MRCETCAMPUS

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(AUTONOMOUSINSTITUTION–UGC,GOVT.OFINDIA)

Department of AERONAUTICAL ENGINEERING

AIRCRAFT SYSTEMS

B.TECH(R-22Regulation)

(IV YEAR – I SEM)

(2025-26)

Prepared by:
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DEPARTMENT OF AERONAUTCAL ENGINEERING

MALLAREDDYCOLLEGEOFENGINEERING&TECHNOLO GY

(AutonomousInstitution–UGC,Govt.ofIndia)

Recognizedunder2(f)and12(B)ofUGCACT1956
(AffiliatedtoJNTUH,Hyderabad,Approved by AICTE-AccreditedbyNBA&NAAC – 'A'Grade-ISO9001:2015 Certified)
Maisammaguda,Dhulapally(PostVia.Hakimpet),Secunderabad–500100,TelanganaState,India

DEPARTMENT OF AERONAUTICAL ENGIERRING

Vision

- Department of Aeronautical Engineering aims to be indispensable source in Aeronautical Engineering which has a zeal to provide the value driven platform for the students to acquire knowledge and empower themselves to shoulder higher responsibility in building a strong nation..

Mission

- The primary mission of the department is to promote engineering education and research. To strive consistently to provide quality education, keeping in pace with time and technology. Department passions to integrate the intellectual, spiritual, ethical, and social development of the students for shaping them into dynamic engineers.

QUALITY POLICY

- Impart up-to date knowledge to the students in Aeronautical area to make them quality engineers. Make the students experience the applications on quality equipment and tools. Provide systems, resources, and training opportunities to achieve continuous improvement. Maintain global standards in education, training, and services.

PROGRAM OUTCOMES
(PO's)

Engineering Graduates will be able to:

- Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
- Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
- Design / development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal and environmental considerations.
- Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
- Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
- The engineer and society: Apply reasoning in formed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
- Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

- Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

- Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

- Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.

- Life- long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

IV Year B.TECH–I-SEM ANE **L/T/P/C**
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(R22A2116) AIRCRAFT SYSTEMS AND INSTRUMENTATION

OBJECTIVE:

- To impart knowledge of the hydraulic and pneumatic systems components and types of instruments and its operation including navigational instruments to the students
- Develop a solid foundation in aircraft instrumentation, including power activation systems, flight control systems, auto pilot and flyby wire systems
- To gain solid undertaking on engine systems, fuel systems, lubricating systems and ignition systems.
- To impart knowledge on Air conditioning and pressurization systems

UNIT I AIRCRAFTSYSTEMS

Hydraulic systems – Study of typical systems – components – Hydraulic systems controllers – Modesofoperation–Pneumaticsystems–Workingprinciples–TypicalPneumaticPowersystem Brake system – Components, Landing Gear Systems – Classification – Shock absorbers – Retractive mechanism.

UNIT II AIRPLANE CONTROL SYSTEMS

Conventional Systems – Power assisted and fully powered flight controls – Power actuated systems–Engine control systems–Push pull rod system–operating principles–Modern control systems–Digital fly by wire systems–Autopilot system, Active Control Technology.

UNIT III ENGINE SYSTEMS

Piston and Jet Engines- Fuel systems – Components - Multi-engine fuel systems, lubricating systems — Starting and Ignition systems.

UNIT IV AIR CONDITIONING AND PRESSURIZING SYSTEM

Basic Air Cycle systems – Vapour Cycle Systems, Boot-strap air cycle system – Evaporative vapour cycle systems – Evaporation air cycle systems – Oxygen systems – Fire extinguishing system and smoke detection system, Deicing and anti – icing system.

UNIT V AIRCRAFT INSTRUMENTS

Flight Instruments and Navigation Instruments – Accelerometers, Air speed Indicators – Mach Meters – Altimeters - Gyroscopic Instruments– Principles and operation – Study of various types of engine instruments–Tachometers–Temperature and Pressure gauges.

TEXTBOOKS

1. Mekinley, J.L.andR.D. Bent, Aircraft Power Plants, McGrawHill1993.
2. Pallet, E.H.J.Aircraft Instruments &Principles, Pitman &Co 1993.

REFERENCES

1. Handbooks of Airframe and Power plant Mechanics, US dept. of Transportation, Federal, Aviation Administration, the English Book Store, New Delhi,1995.
2. McKinley, J.L. and BentR.D. Aircraft Maintenance &Repair,McGrawHill,1993.
3. Teager, S, “Aircraft Gas Turbine technology, McGrawHill1997.

OUTCOMES: Students can able to

- Compare the features of various flight control systems.
- Describe the principle and working of different aircraft systems.
- Analyze the performance of various aircraft engine systems.
- Acquire and interpret data from various aircraft instruments.
- Identify the various cockpit controls.

UNIT 1:

Hydraulics is a division of the science of fluid mechanics that includes the study of liquids and their physical characteristics, both at rest and in motion. The type of hydraulics applied to aircraft and other aerospace-vehicle systems is called power hydraulics because it involves the application of power through the medium of hydraulics.

Hydraulic Terms It is necessary to understand the exact meaning of hydraulic terms in order to understand hydraulic principles and their application to hydraulic systems. These terms are defined as follows.

- Area: is a measurement of a surface. In aircraft hydraulics the technician is concerned withtheareasofpistonheads.Knowingthisarea,theamountofforcerequiredto actuate a mechanism can be determined.
- Force: Is the amountof push,pull, or twist on an object. The force in a hydraulic system is derived from the pressure acting on the area of a piston head. To measure the force of hydraulics, we must be able to determine force per unit area. This is called pressure and is measured in pounds per square inch (psi) or kilopascals (kPa).
- Stroke: Stroke (length) is a measurement of distance & It represents the distance a piston moves in a cylinder.
- Volume: Volume (displacement) is a mesure of quantity, which represents the amount of fluid contained in a reservoir ordisplaced by a pump or actuating cylinder.
- Fluid: is any substance that is liquid or gaseous in form. A liquid isa fluidwhoseparticles form a definite volume.The term
- Hydraulic fluid: is used in this text as the common name for the fluid used in aircraft hydraulic systems and devices.

Liquids are regarded as being incompressible. This means that the volume of a givenquantityof a liquid will remain constant even though it is subjected to high pressure. Because of this characteristic,itis easy to determine the volume of hydraulic fluid required to move a piston through its operating range. The volume of the cylinder through which the piston moves is equal to the area of the piston head multiplied by the length of the cylinder. The area of the piston head is determined by the formula

Hydraulic fluids and other liquids expand as temperature increases; therefore, safeguards must be provided in hydraulic systems to allow for the expansion and contraction of fluid as temperature changes. Liquid seeks its own level

A basic principle of hydraulics is expressed in Pascal's law.

Pascal's Law: Pascal law states that pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part.

Viscosity: When liquids are in motion, certain dynamic characteristics must be taken in to consideration. One of the principal factors in liquid motion is friction.

Friction exists between the molecules of the liquid and between the liquid and the pipe through which it is flowing. The effects of friction increase as the velocity of liquid flow increases.

One of the most important properties of any hyd. Fluid is its viscosity .Viscosity is internal resistance to flow. A Viscosity increases with temperature decreases. A satisfactory liquid for a given hyd. Sys must have enough body to give a good seal at pumps, valves, & piston But it must not be so thick that it offers resistance of low, landing to power loss & higher operating temperature. Viscosity of liquid measured by viscoimeter & viscometer .

Types of Hydraulic Fluids:

Thereare3typesofHydraulicFluidsusedincivilaircraft. 1].

Vegetable Base hyd. Fluid

2].Mineral Base hyd.Fluid

3].Phosphateester-Basehyd.Fluid

1]. Vegetable Base hyd. Fluid- (MIL-H-7644):- Mixture of castor oil & alcohol .It is highly inflammable .It is dyed Blue in color ,Natural rubberseals are used with veg. base fluid . it is used in oldera/c.

2].MineralBasehyd.Fluid-(MIL-H-5606):-consistofahighqualitypetroleumoil.

They are used in many systems, especially where the fire hazard is comparatively low. Small aircraft that have hydraulic power systems for operating wheel brakes, flaps, and landing gear usually use mineral fluid .Mineral base fluids are less corrosive and less damaging to certain parts than other types of fluid.

3]. Phosphate ester-Base hyd. Fluid:- utilized in most transport category aircraft are very fire resistant. Although phosphate ester fluids are extremely fire resistant, they are not fireproof. Under certain conditions phosphate ester fluids will burn.

Itisclassifiedin2classes:

Class 1-Skydrol L-D: A clear purple low weight fluid It is used in large Jumbojet transport a/c where0weight has prime factor.

Class 2- Skydrol 500-B: a clear purple lquid having good low temp. operating characteristics & lowcorrosive side effects .Skydrol is compatible with natural fibers & synthetic including nylon & polyester .

Hydraulic power is used to transferring power from small low energy movements in the cockpit to high energy demands in the aircraft. Hydraulic systems now have an important role to play in all modern aircraft, both military and civil aircraft.

The introduction ofpowered flying controls by using hydraulic power by which the pilot was able tomove the control surfaces with every increasing speeds and demands with less effort.

The system consists of multiple pumps, accumulators to store energy, reservoir, pipelines and actuators and solenoid valves. The hydraulic system today remains a most effective source of power for both primary andsecondary flying controls,and for undercarriage, braking and anti-skid systems.

DesignRequirements

- The principal requirements are low weight, low volume, low initial cost, high reliability and low maintenance.
- The pipe diameters should be less and able to bend themselves to flexibility of installation and end fittings should not give any leakage,
- Theuseofoilas theworkingfluidprovidesahighdegreeoflubrication,and thesystem overloads can be withstood without damage.
- Withinthelimitsoftheirstructuralstrength,actuatorscanstallandinsomecasesactually reverse direction.
- TheworkingFluidshouldreturntoreservoironremovaloftheoverload

Inadditionthefollowingarethesomeparametersneedstounderstandbeforedesigninghydraulic system.

- ***Pressure*** – Whatwill be the primary pressure ofthesystem?This will be determined by the appropriate standards and the technology of the system .

- ***Integrity*** – Is the system critical towards flight safety or can its loss or degradation be tolerated? This determines the number of independent sources of hydraulic power that must be provided, and determines the need for a reversionary source of power.

- ***Flow rate*** – What is the rate of the demand, in angular or linear motion per second, or in liters per second in order to achieve the desired action?

- ***Duty cycle*** – What is the ratio of demand for energy compared to quiescent conditions. This will be high for continuously variable demands such as primary flight control actuation on an unstable aircraft (throughout the flight), whereas it will be low for use as a source of energy for undercarriage lowering and retraction (twice per flight)

• ***Emergency orreversionary use*** – Are there any elements of the system that are intended to provide a sourceof power under emergencyconditions for otherpowergeneration systems?Anexampleof thisis a hydraulic powered electrical generator. Is there a need for a source of power in the event of main engine loss to provide hydraulic power which will demand the use of reversionary devices?

• ***Heat load and dissipation*** – The amount of energy or heat load that the components of the system contribute to hydraulic fluid temperature .

Typesofcomponentsrequiredfordesigninghydraulicsystem

• Asourceofenergy–engine,auxiliarypowerunitorramairturbine

• Areservoir-Tank

• Afiltertomaintaincleanhydraulicfluid

• Amultipleredundantdistributionsystem–pipes,valves,shut-offcocks

• Pressureandtemperaturesensors

• Amechanismforhydraulicoilcooling

• Ameansofexercisingdemand–actuators,motors,pumps

• Ameansofstoringenergysuchasanaccumulator

These requirements together with the type of aircraft, determine the design of a hydraulicsystem. When startingthe design of any new hydraulic systemthe engineer must first determine the functions to be performed, and secondly he must assess their importance to flight safety. Thus lists of functionsare Based on functional severity primary flight controls are critical to flight safety and no single failures can be allowed to prevent, or even momentarily interrupt their operation.

The secondary flight controls, are, flaps and slats, spoilers, airbrakes and stabilizer trim tabs. Other functions, commonly known as ‘services’ or ‘utilities’, may be considered expendable after a failure, or may needed to operate in just one direction after a positive emergency selection by the pilot.

HydraulicFluidProperties

The working fluid will be considered as a physical medium for transmitting power, and the conditions under which it is expected to work, for example maximum temperature and maximum flow rate are described. Safety regulations bring about some differences between military and civil aircraftfluids. The popular mineral based fluid in use are:

• MIL-H-5606intheUSA

• AIR320inFrance

• H515NATO

Thisfluidhasmany advantages.

It is freely available throughout the world, reasonably priced, and has a low rate of change of viscosity with respect to temperature compared to other fluids. These fluids are not fireproof – there are certain combinations of fluid spray and hot surfaces which will allow them to ignite and burn. Industry standard tests are conducted to demonstrate a level of confidence that ignition or fire will not occur and the hydraulic system design is influenced by these test results.

OperatingFluidPressure

Systems should maintain standard pressure of 3000 psi or 4000 psi. These have been chosen to keep weight to a minimum. Many studies have been undertaken by industry to raise the standard working pressure. Pressure targets have varied from 5000 psi to 8000 psi, and all resulting systems studies claim to show reduced system component mass and volume. Interestingly DTD 585 cannot be usedabove 5000 psi because of shear breakdown within the fluid. A detailed study would show that the optimum pressure will differ for every aircraft design. This is obviously impractical and would preclude the common use of well-proven components and test equipment.

OperatingFluidTemperature

With fast jet aircraft capable of sustained operation above Mach 1, there are advantages in operating the system at high temperatures, but this is limited by the fluid used. For many years the use of DTD 585 has limited temperatures to about 130°C, and components and seals have been qualified accordingly. The use of MIL-H-83282has raised thislimitto200°C and many other fluids have been used from time to time.

A disadvantage to operating at high temperatures is that phosphate ester based fluids can degrade as a result of hydrolysis and oxidation. As temperature increases, so the viscosity of the fluid falls. At some point lubricity will be reduced to the extent that connected actuators and motors may be damaged

FunctionsasillustratedinFigure1.1mayappearas:

- **Primaryflightcontrols:**
  - ✓ Elevators
  - ✓ Rudders
  - ✓ Ailerons
  - ✓ Canards

- **Secondaryflightcontrols:**Flaps
  - ✓ Slats
  - ✓ Spoilers
  - ✓ Airbrakes
- **Utilitysystems:**
  - ✓ Undercarriage–gearanddoors
  - ✓ Wheelbrakesandanti-skid
  - ✓ Parkingbrake
  - ✓ Nosewheelsteering
  - ✓ In-flightrefuellingprobe
  - ✓ Cargodoors
  - ✓ Loadingramp
  - ✓ Passengerstairs
  - ✓ Bombbaydoors
  - ✓ Gunpurgingscoop
  - ✓ CanopyActuation

❑ **Primary Flight Controls:**

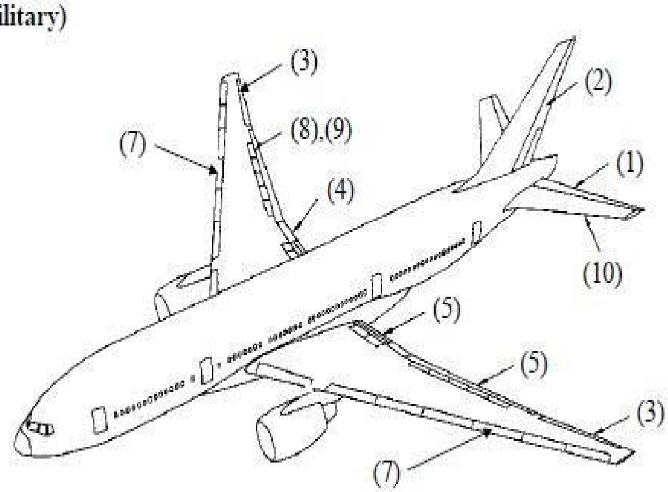
- -Elevators – (1)
- -All-moving tail surfaces (military)
- -Rudders – (2)
- -Ailerons – (3)
- -Flaperons – (4)
- -Canards

❑ **Secondary Flight Controls**

- -Flaps – (5)
- -Slats – (7)
- -Spoilers – (8)
- -Airbrakes – (9)
- -Stabilizer trim – (10)

❑ **Utilities**

- -Landing gear
- -Brakes
- -Gear steering
- -Aerial refueling probes (military)
- -Cargo doors
- -Loading ramp (military)
- -Passenger stairs



BasicHydraulicSystem: Themainpartsofthebasichydraulicsystemareasgivenasfollows:

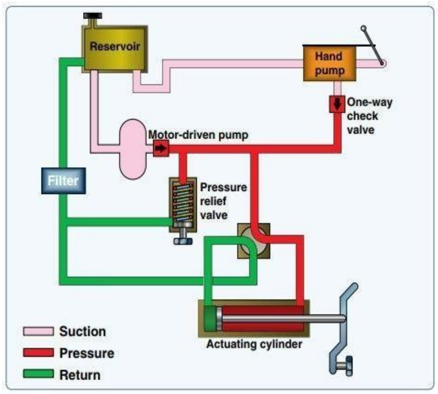


Figure1.4:BasicHydraulicSystems

Components

I. Accumulator:

The accumulator is a steel sphere divided into two chambers by a synthetic rubber diaphragm. The upper chamber contains fluid atsystem pressure,while thelower chamberis charged with nitrogen or air. Cylindrical types are also used in high-pressure hydraulic systems.Manyaircraft have several accumulators in the hydraulic system. There may be a main system accumulator and an emergency system accumulator. There may also be auxiliary accumulators located in various sub-systems.

It may be found that the absolute maximum flow demand is of very short duration, involving verysmall volumesofoil at veryhighvelocities. Inthis case sizing apump to meet thisdemand may notbe justified. An accumulator canbe used toaugmentthe flow available,butcare must be taken. An accumulator contains a compressed gas cylinder, and the gas is used to provide energy to augment system pressure. Therefore, the fluid volume and pressure available will dependon thegas temperature. Ina situationwhere theflowdemandedwill exceedthepump capabilities the system pressureis controlled by the accumulator, not the pump.

Thefunctionofanaccumulatoris to:

- Dampenpressure surges inthe hydraulicsystem causedby actuationof a unitand the effort of the pump to maintain pressure at a preset level.
- Aidorsupplementthepowerpumpwhenseveralunitsareoperatingatonceby supplying extra power from its accumulated, or stored, power.

- Store power for the limited operation of a hydraulic unit when the pump is not operating.
- Supply fluid under pressure to compensate for small internal or external (not desired) leaks that would cause the system to cycle continuously by action of the pressure switches continually kicking in.

TypesofAccumulators

Therearetwogeneraltypesofaccumulatorsusedinaircrafthydraulicsystems:

1. Cylindrical: Cylindrical accumulators consist of a cylinder and piston assembly. End caps are attached to both ends of the cylinder. The internal piston separates the fluid and air/nitrogen chambers. The end caps and piston are sealed with gaskets and packings to prevent external leakage around the end caps and internal leakage between the chambers. In one end cap, a hydraulic fitting is used to attach the fluid chamber to the hydraulic system. In the other end cap, a filler valve is installed to perform the same function as the filler valve installed in the spherical accumulator. [Figure 2]

Figure2.Cylindrical accumulator

2. Spherical: Thespherical-typeaccumulatorisconstructedintwohalvesthatarefastenedand threaded, or welded, together. Two threaded openings exist. The top port accepts fittings to connect to the pressurized hydraulicsystem tothe accumulator. The bottom portis fitted with a gas servicing valve, such as a Schrader valve.

A synthetic rubber diaphragm, or bladder, is installed in the sphere to create two chambers. Pressurized hydraulic fluid occupies the upper chamber and nitrogen or air charges the lower chamber. A screen at the fluid pressure port keeps the diaphragm, or bladder, from extruding through the port when the lower chamber is charged and hydraulic fluid pressure is zero.

A rigid button or disc may also be attached to the diaphragm, or bladder, for this purpose. [Figure 1] The bladder is installed through a large opening in the bottom of the sphere and is securedwith a threaded retainer plug. The gas servicing valve mounts intothe retainer plug.

Figure1.Asphericalaccumulatorwithdiaphragm(left)andbladder(right).

Operation:

In operation, the compressed-air chamber is charged to a predetermined pressure that is somewhat lower than the system operating pressure. This initial charge is referred to as the accumulator preload. As an example of accumulator operation, let us assume that the cylindrical accumulator is designed for a preloadof 1,300 psi in a 3,000-psi system.

When the initial charge of 1,300 psi is introduced into the unit, hydraulic system pressure is zero. As air pressure is applied through a gas servicing valve, it moves the piston toward the opposite end until it bottoms. If the air behind the piston has a pressure of 1,300 psi, the hydraulic system pump has to create a pressure within the system greater than 1,300 psi before the hydraulic fluid can actuate the piston. At 1,301 psi the piston starts to move within the cylinder, compressing the air as it moves. At 2,000 psi, it has backed up several inches. At 3,000 psi, thepiston hasbacked up to its normal operating position, compressing the air untilit occupies a space less than one-half the length of the cylinder. When actuation of hydraulic units lowers the system pressure, the compressed air expands against the piston, forcing fluid from the accumulator. This supplies an instantaneous supply of fluid to the hydraulic system component. The charged accumulator may also supply fluid pressure to actuate a component(s) briefly in case of pump failure.

MaintenanceofAccumulators

Maintenance consists of inspections, minor repairs, replacement of component parts, and testing. There is an element of danger in maintaining accumulators. Therefore, proper precautions must be strictly observed to prevent injury and damage.

Before disassembling any accumulator, ensure that all preload air (or nitrogen) pressure has been discharged. Failure to release the preload could result in serious injury to the technician. Before making this check, be certain you know the type of high-pressure air valve used. When youknow thatallairpressurehasbeen removed,you cantake the unitapart.Besure to follow manufacturer’s instructions for the specific unit you have.

II. Hydraulic Pipelines:

When the system architecture is defined for all aircraft systems using hydraulic power, then itis possible to design the pipe layout in the aircraft. This layout will take into account the need to separate pipes to avoid common mode failures as a result ofaccidental damage orthe effect of battle damage in a military aircraft. Once this layout has been set, it is possible to measure thelengths of pipe and to calculate the flow rate ineach section and branch of pipe.

It is advisable that the first attempts to define a layout will result in straight lines only, but this is adequate for a reasonably accurate initial calculation. If an allowable pressure drop of 25% has been selected throughout the system, this may now be further divided between pressure pipes, return pipes and components. The designer will eventually control the specifications for the components, and in this sense he can allocate any value he chooses for pressure drop across each component. Once pipe lengths, flow rates and permissible pressure drops are known, pipediameters can becalculated using the normal expression governing friction flow in pipes. It is normal to assume a fluid temperature of 0° C for calculations, and in most cases flow in aircraft hydraulic systems is turbulent.

III. HydraulicPumps:

A system will contain one or more hydraulic pumps depending on the type of aircraft .The pump is normally mounted on an engine-driven gearbox. In civil applications the pump is mounted on an accessory gearbox mounted on the engine casing. For military applications the pump is mounted onan Aircraft Mounted Accessory Drive (AMAD) mounted on the airframe.

The pump speed is therefore directly related to engine speed, and must therefore be capable of working over a wide speed range. The degree ofgearing between the pump and the engine varies between engine types.

The universally used pump type is known as variable delivery, constant pressure. Demand on thepumptends tobe continuous throughoutaflight,butfrequentlyvaryinginmagnitude.This typeofpump makesitpossibletomeet thissort ofdemandpatternwithouttoomuch wastage of power. Within the flow capabilities of these pumps the pressure can be maintained within 5% of nominal except during the short transitional stages from low flow to high flow. This also helps to optimise the overall efficiency of the system.

The pumps are designed to sense outlet pressure and feed back this signal to a plate carrying the reciprocating pistons. The plate is free to move at an angle to the longitudinal axis of the rotating drive shaft. There are normally nine pistons arranged diametrically around the plate. Thepositionoftheplatethereforevariestheamountofreciprocatingmovementofeach piston. Examples of different types of hydraulic pump are shown in Figures 4.8 together with their salient characteristics.

