as it would at takeoff or cruising rpm.With the input speed to the drive set at 6,000 rpm, the output speed will be the same. This is known as straight drive and might be compared to an automobile in high gear. However, when the input speed is greater than 6,000 rpm, it must be reduced to provide an output of 6,000 rpm. This is called underdrive, which is comparable to an automobile in low gear. Thus, the large input, caused by high engine rpm, is reduced to givethe desired alternator speed.As a result of this control by the constant speed drive,the frequency output of the generator varies from 420cps at no load to 400 cps under full load.

Accordingly, the purpose of the constant speed drive may be stated as the conversion of the varying speed of the jet engine to a constant speed, so that the generator it drives will produce current at 400Hz within narrow limits. Constant speed drive consists essentially of a hydraulic transmission with mechanical controls governing the output rotation speed. The transmission is capable of either adding to or subtracting from the speed received from the gearbox in order to provide constant output speed to keep the generator on frequency. Mechanical (flyweight) governor action keeps the generator output close to 400Hz.

CSD Functional Description





Each CSD consists essentially of two positive displacement axial slipper piston type hydraulic units, and a mechanical differential, which performs the speed summing function. The hydraulic units are the same in physical size, one unit having a variable hydraulic

Figure 10-314. Constant speed drive.

displacement unit and a variable angle wobbler and the other having a fixed angle wobbler and, therefore a fixed displacement. The hydraulic units rotate independently and are positioned on opposite sides of a common stationary port plate. The variable displacement hydraulic unit runs at a fixed ratio with respect to the transmission input speed. Because the wobbler angle of the variable displacement unit is continuously variable in both directions (from full positive wobbler angle, to zero angle, to full negative wobbler angle), the displacement, of the variable displacement hydraulic unit, is continuously variable, from zero to full rated displacement in both directions. The fixed displacement hydraulic unit is driven by oil delivered by the variable displacement hydraulic unit. The fixed displacement hydraulic unit, will therefore run at any speed, from zero to full rated speed in either direction. The working pressure between the two hydraulic units is proportional to the torque being transmitted to the generator.

At the lower input speeds, the variable displacement unit acts as a hydraulic pump to supply flow to the fixed unit which is added to the input speed through the differential. At the straight through input speed, torque is transmitted directly through the differential unit and the fixed unit is not rotating. The variable displacement unit wobbler will be slightly offset from the zero angle so that some pumping will be accomplished and leakage loses made up. At input speed above straight through, the variable angle wobbler is set to allow negative displacement of the variable displacement hydraulic unit. The working pressure, in this case, is manipulated to allow the fixed displacement hydraulic unit to be motored by the differential and subtract from the input speed. The variable displacement unit is acting as a motor. The multiple piston hydraulic unit in the mechanical differential type CSD unit handles only a portion of the power transmitted, therefore it is reduced in size. Since power loss is less in mechanical differentials than for multiple piston type hydraulic units, heat rejection is low resulting in high efficiency.

Integrated Drive Generators (IDG)

Provide an elegant solution for supplying constant frequency AC electrical power to the aircraft, which can simplify the design of the complete electrical system. The IDG makes use of a highly reliable continuously variable transmission - the constant speed drive - which converts the variable input speed provided by an aircraft's engine into a constant output speed for the IDG's integral AC generator. This integration of drive and generator provides a proven and reliable solution for constant frequency electrical power.

EMERGENCY POWER GENERATION

Aircraft have backup (emergency) electrical power if primary sources of electrical power fail. The various ways of supplying this emergency power are aircraft storage batteries, auxiliary power units, and hydraulic motor driven generators.

Batteries

Aircraft storage batteries provide an emergency source of electrical power for operating electrical systems of an aircraft. During normal aircraft operation, the ac generator and transformer- rectifier combination supply electrical energy and maintain the battery in a charged state. The battery supplies power to the aircraft only when the generating systems are unable to supply power. An aircraft storage battery with a quick disconnect. The battery is the emergency power source for the aircraft, so it should be maintained in perfect condition at all times. Never use the battery for starting engines or servicing equipment if another power source is available; this shortens battery life. The service life of the aircraft battery depends upon the frequency and quality of care it receives. The most common aircraft batteries used today are lead-acid and nickel-cadmium batteries. These batteries have a color-coded case for ease of identification, with red for lead-acid and blue for nickel-cadmium.

Ac/dc Hydraulic Motor-Driven Generators

The ac/dc hydraulic motor-driven generators are emergency power sources. They consist of a hydraulically driven ac/dc generator, a motor-generator control unit, and a control solenoid. The motor- generator provides 115-/200-volt three-phase ac and 28-volt dc power to essential electrical circuits if normal power fails. The kVA rating of this emergency generator is much lower than the primary generator(s), so the emergency generator powers a limited number of circuits.

Auxiliary Power Unit (APU)

Some aircraft have auxiliary power units, which furnish electrical power when engine-driven generators are not operating, external power is not available, or the engine-driven generator fails. APUs are used for ground maintenance as well as emergency in-flight power loss. Using the pneumatic starting system, the gas-turbine APU provides compressed air to start engines and for air conditioning. The aircraft is made independent of the need for ground power units to carry out its mission. There are many types and configurations of gas-turbine units. Because of their similarity in construction and operation, only one is described in the following paragraphs.

GTCP-95 UNIT—The GTCP-95 is a gas-turbine power plant unit (referred to as an APU). It is capable of furnishing electricity, starting air, and air conditioning while on the ground by supplying air for the air-cycle cooling systems. The gas-turbine engine of the APU requires only the aircraft battery and fuel for starting.

Shaft power at the main output drive pad powers the generator. Pneumatic power is available as clean, compressed air at the output end of the engine bleed load control and air shutoff valve. The engine is composed of two main sections and four main systems. The two main sections include an accessory assembly and a compressor and turbine assembly. The four main systems consist of an electrical system, a fuel control system, a bleed-air system, and a lubrication system. The engine develops power by compressing ambient air with a two-stage centrifugal compressor. Compressed air, mixed with fuel and ignited, drives a radial, inward-flow turbine wheel. The rotating shaft of the turbine wheel drives the compressor, the accessories, and the output shaft for the ac generator.

EMERGENCY POWER GENERATION AUXILIARY POWER UNIT (APU)

These units are fitted to provide a source of electrical power, pressurised air (air conditioning and main engine starting), and in some cases hydraulic power (via an integral pump) on the ground when the main engines are shut down. This makes the aeroplane less dependent on ground support equipment. In some instances, the APU is used in flight to provide emergency power, especially for ETOPS operations.
When used in flight, the maximum operating and maximum starting altitude parameters published in the flight manual must be adhered to. The maximum starting and operational heights vary from type to type but for modern aeroplanes can be as much as 43 000 ft and 45 000 ft, respectively.
The minimum to maximum declared airspeed range of the declared relight envelope should cover at least 30 knot. Maintenance is similar to that used on the main aeroplane power units.

The APU is a self-contained unit that normally consists of a small constant-speed gas turbine engine coupled to a gearbox. This

gearbox drives a generator of a similar type and power rating to the main engine-driven generators. This gearbox also drives the APU accessories, such as fuel pump, oil pump, tachometer generator, and a centrifugal switch. The purpose of the centrifugal switch is to control the starting and ignition circuits, the governed speed indication circuit, and the overspeed protection circuit of the APU.

LOCATION

The APU is normally located in an unpressurised compartment of the fuselage, usually in the tail section. This compartment is separated from the remainder of the fuselage by a firewall, and the unit is secured to the structure by rubber-bonded anti-vibration mountings. Access to the compartment is normally via hinged cowling panels.

AIR SUPPLY

Air for the APU compressor is drawn in through either single or twin intakes, connected via ducting to the intake section. Doors provided in these intake sections usually open and close by electrical actuators. These actuator circuits, interconnected with the APU master control switch, ensure the correct operating sequence during starting and shutdown. Indicator lights, which, depending on the installation, connect to micro switches or proximity switches at the door locations, indicate door positions. The APU compressor discharges air not required for combustion into a plenum chamber, connected via ducting to the air conditioning system and the main engine air-starting system of the aeroplane. The air supply automatically regulates to provide the correct amount without overloading the APU.

FUEL SUPPLY

Fuel supply is from one of the tanks in the main fuel system via a solenoid-operated valve and is regulated by a fuel control unit that controls the acceleration of the APU and maintains the speed by proportioning fuel flow to load conditions.

LUBRICATION

A self-contained system, consisting of an oil tank, pump, filter, cooler, and oil jets, lubricates allthe gears and bearings within the APU. Indicator lights monitor the system operation, as well asinstruments associated with functions such as oil pressure, temperature, and quantity.

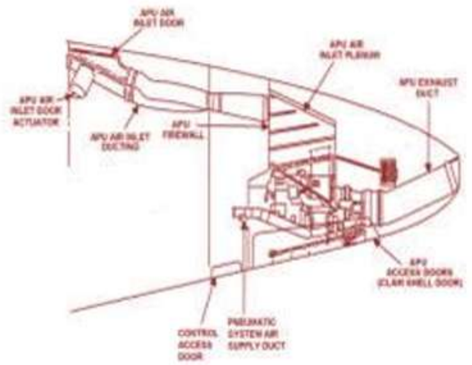
STARTING AND IGNITION

An electric starter motor connected to a drive shaft in the accessory gearbox rotates the engine for starting. Power for the starter motor is drawn from the aeroplane‘s batteries, its APU, or an external power source. The ignition system is of the high-energy type and is controlled from the master control switch.

Note: The APU can already be running, but not started, during refuelling operations.

COOLING

A fan driven by the APU accessory gearbox normally provides cooling and ventilation of the APU compartment. This air also ducts from the fan for cooling the AC generator and APU lubricating oil



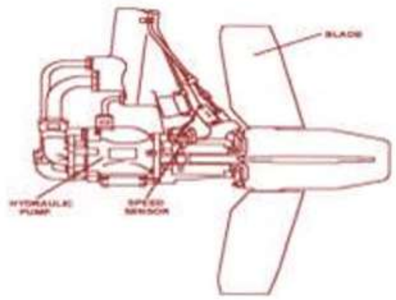
ANTI-ICING

In some APU installations, the air intake area is protected against ice formation by bleeding a supply of hot air from the compressor over the inlet surfaces.

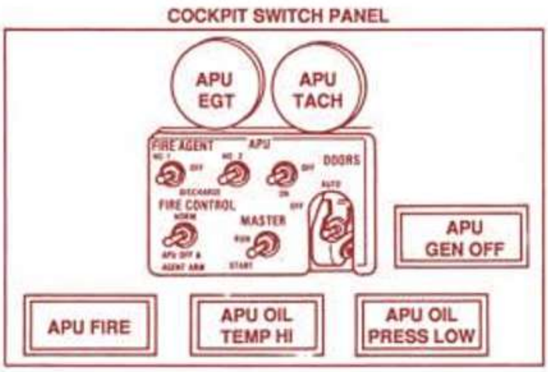
FIRE DETECTION AND EXTINGUISHING

A continuous wire detection system and a single-shot fire extinguisher normally accomplish the detection and extinguishing of a fire in an APU compartment. The arrangement of detection circuits is so that, in addition to actuating warning systems, they automatically shut down the APU. The fire extinguisher bottles can be discharged manually or automatically.

Ram air turbine



(commonly known by the acronym RAT) is a small turbine that is connected to a hydraulic pump, or electrical generator, installed in an aircraft and used as a power source.



The RAT generates power from the airstream due to the speed of the aircraft.
With the exception of crop dusters (see below), modern aircraft only use RATs in emergency — in case of the loss of both primary and auxiliary power sources the RAT will power vital systems (flight controls, linked hydraulics and also flight-critical instrumentation). Some RATs produce only hydraulic power, which is in turn used to power electrical generators. In some early CONTROLS AND INDICATORS

All switches, warning lights, and indicating instruments necessary for the starting, stopping, and normal operation of the APU are located on the flight deck and in fuselage compartments accessible from outside the aeroplane. Normally, an APU can only be started from the flight deck, but can be shut down from either location. Operation of the APU is monitored by an exhaust gas temperature indicating system and, in most installations,, a system to record the number of hours the APU has been in continuous operation. Depending on the installation, provisions for monitoring APU starting current, engine rpm, generator output voltage and frequency, generator bearing temperature, and connection of an APU test set may also be included.

APU SHUT DOWN

An APU is normally shut down by allowing it to operate at no-load governed speed for approximately 2 minutes, and then selecting the OFF or STOP position of the master control switch. Depending on the type of APU and its installation requirements, shut down of an APU can also take place automatically because of any one of the following conditions:
�High exhaust gas temperature
�Loss of exhaust gas temperature signal to the electronic control system
�Overspeed
�Low oil pressure

�High oil temperature
�Opening or closing of cooling air shut-off valve before 95% of governed speed has been attained
�Overheating of the APU bleed air delivery duct just forward of the APU compartment
�APU fire detection system operation
�When specified airspeed or altitude limitations are exceeded
�During take off operation of landing gear shock strut micro- switches In some installations, the APU can also be shut down in an emergency by using a FIRE switch on the control panel, or by pulling a FIRE handle on the flight deck panel. Take care when using a FIRE switch, which arms the fire extinguisher discharge circuit, not to inadvertently discharge the extinguishant. If an automatic shutdown has occurred, select the master switch to the OFF or STOP position.

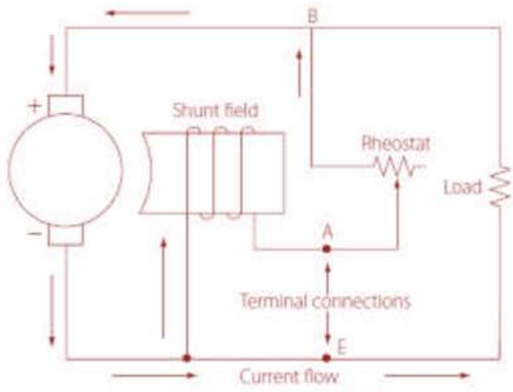
RAM AIR TURBINE (RAT)

The RAT is used to supply the aeroplane with an emergency source of hydraulic power to the flight controls, etc, in the event that all systems fail, and normally stows in the underbelly fuselage. The RAT can be deployed in flight by manual selection at any time. However, if all the hydraulic systems' pressure drops, it deploys automatically. Ground sensors inhibit automatic deployment of the RAT on the ground.

The RAT consists of a variable pitch propeller, driven by the airflow. Bob-weights and springs govern propeller speed, producing a constant speed. When initially deployed, the blades are in fine pitch allowing the propeller to spin up to the governed speed as quickly as possible. When at its governed speed of approximately 4000 rpm, the propeller blade pitch increases to prevent over-speeding.aircraft (including airships), small RATs were permanently mounted and operated a small electrical generator or fuel pump.
Modern aircraft generate power in the main engines or an additional fuel-burning turbine engine called an auxiliary power unit, which is often mounted in the rear of the fuselage or in the main-wheel well. The RAT generates power from the airstream due to the speed of the aircraft. If aircraft speeds are low, the RAT will produce less power. In normal conditions the RAT is retracted into the fuselage (or wing), and is deployed manually or automatically following complete loss of power. In the time between power loss and RAT deployment, batteries are used.
RATs have been used to power centrifugal pumps to pressurize the spray systems on aircraft that are used as crop dusters to deliver liquid agents to cropland. The major reason for choosing a RAT is safety; using a RAT allows, in the case of the US, the FAA- certified engine and power systems on the aircraft to remain unmodified. There is no need to use an engine power takeoff to drive the pump, as the pump can be placed low or below the exterior of the airframe greatly simplifying plumbing. Being the lowest point in the plumbing, it will have gravity feed from the spray tanks and never need to be primed. In the event of a pump failure that could result in seizure, there is no effect on the flying ability of the aircraft or its systems apart from the fact that the spray systems are non-functional.

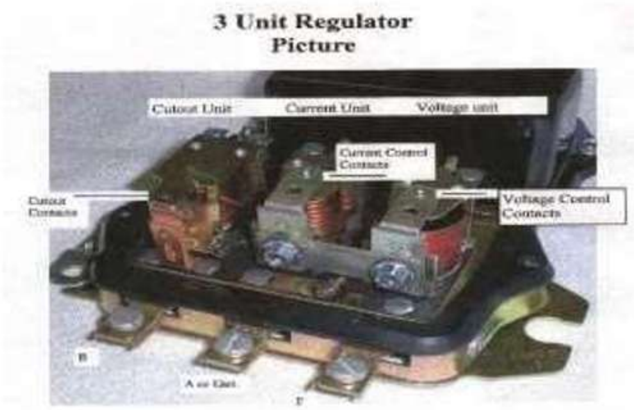
A variable delivery hydraulic pump attaches directly to the output shaft of the propeller. After initial deployment, the pump is off- loaded by porting the pressure line back to the return line, allowing a pre-determined volume of fluid to refill the RATs cartridge.
When the cartridge is full, the porting
to the return line closes and all the fluid produced is directed to the aircraft's primary systems. The deployment and production of full system pressure is achieved in
approximately 3 seconds. A RAT deployment light, which is normally amber or red, is near the RAT manual deployment switch. In addition, there is a green RAT pressure light to indicate that the system is up to pressure.

Voltage regulation



Regulation of Generator Voltage

Efficient operation of electrical equipment in an airplane depends on a constant voltage supply from the generator. Among the factors, which determine the voltage output of a generator, only one, the strength of the field current, can be conveniently controlled. To illustrate this control, refer to the diagram in Figure showing a simple generator with a rheostat in the field circuit. If the rheostat is set to increase the resistance in the field circuit, less current flows through the field winding and the strength of the magnetic field in which the armature rotates decreases. Consequently, the voltage output of the generator decreases. If the



resistance in the field circuit is decreased with the rheostat, more current flows through the field windings, the magnetic field becomes stronger, and the generator produces a greater voltage.

Vibrating contact regulator

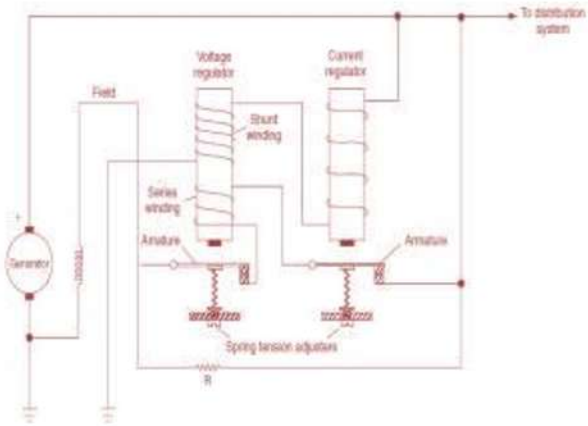
This device comprises voltage and current regulators as shown in Fig. They are used on small general aviation (GA) aircraft that have relatively low generator power outputs. When

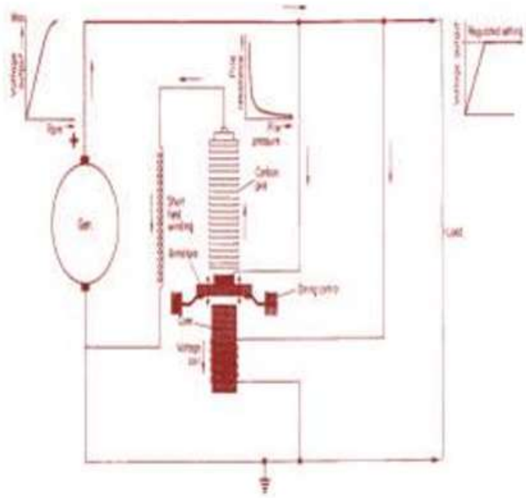
the engine starts, the generator output voltage builds up rapidly to the nominal aircraft level (either 14 or 28 V DC). Contacts of both regulators remain closed to allow current to flow into the field windings. When the generator output voltage increases beyond 14/28 V, the voltage coil contacts open and this introduces the resistor into the field windings, thereby reducing the field excitation current, and subsequently reduces the generator output. Once the output voltage drops to below 14/28 V, the contacts close (by a spring mechanism) and the resistor is bypassed, allowing full excitation current back into the field. The on/off cycle repeats between 50 and 200 times per second, or 50 200 Hz. This process regulates the generator output to a mean level,

typically14 ±0.5 V (or 28 ± 1 volt)

Current regulation

is achieved in a similar way, i.e. by controlling the field current. When loads are high, the voltage output may be insufficient to open the contacts. The result is that the output will continue to increase until the maximum rated current is reached. At this point, the current regulator contacts open and the resistor is connected into the field windings. The accuracy of this type of regulation depends on the resistor

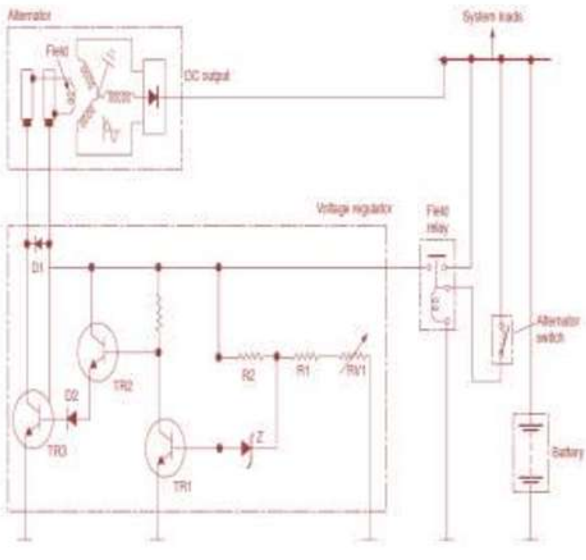




value and spring tensions. In the event of high rotor speed and low electrical load on the generator, the output could exceed the specified system voltage despite the field being supplied via the resistor. In this event, the contact is pulled to ground, thereby reducing the output to below the regulated mean level. Although simple, this type of regulator has the disadvantages of
contact wear; a typical vibrating contact regulator product is shown in Fig. The accuracy of the vibrating contact regulator depends on the resistor value and spring tension.

Carbon-pile regulator

Another type of electromechanical regulator is the carbon-pile device. This type of regulator is used in generator systems with outputs in excess of 50 A and provides smoother regulation compared with the vibrating contact regulator. Carbon-pile regulators consists of a variable resistance in series with the generator's shunt wound field coil. The variable resistance is achieved with a stack (or pile) of carbon discs (washers). These are
retained by a ceramic Tube that keeps



the discs aligned. The surface of each disc is relatively rough; applying pressure to the discs creates more surface contact, thereby reducing the resistance of the pile. When pressure is reduced, the reverse process happens, and the resistance through the pile increases. Pressure is applied to the pile by a spring plate. This compression is opposed by the action of an electromagnet connected to the generator output; the strength of the electromagnet's flux varies in proportion with generator output voltage. Higher generator output increases the current in the electromagnet; this attracts the steel centre of the spring, which reduces compression on the pile, thereby increasing its resistance. Less field current reduces the generator output voltage; the current in the voltage coil reduces electromagnetic effect and the spring compresses the pile, reducing its resistance. The varying force applied by the electromagnet and spring thereby controls the pile's resistance to control field current and maintains a constant generator output voltage. The regulator is contained within a cylinder (typically three inches in length) with cooling fins. Functions of each component are as follows:

- Compression screw : the means of setting up compression on the pile and compensating for erosion of the pile during its life.
- Spring plate and armature : this compresses the pile to its minimum resistance position.
- Voltage coil: contains a large number of turns of copper wire and, with the core screw, forms an electromagnet when connected across the generator output.
- Magnet core : concentrates the coil flux; it is also used for voltage adjustment during servicing.
- Bi-metallic washers : providing temperature Compensation

The boost resistor is normally shorted out; if the switch is opened it allows a slight increase in

generator output to meet short-term increases in loading. This is achieved by temporarily reducing the current through the voltage coil. The boost resistor can either be located in the regulator and/or at a remote location for easy access during maintenance.

Electronic(solid state) voltage regulator

There are many types and configurations of electronic voltage regulators. A representative type is illustrated in Fig. The alternator master switch used in AC systems energizes the field relay and applies current to the base of TR 2 and the resistor network of R 1 , R 2 , RV1 . This network, together with the Zener diode (Z) is used to establish the nominal operating voltage. Current flows through the alternator's field coil via transistors TR 2 and TR 3, allowing the generator's output to increase. When the output reaches its specified value (depending on the installation) Zener diode Z conducts which turns on transistor
TR1, shorting out transistor TR 2 and TR 3. The generator voltage falls and Zener diode Z stops conducting, thereby turning of transistor TR 1 . This turns transistors TR 2 and TR 3 back on, allowing the generator output to increase again. This operation is repeated many times per second as with the vibrating contact regulator; the difference being that electronic circuits have no moving parts and do not suffer from arcing across contacts. Diode
D 1 provides protection against the back e.m.f. induced in the field each time TR 3 is switched. The trimming resistor R V1 can be used to adjust the nominal voltage output of the regulator.

POWER DISTRIBUTION SYSTEM

This section contains a discussion of a representative power distribution system used in F-14 aircraft.
Electrical power is provided to the buses from four sources:

Two engine-driven generator transmissions supply ac. Each one is coupled to a 115-/208-volt ac, 400-Hz, three-phase brushless ac generator. These generators supply electrical power to the main, essential, and monitor ac buses. Either of the two generators can supply the entire electrical demand of the aircraft in the event one generator fails. Two transformer-rectifiers (TR) supply dc power. Each TR unit receives power from its respective main ac bus. The TR units convert 115 Vac to 28 Vdc for distribution to the secondary bus system. Either of the TRs is capable of supplying the entire dc requirements of the aircraft. A hydraulically driven, 5-kVA/50-amp generator provides ac and dc emergency power for essential equipment only. The emergency generator automatically actuates upon multiple generator or multiple TR unit failure. Emergency generator operation terminates upon reactivation of either main generator. The aircraft receives external power through an external ac power contactor. Discussion of each of these power sources, as well as contactor control logic, is contained in the following paragraphs.

AC BUS DISTRIBUTION SYSTEM

The distribution system consists of five three-phase ac buses, which are listed below:

The left and right main ac buses provide power to nonessential equipment throughout the aircraft. The monitor ac bus currently has no load attached to it. When used, it provides power to nonessential equipment only. With both generators operating, ac essential buses number one and number two and the 115-volt ac instrument bus power safety-of-flight equipment. The main generators normally supply power to these two buses, but they also tie in to the emergency generator when it is in operation. A step- down transformer supplies 26 Vac for instruments and navigation systems. The output of the transformer also provides power to safety-of-flight equipment.

DC BUS DISTRIBUTION SYSTEM

The main sources of dc power are the left and right TR units. These units receive power from the left and right main ac, three- phase buses, respectively. The left and right main dc buses provide power to nonessential dc systems. When both generators are operating, the monitor bus provides power to nonessential equipment only. The automatic flight control system (AFCS) bus and essential buses numbers one and two provide power to safety- of-flight equipment. The TR units normally supply these three buses, but they receive power directly from the emergency generator when it is in operation. Either external electrical power or both generators can supply the entire ac and dc bus system. If only one generator is operating, the entire ac and dc bus systems (except the monitor ac and dc buses) have power. If only one TR unit is in operation, the entire dc bus system (except the monitor bus) has power. The emergency generator powers only the ac- essential bus, 115-volt ac instrument bus, 26-volt ac instrument bus, dc essential bus, and AFCS buses. If a complete propulsion system fails, the hydraulic pressure developed by the wind milling of the engines is sufficient to drive the emergency generator. In
this configuration, only the essential ac number one bus and the dc essential number one bus have power.

AC/DC POWER DISTRIBUTION OPERATION

As you have already learned, the two main generators and two TR units of an external ac power source provide electrical power. If engines are operating and hydraulic pressure is available, the emergency generator is available as a source of power. Switching between power supply systems is automatic without pilot action. However, the pilot can selectively isolate power sources and the distribution system in emergency situations. When operating normally, the buses receive power through a series of contacts and logic situations, depending on the power source(s) in use. Normal power sources include external power and the left and right generators. Grounded and ungrounded, single-phase and poly phase systems also are discussed.

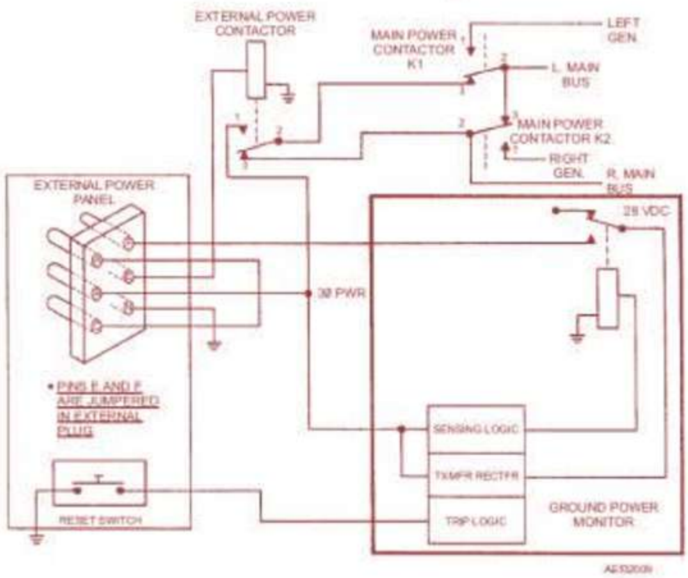
External Power

The external electrical power system (fig. 2-9) permits application of three-phase, ac power to the aircraft electrical power distribution system. External power goes to the ground power monitor (GPM) and de-energized contacts of the external power contactor.

The GPM prevents application of external power not within tolerances. If an undervoltage, overvoltage, underfrequency, overfrequency, or a phase reversal fault occurs, the GPM disconnects external power from the power distribution system. When all the power parameters are within tolerance,

the GPM relay energizes, supplying 28 V dc from the GPM transformer-rectifier to pin F of the external power panel.
NOTE: Pins E and F are jumpered in the external power plug.