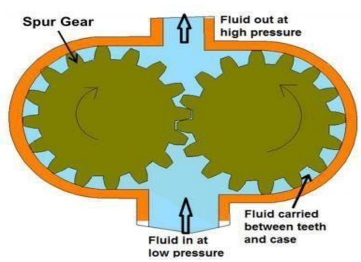
ClassificationofHydraulicPumps: Thesearemainlyclassifiedintotwocategoriesaccordingto thedisplacement:

A. Non-positivedisplacementpumpsB.Positivedisplacementpumps.

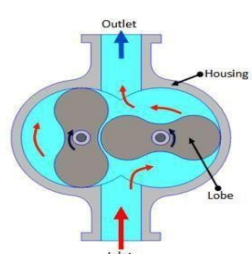
- ✓ **Non-Positive Displacement Pumps:** These pumps are also known as hydro-dynamic pumps. In these pumps the fluid is pressurized by the rotation of the propeller and the fluid pressure is proportional to the rotor speed. These pumps can not withstanding high pressures and generally used for low-pressure and high-volume flow applications. The fluid pressure and flow generated due to inertia effect of the fluid.The fluid motion is generated due to rotating propeller. These pumps provide a smooth and continuous flow but the flow output decreases with increase in system resistance (load). The flow output decreases because some of the fluid slip back at higher resistance. The fluid flow is completely stopped at very large system resistance and thus the volumetric efficiency will become zero. Therefore, the flow rate not only depends on the rotationalspeed but also on the resistance provided by the system. The important advantages of non-positive displacement pumps are lower initial cost, less operating maintenance because of less moving parts, simplicity of operation, higher reliability and suitability with wide range of fluid etc
- ✓ **Positive displacementpump:** These pumps deliver a constant volume of fluid in a cycle. The discharge quantity per revolution is fixed in these pumps and they produce fluid flow proportionalto their displacement and rotor speed.Thesepumps are usedin mostof the industrial fluid power applications. The output fluid flow is constant and is independent of the system pressure (load).The important advantageassociated with these pumps is that the high-pressure and low-pressure areas (means input and output region) are separated and hence the fluid cannot leak back due to higher pressure at the outlets. These features make the positive displacement pump most suited and universally accepted for hydraulic systems. The important advantages of positive displacement pumps over non-positive displacement pumps include capability to generate high pressures, high volumetric efficiency, high NPTEL – Mechanical – Mechatronics and Manufacturing Automation Joint initiative of IITs and IISc – Funded by MHRD Page 10 of 63 power to weight ratio, change in efficiency throughout the pressure range is small andwider operating range pressure and speed.
- ✓ **Gear Pump:** Gear pump is a robust and simple positive displacement pump. It has two meshed gears revolving about their respective axes. These gears are the only moving parts in the pump. They are compact, relatively inexpensive and have few moving parts. The rigid design of the gears and houses allow for very high pressures and the ability to pump highly viscous fluids. They are suitable for a wide range of fluids and offerself-primingperformance.Sometimesgearpumpsaredesignedtofunctionas

either a motor or a pump. These pump includes helical and herringbone gear sets (insteadofspur gears),lobeshaped rotorssimilartoRootsblowers(commonlyusedas superchargers), and mechanical designs that allow the stacking of pumps. Based upon the design, the gear pumps are classified as:

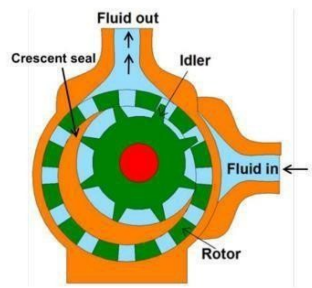
• **External gear pumps :** External gear pump The external gear pump consists of externally meshed two gears housed in a pump case as shown in figure 5.2.1. One of the gears is coupled with a prime mover and is called as driving gear and another is called as driven gear. The rotating gear carries the fluid from the tank to the outlet pipe. The suction side is towards the portion whereas the gear teeth come out of the mesh. When the gears rotate, volume of the chamberexpands leading to pressure drop below atmospheric value. Therefore the vacuum is created and the fluidispushed into the void due to atmospheric pressure. The fluid is trapped between housing and rotating teeth of the gears. The discharge side of pump is towards the portion where the gear teeth run into the mesh and the volume decreases between meshing teeth. The pump has a positive internal seal against leakage; therefore, the fluid is forced into the outlet port.



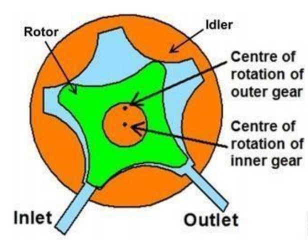
• **Lobe pumps:** Lobe pumps work on the similar principle of working as thatof external gear pumps. However in Lobe pumps, the lobes do not make any contact like external gear pump (see Figure 5.2.3). Lobe contact is prevented by external timing gears located in the gearbox. Similar to the external gear pump, the lobes rotate to create expanding volume at the inlet. Now, the fluid flows into the cavityand is trapped by the lobes. Fluid travels around the interior of casing in the pockets between the lobes and the casing. Finally, the meshing of the lobesforces liquid to pass through the outlet port. The bearings are placed out of the pumped liquid. Therefore the pressureis limited by the bearing location and shaft deflection.



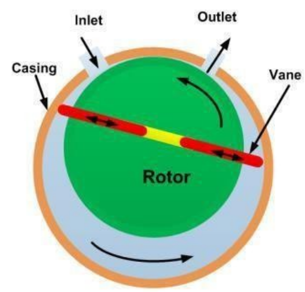
• **Internal gear pumps:** Internal gear pumps are exceptionally versatile. They are often used for low or medium viscosity fluids such as solvents and fuel oil and wide range of temperature. This is nonpulsing, self-priming and can run dry for short periods. It is a variationofthe basicgearpump.It comprisesof aninternal gear,aregularspurgear, a crescent-shaped seal and an external housing. The schematic of internal gear pump is shown in figure 5.2.4. Liquid enters the suction port between the rotor (large exterior gear) and idler (small interiorgear) teeth. Liquid travels through the pump between the teeth and crescent. Crescent divides the liquid and acts as a seal between the suctionanddischargeports.When the teethmeshon thesideopposite tothe crescent seal, the fluid is forced out through the discharge port of the pump. This clearance between gears can be adjusted to accommodate high temperature, to handle high viscosity fluids and to accommodate the wear. These pumps are bi-rotational so that they can be used to load and unload the vessels.



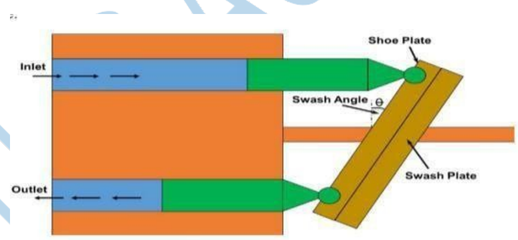
- **Gerotorpumps:** Gerotorisapositivedisplacementpump.ThenameGerotorisderived from"Generated Rotor".Atthe most basic level, a Gerotor is essentially one that ismovedvia fluid power. Originally this fluid waswater,today the wider use is in hydraulic devices.The schematic ofGerotorpump is shown in figure 5.2.5.Gerotor pump isaninternal gearpump without the crescent. It consists of tworotors viz. inner and outer rotor. The inner rotor has N teeth, and the outer rotor has N+1 teeth. The innerrotorislocatedoff-centerandbothrotorsrotate.Thegeometryofthetwo rotors partitions the volume between them into N different dynamically-changing volumes. During the rotation, volume ofeach partition changes continuously.



- **Vane pumps:** Vane pumps generate a pumping action by tracking of vanes along the casing wall. The vane pumps generally consist of a rotor, vanes, ring and a port plate with inlet and outlet ports.The rotorin a vane pump is connected to the prime mover through a shaft. The vanes are NPTEL – Mechanical – Mechatronics and Manufacturing Automation Joint initiative of IITs and IISc – Funded by MHRD Page 17 of 63 located on the slotted rotor.



- **Piston pump:** Piston pumps are meant for the high-pressure applications. These pumps have highefficiency and simple design and needs lower maintenance. These pumps convert the rotary motion of the input shaft to the reciprocating motion of the piston. These pumps work similar to the four stroke engines. They work on the principle that a reciprocating piston draws fluidinside the cylinderwhen the piston retracts in a cylinder boreanddischargethe fluidwhenitextends.Generally,thesepumps havefixedinclined plate or variable degree of angle plate known as swash plate (shown in Figure 5.3.5 and Figure 5.3.6). When the piston barrel assembly rotates, the swash plate in contact with the piston slippers slides along its surface. The stroke length (axial displacement) depends on the inclination angle of the swash plate. They are of two types axial and radial



IV. HydraulicReservoir(tank):

A hydraulic reservoir is a tank or container designed to store sufficient hydraulic fluid for all conditions of operation. Usually the hydraulic reservoir must have the capability of containing extra fluid not being circulated in the system during certain modes of operation. When accumulators, actuating cylinders, and other units do not contain their maximum quantities of fluid, the unused fluid must be stored in the reservoir. On the other hand, when a maximum amount of fluid is being used in the system, the reservoir must still have a reserve adequate to meet all requirements. Reservoirs in hydraulic systems that require a reserve of fluid for the emergency operation of landing gear, flaps, etc., are equipped with standpipes. During normal operation, fluid is drawn through the stand pipe. When system fluid is lost, Emergency fluid is drawn from the bottom of the tank. Reservoirs are not designed to be completely filled; they must allow for an air space above the fluid level to allow for expansion of the fluid when it is headed during system operation. Reservoir will provide some means of checking the fluid level andofbeing replenished. The quantity-indicating methodmay be nothing more thanadipstick on the filler cap, or it may consist of a remote indicating system that displays the quantity on the aircraft flight deck.

The requirements for this tank vary depending on the type of aircraft involved. For most military aircraft the reservoir must be fully aerobatic. This means that the fluid must be fully contained, with no air/fluid interfaces, and a supply of fluid must be maintained in all aircraft attitudes and g conditions. In order to achieve a good volumetric efficiency from the pump, reservoir pressure must be sufficient to accelerate a full charge of fluid into each cylinder while it is open to the inlet port.

The volume of the reservoir is controlled by national specifications and includes all differential volumesin the system, allowance for thermal expansion anda generous emergency margin.

Itis common practice to isolate certain parts of the system when the reservoir level falls below a predetermined point. This is an attempt to isolate leaks within the system and to provide further protection for flight safety critical subsystems. The cut-off point must ensure sufficient volume for the remaining systems under all conditions. The reservoir will be protected by a pressure relief valve which can dump fluid overboard.

Reservoirs can be broken down into two basic types,

- ✓ In-line: In-line reservoirs are those that are separate components in the hydraulic system. This is the most common type of reservoir. These can be pressurized or unpressurized. Unpressurized reservoirs are normally used in aircraft flying at lower altitudes, such as below 15000 ft [4583 m], UI whose hydraulic systems are limited to those associated with ground operations, such as brakes. Pressurized reservoirs are commonly found in aircraft designed for high-altitude flight where atmospheric pressure is low. The most basic rule of hydraulics states that fluid cannot be pulled; it can only be pushed. At sea level the 14.7 psi of atmosphere provides the force to push the fluid from the reservoir to the pump. As altitude increases, atmospheric pressure decreases. With little or no pressure on the fluid, it tends to foam, causing air bubbles to form in the low part of the system. When an aircraft is operating at high altitudes, the pump will be starved for fluid unless some means of pressurization is used. Therefore, to provide a continuous supply of fluid to the pumps, the reservoir is pressurized.
- ✓ Integral: Integral reservoirs are combined with the hydraulic pump. These types of reservoirs are often found in small aircraft, where the compact arrangement of this type of mechanism is desirable. An example of this is the brakemaster cylinder used

with manylight-aircraftsystems.theupperportionof theassemblyservesasthe reservoir and the lower portion serves as the pump to operate the brake.

And these can be further classified as

- ✓ pressurized
- ✓ Unpressurized.

V. Control Valves: In a hydraulic system, the hydraulic energy available from a pump is converted into motion and force by means of an actuator. The control of these mechanical outputs (motion and force) is one of the most important functions in a hydraulic system. The proper selection of control selection ensures the desired output and safe function of the system. In order to control the hydraulic outputs, different types of control valves are required. It is important to know various types of control valves and their functions. This not only helps to design a proper hydraulic system but also helps to discover the innovative ways to improve the existing systems.

There are basically three types of valves employed in hydraulic systems:

1. Directional control valves: Directional control valves are used to control the distribution of energy in a fluid power system. They provide the direction to the fluid and allow the flow in a particular direction. These valves are used to control the start, stop and change in direction of the fluid flow. These valves regulate the flow direction in the hydraulic circuit. These control valves contain ports that are external openings for the fluid to enter and leave. The number of ports is usually identified by the term 'way'. For example, a valve with four ports is named as four-way valve. The fluid flow rate is responsible for the speed of actuator (motion of the output) and should controlled in a hydraulic system. This operation can be performed by using flow control valves. The pressure may increase gradually when the system is under operation. The pressure control valves protect the system by maintaining the system pressure within the desired range. Also, the output force is directly proportional to the pressure and hence, the pressure control valves ensure the desired force output at the actuator.

Directional control valves can be classified in the following manner:

1. Type of construction:
   - Poppet valves
   - Spool valves
2. Number of ports:
   - Two-way valves
   - Three–way valves
   - Four-way valves.
3. Number of switching position:
   - Two–position
   - Three-position

4. Actuating mechanism:
- Manual actuation
- Mechanical actuation
- Solenoid actuation
- Hydraulic actuation
- Pneumatic actuation
- Indirect actuation

Check Valves

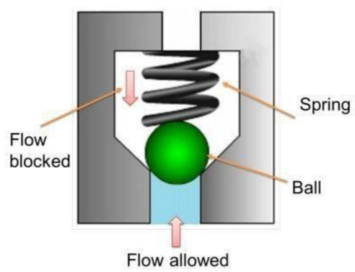


Figure: Inline check valve

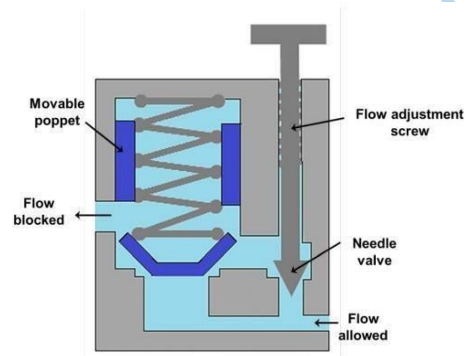


Figure: Restriction check valve

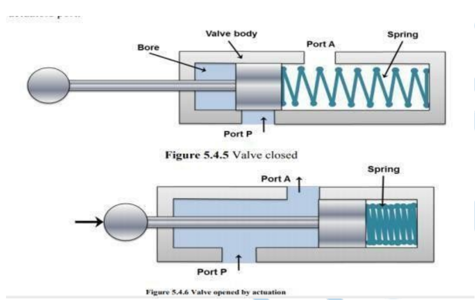


Figure: Valve Pump

2. Flowcontrolvalves:

3. Pressurecontrolvalves:

VI. WarningsandIndication:

Several instruments are normally situated in the hydraulic power generationsystemto monitor continuously its performance. Pressure transducers monitor system pressure and transmitthissignalto gaugesinthe cockpit.Pressureswitchesarealsoincorporated to provide a warning of low pressure in the system on the central warning panel. Filterblockageindicators show the condition of the filter elements to ground servicing personnel, and a fluid temperature warning may be given to the aircrew.With increasing use of microprocessor based system management units, more in-depth health monitoring of all major components is possible with data displayed to ground crews on a maintenance data panel.

More-ElectricHydraulicSystem

The effects on the hydraulic system of adopting more-electric concepts may be seen by comparing the hydraulic system configurations for the Boeing 767 (conventional Boeing wide body) versus the more-electric Boeing 787 as shown

in Figure 10.8. Boeing have been more conservative regarding the use of centralized aircraft hydraulic systems on the Boeing 787 as opposed to the use ofmore de-centralized systems on the Airbus A380 and certainly Lockheed Martin F-35/JSF. Boeing also use conventional hydraulic actuation in general whereas the Airbus A380 makes considerable use of Electro-Hydrostatic Actuators (EHA), and Electric Backup Hydrostatic Actuators (EBHAs) for primary flight control as described in Chapter 1. Nevertheless Figure 10.8 presents a valid comparison as it effectively contrasts conventional and more electric hydraulic system architectures with one another. Furthermore, it is also a valid size comparison as the 787 family is the directmarket successor to the 767. Both 767 and 787 architectures use the Boeing Left (L), Centre (C),Right (R) hydraulic channel philosophy. The key differences are:

• EnginebleedairisremovedwithdeletionoftheAirDrivenPump(ADP)

• Theuseof5000psiratherthan3000psihydraulicssystem

• Theadoptionof230VAC,three-phase,VFprimarypowerratherthan115VAC,three-phase400HzCF

• Theuseofstarter/generatorsversusgeneratorstofacilitateelectricenginestart

• Use of larger Electric Motor Pumps (EMPs), around four times that of previous units Generally there are also increased levels of electrical power with the Primary channels increasing from 120 KVA to 500 kVA. The levels of power for the Ram Air Turbine (RAT) and the Electric Motor Pumps (EMPs) have also increased dramatically The three channel hydraulic system philosophy is more conservative than the ‘2H+2E’ philosophy adopted on the Airbus A380. On the A380 the blue hydraulic channel has effectively beenreplacedby achannel using distributedelectrically poweredactuationusing EHAsandEBHAs. Both aircraft utilize 5000 psi hydraulic systems. More-Electric Environmental Control System The abolition of bleed air means that electrically driven compressors must be used to pressurize the cabin and provide a source of air for the environmental control system. See Figure In common with mostaircraftof this size, the B787 is fitted with two air-conditioning packs, the difference being that they are electricallypowered. Each pack has two electrically driven motor compressors each controlled byamotor controller located in the aft EE bays. Each permanent magnet motor requires 125kVA ofelectric power to drive it. The outputs from these compressors enter a common manifold before being fed through primary and secondary heat exchangers, cooled by external ram air as would be the case in a conventionally driven Air Cycle Machine (ACM). The resulting cold air is mixed with recirculation air to maintainthedesiredcabintemperature.AlthoughthepowerrequiredbytheelectricECSis considerable, the key advantage is that air is not being extracted from the engine's central core. More importantly,the temperature and pressure of the delivered air is considerably lower.

ExampleofHydraulicsystemofAirbusA320:

The aircraft is equipped with three continuously operating hydraulic systems called Blue, Green and Yellow. Eachsystem has its own hydraulic reservoir as a source of hydraulic fluid.

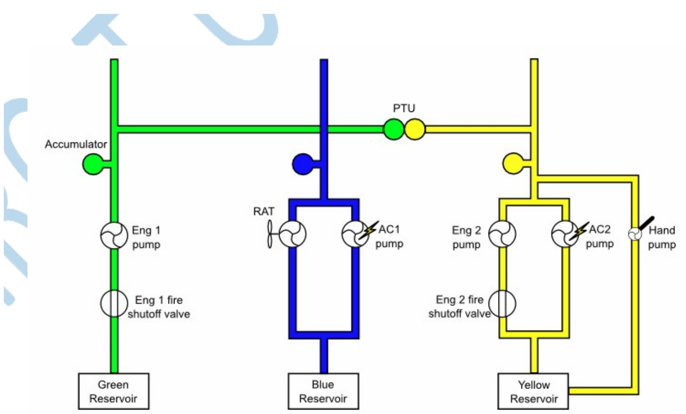
• The Green system (System 1) is pressurised by an Engine Driven Pump (EDP) located on No. 1 engine which may deliver 37 gallon per minute (US gpm) or 140 L/min

• The Blue system (System 2) is pressurised by an electric motor-driven pump capable of delivering 6.1 gpm or 23 L/min. A Ram Air Turbine (RAT) can provide up to 20.6 gpm or 78 L/min at 2175 psi in emergency conditions

• TheYellowsystem(System3)ispressurisedbyan EDP drivenbyNo.2Engine. Anelectricmotor driven pump is provided which is capable of delivering 6.1 gpm or 23L/min for ground servicing operations. This system also has a hand pump to pressurise the system for cargo door operation when the aircraftis on the ground with electrical power unavailable. Each channel has the provision for the supply of ground-based hydraulic pressure during maintenance operations. Each main system has a hydraulic accumulator to maintain system pressure in the eventof transients.

Each system includes a leak measurement valve (shown as L in a square on the diagram), and a priority valve (shown as P in a square).

• The leak measurement valve is positioned upstream of the primary flight controls and is used for the measurement of leakage in each flight control system circuit. They are operated from the ground maintenancepanel



In the event of a low hydraulic pressure, the priority valve maintains pressure supply to essential systems by cutting of the supply to heavy load users The bi-directional Power Transfer Unit (PTU) enables the Green or the Yellow systems to power each other without the transfer of fluid. In flight in the event that only one engine is running, the PTU will automatically operate when Civil Transport Comparison 165 Figure 4.20 Simplified A320 family hydraulic system the differential pressure between the systems is greater than 500 psi. On the ground, while operating the yellow system using the electric motor driven pump, the PTU will also allow the Green system to be pressurized.

The RAT extends automatically in flight in the event of failure of both engines and the APU. In the event of an engine fire, a fire valve in the suction line between the EDP and the appropriate hydraulic reservoir made be closed, isolating the supply of hydraulic fluid to the engine.

Pressure and status readings are taken at various points around the systems which allows the composition of a hydraulic system display to be shown on the Electronic Crew Alerting and Monitoring
(ECAM).

PNEUMATICSYSTEMS

Introduction

The modern turbofan engine is effectively a very effective gas generator and this has led to the use of engine bleed air for a number of aircraft systems, either for reasons of heating, provision of motive power or as a source of air for cabin conditioning and pressurization systems. Bleed air is extracted from the engine compressor and after cooling and pressure reduction/regulation it is used for a variety of functions.

In the engine, high pressure bleed air is used as the motive power – sometimes called 'muscle power' – for many of the valves associated with the bleed air extraction function. Medium-pressure bleed air is used to start the engine in many cases, either using air from a ground power unit, APU or cross bleed from another engine on the aircraft which is already running. Bleed air is also used to provide anti-ice protection by heating the engine intake cowling and it is also used as the motive power for the engine thrust reversers.

On the aircraft, bleed air tapped from the engine is used to provide air to pressurize the cabin and provide the source of air to the cabin conditioning environmental control system. A proportion of bleed air is fed into air conditioning packs which cool the air dumping excess heat overboard; this cool air is mixed with the remaining warm air by the cabin temperature control system such that the passengers are kept in a comfortable environment. Bleed air is also used to provide main wing anti-ice protection.

Bleed air is also used for a number of ancillary functions around the aircraft: pressurizing hydraulic reservoirs, providing hot air for rain dispersal from the aircraft windscreen, pressurizing the water and waste system and so on. In some aircraft Air Driven Pumps (ADPs) are used as additional means of providing aircraft hydraulic power.

Pitot static systems are also addressed in the pneumatic chapter, as although this is a sensing system associated with measuring and providing essential air data parameters for safe aircraft flight, it nonetheless operates on pneumatic principles. Pitot systems have been used since the earliest days of flight using pneumatic, capsule based mechanical flight instruments. The advent of avionics technology led first to centralized Air Data Computers (ADCs) and eventually on to the more integrated solutions of today such as Air Data & Inertial Reference System (ADIRS).

Pneumatic power is the use of medium pressure air to perform certain functions within the aircraft. While the use of pneumatic power has been ever present since aircraft became more complex, the evolution of the modern turbojet engine has lent itself to the use of pneumatic power, particularly on the civil airliner.

The easy availability of high pressure air from the modern engine is key to the use of pneumatic power as a means of transferring energy or providing motive power on the aircraft. The turbojet engine is in effect a gas generator where the primary aim is to provide thrust to keep the aircraft in the air. As part of the turbojet combustion cycle, air is compressed in two or three stage compressor sections before fuel is injected in an atomized form and then ignited to perform the combustion process. The resulting expanding hot gases are passed over turbine blades at the rear of the engine to rotate the turbines and provide shaft power to drive the LP fan and compressor sections. When the engine reaches selfsustaining speed the turbine is producing sufficient shaft power to equal the LP fan/compressor requirements and the engine achieves a stable condition – on the ground this equates to the ground idle condition. The availability of high pressure, high temperature air bled from the compressor section of the engine lends itself readily to the ability to provide pneumatic power for actuation, air conditioning or heating functions for other aircraft subsystems.

Other areas of the aircraft use pneumatic principles for sensing the atmosphere surrounding the aircraft for instrumentation purposes. The sensing of air data is crucial to ensuring the safe passage of the aircraft in flight.

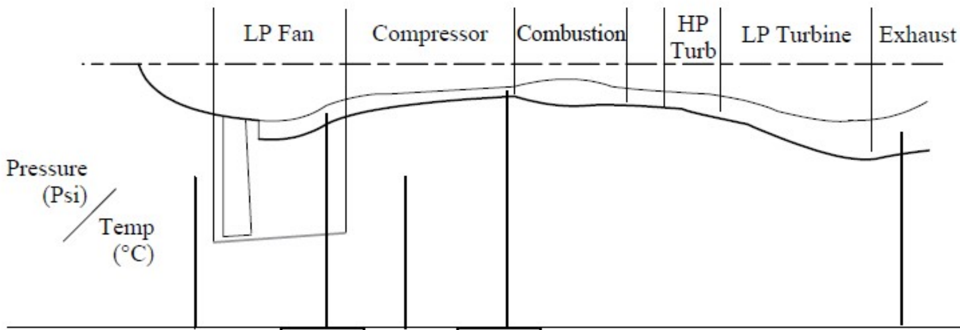
Use of Bleed Air: The use of the aircraft engines as a source of high-pressure, high-temperature air can be understood by examining the characteristics of the turbojet, or turbofan engine as it should more correctly be described. Modern engines 'bypass' a significant portion of the mass flow past the engine and increasingly a small portion of the mass flow passes through the engine core or gas generation section. The ratio of bypass air to engine core air is called the bypass ratio and this can easily exceed 10:1 for the very latest civil engines; much higher than the 4 or 5:1 ratio for the previous generation.

The characteristics of a modern turbofan engine are shown in Figure 6.1. This figure shows the pressure (in psi) and the temperature (in degrees centigrade) at various points throughout the engine for three engine conditions:

1. ground idle,
2. take-off power
3. cruise condition.