The power then runs through pin E and energizes the external power contactor. Three-phase power at pin one of the external power contactor then runs to the left main ac bus and right main ac bus through their respective contactors. Power from the left main ac bus (fig. 2-10) goes to the left TR unit. It also goes through the de-energized contacts of both ac essential power transfer relays to all essential ac buses and to the 26-volt ac transformer. This transformer, in turn, feeds power to the 26 V ac instrument and navigational buses. The right main ac bus supplies power to the right TR unit. Both left and right TR unit, provide power to all dc buses through their respective power contactors and power transfer relays. External electrical power is automatically inhibited from some systems when external air conditioning is not being supplied
to the aircraft. After aircraft engines start and the left generator comes on line, the left main contactor automatically disconnects external power. Some aircraft have a light on the caution/advisory panel that is illuminated by a switch, mounted on the external power receptacle, when the door is open. However, there is no cockpit indication of external power application. The only control the pilot has over external power being applied or removed is the hand signals between the pilot and the plane captain.
Larger aircraft systems
Larger (commuter, business and



passenger) aircraft have many more electrical systems compared with general aviation aircraft; there is s requirement for a comprehensive approach to account for potential failures of generators, wiring, etc. The management of potential failures is addressed by categorizing the various loads and then disconnecting them in accordance with a predetermined sequence. The process of switching loads off the bus is called load-shedding; this can be achieved by automatic or manual control. These loads are connected onto specific busbars that fulfill a specific function. These can be categorized into a hierarchy as illustrated in Fig. 8.11. Connections between busbars are via heavy-duty contactors, or breakers. Aircraft types vary, however the following categories are typical for many installations.

Main bus: this is sometimes called the non-essential, generator, or load bus. It will include loads such as the galleys, in-flight entertainment (IFE) and main cabin lights. These loads can be disconnected and isolated in flight without affecting the safe operation of the aircraft.

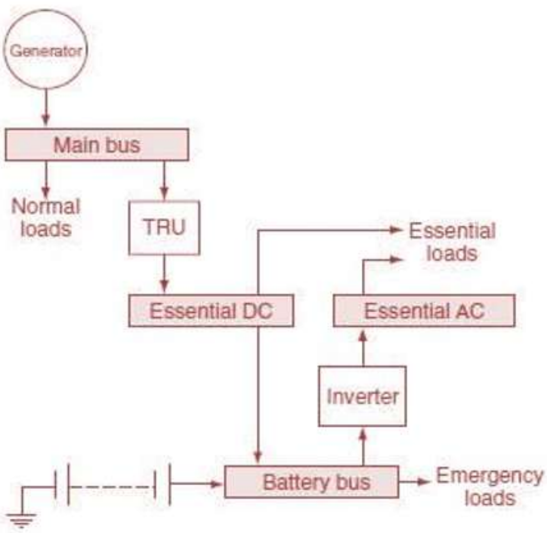
Essential bus: this is sometimes called the vital or safety bus. It will include equipment and instruments required for the continued safe operation of the aircraft.

Battery bus: this is sometimes called the standby, or emergency bus. It supplies the equipment required for the safe landing of the aircraft, e.g. radios, fuel control, landing gear and fire protection.

There are three main types of distribution system architecture used on aircraft to fulfill the above:

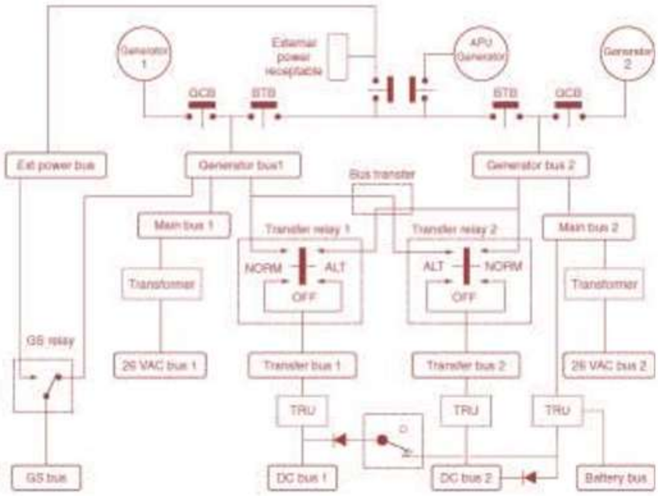
- split bus system
- parallel system
- split parallel system

Split bus system
This is a completely isolated twin generation system, sometimes called a non-parallel system used on twin-engine aircraft, see Fig.
Primary power
is based on two main AC integrated drive generators (typically 40 kVA on each engine). An APU generator (40 kVA) is used as back-up in the event of a main integrated drive generator (IDG) failure. Note that the APU is normally a constant speed device in its own right; therefore an IDG is not required. The advantage of a split-bus system is that the generators do not need to be operating at exactly the same frequency and can be running out of phase with each other. Secondary power is derived from step-down transformers to provide 26 V AC; transformer rectifier units (TRU)
provide 28 V DC for the DC busbars and battery charging. Referring to Fig. the right and left generators feed their own busbars to which specific loads are connected. Each generator bus is connected to a transfer bus via transfer relays. In the event of a generator failure, the remaining generator (engine or APU) supplies essential loads. Control of the system is via a number of flight compartment switches, control breakers and relays arranged to connect and disconnect the generators and busbars. Typical control panel features for a split bus system are shown in Fig. the features of this panel are:
Ammeters for the main generators to indicate load current



Ground power available (blue) when external power supply is connected Ground power on/off switch to select ground power onto the aircraft Transfer bus off (amber) when the transfer relay is de- energized (either normal or transfer) Bus off (amber) both respective generator circuit breakers (GCB) and bus tie breakers (BTB) open Generator bus off (blue) if the respective GCB is open APU generator bus off (blue) APU running at 95% RPM, no power from generator

Parallel bus system



The electrical distribution system on larger passenger aircraft (with three or four engines) are based on a parallel load distribution system, see Fig. In this configuration, all generators are connected to their own AC load bus and a distribution bus; any generator can supply any load bus to provide equal load-sharing. All generator voltages, frequencies and phase relationships must be controlled to very close tolerances. Any attempt to connect generators in

parallel before these conditions are met could result in loss of generator power due to large circulating currents. Referring to when all four GCBs and BTBs are closed; all four generators are synchronized and connected to the tie (or synchronized) distribution busbar. If one generator fails, its GCB is opened; this isolates the generator from its own load busbar. That busbar is now powered from the remaining generators. If this bus becomes overloaded, opening its GCB and BTB isolates it. With more than two generator failures, load-shed ding is introduced. External power can be made available by one or two power supply units (or carts). The APU can also be connected onto the distribution bus.

Split/parallel bus system

This is a flexible load distribution system for large passenger aircraft; it provides the advantages of the parallel system and maintains isolation when needed. Primary power supply features include: one IDG per engine, two APU generators and two external power connections. A split system breaker links left and right sides of distribution system. Any generator can supply any load busbar; any combination of generators can operate in parallel. Standby and essential power Essential 115 VAC power is provided as a single phase supply, see Fig. this is selected from one phase of a main busbar. (On a four-engined aircraft, the normal source is the main AC bus number four.) If this normal source fails, a supply is maintained by selecting a different main bus from the remaining systems. The standby AC bus is normally powered from the essential AC bus; if this source fails, a static inverter (supplied from the main battery) is selected to provide standby AC power. Some aircraft distinguish between battery busbars (that can be disconnected from the battery) and hot battery busbars that are connected directly to the battery, i.e. without any switching; this is illustrated in Fig. This arrangement splits the battery bus with a direct connection (the _hot' battery bus), and a switched battery bus controlled by the battery switch. Essential DC power is from a transformer rectifier unit (TRU) powered from the essential AC bus. Standby AC and DC bus power is normally from the respective essential supplies; when selected ON, standby AC and DC power is from an inverter and the battery respectively.

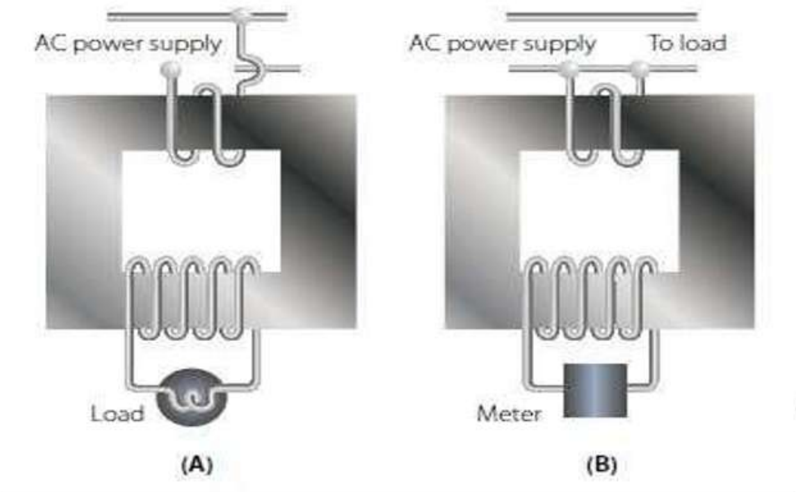
Transformers, Inverters, rectifiers

Transformers

A transformer changes electrical energy of a given voltage into electrical energy at a different voltage level. It consists of two coils that are not electrically connected, but are arranged so that the magnetic field surrounding one coil cuts through the other coil. When an alternating voltage is applied to (across) one coil, the varying magnetic field set up around that coil creates alternating voltage in the other coil by mutual induction. A transformer can also be used with pulsating DC, but a pure DC voltage cannot be used, since only a varying voltage creates the varying magnetic field that is the basis of the mutual induction process.

A transformer consists of three basic parts. These are an iron core which provides a circuit of low reluctance for magnetic lines of force, a primary winding which receives the electrical energy from the source of applied voltage, and a secondary winding which receives electrical energy by induction from the primary coil. The primary and secondary of this closed core transformer are wound on a closed core to obtain maximum inductive effect between the

two coils. There are two classes of transformers: (1) voltage transformers used for stepping up or stepping down voltages, and
(2) current transformers used in instrument circuits.
In voltage transformers, the primary coils are connected in parallel across the supply voltage as shown in Figure. The primary windings of current transformers are connected in series in the primary circuit of the two types, the voltage transformer is the more common.
There are many types of voltage transformers. Most of these are either step-up or step-down transformers. The factor that
determines whether a transformer is a step-up or step-down type is the —turns‖ ratio. The turns ratio is the ratio of the number of turns in the primary winding to the
number of turns in the secondary winding. For example, the turns ratio of the step-down transformer shown, since there are five times as many turns in the primary as in the secondary. The step-up transformer shown in Figure has a
1 to 4 turns ratio. All the magnetic lines of force set up in the primary do not cut across the turns of the secondary coil. A certain amount of the magnetic flux, called leakage flux, leaks out of the magnetic circuit.



The measure of how well the flux of the primary is coupled into the secondary is called the —coefficient of coupling.

Working

Transformers are devices that convert (or transfer) electrical energy from one circuit to another through inductively coupled electrical conductors. The transformer used as a power supply source can be considered as having an input (the primary conductors, or windings) and output (the secondary conductors, or windings). A changing current in the primary windings creates a changing magnetic field; this magnetic field induces a changing voltage in the secondary windings. By connecting a load in series with the secondary windings, current flows in the transformer. The output voltage of the transformer (secondary windings) is determined by the input voltage on the primary and ratio of turns on the primary and secondary windings. In practical applications, we convert high voltages into low voltages or vice versa; this conversion is termed step down or step up. When an AC voltage is connected across the primary terminals of a transformer, an alternating current will flow and self induce a voltage in the primary coil that is opposite and nearly equal to the applied voltage. The difference between these two voltages allows just enough current in the primary to magnetize its core. This is called the exciting, or magnetizing, current. The magnetic field caused by this exciting current cuts across the secondary coil and induces a voltage by mutual induction.

If a load is connected across the secondary coil, the load current flowing through the secondary coil will produce a magnetic field which will tend to neutralize the magnetic field produced by the primary current.

This will reduce the self-induced (opposition) voltage in the primary coil and allow more primary current to flow. The primary current increases as the secondary load current increases, and

decreases as the secondary load current decreases. When the secondary load is
removed, the primary current is again reduced to the small exciting current sufficient only to magnetize the iron core of the transformer.

If a transformer steps up the voltage, it will step down the current by the same ratio. This should be evident if the power formula is considered, for the power (I × E) of the output (secondary) electrical energy is the same as the input (primary) power minus that energy loss in the transforming process. Thus, if 10 volts and 4 amps (40 watts of power) are used in the primary to produce a magnetic field, there will be 40 watts of power developed in the secondary (disregarding any loss). If the transformer has a step-up ratio of 4 to 1, the voltage across the secondary will be 40 volts and the current will be 1 amp. The voltage is 4 times greater and the current is one-fourth the primary circuit value, but the power (I
× E value) is the same.

When the turns ratio and the input voltage are known, the output voltage can be determined as follows

$N_2/N_1=E_2/E_1$

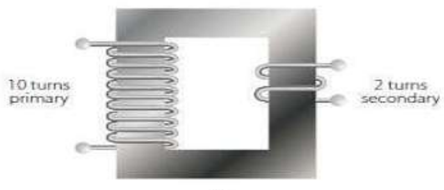
Where E is the voltage of the primary, E2 is the output voltage of the secondary, and N1 and N2 are the number of turns of the primary and secondary, respectively. Transposing the equation to find the output voltage gives:

$E_2 = E_1=N_2/N_1$

The most commonly used types of voltage transformers are as follows:

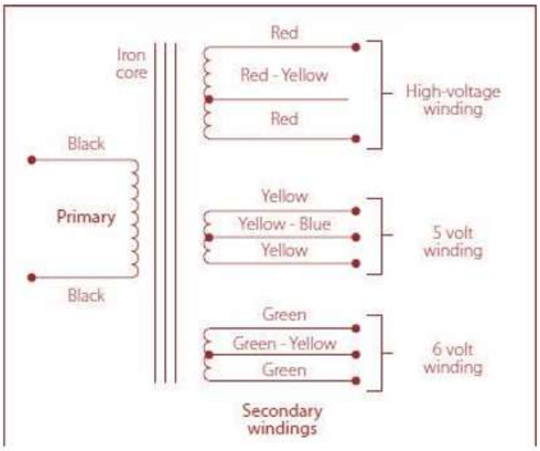
Power transformers are used to step up or step down voltages and current in many types of power supplies. They range in size from the small power transformer used in a radio receiver to the large transformers used to step down high power line voltage to the 110

– 120 volt level used in homes.



(A)

The schematic symbol



for an iron core transformer. In this case,
the secondary is made up of three separate windings. Each winding supplies a different circuit with a specific voltage, which saves the weight, space, and expense of three separate transformers. Each secondary has a midpoint connection, called a ―center tap,‖ which provides a selection of half the voltage across the whole winding. The leads from the various windings are color coded by the manufacturer, as labeled in Figure. This is a standard color code, but other codes or numbers may be used.

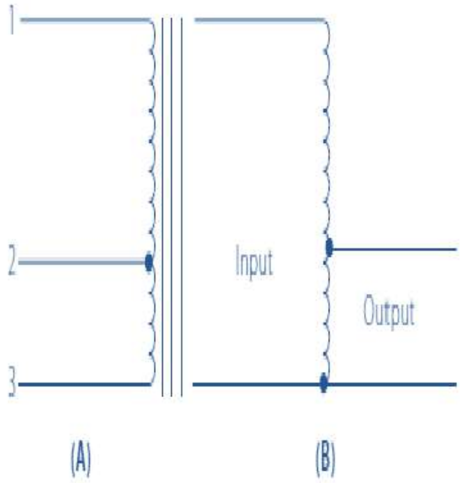
audio circuits are shown in Figure. If used in an RF communication Or navigation circuit same, except there is no symbol for an iron core.
The autotransformer uses part of a winding as a primary; and, depending on whether it is step up or step down, it uses all or part of the same winding as the secondary. For example, the autotransformer shown in Figure could use the following possible choices for primary and secondary terminals.

Circuits needing only small step-up/down ratios employ auto-transformers. These are formed from
single winding, tapped in a specific way to form primary and secondary windings. In practice, auto-transformers are smaller in size and weight than conventional transformers.
Their disadvantage is that, since the primary and secondary windings are physically connected, a breakdown in insulation places the full primary e.m.f. onto the secondary winding

Current Transformers

2. Audio transformers resemble power transformers. They have only one secondary and are designed to operate over the range of audio frequencies (20to 20,000 cps).
3. RF transformers are designed to operate in equipment that functions in the radio range of frequencies. The symbol for the RF transformer is the same as for an RF choke coil. It has an air core as shown in Figure.
4. Autotransformers are normally used in power circuits; however, they may be designed for other uses. Two different symbols for autotransformers used in power or

Current transformers are used in AC power supply systems to sense generator line current and to provide a current, proportional to the line current, for circuit protection and control devices. The current transformer is a ring-type transformer using a current carrying power lead as a primary (either the power lead or the ground lead of the AC generator). The current in the primary induces a current in the secondary by magnetic induction.



The sides of all current transformers are marked ―H1‖ and ―H2‖ on the unit base. The transformers must be installed with the ―H1‖ side toward the generator in the circuit in order to have proper polarity. The secondary of the transformer should never be left open while the system is being operated; to do so could cause dangerously high voltages, and could overheat the transformer. Therefore, the transformer output connections should always be connected with a jumper when the transformer is not being used but is left in the system.

Transformer Losses

In addition to the power loss caused by imperfect coupling, transformers are subject to ―copper‖ and ―iron‖ losses. The resistance of the conductor comprising the turns of the coil causes copper loss. The iron losses are of two types called hysteresis loss and eddy current loss. Hysteresis loss is the electrical energy required to magnetize the transformer core, first in one direction and then in the other, in step with the applied alternating voltage. Eddy current loss is caused by electric currents (eddy currents) induced in the transformer core by the varying magnetic fields. To reduce eddy current losses, cores are made of laminations coated with an insulation, which reduces the circulation of induced currents

Transformer rectifier units (TRU) Transformer rectifier units (TRU) convert AC into DC; these are often used to charge batteries from AC generators. A schematic diagram for a TRU is shown in Fig. The three-phase 115/200 V 400 Hz input is connected to star-wound primary windings of a

transformer. The dual secondary windings are wound in star and delta configuration. Outputs from each of the secondary windings are rectified and connected to the main output terminals. A series (shunt) resistor is used to derive the current output of the TRU. Overheat warnings are provided by locating thermal switches at key points within the TRU.

INVERTER

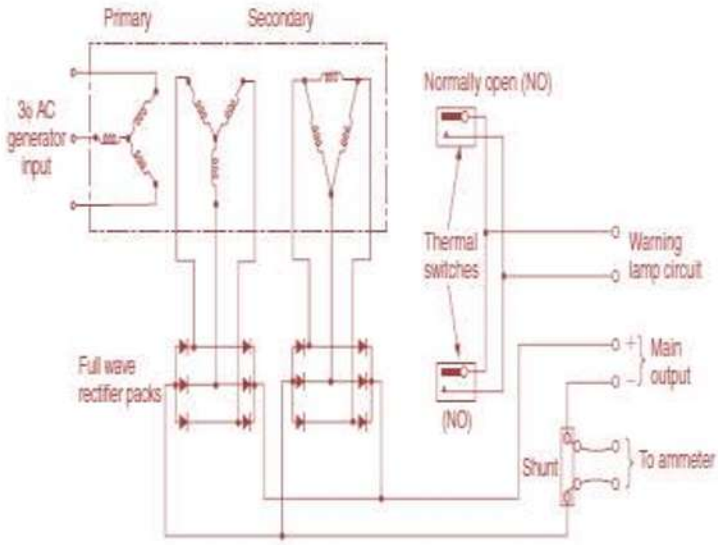
An inverter is used in some aircraft systems to convert a portion of the aircraft‘s DC power to AC. This AC is used mainly for instruments, radio, radar, lighting, and other accessories. These inverters are usually built to supply current at a frequency of 400 cps, but some are designed to provide more than one voltage; for example, 26 volt AC in one winding and 115 volts in another. There are two basic types of inverters: the rotary and the static. Either type can be single phase or multiphase.

The multiphase inverter is lighter for the same power rating than the single phase, but there are complications in distributing multiphase power and in keeping the loads balanced.

Rotary Inverters

There are many sizes, types, and configurations of rotary inverters. Such inverters are essentially AC generators and DC motors in one housing. The generator field, or armature, and the motor field, or armature, are mounted on a common shaft that will rotate within the housing. One common type of rotary inverter is the permanent magnet inverter.

Permanent Magnet Rotary Inverter A permanent magnet inverter is composed of a DC motor and a permanent magnet AC generator assembly. Each has a separate stator mounted within a common housing.



The motor armature is mounted on a rotor and connected to the DC supply through a commutator and brush assembly. The motor field windings are mounted on the housing and connected directly to the DC supply. A permanent magnet rotor is mounted at the opposite end of the same shaft as the motor armature, and the stator windings are mounted on the housing, allowing AC to be taken from the inverter without the use of brushes.

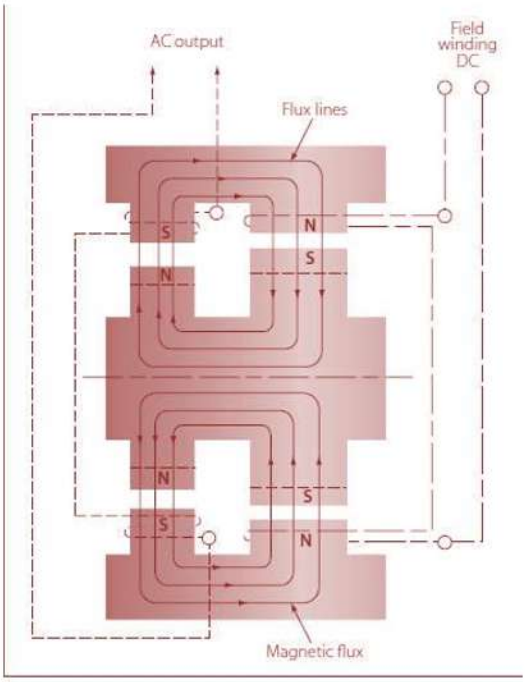
The generator rotor has six poles, magnetized to provide alternate north and south poles about its circumference. When the motor field and armature are excited, the rotor will begin to turn. As the rotor turns, the permanent magnet will rotate within the AC stator coils, and the magnetic flux developed by the permanent magnets will be cut by the conductors in the AC stator coils. An AC voltage will be produced in the windings whose polarity will change as each pole passes the windings. This type inverter may be made multiphase by placing more AC stator coils in the housing in order to shift the phase the proper amount in each coil. As the name of the rotary inverter indicates, it has a revolving armature in the AC generator section.

Inductor-Type Rotary Inverter

Inductor-type inverters use a rotor made of soft iron laminations with grooves cut laterally across the surface to provide poles that correspond to the number of stator poles, as illustrated in Figure. The field coils are wound on one set of stationary poles and the AC armature coils on the other set of stationary poles. When DC is applied to the field coils, a magnetic field is produced. The rotor turns within the field coils and, the poles on the rotor align with the stationary poles, a low reluctance path for

flux is established from the field pole through the rotor poles to the AC armature pole and through the housing back to the field pole. In this circumstance, there will be a large amount of magnetic flux linking the AC coils. When the rotor poles are between the stationary poles, there is a high reluctance path for flux, consisting mainly of air; then, there will be a small amount of magnetic flux linking the AC coils. This increase and decrease in flux density in the stator induces an alternating current in the AC coils. The number of poles and the speed of the motor determine the frequency of this type of inverter. The DC stator field current controls the voltage. A cutaway view of an inductor-type rotary inverter is shown in is a simplified diagram of a typical aircraft AC power distribution system, utilizing a main and a standby rotary inverter

system.
Static Inverters
In many applications where continuous DC voltage must be converted to alternating voltage, static inverters are used in place of rotary inverters or motor generator sets. The rapid progress made by the semiconductor industry is extending the range of applications of such equipment into voltage and power ranges that would have been impractical a few years ago. Some such applications are power supplies for frequency sensitive military and commercial AC equipment, aircraft emergency AC systems, and conversion of wide frequency range power to precise frequency power.



The use of static inverters in small aircraft also has increased rapidly in the last few years, and the technology has advanced to the point that static inverters are available for any requirement filled by rotary inverters.

For example, 250 VA emergency AC supplies operated from aircraft batteries are in production, as are 2,500 VA main AC supplies operated from a varying frequency generator supply. This type of equipment has certain advantages for aircraft applications, particularly the absence of moving parts and the adaptability to conduction cooling. AC output Field winding DC Flux lines.
Static inverters, referred to as solid-state inverters, are manufactured in a wide range of types and models, which can be classified by the shape of the AC output waveform and the power output capabilities. One of the most commonly used static inverters produces a regulated sine wave output.

RECTIFIER
Many devices in an aircraft require high amperage, low voltage DC for operation. This power may be furnished by DC engine driven generators, motor generator sets, vacuum tube rectifiers, or dry disk or solid-state rectifiers.
In aircraft with AC systems, a special DC generator is not desirable since it would be necessary for the engine accessory section to drive an additional piece of equipment. Motor generator sets, consisting of air cooled.

AC motors that drive DC generators eliminate this objection because they operate directly off the AC power system. Vacuum tube or various types of solid state rectifiers provide a simple and efficient method of

obtaining high voltage DC at low amperage. Dry disk and solid-state rectifiers, on the other hand, are an excellent source of high amperage at low voltage. A rectifier is a device that transforms alternating current into direct current by limiting or regulating the direction of current
flow. The principal types of rectifiers are dry disk and solid state. Solid-state, or semiconductor, rectifiers have replaced virtually all other types; and, since dry disk and motor generators are largely limited to older model aircraft, the major part of the study of rectifiers is devoted to solid-state devices used for rectification. The two methods discussed in this text are the half wave rectifier and the full-wave rectifier.

Half-Wave Rectifier

The basic concept of a half wave rectifier. When an AC signal is on a positive swing as shown in illustration A of the input signal, the polarities across the diode and the load resistor will also be positive. In this case, the diode is forward biased and can be replaced with a short circuit as shown in the illustration. The positive portion of the input signal will then appear across the load resistor with no loss in potential across the series diode.

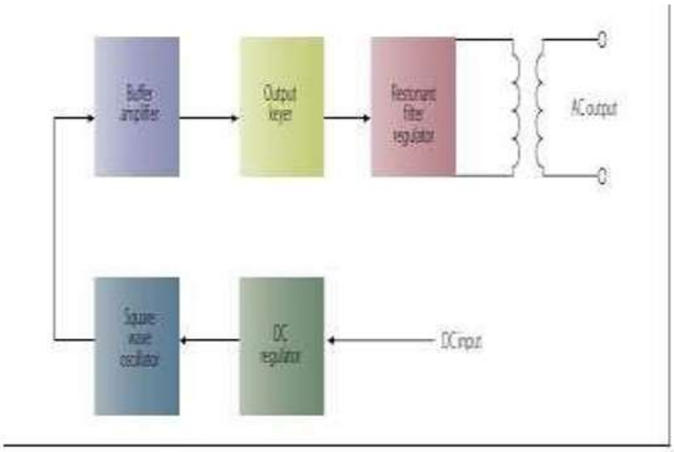


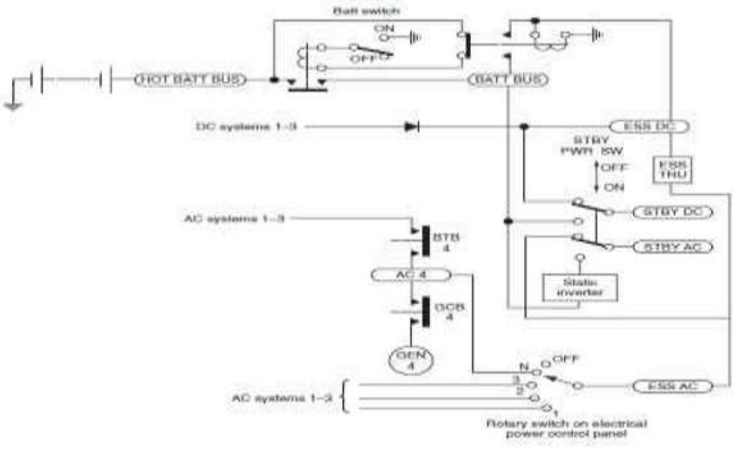
Figure 10-193. Regulated sine wave static inverter.

Illustration B now shows the
input signal being reversed. Note that the polarities across the diode and
the load resistor are also reversed. In this case, the diode is now reverse biased and can be replaced with an equivalent open circuit. The current in the circuit is now 0 amperes and the voltage drop over the load resistor is 0 volts. The resulting waveform for a complete sinusoidal input can be seen at the far right of Figure. The output waveform is a reproduction of the input waveform minus the negative voltage swing of the wave. For this reason, this type of rectifier is called a half-wave rectifier.

Full-Wave Rectifier

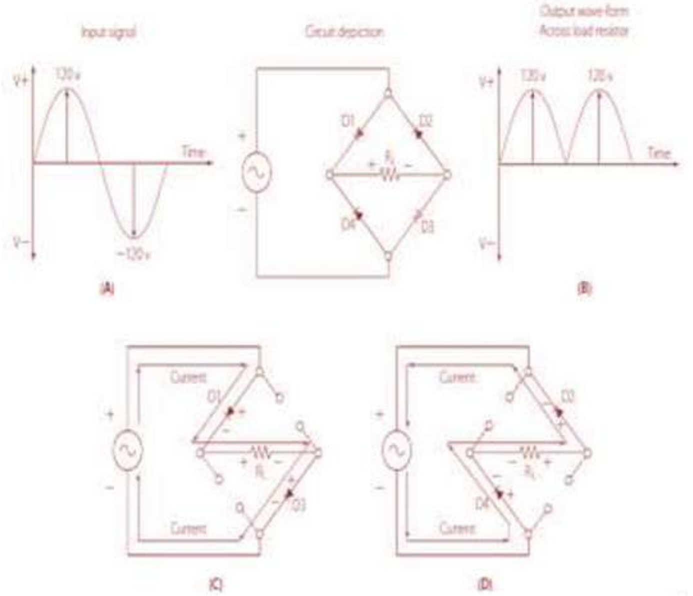
More common use of the diode as a rectifier. This type of a rectifier is called a full-wave bridge rectifier. The term ―full-wave‖ indicates that the output is a continuous sequence of pulses rather than having gaps that appear in the half wave rectifier.