It can be seen that in the least stressful condition – ground idle – the engine is in a state of equilibrium but that even at this low level the compressor air pressure is 50 psi and the temperature 180 °C. At takeoff conditions the compressor air soars to 410 psi/540 °C. In the cruise condition the compressor air is at 150 psi/400 °C. The engine is therefore a source of high pressure and high temperature air that can be 'bled' from the engine to perform various functions around the aircraft.

The fact that there are such considerable variations in air pressure and temperature for various engine conditions places an imposing control task upon the pneumatic system. Also the variations in engine characteristics between similarly rated engines of different manufactures poses additional design constraints. Some aircraft such as the Boeing 777 offer three engine choices, Pratt & Whitney, General Electric and Rolls-Royce, and each of these engines has to be separately matched to the aircraft systems, the loads of which may differ as a result of operator specified configurations.



Idle	14.7/15	16/20	15/16	50/180	14.8/340
Take-Off	14.7/15	39/115	25/65	410/540	23.0/510
Cruise	5.3/–25	14/60	8.5/15	150/400	6.8/340

Figure6.1Characteristicsofamodernturbofanengine

As well as the main aircraft engines the Auxiliary Power Unit (APU) is alsoa source of high pressure bleed air. The APU is in itself a smallturbojet engine, designed more from the viewpoint of an energy and power generator than a thrust provider which is the case for the main engines.

The APU is primarily designed to provide electrical and pneumatic power byashaft driven generator and compressor. The APU is therefore able to provide an independent source of electrical power and compressed air while the aircraft is on the ground, although it can beused as a backup provider of power while airborne. Someaircraft designs are actively considering the use of in-flight operable APUs to assist in in-flight engine re-lighting and to relieve the engines of off take load in certain areas of the flightenvelope.

It is also usual for the aircraft to be designed to accept high pressure air from a ground power cart, for aircraft engine starting.

These three sources of pneumatic power provide the muscle or means by whichthe pneumatic system isableto satisfythe aircraft demands.Inasimplifiedformthe pneumaticsystemmaybe representedby the interrelationships shown in Figure below.

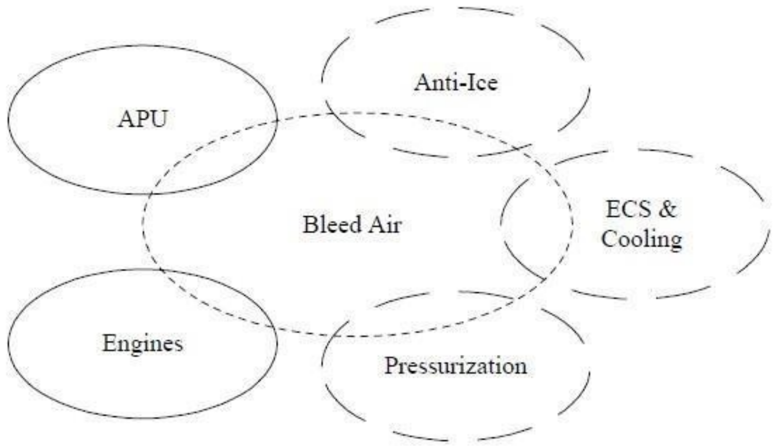


Figure6.2RelationshipofHPairwithmajoraircraftsystems

This simplified drawing – the ground air power source is omitted – shows how the aircraft High Pressure (HP) air sources provide bleed air which forms the primary source for the three major aircraft air related systems:

- Ice protection: the provision of hot air to provide anti icing of engine nacelles and the wing, tailplane or fin leading edges; or to dislodge ice that has formed on the surfaces

- ECSandcooling:theprovisionofthemainairsourceforenvironmentaltemperaturecontroland cooling

- Pressurisation:the provisionofameans by whichthe aircraftmay be pressurised,givingthe crew and passengers a more comfortable operating environment

A simplified representation of this relationship is shown in Figure. This example shows a twin-engine configurationtypical of many business jets and regional jet transport aircraft.

Bleed air from the engines is passed through a Pressure-Reducing Shut-Off Valve (PRSOV) which serves the function of controlling and, when required, shutting off the engine bleed air supply. Air downstream of the PRSOV may be used in a number of ways:

- By means of a cross flow Shut-Off Valve (SOV) the system may supply air to the opposite side of the aircraft during engine start or if the opposite engine is inoperative for any reason

- ASOVfromtheAPUmaybeusedtoisolatetheAPUairsupply

- SOVs provide isolation as appropriate to the left and right air conditioning packs and pressurisationsystems

- Additional SOVs provide the means by which the supply to left and right wing anti-icing systems may be shut off in the event that these functions are not required

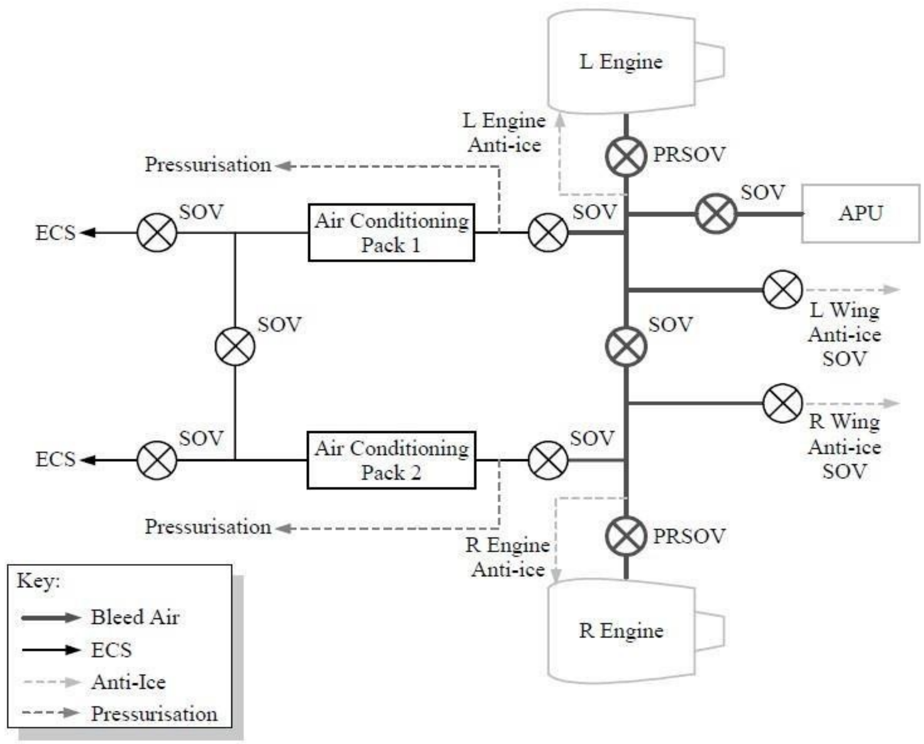


Figure6.3Simplifiedbleedairsystemandassociatedaircraftsystems

This is a simplified model of the use of engine bleed air in pneumatic systems.A more comprehensivelist of those aircraft systems with which bleed air is associated are listed as follows with the accompanying civil ATA chapter classification:

- Airconditioning(ATAChapter21)
- Cargocompartmentheating(ATAChapter21)
- Wingandengineanti-icing(ATAChapter30)
- Enginestart(ATAChapter80)
- Thrustreverser(ATAChapter78)
- Hydraulicreservoirpressurisation(ATAChapter29)
- Rainrepellentnozzles–aircraftwindscreen(ATAChapter30)

- Airdrivenhydraulicpump(ADP)(ATAChapter29)

Several examples will be examined within this pneumatic systems chapter. However, before describing the pneumatically activated systems it is necessary to examine the extraction of bleed air from the engine in more detail.

EngineBleedAirControl:

Figuregivesamoredetailedportrayal oftheleft-hand sideoftheaircraftbleedairsystem,therightside being an identical mirror image of the left-hand side.

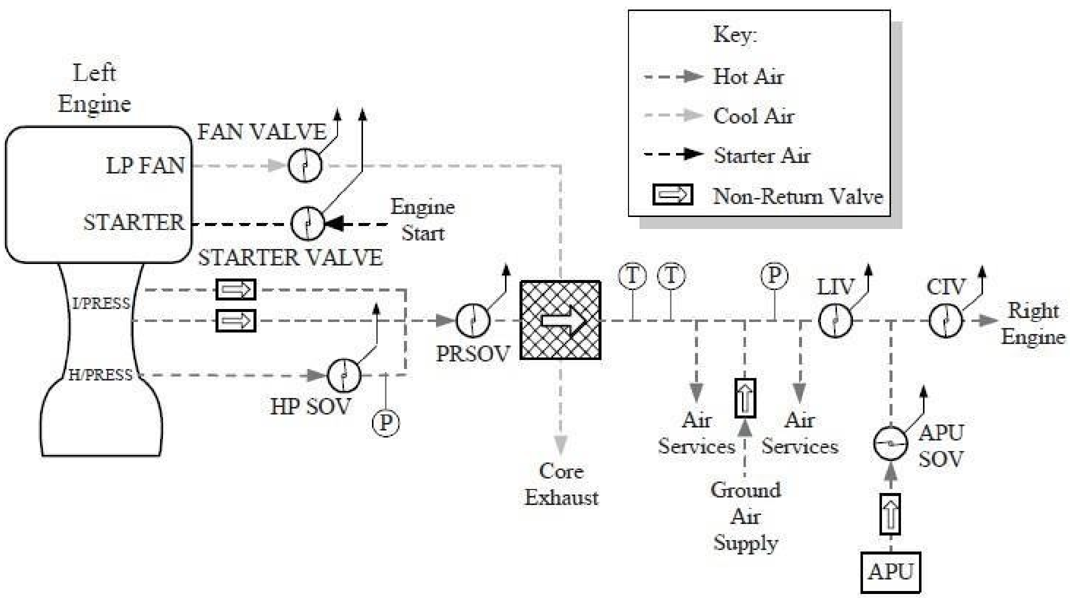


Figure6.4Typicalaircraftbleedairsystem–lefthandside

Air is taken from an intermediate stage or high pressure stage of theengine compressor depending upon the engine power setting. At lower power settings, air is extracted from the high pressure section of the compressor while at higher power settings the air is extracted from the intermediate compressor stage. This ameliorates to some degree the large variations in engine compressor air pressure and temperature for differing throttle settings as already shown in Figure 6.1. A pneumatically controlled High Pressure Shut-Off Valve (HP SOV) regulates the pressure of air in the engine manifold system to around 100 psi and also controls the supply of bleed air from the engine.

The Pressure-Reducing Shut-Off Valve (PRSOV) regulates the supply of the outlet air to around 40 psi before entry into the pre-cooler. Flow of cooling air through the pre-cooler is regulated by the fan valve whichcontrolsthetemperatureoftheLPfanairandthereforeofthebleedairenteringtheaircraft system. Appropriately locatedpressureand temperature sensorsallow the engine bleedair temperature and pressure to be monitored and controlled within specified limits.

AtypicalPRSOVisshowninFigure6.5a;anexampleofaHarrierIIvalvewhichissolenoid controlledand pneumatically operated and which controls temperature, flow and pressure is shown in Figure 6.5b.

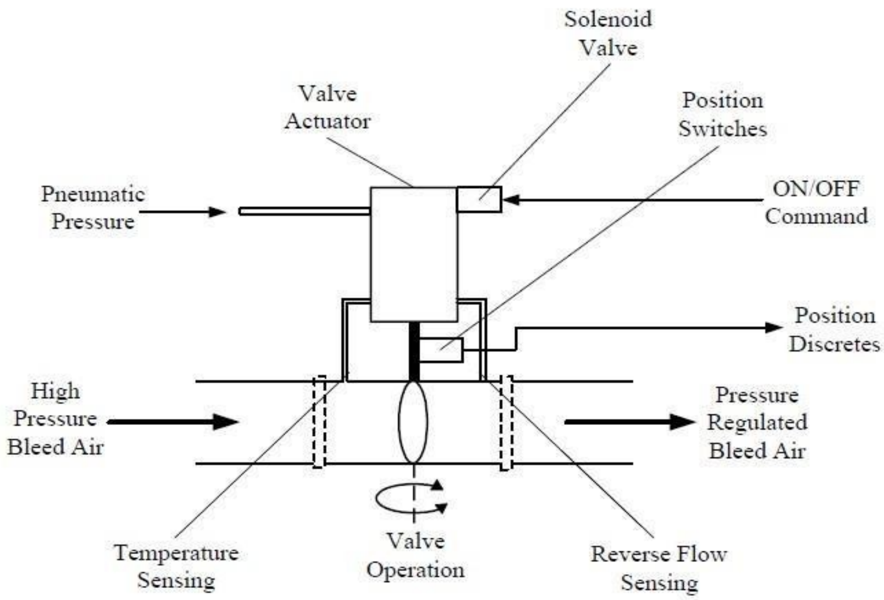


Figure6.5aTypicalPressure-ReducingShut-OffValve(PRSOV)

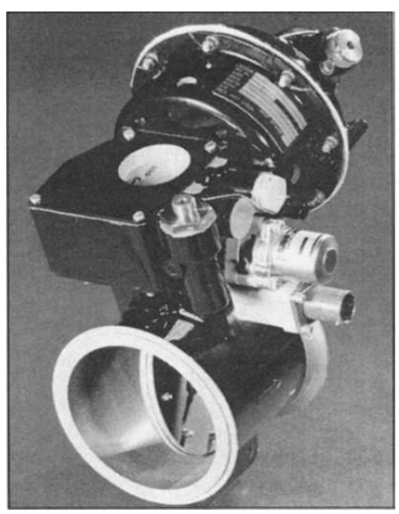


Figure1p.5bHarrierIIpneumaticvalve(CourtesyofHoneywellNormalair-GarretLtd) The

PRSOV performs the following functions:

- On/offcontroloftheenginebleedsystem

- Pressureregulationoftheenginesupplyairbymeansofabutterflyvalveactuatedbypneumatic pressure

- Enginebleedairtemperatureprotectionandreverseflowprotection

- Abilitytobeselectedduringmaintenanceoperationsinordertotestreversethrustoperation

The PRSOV is pneumatically operated and electrically controlled. Operation of the solenoid valve from the appropriate controller enables the valve to control the downstream pressure pneumatically to ~40 psi within predetermined limits. The valve position is signalled by means of discrete signals to the bleed air controller and pressure switches provide over and under-pressure warnings. The various pressure, flow and discrete signals enable the bleed air controller Built-In Test (BIT) to confirm the correct operation of the PRSOV and fan control valve combination. This ensures that medium pressure air (~40 psi) of the correct pressure and temperature is delivered to the pre-cooler and thence downstream to the pneumaticand air distribution system. Downstream of the PRSOV and pre-cooler, the air is available for the user subsystems, a number of which are described below.

A number of isolation valves or SOVs are located in the bleed air distribution system. These valves are usually electrically initiated, pneumatically operated solenoid valves taking 28 VDC electrical power for ON/OFF commands and indication. A typical isolation valve is shown in Figure 6.6. The valve shaft runs almostvertically across the ductas shown in the diagram and the valve mechanism and solenoidvalve is located on the top of the valve.

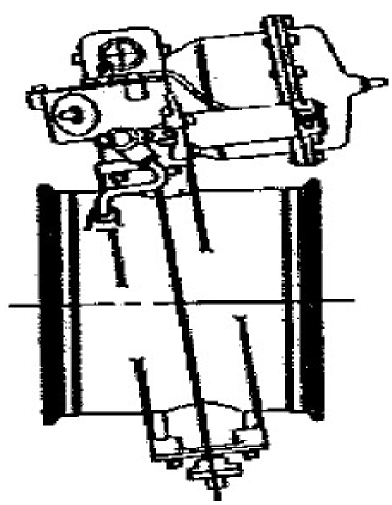


Figure:bleedairsystemisolationvalve

Bleed Air System Indications: It is common philosophy in civil aircraft bleed air systems, in common with other major aircraftsubsystems, to display system synoptic and status data to the flight crew on the Electronic Flight Instrument System (EFIS) displays. In the case of Boeing aircraft the synoptic are shown on the Engine Indication and Crew Alerting System (EICAS) display whereas for Airbus aircraftthe Electronic Crew Alerting and Monitoring (ECAM) displays are used. Bothphilosophies display system data on the colour displays located on the central display console where they may be easily viewed by both Captain and First Officer. A typical bleed air system synoptic is shown in Figure.

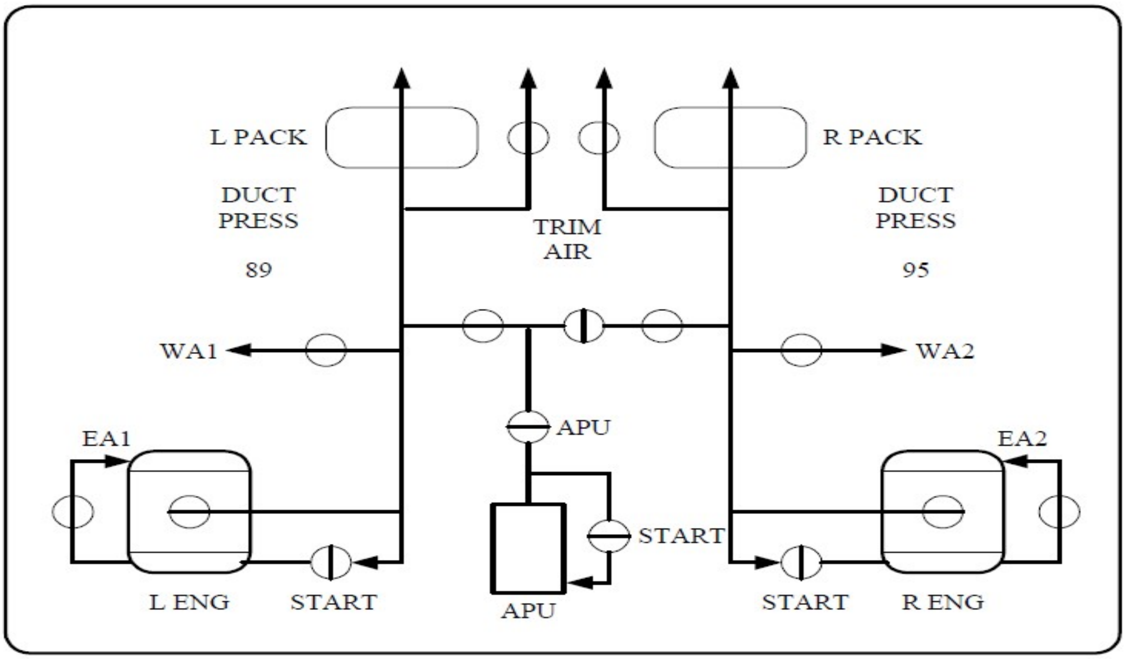


Figure:typicalbleedairsystemsynopticdisplay

The synoptic display as shown portrays sufficient information in a pictorial form to graphically show the flightcrewthe operatingstatus of thesystem.In the example,both mainenginesaresupplyingbleedair normally but the APU is isolated. The cross-flow valve is shut, as are both engine start valves. The wing and engine anti-ice valves are open, allowing hot bleed air to be fed to the engines and wing leading edge to prevent any ice accretion.

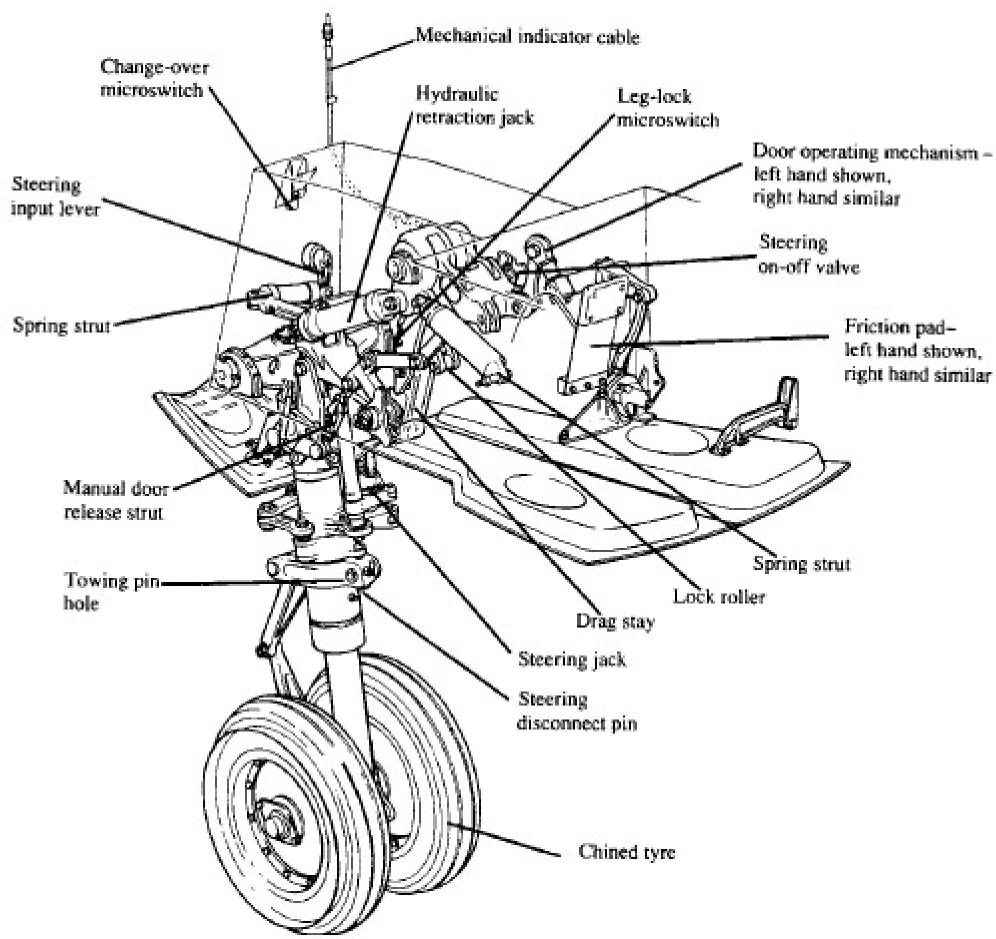
Bleed Air System Users: The largest subsystemuser of bleed air is the air system. Bleed air is used as the primary source of air into the cabin and fulfils the following functions:

- Cabinenvironmentalcontrol–coolingandheating
- Cabinpressurisation
- Cargobay heating
- Fuelsystempressurisationinclosedventfuelsystemusedinsomemilitaryaircraft

LANDINGGEARSYSTEMS

TheRaytheon/BAE 1000isrepresentativeof manymodern aircraft;itslandinggearisshowninFigures 1.22 and 1.23. It consists of the undercarriage legs and doors, steering and wheels and brakes and anti-skid system. All of these functions can be operated hydraulically in response to pilot demands at cockpit mountedcontrols.

Nose Gear The tricycle landing gear has dual wheels on each leg. The hydraulically operated nose gear retracts forward into a well beneath the forward equipment 168 Hydraulic Systems Figure 4.22 The Raytheon 1000 nose landing-gear (Courtesy of Raytheon) bay. Hinged nose-wheel doors, normally closed, are sequenced to open when lowering or retracting the nose gear. The advantage of the doors being normally closed is twofold. First, the undercarriage bay is protected from spray on takeoff and landing, and secondly there is a reduction in drag. A small panel on the leg completes enclosure on retraction and a mechanical indicator on the flight deck shows locking of the gear.



Main Gear: The main gear is also hydraulically operated and retracts inwards into wheel bays. Once retracted the main units are fully enclosed by means of fairings attached to the legs and by hydraulically operateddoors. Each unit isoperated by asinglejack anda mechanicallinkagemaintainsthegearinthe locked position without hydraulic assistance.

The main wheel doors jacks are controlled by a sequencing mechanism that closes the doors when the gear is fully extended or retracted. Figure 4.24 shows thelanding gear sequence for the BAE 146 and also shows the clean lines of the nose wheel bay withthe doors shut.