Illustration C shows the initial condition, during which, a positive portion of the input signal is
applied to the network. Note the polarities across the diodes. Diodes D2 and D4 are reverse biased and can be replaced with an open circuit. Diodes D1 and D3 are forward biased and act as an open circuit. The current path through the diodes is clear to see, and the resulting waveform is developed across the load resistor.



During the negative portion of the applied signal, the diodes will reverse their polarity and bias states. The result is a network shown in illustration D. Current now passes through diodes D4 and D2, which are forward biased, while diodes D1 and D3 are essentially open circuits due to being reverse biased. Note that during both alternations of the input waveform, the current will pass through the load resistor in the same direction. This results in the negative swing of the waveform being flipped up to the positive side of the time line.

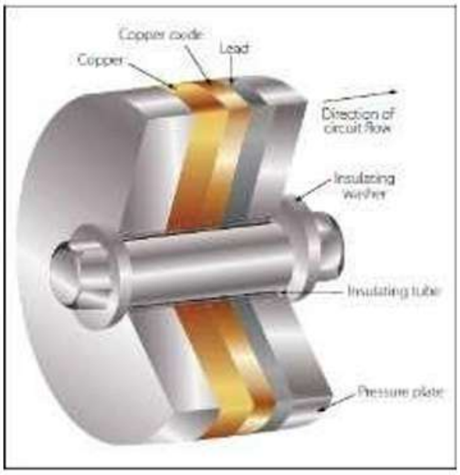
Silicon- controlled rectifier Silicon- controlled rectifiers (or thyristors) are three terminal devices which can be used for switching and AC power control.
Silicon- controlled rectifiers can



switch very rapidly from a conducting to a non-conducting state. In the off state, the silicon-controlled rectifier exhibits negligible leakage current, while in the on state the device exhibits very low resistance. This results in very little power loss within the silicon controlled rectifier even when appreciable power levels are being controlled. Once switched into the conducting state, the silicon controlled rectifier will remain conducting (i.e. it is latched in the on state) until the forward current is removed from the device. In DC applications this necessitates the interruption (or disconnection) of the supply before the device can be reset into its non-conducting state.

Where the device is used with an alternating supply, the device will automatically become reset whenever the main supply reverses. The device can then be triggered on the next half-cycle having correct polarity to permit conduction. Like their conventional silicon diode counterparts, silicon-controlled rectifiers have anode and cathode connections; control is applied by means of a gate terminal. The symbol for a silicon-controlled rectifier was shown earlier in Fig. In normal use, a silicon- controlled rectifier is triggered into the conducting (on) state by means of the application of a current pulse to the gate terminal (see Fig.). The effective triggering of a silicon controlled rectifier requires a gate trigger pulse having a fast rise time derived from a low-resistance source. Triggering can become erratic when insufficient gate current is available or when the gate current changes slowly.

Dry disk rectifiers operate on the principle that electric current flows through a junction of two dissimilar conducting materials more readily in one direction than it does in the opposite direction. This is true because the resistance to current flow in one direction is low, while in the other direction it is high. Depending on the materials used, several amperes may flow in the direction of low resistance but only a few milliamperes in the direction of high resistance. Three types of dry disk rectifiers may be found in aircraft: the copper oxide rectifier, the selenium rectifier, and the magnesium copper-sulfide rectifier. The copper oxide rectifier consists of a copper disk upon which a layer of copper oxide has been formed by heating. It may also consist of a chemical copper oxide preparation spread evenly over the copper surface. Metal plates, usually lead plates, are pressed against the two opposite faces of the disk to form a good contact. Current flow is from the copper to the copper oxide.



2.CIRCUIT PROTECTION DEVICES

Circuit protection devices are used to stop current flow or open the circuit. To do this, a circuit protection device must ALWAYS be connected in series with the circuit it is protecting.
If the protection device is connected in parallel, current will simply flow around the protection device and continue in the circuit.
A circuit protection device operates by opening and interrupting current to the circuit. The opening of a protection device shows that something is wrong in the circuit and should be corrected before the current is restored.
When a problem exists and the protection device opens, the device should isolate the faulty circuit from the other unaffected circuits, and should respond in time to protect unaffected components in the faulty circuit. The protection device should NOT open during normal circuit operation.
Fuses
A fuse is the simplest circuit protection device. It derives its name from the Latin word "fusus," meaning "to melt." Fuses have been

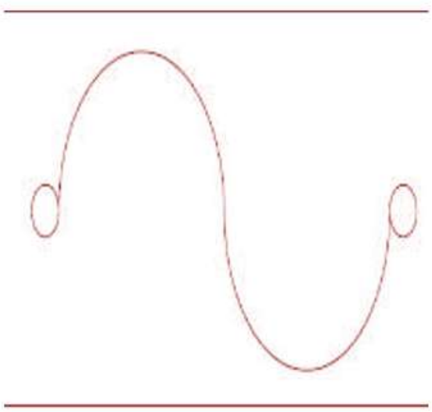


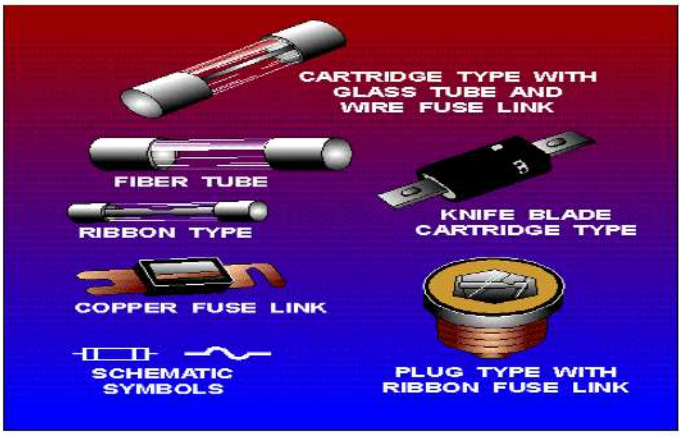
Figure 10-66. Schematic symbol for fuse.

used almost from the beginning of the use of electricity. The earliest type of fuse was simply a bare wire between two connections. The wire was smaller than the conductor it was protecting and, therefore, would melt before the conductor it was protecting was harmed. Some "copper fuse link" types are still in use, but most fuses no longer use copper as the fuse element

(the part of the fuse that melts). After changing from copper to other metals, tubes or enclosures were developed to hold the melting metal. The enclosed fuse made possible the addition of filler material, which helps to contain the arc that occurs when the element melts.

For many low power uses, the finer material is not required. A simple glass tube is used. The use of a glass tube gives the added advantage of being able to see when a fuse is open. Fuses of this type are commonly found in automobile lighting circuits.

Fuses are used to protect the circuit from over current conditions. The fuse is installed in the circuit so that all the current in the circuit passes through it. In most fuses, the strip of metal is made of an alloy of tin and bismuth, which will melt and open the circuit when the current exceeds the rated capacity of the fuse. For example, if a 5-amp fuse is placed into a circuit, the fuse will allow currents up to 5 amps to pass. Because the fuse is intended to protect the circuit, it is quite important that its capacity match the needs of the circuit in which it is used. When replacing a fuse, consult the applicable manufacturer's instructions to be sure a fuse of the correct type and capacity is installed. Fuses are installed in two types of fuse holders in aircraft. —Plug-in holders‖ or in-



line holders are used for small and low capacity fuses. —Clip‖ type holders are used for heavy high capacity fuses and current limiters.

Circuit Breakers

is commonly used in place of a fuse and is designed to break the circuit and stop the current flow when the current exceeds a predetermined value. Unlike the fuse, the circuit breaker can be reset; whereas the fuse or current limiter must be replaced.

While a fuse protects a circuit, it is destroyed in the process of opening the circuit. Once the problem that caused the increased current or heat is corrected, a new fuse must be placed in the circuit. A circuit protection device that can be used more than once solves the problems of replacement fuses. Such a device is safe, reliable, and tamper proof. It is also resettable, so it can be reused without replacing any parts. This device is called a CIRCUIT BREAKER because it breaks (opens) the circuit.

Current Limiter

The current limiter is very much like the fuse. However, the current limiter link is usually made of copper and will stand a considerable overload for a short period of time. Like the fuse it will open up in an over current condition in heavy current circuits such as 30 amp or greater. These are used primarily to sectionalize an aircraft circuit or bus.

Once the limiter is opened, it must be replaced. The schematic symbol for the current limiter is the same as that for the fuse. U

Thermal Protectors

A thermal protector, or switch, is used to protect a motor. It is designed to open the circuit automatically whenever the temperature of the motor becomes excessively high. It has two positions — open and closed. The most common use for a thermal switch is to keep a motor from overheating. If a malfunction in the motor causes it to overheat, the thermal switch will break the circuit intermittently. The thermal switch contains a bimetallic disk, or strip, which bends and breaks the circuit when it is heated. This occurs because one of the metals expands more than the other when they are subjected to the same temperature. When the strip or disk cools, the metals contract and the strip returns to its original position and closes the circuit scored circus and/o is also included.

Circuit controlling devices
The simplest form of switch is the on/off device used to isolate circuits. Other switch types are used to direct the current into pre-
determined parts of a circuit. Switches are characterized by:
- Number of poles
- Number of switched positions
- Type of switched contacts (permanent or momentary). Switches are sometimes guarded or wire-locked with fuse wire to prevent inadvertent operation. Some switch designs have to be pulled out of a detent position before the position can be changed. They are designed to be operated in a number of ways, e.g. toggle, push/pull, rocker or rotary selectors. These switches are designed with multiple contacts; they can be arranged as permanent or momentary contacts. The toggle switch is a very basic device; Fig. Illustrates its internal

schematic and external features. Operating the lever/arm opens and closes switch contacts.
Operating levers on toggle switches are sometimes ganged so that more than one circuit is

operated. The simplest switch has two contact surfaces that provide a link between circuits; these links are referred to as poles . Switch contacts can be normally open or closed and this is normally marked on the switch (NO/NC). The number of circuits that can be linked by a single switch operation is called the throw. The simplest form of switch would be single pole, single throw (SPST). Schematics of switch configurations commonly found in aircraft are illustrated in Fig. Some switches are designed with instinctive tactile features so that the risk of selecting the wrong system is minimized, e.g. the fl ap up/down switch-operating lever would be shaped in the form of an aerofoil; the undercarriage selection switch-operating lever would be shaped in the form of a wheel (see). Push/pull-operated switches incorporate a spring to hold the contacts open or closed; the switch contacts are therefore push-to-make or push-to-break. Rocker switches (Fig. 9.2b) combine the action of toggle and push/pull devices. Rotary switches are formed by discs mounted onto a shaft; the contacts are opened and closed by the control knob Combined switch/light devices.

Modern aircraft panels utilize a combined switch and light display; the display is engraved with a legend or caption indicating system status. These can be used in a variety of ways e.g. to show system on/off. The switch portion of the device can be momentary or continuous; small level signals are sent to a computer or high- impedance device. Internal backlighting is from two lights per legend for redundancy; these are projected via colored filters. The two captions provide such information as press to test (P/TEST). Examples of combined switch/light devices are given in Fig

Micro-switches

These are used to sense if a device has moved or has reached its limit of travel, e.g. flap drive or undercarriage mechanisms. Figure.illustrates the internal schematic and electrical contacts of a typical microswitch product. The contacts open and closeswith a very small movement of the plunger. The distance travelled by the armature between make/break is measured in thousandths of an inch, hence the name _micro‘. A snap action is achieved with a contact mechanism that has a pre-tensioned spring. Micro-switches are attached to the structure and the wiring is connected into a control circuit. An example of micro-switch application is to sense when the aircraft is on the ground; this is achieved by mounting a micro-switch on the oleo leg. When the aircraft is on the ground, the oleo leg compresses and the switch is operated. Micro-switches are used to sense the mechanical displacement of a variety of devices, including:

- control surfaces
- undercarriage
- pressure capsules
- bi-metallic temperature sensors
- mechanical timers.

Proximity switches

Proximity switches perform the same function as micro-switches; they sense the presence of an object by the interruption of a magnetic circuit. There are two types of proximity switch: reed and solid state. The reed switch device comprises two hermetically sealed sections as illustrated in Fig. One section (the actuator) contains a magnet; the other section (the sensor) contains a reed armature with rhodium-plated contacts. The usual arrangement is for the sensor unit to be fixed to the aircraft structure; the actuator is attached to the item being monitored, e.g. a door. When the gap between the actuator and the sensor reaches a pre-determined distance, the reed contacts close thereby completing the circuit. They open again when the actuator and sensor are moved apart.

The solid state proximity switch is based on an inductance loop and steel target as illustrated in this inductance loop is the input stage of an electronicswitch unit incorporated as part of the actuator. As the target moves closer to the coil, the inductance of the coil changes. An electronic circuit determines when the inductance has reached a pre-determined level. The obvious advantage of this type of switch is that there are no switch contacts, hence higher reliability.

External/Ground power External ground power supply

Normally the aircraft generates its own power, but when parked with the engines switched off power provided by the airport would be connected to the plane.

This connected power is typically 115 V at 400 Hz and is called ground power.

Fixed ground power is the supply of suitable 400 Hz power using a permanently installed installation for use on parked aircraft.

How Many Ground Power Units (GPU)

For point of use systems, the number of GPU is dependant on aircraft size.
Best practice from an operational and reliability view is one GPU per plug:

Narrow-Body: 1 x 90 kVA
Wide-Body: 2 x 90 kVA
A380: 4 x 90 kVA

Conversion of the mains power to 400 Hz power is typically done either centralised or at the point of use by frequency converters.

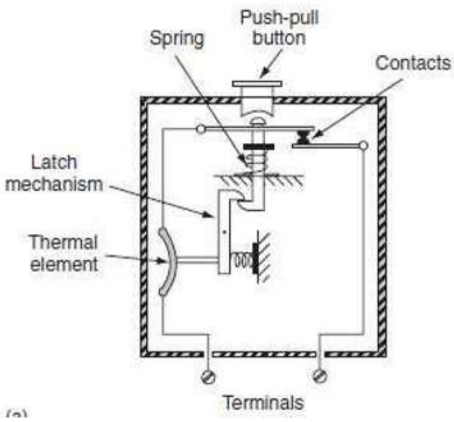
In a centralised system, large quantities of power are converted at a central location and then the 400 Hz power is distributed to the aircraft. In point of use, the mains power is taken close to the aircraft, and the frequency conversion carried at it's point of use.