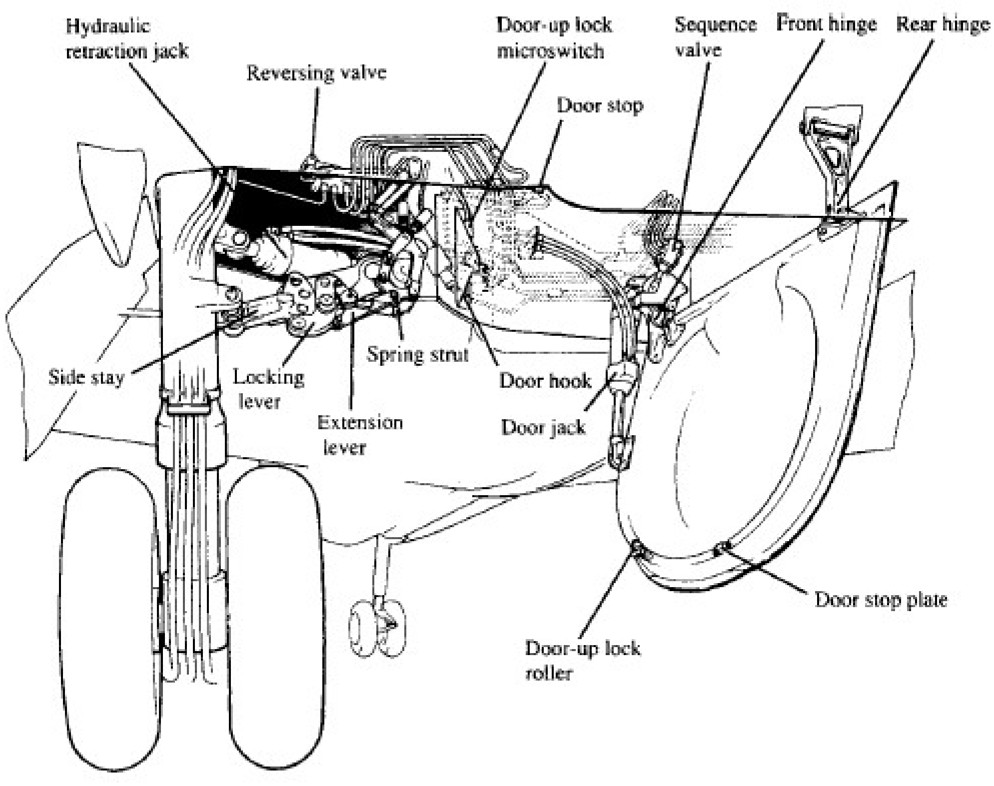


Figure1.23TheRaytheon1000mainlanding-gear(CourtesyofRaytheon)

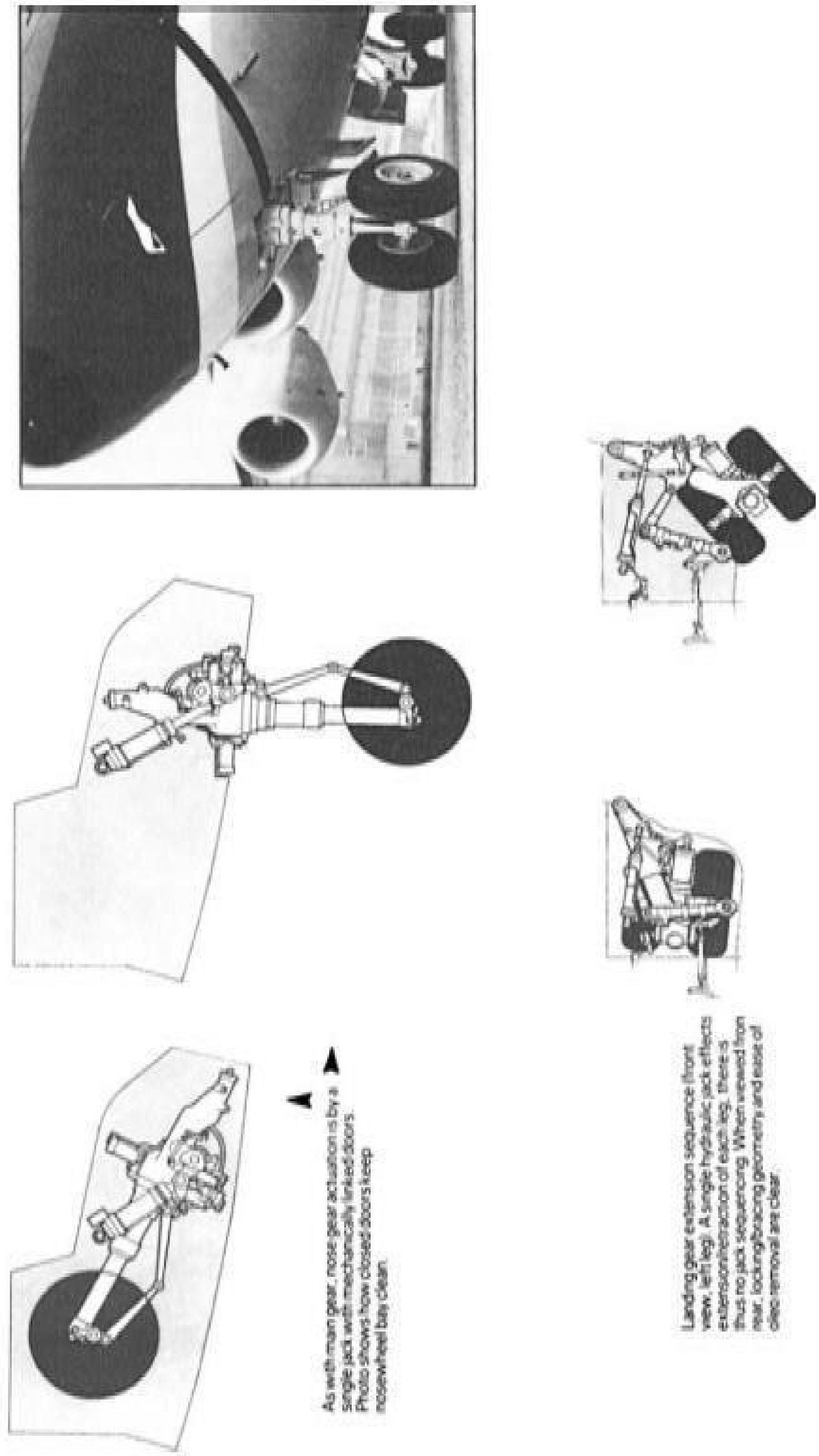
Braking Anti-Skid and Steering: Stopping an aircraft safely at high landing speeds on a variety of runway surfaces and temperatures, and under all weather conditions demands an effective braking system. Its design must take into account tire to ground and brake friction, the brake pressure/volume characteristics,and the response of the aircrafthydraulicsystem and the aircraftstructural and dynamic characteristics.

Simple systems are available which provide reasonable performance at appropriate initial and maintenance costs. More complex systems are available to provide minimum stopping distance performance with features such as auto-braking during landing and rejected take-off, additional redundancy and self test. Some of the functional aspects of brakes and steering are illustrated inFigure.

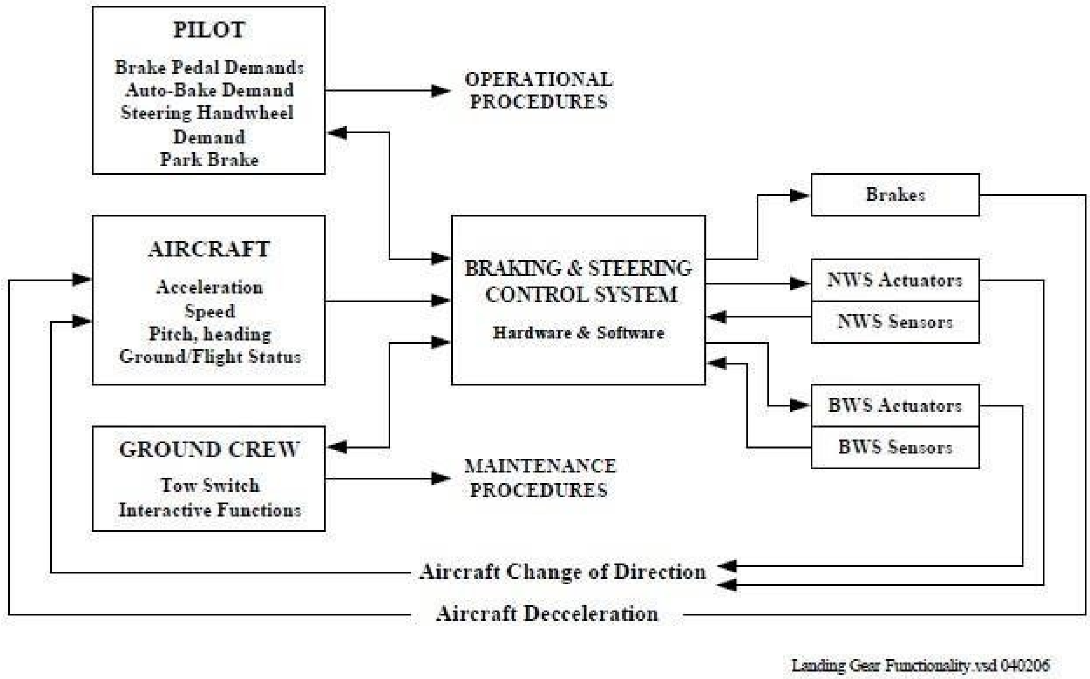
The normal functions of landing, deceleration and taxying to dispersal or the airport gate require large amounts of energy to be applied to the brakes. Wherever possible, lift dump andreversethrust will used to assist braking.

However it is usual for a large amount of heat to be dissipated in the brake pack. This results from the application of brakes during the initial landing deceleration, the use of brakes during taxying, and the need to hold the aircrafton brakes for periods of time atrunway or taxiway intersections.

When the aircraft arrives at the gate the brakes, and the wheel assembly will be very hot. This poses a health and safety risk toground crew workingin the vicinity of the wheels during the turnaround. This is usually dealt with by training.


As with main gear, nosegear actuation is by a single jack with mechanically linked doors. Photo shows how closed doors keep nosewheel bay clean.
Landing gear extension sequence (front view, left leg). A single hydraulic jack effects extension/retraction of each leg; there is thus no jack sequencing. When viewed from rear, locking/bracing geometry and ease of oleo removal are clear.

figure



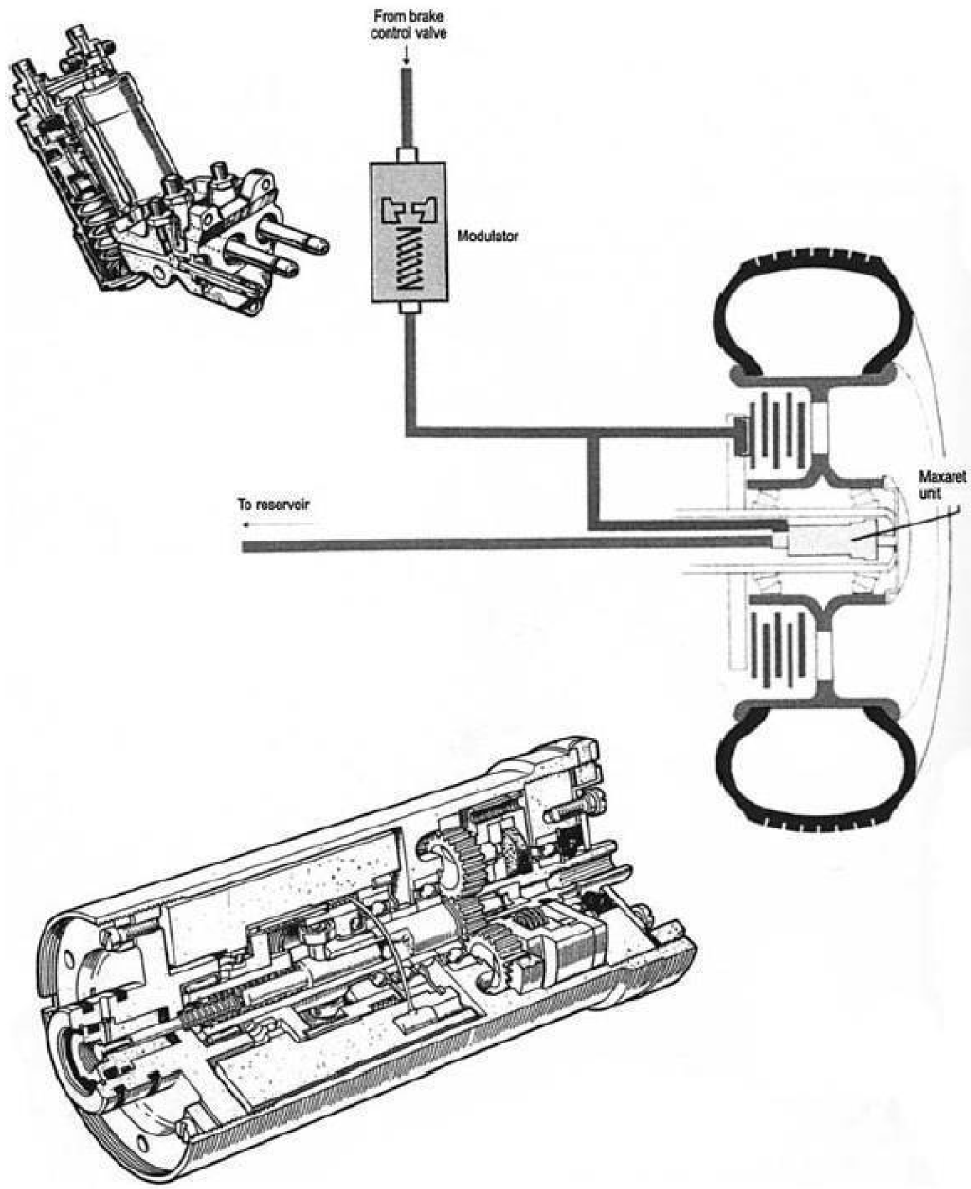
figure

A more serious operational issue is that the aircraft cannot depart the gate until the brake and wheel assembly temperature cools to a value that will not support ignition of hydraulic fluid. This is to ensure that, during the taxi back to the take-off runway, further brake applications will not raise the temperature of the brake pack to a level that will support ignition if a leak of fluid occurs during retraction. Departure from the gate, therefore, may be determined bybrake temperature as indicated by a sensor in the brake pack rather than by time taken to disembark and embark passengers. Some aircraft address this issue by installing brake cooling fans in the wheel assembly to ventilate the brakes. Analternative method is to install fire detection and suppression systems in the wheel bays.

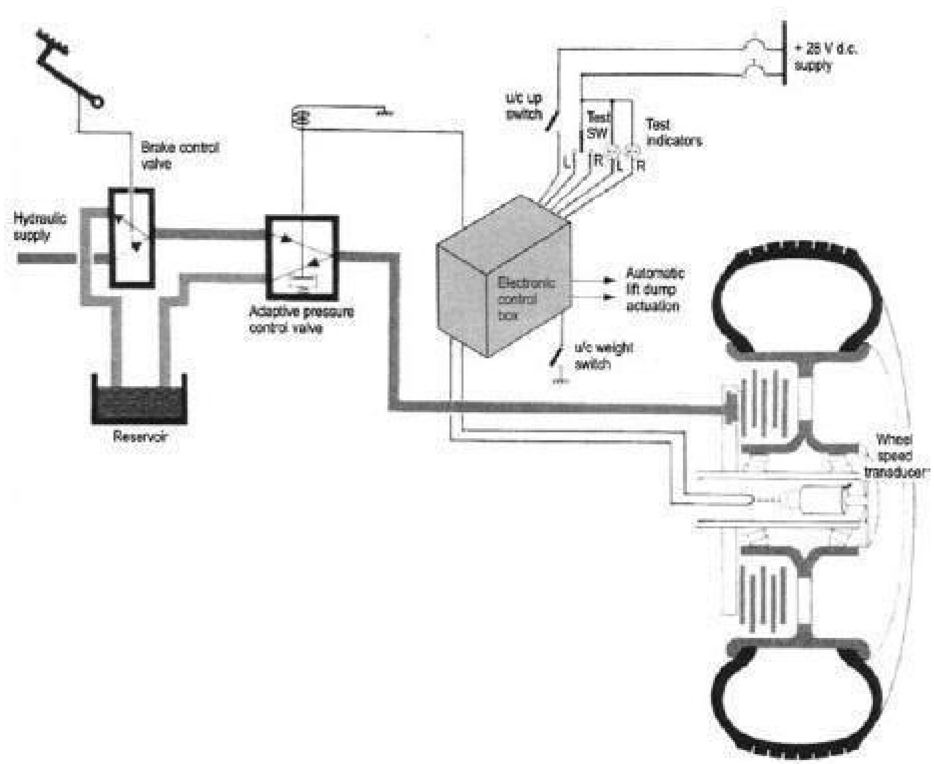
There are events that can raise the temperature of the brakes to the extentthat a fire may occur andthe tyres can burst. Examples of this are an aborted take-off (maximum rejected take-off) or an immediate go around and heavy landing. In both circumstances the aircraft will be fully laden with passengers and fuel. Thermal plugs will operate to deflate the tyres and fire crews willattend theaircraft to extinguish the fire while the passengers disembark.

One of the simplest and most widely known anti-skid system is the Dunlop Maxaret unit which consists of a hydraulic valve assembly regulated by the dynamics of a spring loaded g sensitive flywheel. Figure shows an axle mounted Maxaret together with a modulator.

Rotation of the flywheel is by means of a self-aligning drive from the hub of the wheel, allowing the entire unit to be housed within the axle and protecting the unit from the effects of weather and stones thrown up by the aircraftwheels. Skidconditions are detected by the overrun of the flywheel which opens the Maxaret valve to allow hydraulic pressure to dissipate. A combination of flow sensitive hydraulic units and switches in the oleo leg provide modulation of pressure for optimum braking force and protection against inadvertent application of the brakes prior to touchdown. This ensures that the aircraft does not land with the brakes applied by only allowing the braking system tobecome activeafter the oleo switches have sensed that the oleo is compressed. This condition is known as 'weight-on-wheels'. Without this protection the effect of landing with full braking applied could lead to loss of control of the aircraft; at a minimum a setof burst tyres.



Electronic Control: Electronic control of braking and anti-skid systems has been introduced in various forms to provide different features. An electronic anti-skid system with adaptive pressure control is shown in Figure.



In this system the electronic control box contains individual wheel deceleration rate skid detection circuits with cross reference between wheels and changeover circuits to couple the control valve across the aircraft should the loss of a wheel speed signal occur.

If a skid develops the system disconnects braking momentarily and the adaptive pressure coordination valve ensures that brake pressure is re-applied at a lower pressure after the skid than the level which allowed the skid to occur.A progressive increase in brake pressurebetween skids attemptsto maintaina high level of pressure and braking efficiency.

The adaptive pressure control valve dumps hydraulic pressure from the brake when its first stage solenoid valve is energized by the commencement of a skid signal. On wheel speed recoverythe solenoid is de-energized and the brake pressure re-applied at a reducedpressure level, depending on the time interval of the skid. Brake pressure then rises at a controlled rate in search of the maximum braking level, until the next incipient skid signal occurs.

Automatic Braking: A more comprehensive system is the Dunlop automatic brake control system illustrated in Figure 4.28, which allows an aircraft to be landed and stopped without pilot braking intervention. During automatic braking a two-position three-way solenoid valve is energised following wheel spin-up to feed system pressure via shuttle valves directly to the anti-skid valves where it is modulated and passed to the brakes. Signals from the auto-braking circuit are responsible for this modulation of pressure at the brake to match a preselected deceleration. However, pilot intervention in the anti-skid control circuit or anti-skid operation will override auto-brake at all times to cater for variations in runway conditions.

Intheinterestofsafetyanumberofprerequisitesmustbesatisfiedbeforeauto-brakingisinitiated:

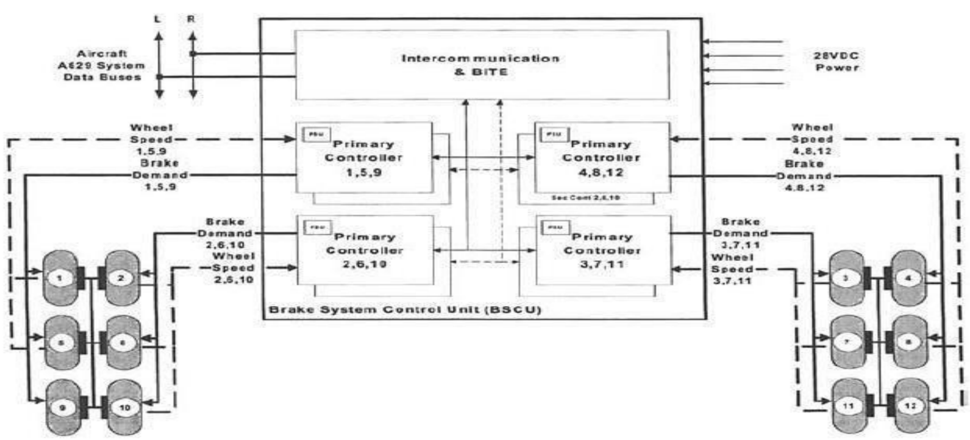
- Auto-brake switch must be on and required decelerations selected
- Anti-skid switch must be on and operative
- Throttle must be correctly positioned
- Hydraulic pressure must be available
- Brake pedals must not be depressed
- Wheels must be spun up

With all these conditions satisfied auto-braking will be operational and will retard the aircraft at a predetermined rate unless overridden by anti-skid activity. At any time during the landing roll the auto-braking may be overridden by the pilot by advancing the throttle levers for go-around, or by normal application of the brakes.

Multi-Wheel Systems: The systems described thus far apply to most aircraft braking systems. However, large aircrafthave multi-wheel bogies and sometimesmore thantwo maingears. The B747-400has four main oleos, each with a total of four wheels each. The B777 has two main bogies with six wheels each. These systems tend to be more complex and utilise multi-lane dual redundant control. The B777 main gear shown in Figure 4.29 is an example.

For control purposes the wheels are grouped in four lines of three wheels, each corresponding to an independentcontrol channels as shown in the figure. Each of the lines of three wheels – 1, 5, 9; 2, 6, 10 andsoon –is controlledbya dualredundant controllerlocatedin theBrakeSystemControl Unit(BSCU). Brake demands and wheel speed sensor readings are grouped by each channel and interfaced with the respective channel control. Control channels have individual power supplies to maintain channel segregation and integrity. The BSCU interfaces with the rest of the aircraft by means of left and right A629 aircraft systems data buses. This system is supplied by the Hydro-Aire division, part of Crane Aerospace, and isindicative ofthe sophistication which modern brake systems offer for larger systems.

The landing gear configuration for the Airbus A380 is shown in Figure 4.30. Goodrich provide two six-wheel under-fuselage landing gear and the two four-wheeled wing-mounted landing gear. The wing-mounted landing gear is slightly forward of the fuselage-mounted gear. The wheels on the main landing gear are fitted with carbon brakes.



Figure

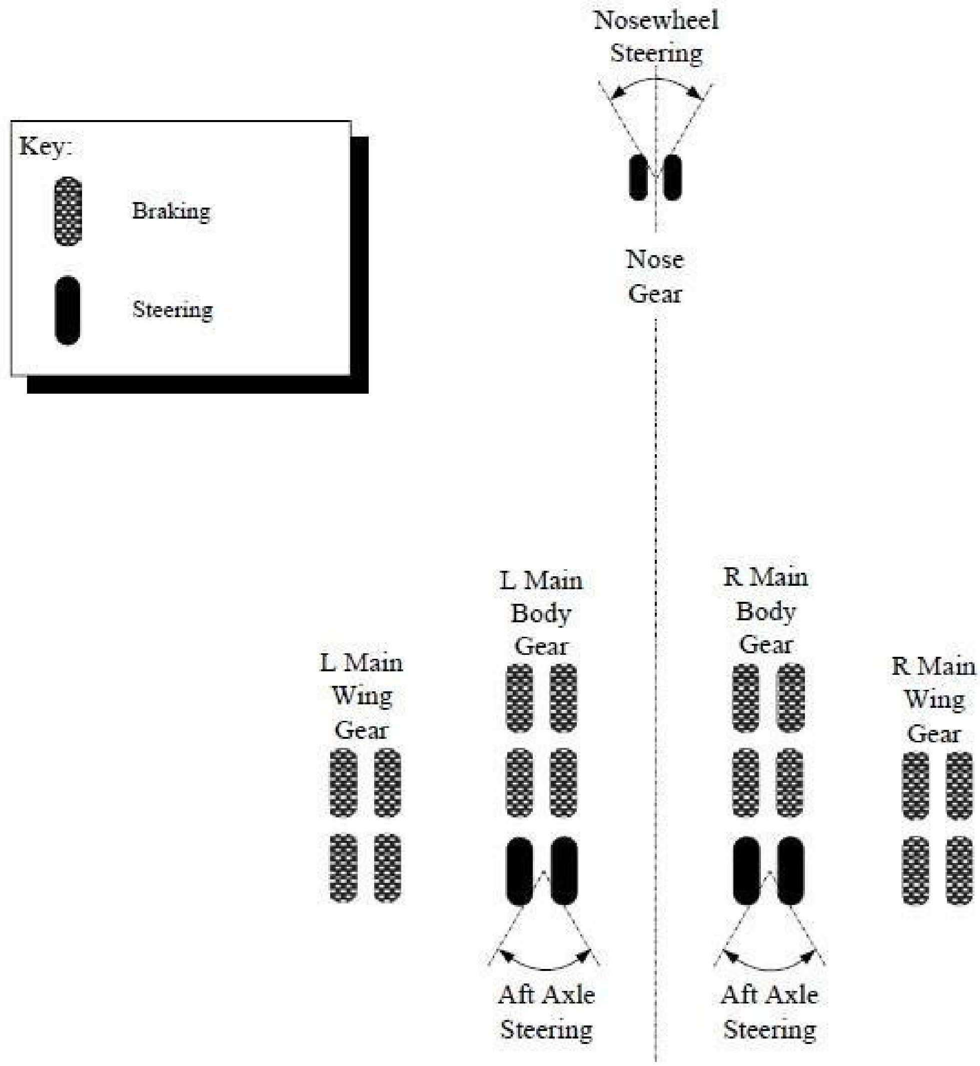
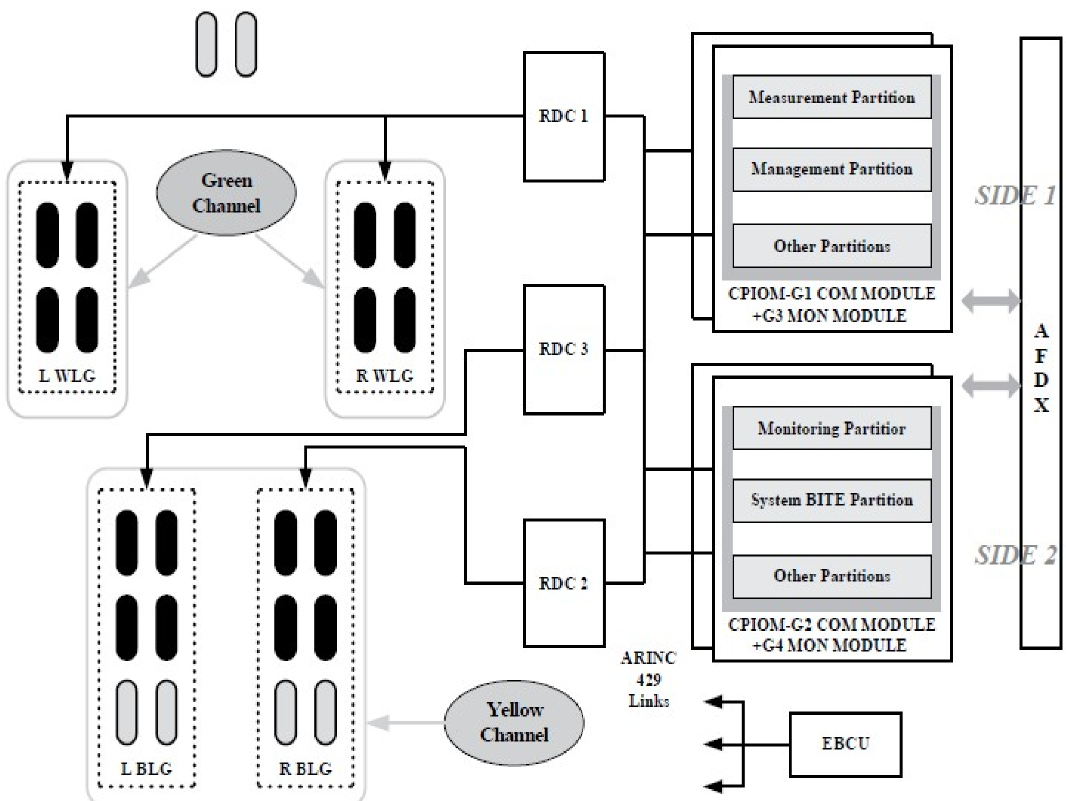


Figure1.30TheAirbusA380landinggearconfiguration

The twin wheel noselanding gearis supplied by Messier-Dowty. The steering control isvia the nosegear and via the rear axle of the fuselage landing gear. The gear allows U-turn maneuvers on a 60 m-wide runway. Maneuverability is improved by having a hydraulically steerable aftaxle which helps the aircraft attain tight turns without applying unacceptable torsion loads to the main oleo.