Centralised power systems while cheaper to construct, do have several disadvantages. These include the balancing of the system, maintaining adequate voltage drops amongst others.

Mobile Power
Where fixed ground power is not available, mobile power units can be deployed. These are typically towed or mounted on vehicles and deliver power by utilising diesel generators.

History of 400 Hz

400 Hz was first chosen for aircraft design as it ensured a more compact design (and hence lighter weight) for the electrical systems.



Frequency Converters

Generators providing 400 Hz power use less copper in their windings and smaller magnetic cores than those of 50 or 60 Hz - making them lighter.

Given the relative short transmission distances in aircraft, the negative aspects of larger voltage drops at 400 Hz are not so serious. The reduction in weight of equipment more than compensates for this.

Pit systems typically contain the 400 Hz cable, which is accessed by lifting a lid on the pit. Additionally, some pop-up type pit systems are available, which simply the cable handling. In addition to cable handling, pits systems also need to be designed to take the mechanical load of aircraft driving over them. Being buried, they are also considered to be confined spaces.

Connection to the Aircraft

Connection to the aircraft itself is made using special plug in connectors. Depending on the size of the plane, the number of required connectors varies from one to four.

Aircraft connectors are standardized and rated at IP67.

Connectors are often integrated with push buttons and LEDs for operating frequency converters and power delivery systems. Typical specification ratings would be 200 V, 200 A continuous within a temperature range: -55°C to +125°C.

External Power

Two 90 kVA point of use frequency converters

Commercial mains power at most airports operates on either 50 or 60 Hz. Frequency converters are required to change this to the 400 Hz required for aircraft operation.

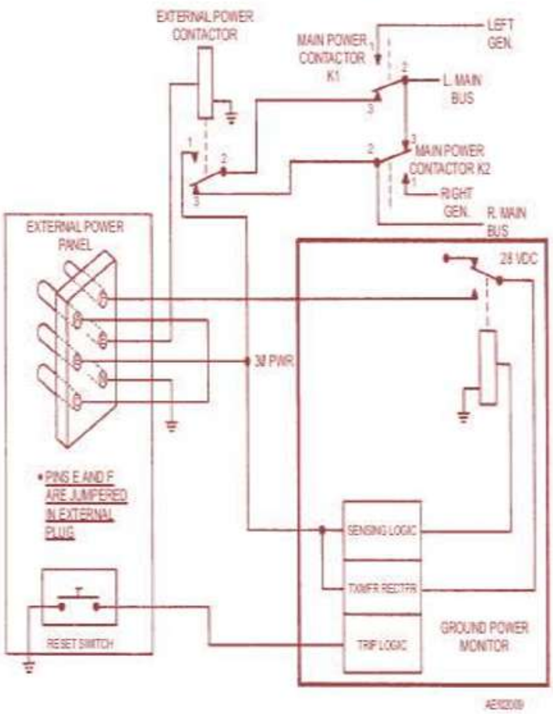
Final Power Delivery

There are many ways for delivering 400 Hz power to the aircraft. Two common methods employed at larger airports are bridge mounted cable reel devices or apron buried pit
systems.

Bridge mounted devices are attached to the passenger embarkation/disembarkation bridges and electrically controlled to dispense the 400 Hz cable. After operations, the device will electrically rewind the cable back onto it's cable reel.

The external electrical power system (fig. 2-9) permits application of three-phase, ac power to the aircraft electrical power distribution system. External power goes to the ground power monitor (GPM) and de-energized contacts of the external power contactor.

The GPM



prevents application of external power not within tolerances. If an undervoltage, overvoltage, underfrequency, over frequency, or a phase reversal fault occurs, the GPM disconnects external power from the power distribution system. When all the power parameters are within tolerance, the GPM relay energizes, supplying 28 Vdc from the GPM transformer-rectifier to pin F of the external power panel.

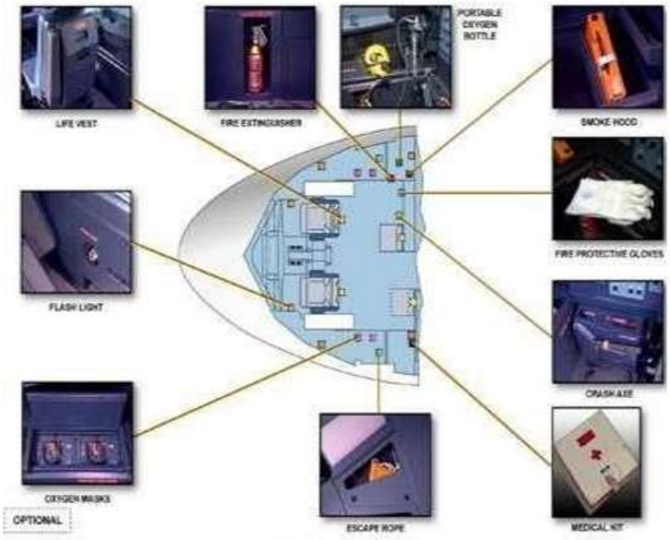
NOTE: Pins E and F are jumpered in the external power plug.

The power then runs through pin E and energizes the external power contactor. Three-phase power at pin one of the external power contactor then runs to the left main ac bus and right main ac bus through their respective contactors. Power from the left main ac bus (fig. 2-10) goes to the left TR unit. It also goes through the de-energized contacts of both ac essential power transfer relays to

all essential ac buses and to the 26-volt ac transformer. This transformer, in turn, feeds power to the 26 Vac instrument and navigational buses. The right main ac bus supplies power to the right TR unit. Both left and right TR unit provides power to all dc buses through their respective power contactors and power transfer relays. External electrical power is automatically inhibited from some systems when external air conditioning is not being supplied to the aircraft. After aircraft engines start and the left generator comes on line, the left main contactor automatically disconnects external power. Some aircraft have a light on the caution/advisory panel that is illuminated by a switch, mounted on the external power receptacle, when the door is open. However, there is no cockpit indication of external power application. The only control the pilot has over external power being applied or removed is the hand signals between the pilot and the plane captain.

13.6 EQUIPMENT AND FURNISHINGS (ATA 25)

Electronic emergency equipment requirements
Emergency equipment on just about any airline aircraft consists of
fire extinguishers, crash axe, megaphone(s) , flashlights, first aid kits, life vests, escape ropes,



EMERGENCY EQUIPMENT

protective breathing equipment (PBE),
Emergency
Locator Transmitters (ELTs), and
for some life rafts.
The extinguishers on an aircraft are a bit different from what might see in the home or business. Water extinguishers are much like you have seen and contain a mixture of water and anti-freeze. They are used for Class A fires which are basically paper, rubber, and wood fires. Just like at home, don't use these on an electrical or greasetype fire. Halon extinguishers contain a liquefied gas agent under pressure. Halon is used on electrical, fuel, and grease fires and basically smothers the fire when applied.
These fire extinguishers are found throughout aircraft, including the flight deck, and are major items that flight crew checks as part of their preflight checks. They check that it is safety-wired or that a safety pin is installed (to ensure that it hasn't been discharged), or that a needle is in the green band (indicating the proper pressure and/or quantity is full).

A crash ax is usually located on the flight deck, and can imagine, can be used for wide variety of things.
The megaphone(s) would provide an alternate means of communications to everyone, especially for emergency instructions, in case power was lost to the public address (PA) system.
Emergency flashlights are located by the doors and are self- powered and are high intensity. They have a flashing LED (Light Emitting Diode) that flashes continuously to show that it is working and is also a major item for the flight attendants to check on their preflight checks.
Other emergency equipment that the flight attendants must check are first aid kits, including the Automatic External Defibrillator (AED).
Most aircraft can have an Enhanced Emergency Medical Kit (EEMK), Reserve Emergency Medical Kit (REMK), and a Universal Precautions Kit (UPK). All of these kits contain basic medicines and equipment that licensed medical providers (doctors, nurses, and paramedics) could use in case of an medical emergency.

The AED can be used by trained personnel and can develop electrical shocks to passengers experiencing cardiac arrests or heart rhythm abnormalities. It can also be used to monitor a person's heart rhythm.

One life vest is supplied per seat, usually located underneath the seat. If have to use it, make sure that don't inflate it before leave the aircraft.

While the flight attendants will give a demo of how to wear the life vest in the safety brief if an overwater flight is expected (more than fifty miles from shore), rarely do people think about all the airports that are located near major water in the first place! As evidenced by the USAir flight ditching into the Hudson River, I would say

you are more likely to have to use a life vest during the takeoff or landing phase of your flight.

Along with life vests for water survival, in many aircraft, especially wide-body aircraft (international, over ocean), life rafts will be installed. Depending on the aircraft you are on, these can be found in various places. Some are in the overhead ceiling above the aisle near the window exits.

Some aircraft even use the evacuation slide as a life raft! Of course, the life rafts installed must have enough capacity for every passenger seat and crew. These life rafts will have survival kits that will contain things such as a canopy to put over the raft to keep the elements and hot sun out, signal flares, knives, etc.

Escape ropes are located in the flight deck above a window on each side for each pilot; and in the cabin near the window exits. These ropes above your window exits can be tied to attachment points on the wings to aid in evacuation and/or getting into life rafts.
PBEs are breathing equipment used by the crew to help protect the eyes and breathing in a heavy smoke situation. It is a hood assembly with a clear visor you pull over your head. It is sealed around the neck and an oxygen chemical canister is activated that will provide 15-20 minutes duration.
ELTs are usually installed in the evacuation slides and/or life rafts. They will automatically transmit when submerged in water. They can transmit from 50 to 100 hours depending on model and will continuously transmit on "Guard" frequencies. These are frequencies reserved for emergencies and are 121.5 MHz on Very High Frequency (VHF) and 243.0 Mhz on Ultra High Frequency (UHF).
An evacuation slide is an inflatable slide used to evacuate an aircraft quickly. An escape slide is required on all commercial (passenger carrying) aircraft where the door sill height is such that, in the event of an evacuation, passengers would be unable to step

down from the door uninjured (Federal Aviation Administration requires slides on all aircraft doors where the floor is 6 feet (1.8 m) or more above the ground).

Escape slides are packed and held within the door structure inside the slide bustle, a protruding part of the inside of an aircraft door that varies with aircraft size, door size and door location. In many modern planes, to reduce evacuation time, evacuation slides deploy automatically when a door is opened in an "armed" condition. Modern planes often indicate an armed condition with an indicator light.

Cabin entertainment equipment

3. IN-FLIGHT ENTERTAINMENT (IFE)

Refers to the entertainment available to aircraft passengers during a flight. In 1936, IFE was delivered in the form of food and drink services, along with an occasional projector movie during lengthy flights.

In 1985 the first personal audio player was offered to passengers, along with noise cancelling headphones in 1989.During the 1990s the demand for better IFE was a major factor in the design of aircraft cabins.

Before then, the most a passenger could expect was a movie projected on a screen at the front of a cabin, which could be heard via a headphone socket at his or her seat. Now, in most aircraft, private IFE TV screens are offered on most airlines.

4. AUDIO ENTERTAINMENT

Audio entertainment covers music, as well as news, information, and comedy. Most music channels are pre-recorded and feature their own DJs to provide chatter, song introductions, and interviews with artists. In addition, there is sometimes a channel devoted to the plane's radio communications, allowing passengers to listen in on the pilot's in-flight conversations with other planes and ground stations.

In audio-video on demand (AVOD) systems, software such as Music Match is used to select music off the music server. Phillips Music Server is one of the most widely used servers running under Windows Media Centre used to control AVOD systems.

This form of in-flight entertainment is experienced through headphones that are distributed to the passengers. The headphone plugs are usually only compatible with the audio socket on the passenger's armrest (and vice versa), and some airlines may charge a small fee to obtain a pair. The headphones provided can also be used for the viewing of personal televisions.

5. VIDEO ENTERTAINMENT

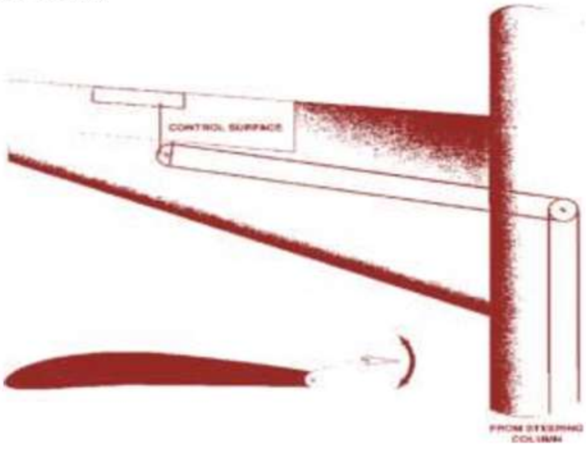
Video entertainment is provided via a large video screen at the front of a cabin section, as well as smaller monitors situated every few rows above the aisles. Sound is supplied via the same headphones as those distributed for audio entertainment. However, personal televisions (PTVs) for every passenger provide passengers with channels broadcasting new and classic films, as well as comedies, news, sports programming, documentaries, children's shows, and drama series. Some airlines also present news and current affairs programming, which are often pre- recorded and delivered in the early morning before flights commence.

PTVs are operated via an In-flight Management System which stores pre-recorded channels on a central server and streams them to PTV equipped seats during flight. AVOD systems store individual programs separately, allowing a passenger to have a specific program streamed to them privately, and be able to control the
playback.

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 push- rods. 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-per- formance 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,



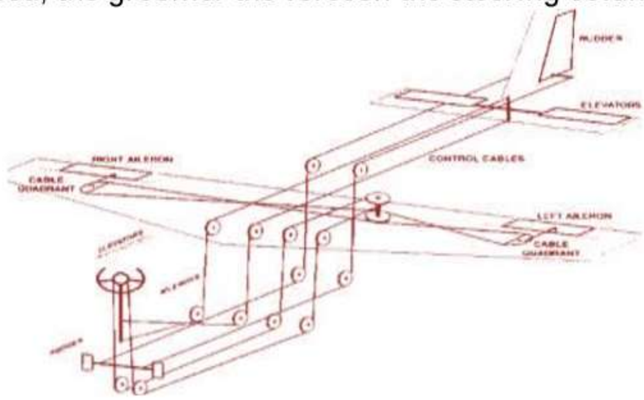
hydraulic actuators are used within the linkage to assist the pilot in moving the control surface. Because these systems reduce pilot fatigue and improve system performance. They are now commonly used. Such systems include automatic pilot, automatic landing systems, and stability augmentation systems.

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

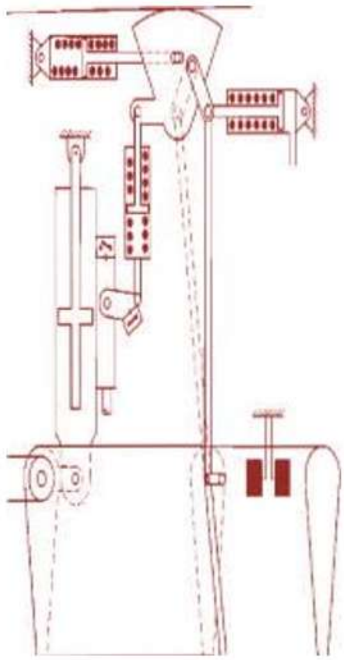
through the fuselage, it is supported by the pulleys. The pulleys also enable the direction of the control cable to be changed. Tension of the control cable system is critical. This kind of control is only usable in low speed general aviation aeroplanes. See Figure 2 on page 3. The force the pilot feels on the steering column while steering the plane, is in direct relation to the airspeed.

Therefore, the higher the airspeed, the groomer the forceon the steering column.



Aerodynamic ally Controlled Control System

The control tabs are controlled by the control wheels in the flight deck 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 are the opposite direction



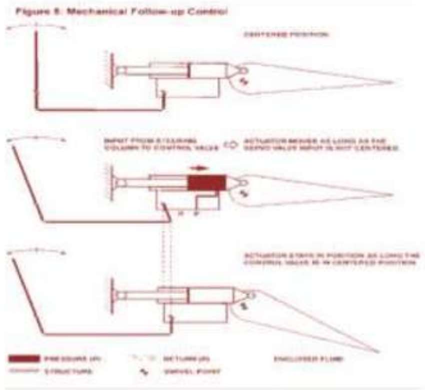
Hydraulically Assisted Control System

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

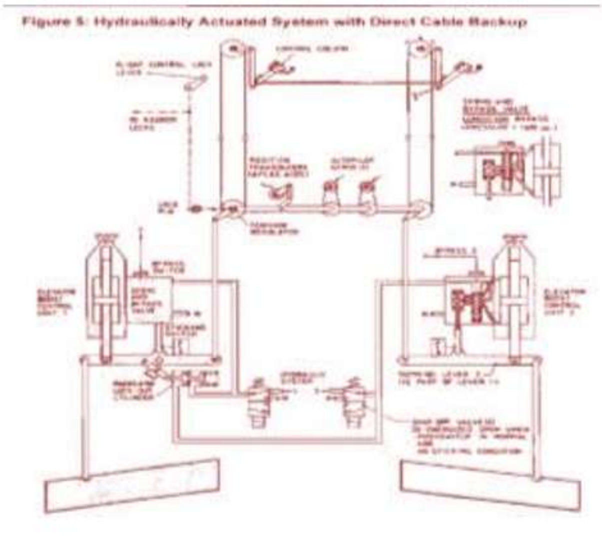
It is to say, that these days the described system is replaced with a more advanced architecture. In normal operation, the direct connection between the steering column and the control surface is in a disconnected mode, and the input coming from the flight deck is only directed to the actuators control 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.



Hydraulic Actuating System with Control Tab Backup

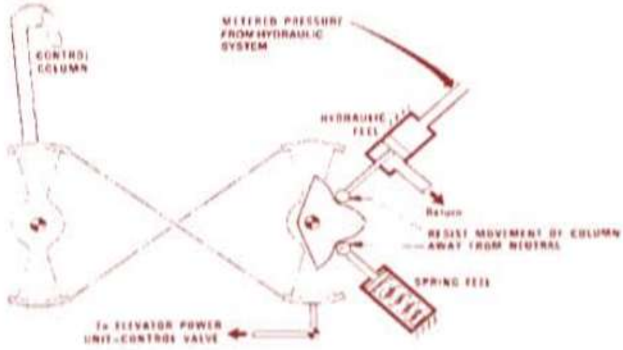
In the event of a hydraulic system failure, the control forces are too great for the pilot to manually move the surfaces, so, they are controlled with servo tabs. In the manual mode of operation, the flight control column moves the tab on the control surface, and the aerodynamic forces caused by the deflected tab move the main control surface.

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 too 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

Figure 12: Artificial Feel Unit Lay-Out



control surface actuators.

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.

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 Me 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 teethes] signals which are serf 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 control 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-ware aeroplanes use a sidestick controller.

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 via 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 extreme attitudes (pitch and roll). Overspeed, excessive loads factors and stall.

Redundancy / Fail Safe

Hydraulic operated primary flight control system are

ENCLOSED FLUID

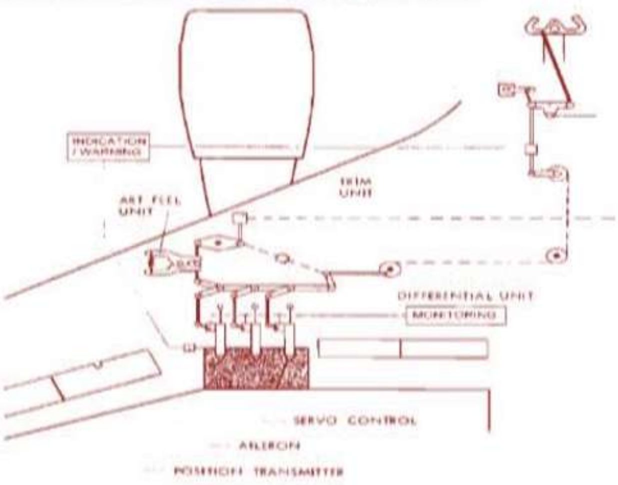
often designee redundant, this mean two or three

actuators (servo control unit) perform the same function, fed from independent hydraulic systems As described before. Modern systems are controlled through flight control computers. For safety reasons, more than one compute, 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 automate changeover will take place what brings the faulty computer in an isolated state.

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.

Artificial Feel System

Figure 10: Redundant Hydraulic Power Operated System



Since the pilot has no actual feel of the flight loads in hydraulically actuated sys-tems, 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 is a typical artficial 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.

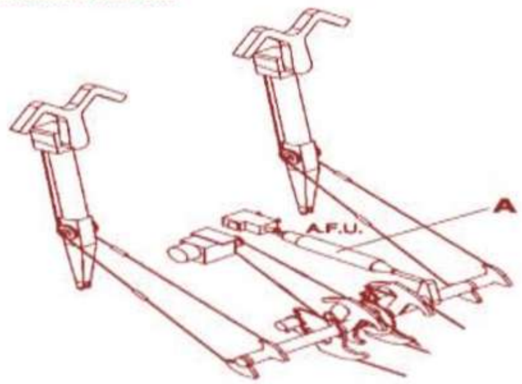
Operation of a Fly By Wire Actuator

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 lire to the system LP Servo control in the active mode

Figure 13: Arificial Feel Unit



In this case, the solenoid valve (13) is energized. This lets in the HP which puts the mode selector valve (5) the active mode. The two chambers of the actuator are thus connected to the users ports of the servovalve. The serve 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 servo loop feedback.

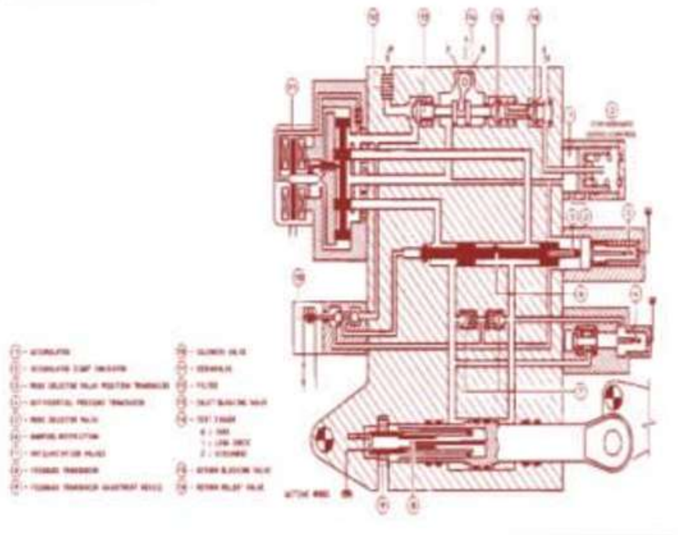
Servo control in the damping mode

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 d splay 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 modeselector valve

Figure 14: Airbus Aileron Actuator



(5) moves under the act on 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) s 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 he 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 vane (16)
- using the accumulator sight indicator (2) and test finger (14) (manually operated).
- Different test finger (14) positions:
- ZERO Check sealing of: in ret blocking valve (13), Thar. blocking valve (15) return relief valve (16)

LEAK CHECK Check sealing of inlet blocking valve (13). return relief valve (16).

DISCHARGE Check stroke of accumulator piston

13.8 Instruments (ATA 31)

CLASSIFICATION

The complexity of modern aircraft and all allied equipment, and the nature of the environmental conditions under which they must operate, require conformity of design, development and subsequent operation with established requirements and standards. This is, of course, in keeping with other branches of mechanical and transport engineering, but in aviation requirements and standards are unique and by far the most stringent.

Location, Visibility and Grouping of Instruments

1. AI1 instruments shall be located so that they can be read easily by the appropriate member of the flight crew.
2. When illumination of instruments is provided there shall be sufficient illumination to make them easily readable and discernible by night. Instrument lights shall be installed in such a manner that the pilot's eyes are shielded from their direct rays and that no objectionable reflections are visible to him
3. Flight, navigation and power-plant instruments for use by a pilot shall be plainly visible to him from his station with the minimum practicable deviation from his normal position and line of vision when he is looking out and forward along the flight path of the aircraft.
4. All flight instruments shall be grouped on the instrument panel and, as far as practicable, symmetrically disposed about the vertical plane of the pilot's forward vision.
5. All the required power-plant instruments shall be conveniently grouped on instrument panels and in such a manner that they may be readily seen by the appropriate crew member.
6. In multi-engined aircraft, identical power-plant instruments for the several engines shall be located so as to prevent any misleading impression as to the engines to which they relate Instrument Panels

The vibration characteristics of instrument panels shall be such as not to impair seriously the accuracy of the instruments or to damage them. The minimum acceptable vibration insulation characteristics are established by standards formulated by the appropriate national organization.

Instruments to be Installed

Right and Navigation Instruments

1. Altimeter adjustable for changes in barometric pressure
2. Airspeed indicator
3. Vertical speed indicator
4. Gyroscopic bank-and-pitch attitude indicator
5. Gyroscopic rate-of-turn indicator (with bank indicator)
6. Gyroscopic direction indicator
7. Magnetic compass
8. Outside air temperature indicator
9. Clock

Pitot-static System

Instruments 1, 2 and 3 above form part of an aircraft's pitot-static system, which must also conform to certain requirements. These are summarized as follows:

a) The system shall be air-tight, except for the vents to atmosphere, and shall be arranged so that the accuracy of the instruments cannot be seriously affected by the aircraft's speed, attitude, or configuration ; by moisture, or other foreign matter.

b) The system shall be provided with a heated pitot-pressure probe to prevent malfunctioning due to icing.

c) Sufficient moisture traps shall be installed to ensure positive drainage throughout the whole of the system.
d) In aircraft in which an alternate or emergency system is to be installed, the system must be as reliable as the primary one and any selector valve must be clearly marked to indicate which system is in use.
e) Pipelines shall be of such an internal diameter that pressure lag and possibility of moisture blockage is kept to an acceptable minimum.
f) Where static vents are used, to obviate yawing errors they shall be situated on opposite sides of the aircraft and connected together as one system. Where duplicate systems are prescribed, a second similar system shall be provided.

Gyroscopic Instruments

Gyroscopic instruments may be of the vacuum-operated or electrically operated type, but in all cases the instruments shall be provided with two independent sources of power, a means of selecting either power source and a means of indicating that the power supply is working satisfactorily. The installation and power supply system shall be such that failure of one instrument, or of the supply from one source, or a fault in any part of the supply system, will not interfere with the proper supply of power from the other source.

Duplicate Instruments

In aircraft involving two-pilot operation it is necessary for each pilot to have his own pilot-static and gyroscopic instruments. Therefore two independent operating systems must be provided and must be so arranged that no fault which might impair the operation of one is likely to impair the operation of both system

Magnetic Compass

The magnetic compass shall be installed so that its accuracy will not be excessively affected by the aircraft vibration or magnetic fields of a permanent or transient nature.

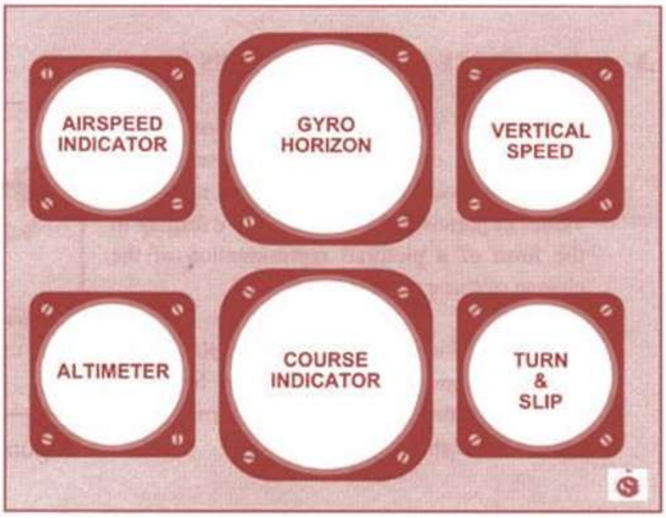
Power Plant Instruments

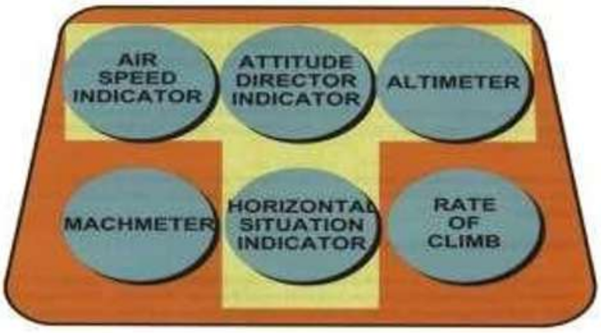
1. Tachometer to measure the rotational speed of a crankshaft or a compressor as appropriate to the type of power plant.
2. Cylinder-head temperature indicator for an air-cooled engine to indicate the temperature of the hottest cylinder.
3. Carburettor-intake air temperature indicator.
4. Oil temperature indicator to show the oil inlet and/or outlet temperature.
5. For turbojet and turbo propeller engines a temperature indicator to indicate whether the turbine or exhaust gas temperature is maintained within its limitations.
6. Fuel-pressure indicator to indicate pressure at which fuel is being supplied and a means for warning of low pressure.
7. Oil-pressure indicator to indicate pressure at which oil is being supplied to a lubricating system and a means for warning of low pressure.
8. Manifold pressure gauge for a supercharged engine.
9. Fuel-quantity indicator to indicate in gallons or equivalent units the quantity of usable fuel in each tank during flight. Indicators shall be calibrated to read zero during cruising level flight, when the quantity of fuel remaining is equal to the unusable fuel, i.e. the amount of fuel remaining when, under the most adverse conditions, the first evidence of malfunctioning of an engine occurs.
10. Fuel-flow indicator for turbojet and turbopropeller engines. For piston engines not equipped with an automatic mixture control a fuel flowmeter or fuel air ratio indicator.
11. Thrust indicator for a turbojet engine.
12. Torque indicator for a turbopropeller engine.