The aircraft can maneuver on 23 m-wide taxiways and 45 m-wide runways. The French aerospace company Latecoere, based in Toulouse, developed theExternal and Taxi Aid Camera System (ETACS). The ETACS consists of five video cameras and an onboard computer. The camerasare installed on the top of the tailfin and under the fuselage and the image data is relayed to cockpit displays to assist the crew in ground maneuvers. The Honeywell terrain guidance and on-ground navigation systems are integrated to the aircraft's flight management system.

The braking system for the A380 is shown in Figure 4.31.This system is provided byMessier-Bugatti. This system is based on self-adapting braking algorithms that were successfully introduced on the A340-500/600. These allow optimised braking by managing the braking function wheel by wheel and landing by landing based on the prevailing conditions of runway, tyres and brakes. Each wheel is thus continuously and independently controlled in real time, taking account of its individual parameters and itsparticularenvironment.Both thenumber of wheels and the rapidity required in the feedback loopfor controlling the wheel speed, necessitated introducing three dedicated computers, called RDCs (Remote Data Concentrator), each equipped with specific operating software. They are connected tothe IMA bya digital bus.



FigureA380brakecontrolsystem

Brake Parachute: Military aircraft often require assistance to achieve a high-speed landing on short runways. A brake parachute can be used to provide this facility. The system can be armed in flight and commanded by a weight on wheels switch when the main wheels touchdown. Figure 4.32 shows an F-117 with brake parachute deployed. The chute is jettisoned on to the runway and must be collected before the next aircraft attempts a landing.

FigureF117deployingbrakeparachute(CourtesyofUSAirForce/SeniorAirmanDarnell Cannady)

Steering: Nose wheel steering is normally not engaged for landing – the rudder can be useduntil forward speed makes itineffective. Atthis pointsteering is engaged manually or automatically. Steering motors respond to demands from the rudder pedals when nose wheel steering is selected.

The angular range of the wheels, and the rate of change of steering angle are selected to enable the aircraft to steer on runways and taxi-ways with no risk of theaircraft over-steering or scrubbing thetires.

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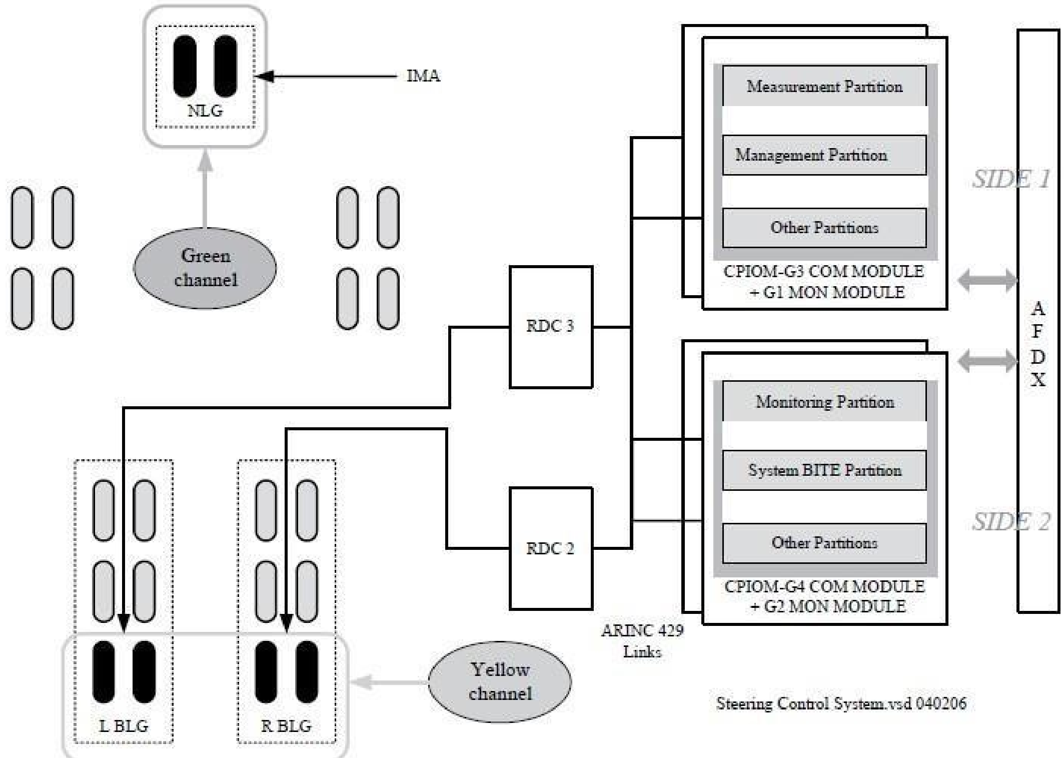
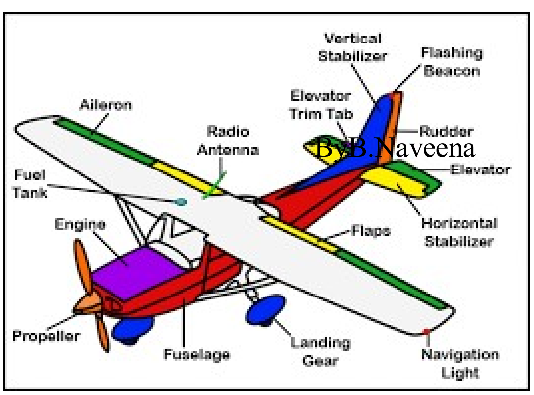


Figure1.33A380steeringcontrolsystem

An example of the Airbus A380 steering system is shown in Figure 4.33. The A380 steers with the nose-wheels, and also the after wheels of the main gear. This enables the aircraft to complete a 180 _ turn within 56.5 m,safely within the standard 60 m runway width.

UNIT 2: AIRPLANE CONTROL & MODERN CONTROL SYSTEMS

AEROPLANE CONTROL SYSTEMS



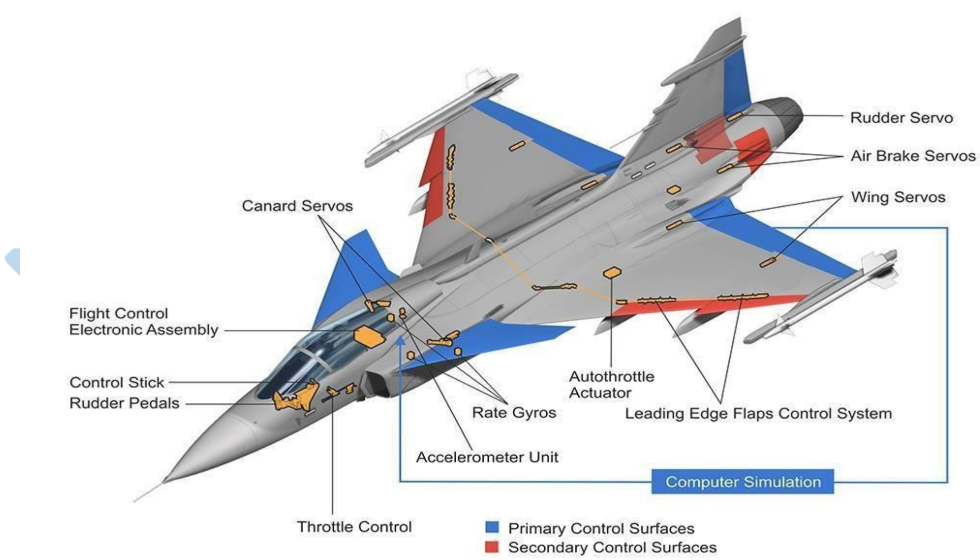
UNIT2: AIRPLAN CONTROL & MODERN CONTROL SYSTEMS

Introduction: The flight controls are the devices and systems that govern the attitude of an aircraft and, as a result, the flight path followed by the aircraft. In the case of many conventional airplanes, the primary flight controls utilize hinged, trailing edge surfaces called elevators for pitch, ailerons for roll, and the rudder for yaw. These surfaces are operated by the pilot in the flight deck or by an automatic pilot the inputs necessary to manipulate the aircraft by the pilot. The flight control systems will vary from aircraft to aircraft but always consists of some combination of primary and secondary flight controls

Flight control systems used by pilot to control the forces of flight and the aircraft's direction and attitude. It should be noted that flight control systems and characteristics can vary greatly depending on the type of aircraft flown. The most basic flight control system designs are mechanical and date back to early aircraft. They operate with a collection of mechanical parts, such as rods, cables, pulleys, and sometimes chains to transmit the forces of the flight deck controls to the control surfaces. Mechanical flight control systems are still used today in small general and sport category aircraft where the aerodynamic forces are not excessive

FLIGHT CONTROL SYSTEMS: Are classified according to the type of Actuation power as follows:

1. Mechanical/Conventional.
2. Hydro mechanical.
3. Fly By Wire.
4. Fly-by-optics–under research
5. Fly-by-wireless –under research
6. Intelligent flight control system–under research



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According to the function they utilized they are classified as:

1. Primary.
2. Secondary.

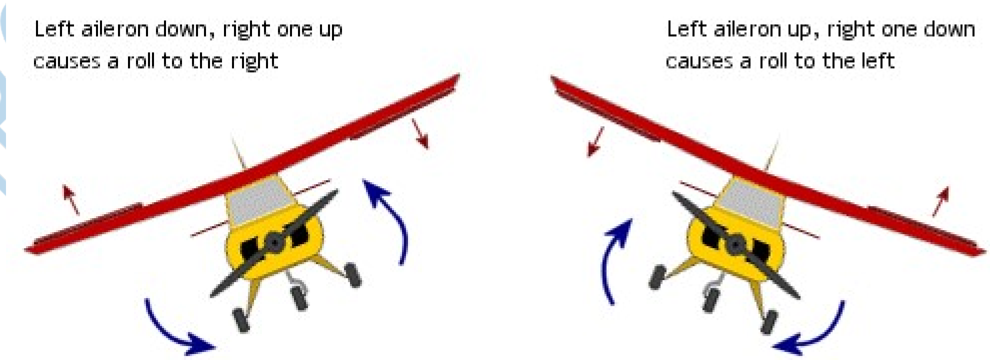
I. **Primary Flight Controls:** Deflection of trailing edge control surfaces, such as the aileron, alters both lift and drag.

1. Ailerons:

i. Ailerons (French for "little wing") are control surfaces on each wing which control the aircraft about its longitudinal axis allowing the aircraft to "roll" or "bank"
   - Thisactionresultsintheairplaneturninginthedirectionoftheroll/bank
   - With aileron deflection, there is asymmetrical lift (rolling moment) about the longitudinal axis and drag (adverse yaw)

ii. They are located on the trailing(rear)edge of each wing near the outer tips
   - They extendfrom about the midpointof each wing outward toward the tip, and move in opposite directions to create aerodynamic forces that cause the airplane to roll

iii. The yoke manipulates the airfoil through a system of cables and pulleys and act in an opposingmanor
   - Yoke"turns"left:leftaileronrises,decreasingcamberandangleofattack onthe right wing which creates downward lift
     - At the same time, the right aileron lowers, increasingcamber (curvature) and angle of attack which increases upward lift and causes the aircraft to turn left
   - Yoke "turns" right: right aileron rises decreasing camber and angle of attack on the right wing which creates downward lift
     - At the sametime, the left aileron lowers, increasing camber and angle of attack on the left wing which creates upward lift and causes the aircraft to turn right



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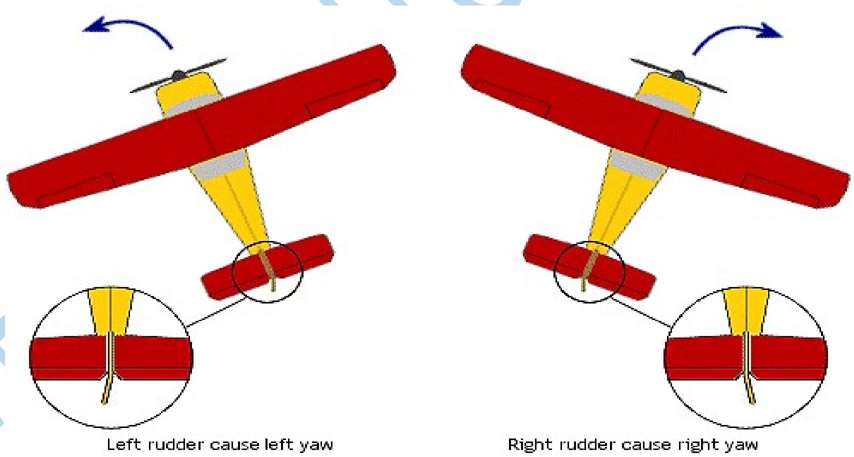
2. Rudder:

i. Rudders are used to control the direction (left or right)of"yaw"aboutan airplane's vertical axis

ii. Liketheotherprimarycontrolsurfaces,therudderisamovablesurfacehingedtoa fixed surface that, in this case, is the vertical stabilizer, or fin

iii. Itsactionisverymuchlikethatoftheelevators,exceptthatitswingsinadifferentplane - From sidetosideinsteadofupanddown
   - Itisnotusedtomaketheairplaneturn,asisoftenerroneouslybelieved
   - In practice, both aileron and rudder control input are used together to turn an aircraft, the ailerons imparting roll
     - Thisrelationshipiscriticalinmaintainingcoordinationorcreatingaslip
     - Improperlyrudderedturnsatlowspeedcanprecipitateaspin

iv. Ruddersarecontrolledbythepilot with his/herfeetthroughasystemofcablesand pulleys:
   - "Step"ontherightrudderpedal:ruddermovesrightcreatingayawtotheright
   - "Step"ontheleftrudderpedal:ruddermovesleftcreatingayawtotheleft



3. Elevators/Stabilators:

i. Elevators and stabilators are both control surfaces which control the aircraft about its lateral axis allowing the aircraft to pitch

ii. Elevators are attached to thetrailingedgeofthehorizontalstabilizer

iii. Astabilatorisacombinationofboththehorizontalstabilizerandtheelevator(the entire surface moves)

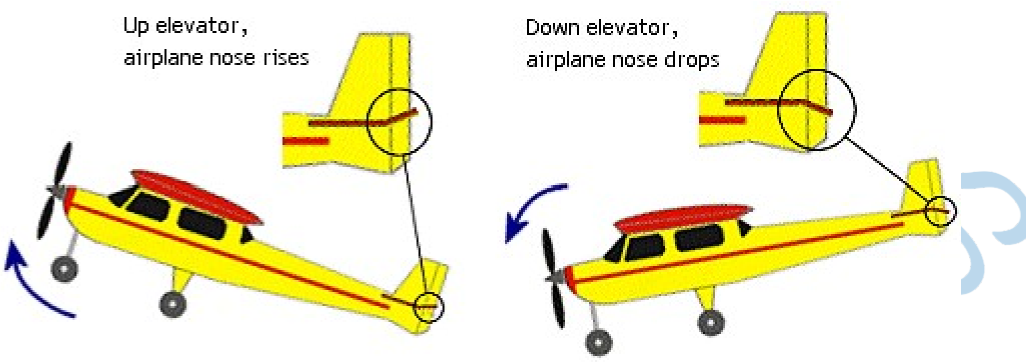
iv. Usedtopitchtheaircraftupanddownbycreatingaloadon thetail

v. Theelevatorscontroltheangleofattackofthewings

vi. Theyokemanipulatestheairfoilthroughasystemofcablesandpulleys:
   - Yoke"pulls"back: elevatorraises,creatingdownwardlift,raisingthenose, increasing the wing's angle of attack

UNIT2: AIRPLANE CONTROL & MODERN CONTROL SYSTEMS

- Yoke "pushes" forward: elevator lowers creating upward lift, lowering the nose, decreasing the wing's angle of attack



II. **SecondaryFlightControls:**SecondaryFlightControlsconsistof:

i. Flaps:
  - TrailingEdgeFlaps
  - LeadingEdgeFlaps

ii. Trimsurfaces

iii. Spoilers/Speedbrakes

1. **Flaps:** Flaps allow for the varying of an airfoil's camber. The term, "clean configuration" refersto flapsand gearup. The term,"dirtyconfiguration"refers toflaps and geardown Many attempts have been made to compromise the conflicting requirement of high speed cruise and slow landing speeds
   - Highspeedrequiresthin,moderatelycamberedairfoilswithasmallwingarea
   - The high lift needed for low speeds is obtained with thicker highly cambered airfoilswith a larger wing area

   Since an airfoil cannot have two different cambers at the same time, one of two things must be done
   - Theairfoilcanbeacompromise
   - A cruise airfoil can be combined with devices for increasing the camber of the airfoil for low-speed flight (i.e., flaps)

   Flap deflection does not increase thecritical (stall) angle of attack, and in some cases flap deflection actually decreases the critical angle of attack. The aircraft stalling speed however (different from angle of attack), will lower. Wing flaps should not induce a roll or yaw effect, and pitch changes depend on the airplane design. Un-commanded roll/yaw with flaps alone could indicate a split flap condition Pitch behavior depends on the aircraft's flap type, wing position, and horizontal tail location This produces a nose-down pitching moment; however, the change in tail load from the down-wash deflected by the flaps over the horizontal tail has a significant influence on the pitching moment Flap deflection of up to 15° primarily produces lift with minimal drag Deflection beyond 15° produces a large increase in drag Drag from flap deflection is parasite drag, and as such is proportional to the square of the speed Also, deflection beyond 15° produces a significant nose-up pitching moment in most high-wing airplanes because the resulting down-wash increases the airflow over the horizontal tail

i. TrailingEdgeFlaps:

- Flap operation is used for landings and takeoffs, during which the airplane is in close proximity to the ground where the margin for error is small
  - Since the recommendations given in the AFM/POH are based on the airplane and the flap design combination, the pilot must relate the manufacturer's recommendation to aerodynamic effects of flaps
  - The increasedcamber from flapdeflectionproduces liftprimarily onthe rear portion of the wing allowing for decreased approach speed and steeper approach paths
- With this information, the pilot must make a decision as to the degree of flap deflection and time of deflection based on runway and approach conditions relative to the wind conditions
- The time of flap extension and degree of deflection are related and affect the stability of an approach
  - Large flap deflections at one single point in the landing pattern produce large lift changes that require significant pitch and power changes in order to maintain airspeed and glide slope
  - Incremental deflection of flaps on downwind, base, and final approach allow smaller adjustment of pitch and power compared to extension of full flaps all at one time
- The tendency toballoon up with initial flapdeflection is because of liftincrease, but the nose-down pitching moment tends to offset the balloon
- Asoft-orshort-fieldlandingrequiresminimalspeedattouchdown
- The flap deflection that results in minimal ground-speed, therefore, should be used
- If obstacle clearance is a factor, the flap deflection that results in the steepest angle of approach should be used
- It should benoted, however, that the flap setting that gives the minimal speed at touchdown does not necessarily give the steepest angle of approach; however, maximum flap extension gives the steepest angle of approach and minimum speed at touchdown
- Maximum flap extension, particularly beyond 30 to 35°, results in alarge amount of drag
- Thisrequireshigherpowersettingsthanusedwithpartialflaps
- Because of the steep approach angle combined with power to offset drag, the flare with full flaps becomes critical
- The drag produces a high sink rate that must be controlled with power, yet failure to reduce power at a rate so that the power is idle at touchdown allows the airplane to float down the runway
- Areductioninpowertooearlyresultsinahardlanding
- CrosswindConsiderations:
  - Crosswind component must be considered with the degree of flap extension because the deflected flap presents a surface area for the wind to act on

UNIT2: AIRPLANE CONTROL & MODERN CONTROL SYSTEMS

- In a crosswind, the "flapped" wing on the upwind side is more affected than the downwind wing

- This is, however, eliminated to a slight extent in the crabbed approach since the airplane is more nearly aligned with the wind
- When using a wing low approach, however, the lowered wing partially blankets the upwind flap, but the dihedral of the wing combined with the flap and wind make lateral control more difficult
- Lateral control becomes more difficult as flap extension reaches maximum and the crosswind becomes perpendicular to the runway
- Crosswind effects on the "flapped" wing become more pronounced as the airplane comes closer to the ground
- The wing, flap, and ground form a "container" that is filled with air by the crosswind
- With the wind striking the deflected flap and fuselage side and with the flaplocated behind the main gear,the upwind wingwill tendtorise and the airplane will tend to turn into the wind
- Proper control position, therefore, is essential for maintaining runway alignment
- Also, it may be necessary to retract the flaps upon positive ground contact
- The go-around is another factor to consider when making a decision about degree of flap deflection and about where in the landing pattern to extend flaps
- Because of the nose-down pitching moment produced with flap extension, trim is used to offset this pitching moment
- Applicationoffull powerinthe go-aroundincreasesthe airflow over the "flapped"wing
- Thisproducesadditionalliftcausingthenosetopitchup
- Thepitch-uptendencydoesnotdiminishcompletelywithflapretraction because of the trim setting
- Expedient retraction of flaps is desirable to eliminate drag, thereby allowing rapid increase in airspeed; however, flap retraction also decreases lift so that the airplane sinks rapidly
- The degree of flap deflection combined with design configuration of the horizontal tail relative to the wing requires that the pilot carefully monitor pitch and airspeed, carefully control flap retraction to minimize altitude loss, and properly use the rudder for coordination
- Considering these factors, the pilot should extend the same degree of deflection at the same point in the landing pattern

- Thisrequiresthataconsistenttrafficpatternbeused
- Therefore, the pilot can have a preplanned go-around sequence based on the airplane's position in the landing pattern
- There is no single formula to determine the degree of flap deflection to be used on landing, because a landing involves variables that are dependent on each other

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- The manufacturer's requirements are based on the climb performance produced by a given flap design
- Under no circumstances should a flap setting given inthe AFM/POH be exceeded for takeoff

a) PlainFlaps:

- Plain flaps are the most common,but least efficientflap system [***Figure 1***]
- Attached on a hinged pivot, which allows the flap to the moved downward
- The structure and function are comparable to the other control surfaces-ailerons, rudder, and elevator
- When extended, itincreases the chord line,angle of attack, and camber of the wing, which results in an increase in both lift and drag
- It is important to remember that control surfaces are nothing more than plain flaps themselves
- Theytheycallsameasa wingexceptitwillonlystallonewingat a time

b) SplitFlap:

- Similartotheplainflap,butmorecomplex[***Figure1***]
- Itisonlythelowerorundersideportionofthe wing
- The deflection of the flap leaves the trailing edge of the wing undisturbed
- It is more effective than the hinge flap because of greater lift and less pitching moment, but there is more drag
- More useful for landing, but the partially deflected hinge flaps have the advantage in takeoff
- The split flap has significant drag at small deflections, whereas the hinge flap does not because airflow remains "attached" to the flap

c) SlottedFlap:

- The slotted flap has greater lift than the hinge flap butless than the split flap; but, because of a higher lift-drag ratio, it gives better takeoff and climb performance [***Figure 1***]
- Small deflections of the slotted flap give a higher drag than the hinge flap but less than the split
- Thisallowstheslottedflaptobeusedfortakeoff
- Aslottedflapwillproduceproportionallymoreliftthandrag
- Itsdesignallowshigh-pressureairbelowthewingtobedirected through a slot to flow over the upper surface of theflap delaying the airflow separation at higher angles of attack
- Thisdesignlowersthestallspeedsignificantly

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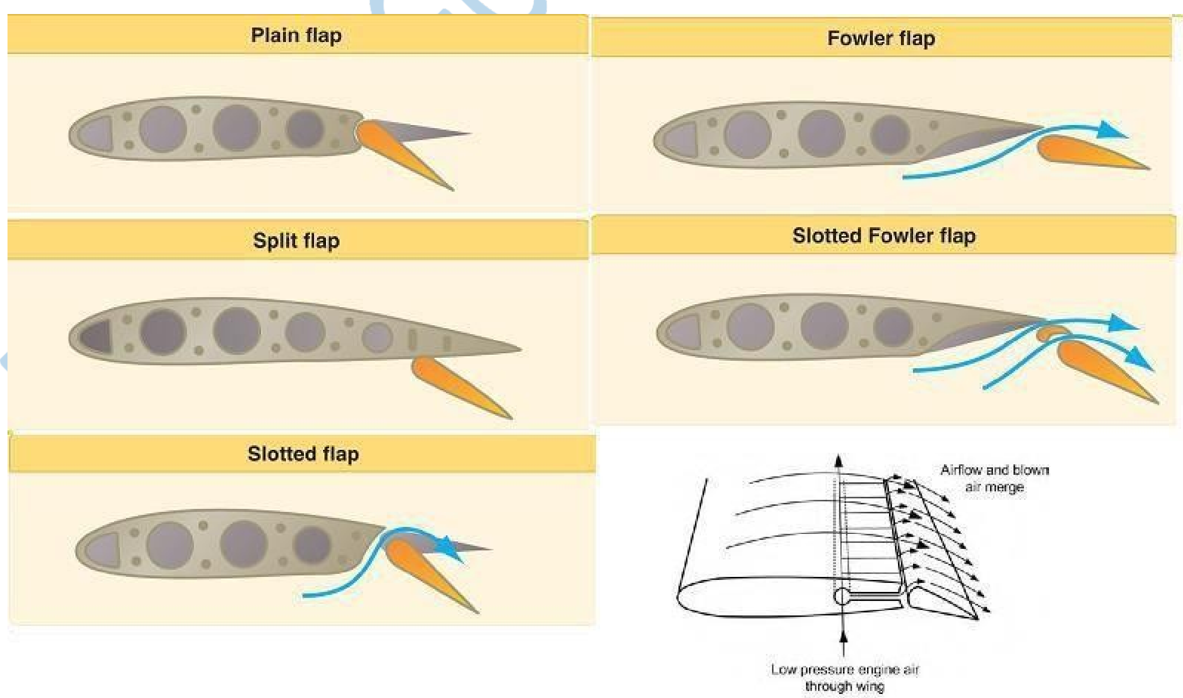
d) FowlerFlap:

- Mostefficientdesign[***Figure1***]
- Moves backward on first part of extension increasing lift with little drag; also utilizes a slotted design resulting in lower stall speeds and increased wing area
- Createsthegreatestchangeinpitchingmoment
- Providesgreatest increase in lift coefficient with theleast change in drag
- Thisflapcan bemulti-slottedmaking itthemostcomplex ofthe trailing edge systems
- Drag characteristicsat small deflections are much likethe slottedflap
- Becauseofstructuralcomplexityanddifficultyinsealingthe slots,Fowler flaps are mostcommonly used on larger airplanes

e) BlownFlap:

- An aircraft with wing-mounted propellers, exhibits a blown flap effect
- Providesextraairflowforwingsbyblowingairoverthesurfaces
- Preventsboundarylayerfromstagnating,improvinglift
- Atlow speeds this system can"fool"the airplane intothinking it is flying faster
- Can improve lift 2 or 3 times; however, the bleed air off the engine causes a decrease in thrust for phases of flight such as take off



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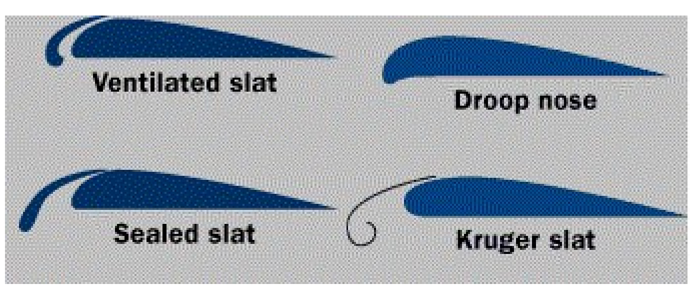
ii. ***LeadingEdgeFlaps:****LeadingedgeflapsincreasestallmarginThereareseveraltypes:*

a) **Slats:**

- Aerodynamicsurfacesontheleadingedgeofthewings
- When deployed, they allow the wing to operate at ahigher angle of attack, so it can fly slower or take off and land in a shorterdistance
- Usually used while landing or performing maneuvers,which take the aircraft close to the stall, but are usually retracted in normal flight to minimize drag
- Slats work by increasing the camber of the wing, and also by opening a small gap (the slot) between the slat and the wing leading edge, allowing a small amount of high-pressure air from the lower surface to reach the upper surface, where it helps postpone the stall
- The chord of the slat is typically only a few percent of the wing chord
- They may extend over the outer third of the wing or may cover the entire leading edge
- The slathas a counterpartfound in the wings of some birds,the Alula, a feather or group of feathers which the bird can extend under control of its "thumb"
- ***TypesofSlatSystems:***
    - Automatic:
        - The slat lies flush with the wing leading edge until reduced aerodynamic forces allow it to extend by way of springs when needed
        - Thistypeistypicalonlightaircraft
    - Fixed:
        - Thisslatispermanentlyextended
        - This is rarely used, except on special low-speed aircraft (these are referred to as slots)
    - Powered:
        - Theslatextensioncanbecontrolledbythe pilot
        - Thisiscommonlyusedonairliners



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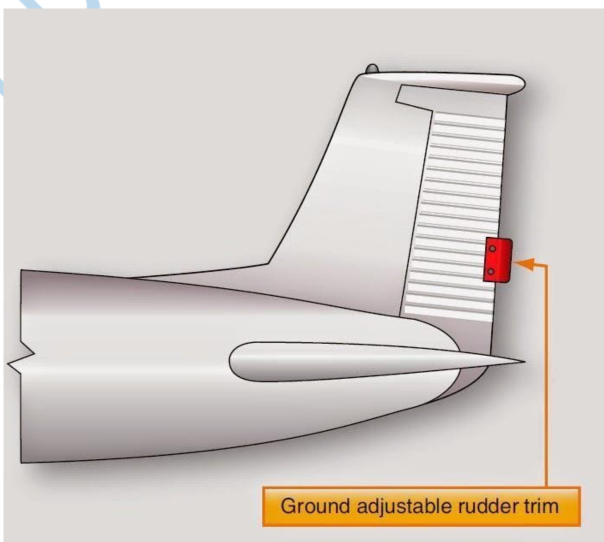
2. ControlSurfaceTabs:

- Tabsaresmall,adjustableaerodynamicdevicesonthe trailingedgeofthecontrol surface
- Thesemovablesurfacesreducepressuresonthecontrols
- Trimcontrols aneutralpoint, likebalancingtheaircraft on apin withunsymmetrical weights
-
- This is done either by trim tabs (small movable surfaces on thecontrolsurface) or bymoving the neutral position of the entire control surface all together
- Thesetabsmaybeinstalledontheailerons,therudder,and/ortheelevator

a) TrimTabs:

- The force of the airflow striking the tab causes the main control surface to bedeflected to a position that corrects the unbalanced condition of the aircraft
- An aircraft properly trimmed will, when disturbed, try to return to its previous state due to aircraft stability
- Trimming isaconstanttask requiredafterany powersetting,airspeed,altitude, or configuration change
- Proper trimming decreases pilot workload allowing for attention to be diverted elsewhere, especially important for instrument flying
- Trimtabsarecontrolledthroughasystemofcablesandpulleys
  - Trim tabadjusted up:trim tab lowerscreating positive lift,lowering the nose
    - Thismovementisveryslight
  - Trim tabadjusted down:trim tabraises creating positive lift,raising the nose
    - Thismovementisveryslight



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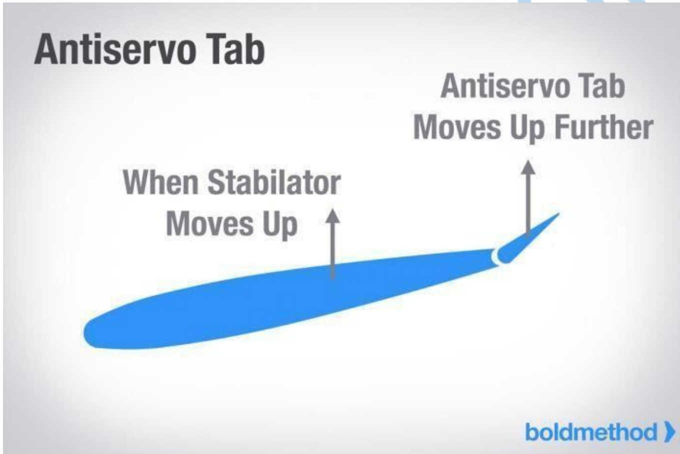
b) ServoTabs:

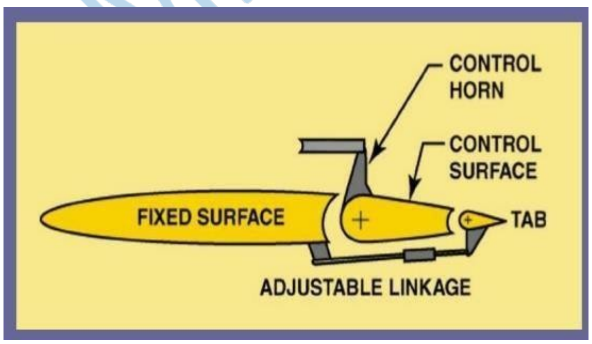
- Servotabsaresimilartotrimtabsinthattheyaresmallsecondarycontrols which help reduce pilot workload by reducing forces
- The defining difference however, is that these tabs operate automatically, independent of the pilot

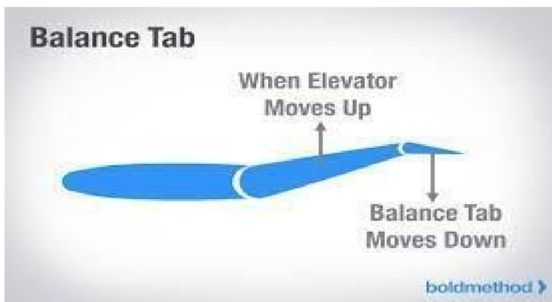
ServoTabDesigns:

- *Anti-servo:*
  - Also called an anti-balance tab, are tabs that move in the same direction as the control surface
- *Servo:*
  - Tabsthatmoveintheoppositedirectionasthecontrol surface



c) 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 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 counterbalances some of the air pressure against theprimary control surface and enables the pilot to move the control more easily and hold the control surface in position.





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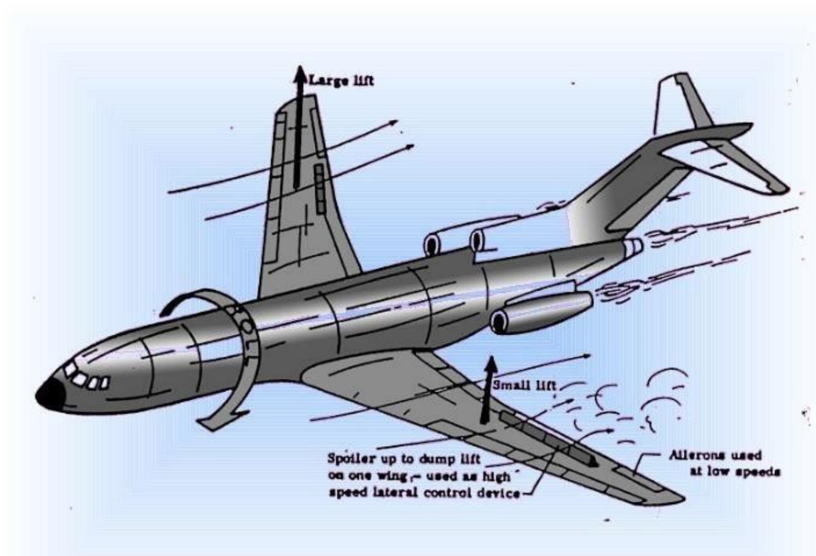
3. **Spoilers:** Found on some fixed-wing aircraft, high drag devices called spoilers are deployed from the wings to spoil the smooth airflow, reducing lift and increasing drag. On gliders,spoilers are mostoften used to control rate of descent for accurate landings. On other aircraft, spoilers are often 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, theytransfer weight to the wheels, improving braking effectiveness.



UNIT2: AIRPLANE CONTROL & MODERN CONTROL SYSTEMS

I. **Mechanical / Conventional Control Systems:** The conventional older aircrafts used to employ Push pull rod for moving the control surfaces. This was making the aircraft heavier because the rods used to run along the fuselage to connect the control surfaces. The linkage from cabin to control surface can be fully mechanical if the aircraft size and its flight envelop allow. In this case the hinge moment generated by the surface deflection is low enough to be easily contrasted by the muscular effort of the pilot.

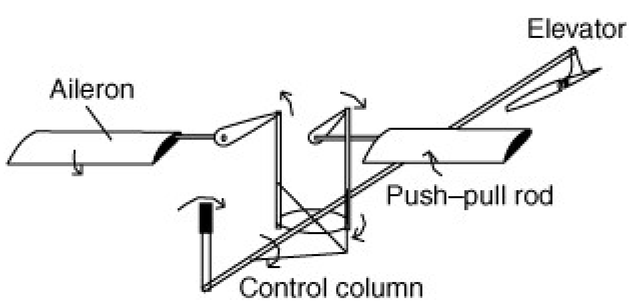
Twotypesofmechanicalsystemsareused:

1. PUSH-PULLrods and:In this case a sequence of rods links the control surface to the cabin input. Push-pull rod system for elevator control
   Fig. sketches the push-pull control rod system between the elevator and the cabin control column.
2. CablePulley:

a) Push-Pullrod:

Astiffrodorhollowtubeinanaircraftcontrolsystem thatmovesa controlsurfaceby either pushing it or pulling it.

- In a push-pull tube system, metal push-pull tubes (or rods) are used as a substitute for the cables .
- Push-pulltubesgettheirnamefromthewaytheytransmitforce.Inthetorque tubesystem,metaltubes (rods) withgears attheends of the tubes are used. Motion is transmitted by rotating the tubes and gears. On all high-performance aircraft, the control surfaces have great pressure exerted on them.
- At high airspeed, it is physically impossible for the pilot to move the controls manually. As a result, power-operated control mechanisms are used. In a power-operated system, a hydraulic actuator (cylinder)is located within the linkage to assistthe pilotin moving the control surface. A typical flightcontrol mechanism is shown in figure4-12. This is the elevator control of a light weight trainer-type aircraft. It consistsof a combination of push-pull tubes andcables.
- The control sticks in the system shown in figure4-12 are connected to the forward sector by push-pull tubes. The forward sector is connected to the aft (rear) sector by means of cable assemblies. The aft sector is connected to the flight control by another push-pull tube assembly.



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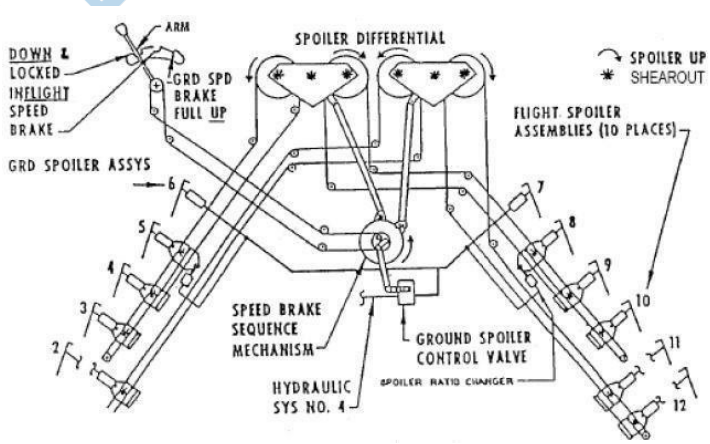
b) Cable and Pulley system: The cable and pulley system is widely used for commercial aircraft; sometimes used in conjunction with push–pull control rods.

- Manual control inputs are routed via cables and a set of pulleys from both captain's and first officer's control yokes to a consolidation area in the centre section of the aircraft.
- At this point aileron and spoiler runs are split both left/right and into separate aileron/spoiler control runs. Both control column/control yokes are synchronized.
- A breakout device is included which operates at a predetermined force in the event that one of the cable runs fails or becomes jammed. Control cable runs are fed through the aircraft by a series of pulleys, idler pulleys, quadrants and control linkages in a similar fashion to the push–pull rod system already described.
- Tensiometer / lost motion devices situated throughout the control system ensure that cable tensions are correctly maintained and lost motion eliminated. Differing sized pulleys and pivot/lever arrangements allow for the necessary gearing changes throughout the control runs. Figure 4 shows a typical arrangement for interconnecting wing spoiler and speed brake controls. Trim units, feel units and PCUs are connected at strategic points throughout the control runs as for the push–pull rod system.

Advantageofcable-pulleysystem

• Thesameoperationdescribedcanbedonebyacable-pulleysystem,wherecouplesofcables are used in place of the rods.
• Inthiscasepulleysareusedtoalterthedirectionofthelines,equippedwithidlerstoreduce any slack due to structure elasticity, cable strands relaxation or thermal expansion.
• Oftenthe cable-pulleysolutionispreferred,becauseitismoreflexibleandallowsreaching more remote areas of the airplane.
• AnexampleisshowninFig.,wherethecabincolumnislinkedviaarodtoaquadrant,which the cables are connected to.
• For this reason the actuation system in charge of primary control has a high redundancy and reliability,andiscapableofoperatingclosetofullperformanceevenafteroneormorefailures.



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II. Hydro Mechanical Control systems: The Complexity and Weight of the system (Mechanical) increased with Size and Performance of the aircraft.

- When the pilot's action is not directly sufficient for the control, the main option is a powered system that assists the pilot.
- The hydraulic system has demonstrated to be a more suitable solution for actuation in terms of reliability, safety, weight per unit power and flexibility, with respect to the electrical system Powered Assisted Control System
- The pilot,via the cabin components,sends a signal,or demand,toa valve that opens ports through which high pressure hydraulic fluid flows and operates one or more actuators.
- Thevalve, that is located near the actuators, can be signaled in two different ways: mechanically or electrically
- Mechanical signaling is obtained by push-pull rods, or more commonly by cables and pulleys
- Electricalsignalingisasolutionofmoremodernandsophisticatedvehicles
- The basic principle of the hydrauliccontrol is simple,buttwo aspects must be noticed when a powered control is introduced:
- The system must control the surface in a proportional way, i.e. the surface response (deflection) mustbe function to the pilot's demand (stick deflection, forinstance)
- Thepilotthatwithlittleeffortactsona controlvalve musthaveafeedback on the maneuver intensity.
- The first problem is solved by using (hydraulic) servo-mechanisms, where the components are linked in such a way to introduce an actuator stroke proportional to the pilot's demand

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- The pilot,in normal hydraulicoperatingconditions,isrequestedforaverylow effort, necessary to contrast the mechanical frictions of the linkage and the movement of the control valve
- The pilot is then no more aware of the load condition being imposed to the aircraft.
- Anartificial feelisintroducedinpoweredsystems,acting directly onthe cabin control stick or pedals.
- The simplest solution is a spring system, then responding to thepilot's demand with a force proportional to the stick deflection; this solution has of coursethe limitto be not sensitive to the actual flight conditions.
- A more sophisticated artificial feel is the socalled Q feel. This system receives data from the pitot-static probes, reading the dynamic pressure, or the difference between total (pt) and static (ps) pressure, that is proportional to the aircraftspeed v through the air density ρ:This signal is used tomodulate a hydraulic cylinder that increases the stiffness in the artificial feel system, in such a way that the pilot is given a contrast force in the pedals or stick that is also proportional to the aircraft speed.

DisadvantagesofMechanicalandHydro-MechanicalSystems

- Heavy and require careful routing of flight control cables through the aircraft using pulleys, cranks, tension cables and hydraulic pipes.
- Theyrequireredundant backuptodealwith failures, which again increases weight.
- Limitedabilitytocompensateforchangingaerodynamicconditions
  Disadvantages of Mechanical and Hydro-Mechanical Systems
- Dangerous characteristics such as stalling, spinning and pilot-induced oscillation (PIO), which depend mainly on the stability and structure of the aircraft concerned rather than the control system itself, can still occur with thesesystems
- Byusing electrical control circuits combined with computers, designers can save weight, improve reliability, and use the computers to mitigate the undesirable characteristics mentioned above. Modern advanced fly-by-wire systems are also used to control unstable fighter aircraft

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III. **FLY BY WIRE:** The fly-by-wire means that in the aircraft, the (pilot or autopilot) control inputs are fed to the (flight) computer, which processes them and determines the required control surface movements and transmits this by electrical signals (through wires, hence the term fly-by-wire) to the appropriate actuators.

Thefirstaircrafttouse thismode of controlwas the AvroArrow,which useda dual-channelfly- by-wire system made of analog circuits.

Fly-by-wire means that the control commands travel by wire to the control surfaces. There, either electric motors or hydraulic actuators do the physical work of moving the surfaces. The pilot has either a conventional control column or a side stick with transducerswhich will encode the commands of the pilot into electric signals. Optionally, a computer canbe employed to modify the signals such that overload conditions or dangerous maneuvers are avoided.

Actuation:

TheconventionallinearactuatorusedinpoweredflightcontrolswouldbeofthetypeshowinFigure 2.12. This type of actuator would usually be powered by one of the aircraft hydraulic systems – in this case the blue channel is shown. In functionally critical applications a dual hydraulic supply from another aircraft hydraulic system may be used. A mechanically operated Servo Valve (SV) directs the hydraulic supply to the appropriate side of the piston ram.

As the pilot feeds a mechanical input to the flight control actuator, the summing link will rotate aboutthe bottom pivot,thus applying aninputto 20 FlightControl Systems the servo valve.Hydraulicfluid will then flow into one side of the ram while exiting the opposite side resulting in movement of the ram in a direction dependent upon the direction of the pilot's command. As theram moves, thefeedback link will rotate the summing link aboutthe upper pivotreturning the servo valve inputto the null position as the commanded position is achieved. The attributes of mechanical actuation are straightforward; the system demands a control movement and the actuator satisfies that demand with a power assisted mechanical response. The BAE Hawk 200 is a good example of a system where straightforward mechanical actuation is used for mostof the flightcontrol surfaces.

For most applications the mechanical actuator is able to accept hydraulic power from two identical/redundant hydraulic systems. The obvious benefit of this arrangement is that full control is retained following loss of fluid or a failure in either hydraulic system. This is important even in a simple system as the loss of one or more actuators and associated control surfaces can severely affect aircraft handling. The actuators themselves have a simple reversion mode following failure,that is to centre automatically under the influence of aerodynamic forces.

This reversion mode is called aerodynamic centre and is generally preferred for obvious reasons over a control surface freezing orlocking at some intermediate point initstravel. Insome systems 'freezing'

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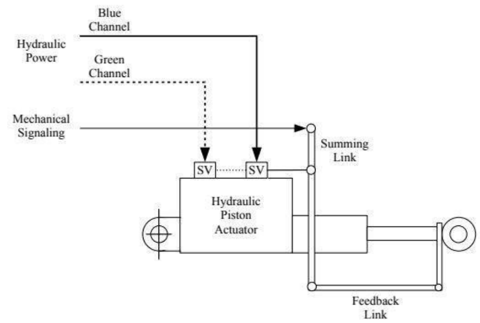

Figure:Conventionallinearactuator

the flight control system may be an acceptable solution depending upon control authority and reversionary modes that the flight control system possesses. The decision to implement either of these philosophies will be a design decision based uponthe system safety analysis.

Mechanical actuation may also be used for spoilers where these are mechanicallyratherthan electrically controlled. In this case the failure mode is aerodynamic closure, that is the airflow forces the control surface to the closed position where it can subsequently have no adverse effect upon aircraft handling. Figure 1.13 illustrates the mechanical spoiler actuator supplied by

This unit is simplex in operation. It produces thrust of 59.9 kN (13 460 lb) over a workingstroke of 15 mm (0.6 inch). It has a length of 22.4 mm (8.8 inch) and weighs 8.3 kg (18.2 lb). The unit accepts hydraulic pressure at 20.7 MN/sqm (3000 psi).