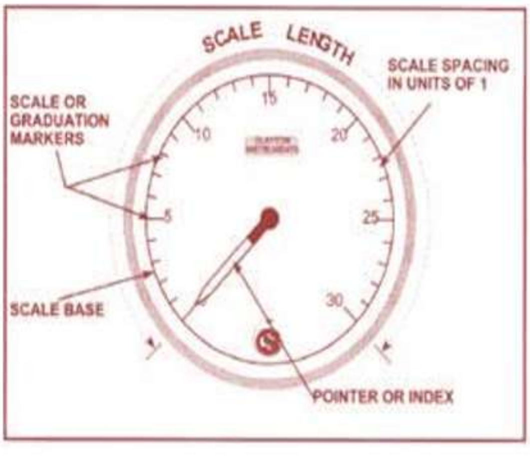
THE INSTRUMENT LAYOUT

The rapid advances in aeronautics meant that aero planes were now capable of flying for hours instead of minutes and flying for miles instead of yards. Inevitably this meant that aero planes might find themselves in cloud, without a visible horizon and this posed more problems. The cockpit was being filled with more and more dials and indicat ors and it was necess ary to create some order out of chaos, to decide which instru ments should have prominence and to achieve some standardization. The 'flying' instruments which covered the handling of the aircraft were arranged in the layout of the 'basic six'. Other instruments tended to be scattered around the cockpit in positions most convenient to the designer and manufacturer, seldom to suit the needs of the pilot.

Since the introduction of the 'basic six' developments in aircraft instruments and operations led to the introduction of the 'basic T'. These layouts are shown







THE THREE DIFFERENT TYPES OF DISPLAY.

Instruments may give information in a quantitative display where a pointer moves over a graduated scale and gives numerical values Of parameters or a qualitative display in the form Of a pictorial representation of the change of these parameters. Yet another form is the director display which will show how an aircraft should be flown (directed), rather than supplying information on speeds or heights or pressures.

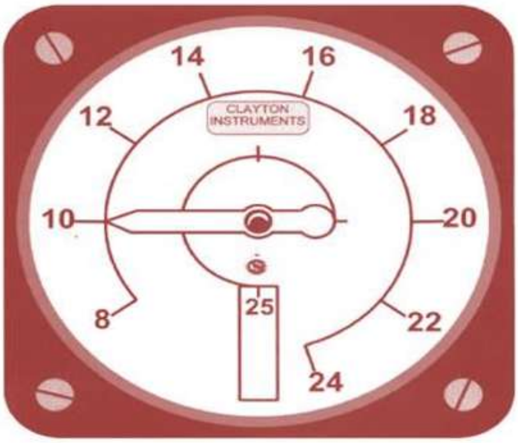
QUANTITATIVE DISPLAYS.

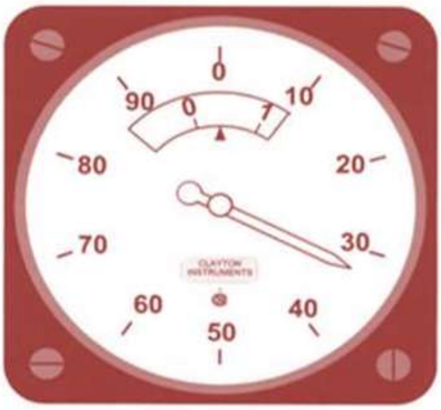
Circular Scale (Linear).

A simple indicator showing the change of value ofthe parameter to be measured over a range of 0 to 30 units is shown. The accuracy with which these values need to be measured will govern the spacing of the graduation.

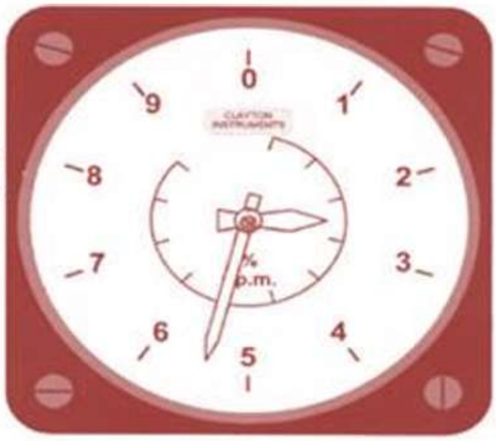
Circular Scale (Non-Linear).
Some instruments are required to show changes Of parameters more accurately at certain parts Of the scale. The example in Figure shows a rate of climb indicator where slow rates Of climb show more readily than high rates. This is a logarithmic scale.

A less confusing display uses two concentric pointers moving over two separate scales, as shown on the revolution counter in Figure
High Range Long Scale Displays
Where the instrument needs to show changes over a high range of values and these changes need to be read with a fair degree of accuracy, 3600 of movement of the pointer may not be sufficient. The pointer may make more than one revolution to cover the required range, as on the air speed indicator shown in figure, though this type of display may lead to some confusion.

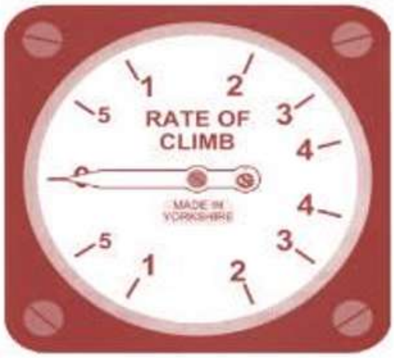




Air Speed Indicator



Revolution Counter



Three Pointer Altimeter

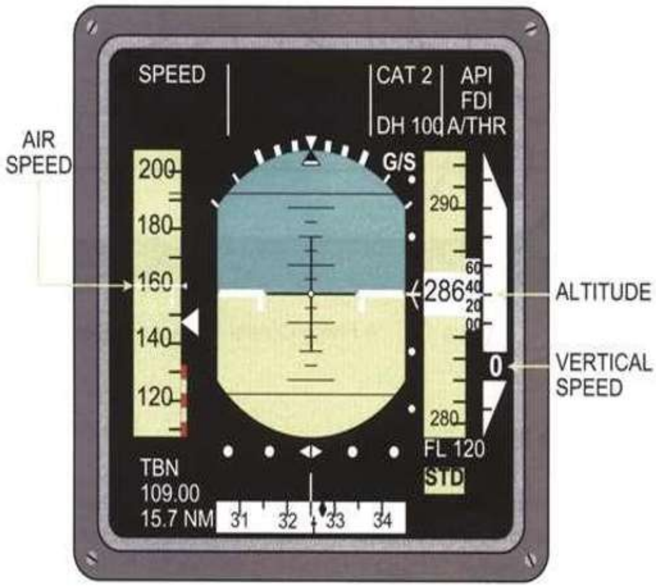
units (hundreds Of knots).

Another solution is to have a pointer moving over a fixed scale (e.g. tens Of knots) with a moving scale indicating larger A further solution, shown in Figure, is to display information in a similar fashion to a clock, with pointers showing hours, minutes and seconds. This system is used on many altimeters. The long pointer will cover 1000 feet in one revolution, so each division of the scale represents 100 feet, the middle pointer will cover 10,000 feet per revolution, each division marking 1000
feet and the smallest pointer (sometimes in the form of a 'bug' on the Outside of the scale) will cover

100,000 feet, each division representing 10,000 feet.

STRAIGHT SCALE DISPLAYS.

Until recently most instruments displayed information on a circular scale, but with the introduction of Electronic Flight Information Systems (EFIS) increasing use of straight scale displays has been made. In the example below, airspeed, altitude and vertical speed are shown on an Electronic Attitude Director



Indicator (EADI) otherwise known as Primary Flight Display (PFD).

ATMOSPHERE

The atmosphere of Earth is composed of nitrogen (about 78%), oxygen (about 21%), argon (about 0.9%) with carbon dioxide and other gases in trace amounts.

Earth's atmosphere of a number of layers that differ in properties such as composition, temperature and pressure. The lowest layer is the troposphere, which extends from the surface to the bottom of the stratosphere. Three quarters of the atmosphere's mass resides within the troposphere, and is the layer within which the Earth's terrestrial weather develops. The depth of this layer varies between 17 km at the equator to 7 km at the poles. The stratosphere, extending from the top of the troposphere to the bottom of the mesosphere, contains the ozone layer. The ozone layer ranges in altitude between 15 and 35 km, and is where most of the ultraviolet radiation from the Sun is absorbed. The top of the mesosphere, ranges from 50 to 85 km, and is the layer wherein most meteors burn up. The thermosphere extends from 85 km to the base of the exosphere at 690 km and contains the ionosphere, a region where the atmosphere is ionised by incoming solar radiation. The ionosphere increases in thickness and moves closer to the Earth during daylight and rises at night allowing certain frequencies of radio communication a greater range. The Kármán line, located within the thermosphere at an altitude of 100 km, is commonly used to define the boundary between Earth's atmosphere and outer space. The exosphere begins variously from about 690 to 1,000 km above the surface, where it interacts with the planet's magnetosphere. Each of the layers has a different lapse rate, defining the rate of change in temperature with height.

The atmosphere has five different layers that are determined by the changes in temperature that happen with increasing altitude.

Troposphere

Living at the surface of the Earth, we are usually only aware of the events happening in the lowest layer, the troposphere, where all weather occurs. The base of this layer is warmer than its top because the air is heated by the surface of the Earth, which absorbs the Sun‘s energy.

Stratosphere

Above the troposphere lies the stratosphere where jet airplanes fly. Temperatures increase with altitude because of increasing amounts of ozone. The ozone layer within the stratosphere absorbs harmful ultraviolet rays of sunlight.

Mesosphere

As the mesosphere extends upward above the stratosphere, temperatures decrease. The coldest parts of our atmosphere are located in this layer and can reach –90°C.

Thermosphere

In the forth layer from Earth‘s surface, the thermosphere, the air is thin, meaning that there are far fewer air molecules. The thermosphere is very sensitive to solar activity and can heat up to 1,500°C or higher when the Sun is active making an aurora that lights up the night sky. Astronauts orbiting Earth in the space station or space shuttle spend their time in this layer.

Exosphere

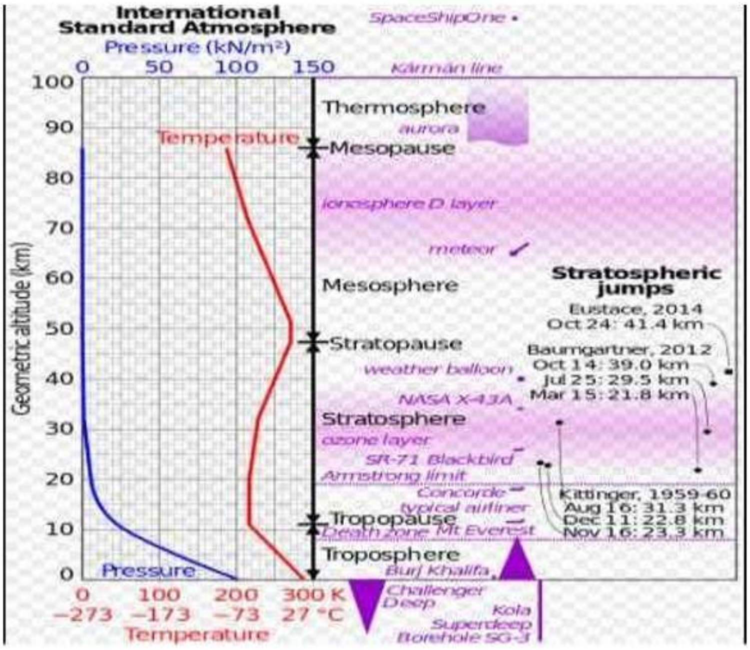
The upper layer of our atmosphere, where atoms and molecules escape into space, is called the exosphere.

Atmospheric pressure

Atmospheric pressure at a particular location is the force per unit area perpendicular to a surface determined by the weight of the vertical column of atmosphere above that location. On Earth, units of air pressure are based on the internationally recognized standard atmosphere (atm), which is defined as 101.325 kPa (14.696 psi). It is measured with a barometer. Atmospheric pressure decreases with increasing altitude due to the diminishing mass of gas above. Atmospheric pressure, also called barometric pressure, force per unit area exerted by an atmospheric column (that is, the entire body of air above the specified area). Atmospheric pressure can be measured with a mercury barometer (hence the commonly used synonym barometric pressure), which indicates the height of a column of mercury that exactly balances the weight of the column of atmosphere over the barometer. Atmospheric pressure is also measured using an aneroid barometer, in which the sensing element is one or more hollow, partially evacuated, corrugated metal disks supported against collapse by an inside or outside spring; the change in the shape of the disk with changing pressure Atmospheric pressure is expressed in several different systems of units: millimetres (or inches) of mercury, pounds per square inch (psi), dynes per square centimetre, millibars (mb), standard atmospheres, or kilopascals.

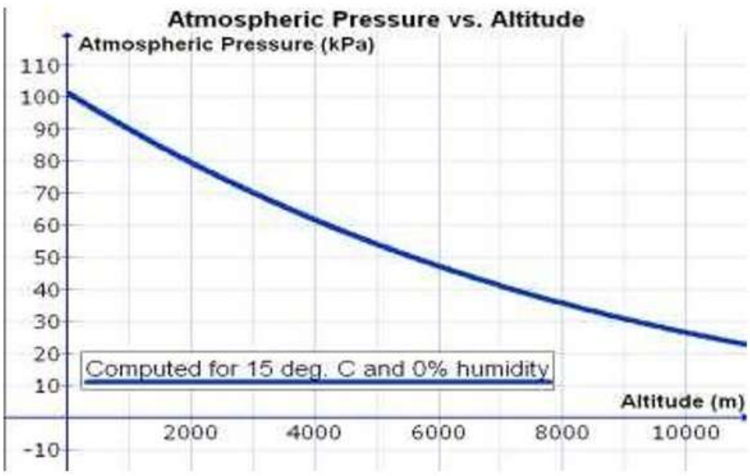
Atmospheric temperature

In the Earth's atmosphere, temperature varies greatly at different heights relative to the Earth's surface. The coldest temperatures lie near the mesopause, an area approximately 80 km above the surface. In contrast, some of the warmest temperatures can be found in the thermosphere, which receives strong ionizing radiation. Temperature varies as one moves vertically upwards from the Earth's surface. It also depends on the change of latitude.



Atmospheric density
The density of air is the mass per unit volume of Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature and humidity. At sea level and at 15 °C air has a density of

approx imatel y 1.225
kg/m3 (1.225 x10−3
g/cm3, 0.0023
769 slu g/(cu ft), 0.0765
lb/(cu ft)) according to ISA (International Standard Atmosphere).



PRESSURE MEASURING DEVICE AND SYSTEM
In many of the systems associated with the operation of aircraft and engines, liquids and gases are used the pressures of which must be measured and indicated. The gauges and indicating systems fall into twomain categories: (i) direct-reading, or those to which the source of pressure is directly connected, and (ii) remo te-indicating, or those having a separate sensing element connected to a pressure source at some remote point