MechanicalActuationwithElectricalSignaling

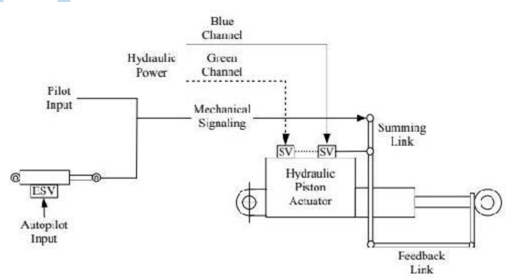

Figure:Conventionallinearactuatorwithautopilotinterface

The use of mechanical actuation has already been described and is appropriate for a wide range of applications. However the majority of modern aircraft use electrical signaling and hydraulically powered (electro-hydraulic) actuators for a wide range of applications withvarying degrees of redundancy.

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The demands for electro-hydraulic actuators fall into two categories: simple demand signals or autostabilisationinputs.

As aircraftacquired autopilots to reduce pilotwork load then itbecame necessary to couple electrical as well as mechanical inputs to the actuator as shown in Figure 1.14. The manual (pilot) input to the actuator acts as before when the pilot is exercising manual control. When the autopilot is engaged electrical demands from the autopilot computer drive an electrical input which takes precedence over the pilot's demand. The actuator itself operates in an identical fashion as before with the mechanical inputs to the summing link causing the Servo-Valve (SV) to move. When the pilot retrieves control by disengaging the autopilot the normal mechanical link to the pilot through the aircraft control run is restored. Simple electrical demand signals are inputs from the pilots that are signaled by electrical means. For certain noncritical flight control surfaces it may be easier, cheaper and lighter to utilise an electrical link. An example of this is

FlightControlSystems

The airbrake actuator used on the BAE 146; simplex electrical signaling is used and in the case of failure the reversion mode is aerodynamic closure. In most cases where electrical signaling is used this will at least be duplex in implementation and for fly-by-wire systems signaling is likely to be quadruplex; these more complex actuators will be addressed later. An example of duplexelectrical signalingwith a simplex hydraulic supply is the spoiler actuators on Tornado. There are four actuators fitted on the aircraft, two per wing, which are used for roll augmentation.

In general,those systems which extensively usesimplex electrical signaling dosofor autostabilisation.In thesesystemsthe electricaldemandisa stabilizationsignalderivedwithinacomputer unit. Thesimplest form of autostabilisation is the yaw damper which damps out the cyclic cross-coupled oscillations which occur in roll and yaw known as 'Dutch roll'. The Hawk200 illustrated this implementation. Aircraftwhich require a stable platform for weapon aiming may have simplexautostabilisation in pitch, roll and yaw;an example of this type of system is the Harrier/AV-8A. A similar system on the Jaguar uses simplex autostabilisation in pitch and roll.

1.10.3MultipleRedundancyActuation:

Modern flight control systems are increasingly adopting fly-by-wire solutions as the benefits to be realized by using such a system are considerable.

These benefits include a reduction in weight, improvement in handling performanceand crew/passenger comfort. Concorde was the first aircraft to pioneer these techniques in the civil field using a flight control system jointly developed by GEC (now Finmeccanica) and SFENA.[3] The Tornado, fly-by-wireJaguarandEAPhaveextendedthe useof thesetechniques; thelatter twoweredevelopment programmes into the regime of the totally unstable aircraft. In the civil field the Airbus A320 and the Boeing777introduced modernstate-of-the-artsystemsintoservice.Forobviousreasons,agreatdealof careis takenduring thedefinition,specification,design,developmentandcertification of these systems.

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Multiple redundantarchitectures for the aircraft hydraulicand electrical systems mustbe considered as well as multiple redundant lanes or channels of computing and actuation for control purposes. The implications of the redundancy and integrity of the other aircraftsystems will be addressed.

For the present, attention will be confined to the issues affecting multiple redundant electro-hydraulic actuations.

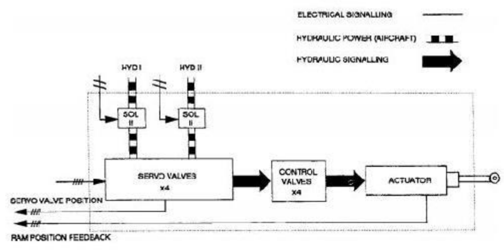

Figure:Simplifiedblockschematicdiagramofamultipleredundantelectricallysignalledhydraulic actuator

A simplified block schematic diagram of a multiple redundant electro-hydraulic actuator is shown in Figure 1.15. For reasons ofsimplicity only one lane or channel is shown; in practice the implementationis likely to be quadruplex, i.e. four identical lanes. The solenoid valve is energized to supply hydraulic powerto the actuator,oftenfrom two of the aircrafthydraulicsystems.Controldemandsfromthe flight control computers are fed to the servo valves. The servo valves control the position of the first-stage valves that are mechanically summed before applying demands to the control valves. The control valves modulate the position of the control ram. Linear variable electrically signaled hydraulic actuator differential transformers (LVDTs) measure the position of the first-stage actuator and output ram positions of each lane and these signals are fed back to the flightcontrol computers, thereby closing the loop. Two examples of this quadruplex actuation system are given below: the Tornado quadruplex taileron and rudder actuators associated with the Control Stability Augmentation System (CSAS) and the EAP flight control system. Both of these systems are outlined at system level in reference [1]. The description given here will be confined to that part of the flight control system directly relevant to the actuator drives. The Tornado CSAS flightcontrol computation is provided by pitch and lateral computers supplied by GEC (now part of Finmeccanica) and Bodenseewerk (now Thales). The pitch computer predominantly handles pitch control computations and the lateral computer roll and yaw computations though there are interconnections between the two (see Figure 1.16a). Thereare three computing lanes; computing is analogue in nature and there are a number of voter-monitors within the system to vote out lanes operating outside specification. The combined pitch/roll output to the taileron actuatorsis consolidated from three lanes to four within the pitch computersothe feedto thetaileron actuators is quadruplex. The quadruplex taileron actuator is provided by Fairey Hydraulics (now Hamilton Sundstrand) and is shown in Figure 1.16b. This actuator provides a thrust of 339.3 kN (76 291 lb) over a working stroke of 178 mm. The actuator is 940 mm (37.0 in) long and weighs 51.0 kg and operates with the two aircraft 4000 psi hydraulic systems. The rudder actuator similarly receives a quadruplex rudder demandfromthelateralcomputer,alsoshowninFigure1.14b.Therudderactuatorissomewhat smallerthan thetaileronactuator deliveringathrust of80.1 kN.TheCSASis designedso that followinga second critical failure it is possible to revert to a mechanical link for pitch and roll. Inthese circumstances the rudder is locked in the central position.

The Tornado example given relates to the analogue system that comprises the CSAS. The EAP flight control system (FCS) is a quadruplex digital computing

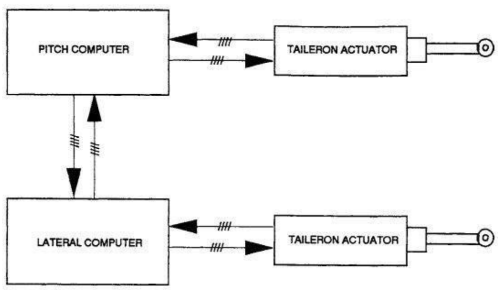

Figure2.16a:TornadoTaileron/RudderCSASdriveinterface

Figure 2.16b Tornado taileron and rudder actuators (Courtesy of Claverham/Hamilton Sundstrand) system in which control computations are undertaken in all four computing lanes. The system is quadruplex rather than triplex as a much higher level of integrity is required. As has been mentioned earlier the EAP was an unstable aircraft and the FCS has tobe able to survive two critical failures. Figure 2.17a shows the relationship between the flight control computers (FCCs), Actuator Drive Units (ADUs) and the actuators. The foreplane actuators are fed quadruplex analogue demands from the quadruplex digital FCCs. Demands for the left and right, inboard and outboard flaperons and the rudder are fed in quadruplex analogue form from the four ADUs. The ADUs receive the pitch, roll and yaw demands from the FCCs via dedicated serial digital links and the digital to analogue conversion is carried out within the ADUs.

ThetotalcomplementofactuatorssuppliedbyDowty(nowGEAviation)fortheEAPisasfollows:

• Quadruplexelectrohydraulicforeplaneactuators:2

• Quadruplexelectrohydraulicflaperonactuators:

– outboardflaperons–100mmworkingstroke: 2

– inboardflaperons–165mmworkingstroke: 2

• Quadruplexelectrohydraulicrudderactuators–100mmworkingstroke:1

All seven actuators are fed from two independent hydraulic systems. The EAP flight control system represented the forefront of such technology of its time and the aircraft continued to exceed expectations following the first flight in August 1986 until the completion of the programme. Further detailregardingtheEAPsystemandtheprecedingJaguarfly-by-wireprogrammemaybefoundina number of technical papers which have been given in recent years references [3–8]. Most of these papers are presented from an engineering perspective. The paper by Chris Yeo, Deputy Chief TestPilot at British Aerospace at the time of the fly-by-wire programme, includes an overview of the aircraft control laws.

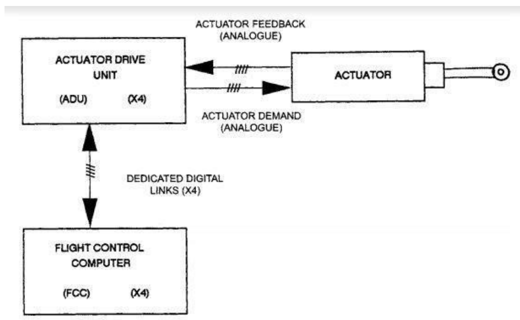

Figure2.17a:EAPactuatordriveconfiguration Mechanical

Screw jack Actuator

The linear actuators described so far are commonly used to power aileron, elevator and rudder control surfaces where a rapid response is required but the aerodynamicloads are reasonably light.

Thereareotherapplicationswherea relativelylowspeedofresponsemaybetoleratedbut theabilityto apply or withstand large loads is paramount. In these situations a mechanical screw jack is used to provide a slow response with a large mechanical advantage. This is employed to drive the Tailplane Horizontal Stabilator or Stabilizer (THS), otherwise known years ago as a 'moving tailplane'.

The THS is used to trim an aircraft in pitch as airspeed varies; being a large surface it moves slowly over small angular movements but has to withstand huge loads. The mechanicalscrew jack shown in Figure 2.18often has one or twoaircraft hydraulicsystemsuppliesandasumminglinkthatcausesSVs to move in response to the mechanical inputs. In this case the SVs moderate the pressure to hydraulic motor(s) which in turn drive the screw jack through a mechanical gearbox.

As before the left-hand portion of the jack is fixed to aircraft structure and movement of the screw jack ram satisfies the pilot's demands, causing the tailplane to move, altering tailplane lift and trimming the aircraft in pitch.

Asinpreviousdescriptions,movementof theram causesthe feedback linkto null theoriginal demand, whereupon the actuator reaches the demanded position.

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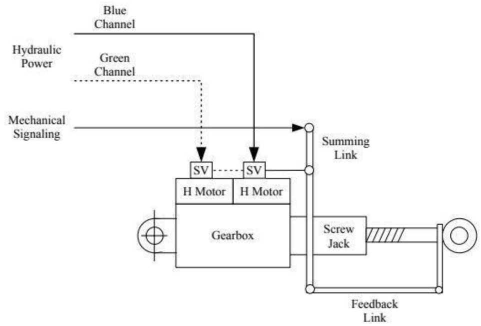

Figure:Mechanicalscrewjackactuator

Integrated Actuator Package (IAP)

In the UK, the introduction of powerful new AC electrical systems paved the way for the introduction of electrically powered power flying controls. Four channel AC electrical systems utilized on theAvro Vulcan B2 and Handley Page Victor V-Bombers and the Vickers VC10 transport aircraft utilized flight control actuators powered by the aircraft AC electrical system rather than centralized aircraft hydraulic systems.

Figure 2.19 shows the concept of operation of this form of actuator known as an Integrated Actuator Package (IAP). The operation of demand, summing and feedback linkage is similar to the conventional linear actuator already described.

The actuator power or 'muscle' is provided by a three-phase constant speed electrical motor driving a variable displacement hydraulic pump. The hydraulic pump and associated system provides hydraulic pressure topower the actuator ram. The variable displacementhydraulicpumpis the hydraulicpressure source for the actuator.

A bi-directional displacement mechanism which is controlled via a servo valve determines the pumps flow and hence actuator velocity. As with the linear actuator, a feedback mechanism nulls off the input to the servo valve as the desired outputposition is achieved.

Therefore when the actuator is in steady state,the pump displacementis set to the null position butthe pump continues to rotate at a constant speed imposing a significant 'windage' power loss which is a significant disadvantage with this design. The more modern integrated actuator designs, specifically the Electro-Hydrostatic Actuator (described later) eliminates this problem.

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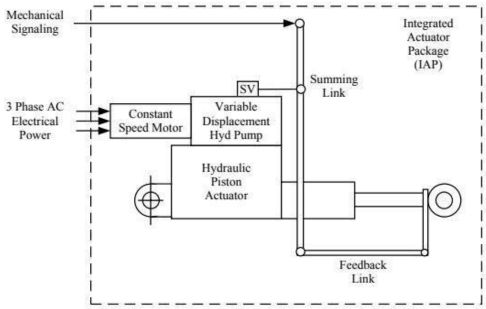

Figure 1.20 depicts an overview of a typical IAP used on the Vickers VC-10 flight control system. A total of 11 such units were used in the VC-10system topower eachof the following flightcontrol surfaces:

- Ailerons:4sections
- Elevators:4sections
- Rudder:3sections

The power consumption of each of the IAPs is in the region of 2.75 kVA and are still flying today in the Royal Air Force's VC-10 Tanker fleet. The units are powered by a constant frequency, split-parallel, 115 VAC three-phase electrical system.

The Avro Vulcan B-2 also used IAP to power the primary flight control surfaces. Being a large delta aircraft this system had an unusual configuration comprising eight elevons powered by IAPs located on the trailing edge of the delta wing plus two on the aircraft rudder. The elevons provided a combined elevator and aileron function to control the aircraft in pitch and roll.

Figure 1.21 Avro Vulcan B-2 FCS architecture using IAPs illustrates how the total complement of ten power flight control units were powered by the four aircraft AC buses. 1.10.6 Advanced Actuation Implementations The actuation implementations described so far have all been mechanical or electro-hydraulic in function using servo valves. There are a number of recent developments that may supplant the existing electro-hydraulic actuator. These newer types of actuation are listed below and have found application in aircraft over the past 10–15 years:

- Directdriveactuation
- Fly-by-Wire(FBW)actuation
- Electro-HydrostaticActuator(EHA)
- Electro-MechanicalActuator(EMA)

Direct Drive Actuation

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In the electro-hydraulic actuator a servo valve requires a relatively small electrical drive signal, typically in the order of 10–15 mA. The reason such low drive currents are possible is that the control signal is effectively amplified within the hydraulic section of the actuator. In the direct drive actuator theaim is to use an electrical drive with sufficient power to obviate the need for the servo valve/1st stage valve. The main power spool is directly driven by torque motors requiring a higher signal current, hence the term 'direct drive'. Development work relating to the direct drive concept including comparison with Tornado requirements and operation with 8 000psi hydraulic systems has been investigated by Fairey Hydraulics.

Fly-By-WireActuator

The adventof Fly-By-Wire (FBW) flightcontrol systemsin civil aircraftcommencing with the Airbus A320 introduced the need for a more sophisticated interface between the FCS and actuation. Most first generation FBW aircraft may operate in three distinct modes that may be summarised in general terms as follows:

• FullFBW Mode.This mode encompassesthefullFBW algorithmsand protection and is the normal mode of operation

• Direct Electrical Link Mode. This mode will usually provide rudimentary algorithms or possibly only a direct electrical signaling capability in the event that the primary FBW mode is not available

• MechanicalReversionMode.Thisprovidesacrudemeansofflyingtheaircraftprobablyusingalimited number of flight control surface following the failure of FBWand direct electrical link modes.

In later implementations such as the Airbus A380 and Boeing 787 no mechanical reversion is provided. The interface with the actuator is frequently achievedby means of an Actuator Control Electronics (ACE) unit that closes the control loop electrically around the actuator rather than mechanical loop closure as hitherto described (see Figure 1.22). The digital FBW or direct link demands from the flight control system are processed by the ACE which supplies an analogue command to the actuator SV. This allows aircraft systems hydraulic power to be supplied to the appropriateside of the ram piston moving the ram to the desired position. In this implementation the ram position is detected by means of a Linear Variable Differential Transducer (LVDT) which feeds the signal back to the ACE where the loop around the actuator is closed. Therefore ACE performs two functions: conversion of digital flight control demands into analogue signals and analogue loop closure around the actuator.

Electro-Hydrostatic Actuator (EHA) The move towards more-electric aircraft has coincided with another form of electrical actuation – the Electro-Hydrostatic Actuator (EHA) which uses state-of-the-art power electronics and control techniques to provide more efficient flight control actuation. The conventional actuation techniques described so far continually pressurize the actuator whether or not there is any demand.

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In reality for much of the flight, actuator demands are minimal and this represents a wasteful approach as lost energy ultimately results in higher energy offtake from the engine and hence higher fuel consumption. The EHA seeks to provide a more efficient form of actuation where the actuator only draws significant power when a control demand is sought; for the remainder of the flight the actuator is quiescent (see Figure 1.23). The EHA accomplishes this by using the three-phaseAC power to feed power drive electronics which in turn drive a variable speed pump together with aconstant displacement hydraulic pump. This constitutes a local hydraulic system for the actuator in a similar fashion to the IAP; the difference being that when there is no demand the only power drawn is that to maintainthecontrol electronics.Whena demandisreceivedfromtheACEthe powerdriveelectronicsis able to react sufficiently rapidly to drive the variable speed motor and hence pressurize the actuatorsuch that the associated control surface may be moved to satisfy the demand. Once the demand has been satisfied then thepowerelectronics resumes its normal dormant state. Consequently power is only drawn from the aircraft buses bars while the actuator is moving, representing a great saving in energy. The ACE closes the control loop around the actuator electrically as previously described. EHAs are being applied across a range of aircraft and Unmanned Air Vehicle (UAV) developments. The Airbus A380 and Lockheed Martin F-35 Lightning II both use EHAs in the flight control system. For aircraft such as the A380 with a conventional three-phase, 115 VAC electrical system, the actuator uses an in-built matrix converter to convert the aircraft three-phase AC power to 270 VDC to drive a brushless DC motor which in turn drives the fixed displacement pump. The Royal Aeronautical Society Conference, More- Electric Aircraft, 27–28 April 2004, London is an excellent reference for more-electric aircraft and more- electric engine developments where some of these solutions are described.

Aircraft such as the F-35 have an aircraft level 270 VDC electrical systemand so the matrix converter may be omitted with further savings in efficiency. Furthermore, electric aircraft/more-electric engine development programmes with civil applications envisage the use of 540 VDC or ±270 VDC systems on the aircraft or engine platform and therefore making similar savings in energy. These developments, including a European Community (EC) funded programme called Power Optimised Aircraft (POA), were described and discussed at the Technologies for Energy Optimised Aircraft Equipment Systems (TEOS) forum in Paris, 28–30 June 2006.

A common feature of all three new actuator concepts outlined above is the use of microprocessors to improve control and performance. The introduction of digital control in the actuator also permits the consideration of direct digital interfacing to digital flight control computers by means of data buses (ARINC 429/ARINC 629/1553B). The directdrivedevelopmentsdescribedemphasiseconcentrationupon the continued use of aircraft hydraulics as the power source, including the accommodation of system pressures up to 8000 psi. The EMA and EHA developments, on the other hand, lend themselves to a greater use of electrical power deriving from the all-electric aircraft concept, particularly if 270 VDC power is available.

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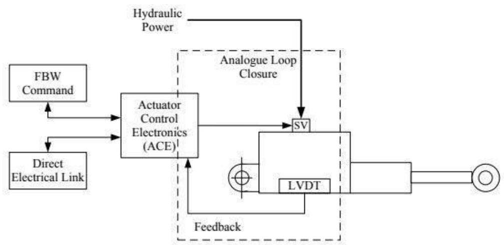

Figure2.22:Fly-by-wireactuator

Electro-MechanicalActuator(EMA)

The electromechanical actuator or EMA replaces the electrical signalling and power actuation of the electro-hydraulic actuator with an electric motor and gearbox assembly applying the motive force to move the ram. EMAs have been used on aircraft for many years for such uses as trim anddoor actuation; however the power, motive force and response times have been less than that required for flight control actuation. The three main technology advancements that have improved the EMA to the point where it may be viable for flight control applications are: the use of rare earth magneticmaterials in 270 VDC motors; high power solid-state switching devices; and microprocessors forlightweight control of the actuator motor.

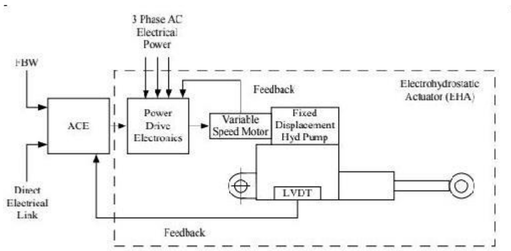

Figure2.23:Electro-HydrostaticActuator(EHA)

As the EHA is the more-electric replacement for linear actuators so the Electro-Mechanical Actuator (EMA)isthe more-electricversionof the screwjack actuator asshown inFigure1.24. The conceptof the EMA is identical with the exception that the power drive electronics drives a brushless DC motor operating a reduction gear that applies rotary motion allowing the jack ramto extend or retract to satisfy input demands.

EMAs are therefore used to power the THS on civil aircraftand flap and slat drives and also find a use in helicopter flight control systems. A major concern regarding the EMA is the consideration ofthe actuator jamming case and this has negated their use in primary flightcontrols on conventional aircraft.

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ActuatorMatrix

Most ofthese actuationtypes areused incivil aircraft today.Table 1.1 listshow thevarious actuator types may be used for different actuation tasks on a typical civil airliner.

Table2.1:Typicalapplicationsofflightcontrolactuators

Actuator type	*Power source*	*Primary flight control*	*Spoilers*	*Tailplane horizontal stabilator*	*Flaps and slats*
Conventional Linear Actuator	Aircraft Hydraulic Systems: B/Y/G or L/C/R [1]	X	X		
Conventional Screw-jack Actuator	Aircraft Hydraulic or Electrical Systems [2]			X	X
Integrated Actuator Package (IAP)	Aircraft Electrical System (115VAC)	X	X		
Electrically Signalled Hydraulic Actuator	Aircraft Hydraulic Systems	X	X		
Electro-Hydrostatic Actuator (EHA)	Aircraft Electrical System [3] [4]	X	X		
Electro-Mechanical Actuator (EMA)	Aircraft Electrical System [3]			X	X

Notes: (1) B/Y/G = Blue/Green/Yellow or L/C/R = Left/Centre/Right (Boeing)
(2) For THS and Flaps & Slats both hydraulic and electrical supplies are often used for redundancy
(3) 3-phase VAC to 270 VDC matrix converter used in civil
(4) 270 VDC aircraft electrical system used on F-35/JSF

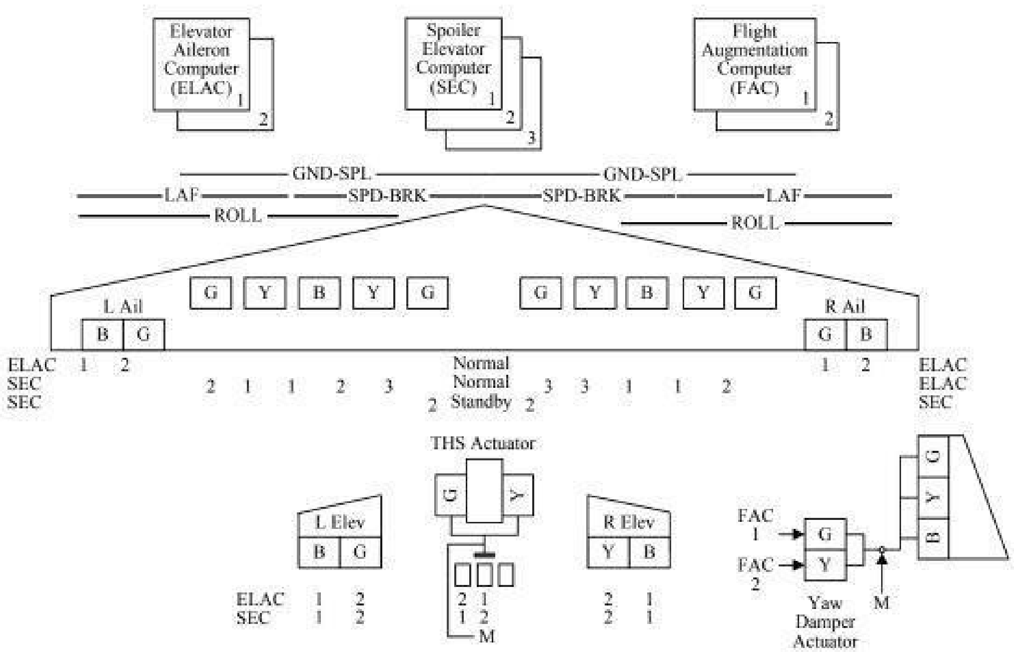

Figure:2.26:A320flightcontrol system

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Example:A320FBWSystem:

Aschematic of the A320 flight control system is shown inFigure 1.26. The flight control surfaces are all hydraulically powered and are tabulated as follows:

• Electricalcontrol:

Elevators 2

Ailerons2

Rollspoilers8

Tailplanetrim1

Slats10

Flaps4

Speedbrakes 6

Liftdumpers10

Trims

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• Mechanicalcontrol:

Rudder

Tailplanetrim(reversionarymode)

Theaircrafthasthreeindependenthydraulicpowersystems:blue(B),green(G)andyellow(Y).Figure 1.26showshow thesesystemsrespectivelypowerthehydraulicflightcontrolactuators.Atotalofseven computers undertake the flight control computation task as follows:

• Two Elevator/Aileron Computers (ELACs). The ELACs control the aileron andelevator actuators according to the notation in the figure

• Three Spoiler/Elevator Computers (SECs). The SECs control all of the spoilers and in addition provide secondary control to the elevator actuators.

Thevariousspoilersectionshavedifferentfunctionsasshownnamely: –

ground spoiler mode: all spoilers

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– speedbrakemode:inboardthreespoilersections

– load alleviation mode: outboard two spoiler sections (plus ailerons); this function has recently been disabled and is no longer embodied in recent models

– rollaugmentation:outboardfourspoilersections

• TwoFlightAugmentationComputers(FACs).Theseprovideaconventionalyawdamperfunction, interfacing only with the yaw damper actuators

The three aircraft hydraulic systems; blue, green and yellow provide hydraulic power totheflight control actuators according to the notation shown on the diagram. In the very unlikely event of the failure of all computers itis still possible to fly and land the aircraft – this has been demonstrated during certification.

In this case the Tailplane Horizontal Actuator (THS) and rudder sections are controlled directly by mechanical trim inputs – shown as M in the diagram – which allow pitch and lateral control of the aircraft to be maintained.

Another noteworthy feature of the Airbus FBW systems is that they do not use the conventional pitch and roll yoke. The pilot's pitch and roll inputs to the system are by means of a side-stick controller and this has been widely accepted by the international airline community. In common with contemporary civil aircraft, the A320 is not an unstable aircraft like the EAP system briefly described earlier in this chapter. Instead the aircraft operates with a longitudinal stability margin of around 5% of aerodynamic mean chord or around half what would normally be expected for an aircraft of this type. This is sometimes termed relaxed stability. The A320 family can claim to be the widest application of civil FBW with over 3000 examples delivered.

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Trim: The need for trim actuation may be explained by recourse to a simple explanation of the aerodynamic forces which act upon the aircraft in flight. Figure 2.10 shows a simplified diagram of the pitch forces which act upon a stable aircraft trimmed for level flight.

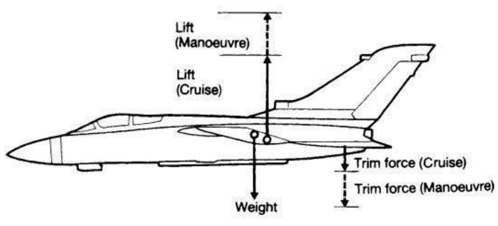

Figure2.10Pitchforcesactinginlevelflight

The aircraft weight usually represented by the symbol W, acts downwards at the aircraft centre-of-gravity or CG. As the aircraft is stable the CG is ahead of the 16 centre of pressure where the lift force acts (often denoted by the symbol L) and all aerodynamic perturbations should be naturally damped.The distance between the CG and the centre of pressure is a measure of how stable and also how manoeuvrable the aircraft is in pitch. The closer the CG and centre of pressure, the less stable and more manoeuvrable the aircraft. The converse is true when the CG and centre of pressure are further apart. Examining the forces acting about the aircraft CG it can be seen that there is a counter-clockwise moment exerted by a large lift force acting quite close to the pivot point. If the aircraft is not to pitch nose-down this should be counterbalanced by a clockwise force provided by the tailplane. This will be a relativelysmall forceactingwitha largemoment.Iftherelativepositionsofthe aircraftCGand centreof pressure were to remain constant throughout all conditions of flight then the pilot could set up the trim and no further control inputs would be required.

In practice the CG positions may vary due to changesin the aircraftfuel load and the stores or cargo and passengers the aircraftmay be carrying. Variations in the position of the aircraftCG position are allowed within carefully prescribed limits. These limits are called the forward and aft CG limits and they determine how nose heavy or tail heavy the aircraft may become and still be capable of safe and controllable flight. The aerodynamic centre of pressure similarly does not remain in a constant position as the aircraft flight conditions vary. If the centre of pressure moves aft then the downward force required of the tailplane will increase and the tailplane angle of incidence will need to be increased. This requires a movement of the pitch control run equivalent to a small nose-up pitch demand. It is inconvenient for the pilot constantly toapply the necessary backward pressure on the control column, so a pitch actuator is provided to alter the pitch control run position and effectively apply this nose-up bias. Forward movement of the centre of pressure relative to the CG would require a corresponding nose-down bias to be applied. These nose-up and nose-down biases are in fact called nose-up and nose- down trim respectively.

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Pitch trim changes may occur for a variety of reasons: increase in engine power, change in airspeed, alteration of the fuel disposition, deployment of flaps or airbrakes and so on. The desired trim demands may be easily inputto the flightcontrol system by the pilot. In the case of the Hawk the pilothas a four-way trim button located on the sticktop; this allows fore and aft (pitch) and lateral (roll) trim demands to be applied withoutmoving his hand from the control column.

The example described above outlines the operation of the pitch trim system as part of overall pitch control. Roll or aileron trim is accomplished in a very similar way to pitch trim by applying trim biases to the aileron control run by means of an aileron trim actuator. Yaw or rudder trim is introduced by the separate trim actuator provided; in the Hawk this is located in the rear of the aircraft. The three trim systems therefore allow the pilot to offload variations in load forces on the aircraft controls as the conditions of flight vary.

Feel

The provision of artificial 'feel' became necessary when aircraft performance increased to the point where it was no longer physically possible for the pilot to apply the high forces needed to move theflight control surfaces. Initially with servo-boosting systems, and later with powered flying controls, it became necessary to provide powered assistance to attain the high control forces required. This was accentuated as the aircraft wing thickness to chord ratio became much smaller for performance reasons and the hinge moment available was correspondinglyreduced. However, a drawback with a pure power assisted system is that the pilot may not be aware of the stresses being imposed on the aircraft. Furthermore,a uniform feel from the control system is nota pleasantcharacteristic;pilots are notalone in this regard; we are all used to handling machinery where the response and feel are sensibly related.
Thetwo types offeel commonlyusedinaircraftflightcontrol systemsare

spring feel

'Q'feel.

Typically the goal is to provide a fairly constant 'Stick force per g' over the full flight envelope. In this regard, the feel system is further complicated with variable geometry aircraft such as the Tornado since aircraft response in pitch and roll varies dramatically with wing sweep. The feel system must therefore take into account both Q and wing sweep.

Spring feel, as the name suggests, is achieved by loading the movement ofthe flight control run against a spring of a predetermined stiffness. Therefore when the aircraft controls are moved, the pilot encounters an increasing force proportional to the spring stiffness. According to the physical laws spring stiffness is a constant and therefore spring feel is linear unless the physical geometry of the control runs impose any nonlinearities. In the Hawk 200, spring feel units are provided in the tailplane, aileron and rudder control runs. The disadvantage of spring feel units is that they only impose feel proportional to control demand and take no account of the pertaining flight conditions.

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'Q' feel is a little more complicated and is more directly related to the aerodynamics and precise flight conditions that apply at the time of the control demand. As the aircraft speed increasesthe aerodynamic load increases in a mathematical relationship proportional to the air densityand the square of velocity. The air density is relatively unimportant; the squared velocity term has a much greater effect, particularly at high speed. Therefore it is necessary to take account of this aerodynamic equation; that is the purpose of 'Q' feel. A 'Q' feel unit receives air data information from the aircraft pitot-static system. In fact the signal applied is the difference between pitot and static pressure, (known asPt-Ps) andthis signal is used to modulate thecontrol mechanism withinthe'Q' feel unitand operate a hydraulic load jack which is connected into the flight control run. In this way the pilot is given feel which is directly related to the aircraft speed and which will greatly increase with increasing airspeed. It is usual to use 'Q'feel in the tailplane or rudder control runs; where this method of feel is used depends upon the aircraft aerodynamics and the desired handling or safety features. The disadvantage of 'Q'feel is that it is more complex and only becomes of real useat high speed.

Figure 2.11 is a photograph of a 'Q' feel unit supplied by Dowty for the BAE Harrier GR5 and McDonnell Douglas AV-8B aircraft.

This unitis fitted with an electrical solenoid so that the active partof the system may be disconnected if required. This unit is designed to operate with an aircraft 20.7 MN/sq m (3000 psi) hydraulic system pressure.

The rudder control run on Hawk 200 shown in Figure 1.6 uses both spring and 'Q' feel. It is likely that these two methods have been designed to complementeach other. The spring feel will dominate atlow speed and for high deflection control demands. The 'Q' feel will dominate at high speedsand low control deflections.

UNIT 3: ENGINE CONTROL & FUEL SYSTEMS

Introduction: In early days centrifugal compressor used for controlling fuel to the jet engines engine combustion chamber that used as a fuel pump, a relief valve and a throttle valve.
Later axial compressor and reheat (afterburning) created a demand for more complex methods of controlling airflow, fuel flow and exhaust gas flow.

As engine and materials development continued a need arise to exercise greater control of turbine speeds and temperatures to suit prevailing atmospheric conditions and to achieve surge-free operation. The latter was particularly important in military engines where handling during rapidacceleration tended to place the engine under severe conditions of operation.

In support of the needed improvements, limited authority electronic trimmers so called as **'supervisory controls'** were developed to provide added functions such as **temperature limiting and thrust management** thus relieving the flight crew of this workload. This became important as new aircraft entering service eliminated the flight engineer position on the flight deck. Further developments in engine design led to the need to control more parameters and eventually led to the use of full authority analogue control systems with electrical signaling from the throttle levers.

Engine / Air frame Interfaces

The engine is a major, high value item in any aircraft procurement programme. Often an engine is especially designed for a new military aircraft as per demand specifications. The control of the interfaces between the **engine and the airframe** is essential to allow the airframe contractor and the engine contractor to develop their products independently. The interface may be between the **engine and a nacelle** in the case of a podded, under-wing engine, for commercial aircraft; or between the **engine and the fuselage** for jet military aircraft. Later full authority control systems were introduced in analogue form,semi conductor technology demanded that he electronic control units were mounted on the airframe. This led to a large number of wire harnesses and connectors at the engine–airframe interface. Together with the mechanical, fluid and power off take interfaces, this was a measure of complexity that had the potential for interface errors that could compromise an aircraft development programme. Although the emergence of rugged electronics, data buses and bleedless engines has simplified this interface, nevertheless it needs to be controlled. What often happens is that an Interface Control Document or ICD is generated that enables the major project contractors to declare and agree their interfaces. The nature of the interfaces and the potential for rework usually means that the ICD becomes an important contractual document.
Typical of the interfaces declared in ICD arethefollowing.

Installation

- **Engine mass, centre of mass and volume**
- **Engine space envelope**
- **Engine clearance sunder static and dynamic conditions**
- **Attachments**
- **Thrust bearings and fuselage loads**
- **Interface compatibility**
- **Turbine/ disccontainment measures**
- **Maintenance access points**
- **Drains and vents**

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- **Engine change/winchingpoints**
- **Groundcrewintakeandexhaustsafetyclearances**
- **Noise**

SystemConnections

- **Fuelconnections**
- **Controlsystemconnections(throttles,reversethrustcommand)**
- **Cockpitindications,alertsandwarnings**
- **Airstartinterconnections**
- **Airdata requirements**
- **Firedetectionandprotection**
- **Enginestart/relightcommands**
- **Enginehealthmonitoring**
- **Groundequipmentconnections**
- **Inspectionaccess**

PowerOff-takes

- **Hydraulicpowergeneration**
- **Electricalpowergeneration**
- **Airbleeds**

EngineTechnologyandPrinciplesofOperation

The introduction of digital technology and serial data transmission systems, as well as higher performance electronic devices led to the FADEC (Full Authority Digital Electronic Control). This, in turn led to integrate the control systems with the aircraft avionics and flight controlsystems.When mounting these electroniccontrols on the engine,great care mustbe taken to isolate the units from the hostile environment by providing anti-vibration mountings.

Engine technology has advanced considerably with new materials and new manufacturing techniques leading to smaller, lighter and more efficient engines capable of delivering more thrust andmore reliable engines. Most of the thrust is generated by the fan since most of the high energy gas from the gas generator section is dissipated in the turbine connected to the fan. In the turbofan engine, thrust is generated by imparting a relatively small increase in velocity to a very large air mass flowthrough the fan while, in the older turbojet engines, the total air mass flow through the engine is much smaller and therefore,to achieve the same thrust, the velocity of the exhaust gasses must be much greater,i.e.

• Turbofan:Thrust=$\dot{\mathbf{M}}\times\mathbf{v}$Largemassflow,smallvelocitychange

• Turbojet:Thrust=$\dot{\mathbf{m}}\times\mathbf{V}$Smallmassflow,largevelocitychange

It is for this reason that today’s large fan engines are much quieter than their turbojet or low by-pass ratioEngines.

TheControlProblem

The basiccontrol action is to control fuel flow and air to the engine to allow itto operate atits optimum efficiency over a wide range of forward **speeds, altitudes and temperatures** while allowing the pilot to handle the engine without fear of malfunction. The military aircraft is usually specified to operate in worldwide conditions, and is expected to experience a wide range of operating temperatures. To be successful in combat the aircraft must be maneuverable. The pilot, therefore, expects to be able to demandminimumormaximumpowerwithoptimumaccelerationrates,aswellastomakesmall adjustments with equal ease, without fear of surge, stall, flame-out, over-speed or over-temperature. The pilotalso needs a fairly linear relationship between throttle lever position and thrust. The civil pilots requires reliable, economical and long-term operation under clearly defined predictable conditions with minimumrisktopassengersandschedules.To obtain theseobjectives,control canbe exercisedoverthe following aspects of engine control:

• *Fuelflow*– to allowvaryingenginespeeds to be demandedandto allowtheengineto behandled withoutdamage by limiting rotating assembly speeds,rates of acceleration and temperatures.
• *Air flow*– to allow the engineto be operated efficiently throughout the aircraft flight envelope andwith adequate safety margins.
• *Exhaustgasflow*–byburningtheexhaust gasesand varyingthenozzlearea toprovideadditional thrust.

Electronic control has been applied in all these above cases with varying degrees of complexity and control authority. Such control can take the form of simple limiter functions through to sophisticated multi-variable, full authority control systems closely integrated withother aircraft systems.

Fuel Flow Control Control of power or thrust is achieved by regulating the fuel flow into the combustor. On turbo jet or turbo fan engines thrust can be controlled by setting an enginepressure ratio or, in the case of the larger commercial fan engines, by controlling fan speed, while on shaft power engines the speed of the gas generator is a measure of the power delivered to the propeller or to the rotor. When changing the thrust or power setting the fuel control system must limit the rate of acceleration and deceleration of the engine rotating assemblies in order to preventcompressor surge or flame out. This control process is further complicated by the change in engine inlet conditions, i.e. inlet temperature, inlet pressure and Mach number that can occur as the aircraft moves around the flight envelope. Airflow modulation through the compressor may also be necessary by the use of variable vanes and/or bleed valves to provide adequate surgemargin under all operating conditions.

The control of power or thrust of the gas turbine engine is obtained by regulating the quantity of fuel injected into thecombustion system. When a higher thrust is required the throttle is opened and the fuel pressure to the burners increases due to the higher fuel flow. This has the effect of increasing the gas temperature which, in turn, increases the acceleration of the gases through the turbine to give a higher engine speed and correspondingly greater air flow,resulting in an increase in thrust.

The relationship between the air flow induced through the engine and the fuel supplied is, however, complicated by changes in altitude,air temperature and aircraftspeed. To meetthis change in air flow a similar change in fuel flow must occur, otherwise the ratio of air to fuel will alter and the engine speed will increase or decrease from that originally selected by the pilot in setting the throttle lever position. Fuel flowmust, therefore, bemonitored to maintaintheconditions demandedby thepilot whateverthe changes in the outside world.

Failuretodoso wouldmean thatthepilotwouldconstantlyneedto makeminoradjustments to throttle lever position, increasing his work load and distracting his attention from other aspects of aircraft operation. The usual method of providing such control is by means of a fuel control unit (FCU) or fuel management units (FMU). The FCU/FMU is a hydro chemical device mounted on the engine. It is a complexengineeringmechanismcontainingvalvestodirectfuelandtorestrictfuelflow,pneumatic

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capsules to modify flows according to prevailing atmospheric conditions. The engine speed must be controlled from idle to maximum rating. Over speed must be avoided to reduce stresses in the rotating assemblies, and over temperature must be avoided to prevent blade damage and to reduce thermal creep. The engine mustbe allowed to accelerate and decelerate smoothly with no risk of surge.

Such control influences are difficultto achieve manually. Therefore the FCU has,over the generations of jet engines, been designed to accommodate control inputs from external electronic devices. Electrical valves in the FCU can be connected to electronic control units to allow more precise and continuous automatic control of fuel flows in response to throttle demands, using measurements derived from the engine,to achieve steady state and transient control of the engine withoutfear ofmalfunction.

A typical fuel control circuit is shown in Figure On some military aircraft the fuel system receives a demand from the weapon release switch or gun trigger topreempt weapon release. This allows fuelflow to the engines to be modified to prevent an engine surge resulting from disturbance of the intake conditions from missile exhaust, shock from the gun muzzle or smoke from the gun breech. This facilityis known as ‘**fuel dip’**.

AirFlowControl

It is sometimes necessary to control the flow of air through to the engine to ensure efficient operation over a wide range of environmental and usage conditions to avoid **engine surge**. Most modern commercial engines have variable compressor vanes and/or bleed valves to provide optimum acceleration without surge. The figure shows air is bled from the engine for various purposes, including engine stability reasons and also to provide a source of air for conditioning systems andbleed air systems such as wing leading edge anti-icing.
The number of variables that affect engine performance is high and the nature of the variables is dynamic, so that the pilot cannot be expected constantly to adjust the throttle lever to compensate for changes, particularly in multiengine aircraft.
A throttle movementcauses a change in the fuel flow to the combustion chamber spray nozzles. This,in turn, causes a change in **engine speed and in exhaust gas temperature.** Both of these parameters are measured; engine speed by means of a gearbox mounted speed probe and Exhaust Gas Temperature (EGT), or Turbine Gas Temperature (TGT), by means of thermocouples, and presented to the pilot as analogue readings on cockpit-mounted indicators. The FCU, with its internal capsules, looks after variations due to atmospheric changes. In the dynamic conditions of an aircraft in flight at different altitudes, temperatures and speeds, continual adjustment by the pilot soon becomes impractical. He cannot be expected continuously to monitor the engine conditions safely for a flight of any significant duration. For this reasonsome form of automatic control is essential.

ControlSystemParameters

To perform any of the control functions electrically requires devices to sense engine operating conditions and toperform a controlling function. These can usually be conveniently subdivided into input and output devices producing input and output signals to the control system. To put the control problem into perspective the control system can be regarded as a boxon ablock diagram receiving input signals from the aircraft and the engine and providing outputs to the engine and the aircraft systems. This system is shown diagramatically in Figure 2.5.

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The input signals provide information from the aircraft and the engine to be used in control algorithms, while the output signals provide the ability to perform a control function. Further signals derived from outputdevices provide feedback to allow loop closure and stable control. Typical inputs and outputs are described below.

InputSignals

• *Throttle position*– A transducer connected to the pilot's throttle lever allows thrust demand to be determined. The transducer may be connected directly to the throttle lever with electrical signalling to the control unit, or connected to the end of control rods to maintain mechanical operation as far as possible. The transducer may be a potentiometer providing a DC signal or a variable transformer to provide an AC signal. To provide suitable integrity of the signal a number of transducers will be used to ensure that a single failure does not lead to an uncommanded change in engine demand.
• *Air data*– Airspeed and altitude can be obtained as electrical signals representing the pressure signals derived from airframe mounted capsule units. These can be obtained from the aircraft systems such as an air data computer (ADC) or from the flight control system air data sensors
• *Total temperature*– A total temperature probe mounted at the engine face provides the ideal signal. Temperature probes mounted on the airframe are usually provided, either in the intakes or on the aircraftstructure
• *Engine speed*– The speed of rotation of the shafts of the engine is usually sensed by pulse probes located in such a way as to have their magnetic field interrupted by moving metallic parts of the engine or gearbox. The blades of the turbine or compressor, or gear box teeth, passing in front of a magnetic pole piece induce pulses into a coil or a number of coils wound around a magnet.The resulting pulses are detected and used in the control system as a measure ofengine speed
• *Engine temperature*– The operating temperature of the engine cannotbe measured directly since the conditions are too severe for any measuring device. The temperature can, however, be inferred from measurements taken elsewhere in the engine. The traditional method is to measure the temperature of the engine exhaust gas using thermocouples protruding into the gas stream. The thermocouples are usually arranged as a ring of parallel connected thermocouples to obtain a measurement of mean gas temperature and are usually of chromel-alumel junctions. A cold junction is provided to obtain a reference voltage. An alternative method is to measure the temperature of the turbine blades with an optical pyrometer. This takes the form of a fiber optic with a lens mounted on the engine casing and a semiconductorsensormountedina remoteandcoolerenvironment.Bothof thesetemperatures canbe used todetermine anapproximation of turbine entry temperature,which is the parameter on which the temperature control loop should ideally be closed
• *Nozzle position*– For those aircraft fitted with reheat (or afterburning) the position of the reheat nozzle may be measured using position sensors connected to the nozzle actuation mechanism or to the nozzle itself. An inductive pick-off is usually used since such types are relatively insensitive to temperature variations,animportant point because of the harsh environment of the reheat exhaust
• *Fuel flow*– Fuel flow is measured by meansof a turbine type flow meter installedin the fuel pipe work to obtain a measure of fuel inlet flow as close to the engine as possible. Fuel flow measured by the turbine flow meter is for instrumentation and monitoring purposes and is not used as an input to the engine control system. The dynamic response of this device is much too slow for this function. Instead the position of the fuel metering valve within the FCU is used as a measureof fuel flow

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• *Pressure ratio*– The ratio of selected pressures between different stages of the engine can be measured by feeding pressure to both sides of a diaphragm operated device. The latest technology pressure ratiodevices use twohighaccuracy pressure sensorsandelectronics togeneratepressure ratio

OutputSignals

• *Fuel flow control*– The fuel supply to the engine can be varied in a number of ways depending on the type of fuel control unit used. Solenoid operated devices, torque motor or stepper motor devices have all been employed on different engine types. Each device has its own particular failure modes and its ownadherents
• *Air flow control*– The control of air flow at different stages of the engine can be applied by the use of guide vanes at the engine inlet, or by the use of bleed valves between engine stages. These are controlled automatically to preserve a controlled flow of air through the engine for varying flight conditions

FADCSystemsExample

Using various combinations of input and output devices to obtain information from the engine and the airframe environment, a control system can be designed to maintain the engine conditions stable throughout a range of operating conditions. The input signals and output servo demands can be combined in varying degrees of complexity to suit the type of engine, the type of aircraft, and the manner in which the aircraft is to be operated. Thus the systems of civil airliners, military trainers and high speed combat aircraft will differ significantly.

In a simple control system, such as may be used in a single engine trainer aircraft the primary pilot demand for thrust is made by movements of a throttle lever. Rods and levers connect the throttle lever to a fuel control unit (FCU) so that its position corresponds to a particular engine condition, say rpm or thrust. Under varying conditions of temperature and altitude this condition will not normally stay constant, but will increase or decrease according to air density, fuel temperature or demands for take-off power. To obtain a constant engine condition, the pilotwould have continually to adjust the throttle lever,as wasthecase in theearly days of jet engines. Such asystem with the pilot in the loopis shown in Figure 2.6.

The flow of fuel to the combustion chambers can be modified by an electrical valve in the FCU that has either an infinitely variable characteristic, or moves in a large number of discrete steps to adjust fuel flow. This valve is situated in the engine fuel feed line so that flow is constricted, or is by-passed and returnedto thefuel tanks,so thattheamountof fuel enteringtheengineisdifferentfrom thatselected. This valve forms part of a servo loop in the control system so that continuous smallvariations of fuel flow stabilize the engine condition around that demanded by the pilot. This will allow the system to compensate for varying atmospheric and barometric conditions, to ensure predictable acceleration and deceleration rates and to prevent over-temperature or over-speed conditions occurring over the available range – acting as a range speed governor; Figure 2.7 illustrates such a control system. It can be seen that the pilot shown in Figure 2.6 now acts in a supervisory role, relying on the control system to maintain basic control conditions while he monitors the indicators for signs of over-speed or over-temperature.

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Even this task can be reduced considerably by incorporating an automatic means of signalling an over-speed or over-temperature. This can be performed in the control unit by setting a datum related to a particular engine type, or by setting a variable 'bug' on the cockpit indicator. If either preset datum is exceeded a signal is sent to the aircraft warning system to warn the pilot by means of a red light and signal tone (see Chapter 9). This principle is illustrated in Figure 2.8 which shows warning systems for both over-temperature and over-speed conditions. In thisdiagram the over-speed warning is provided by a mechanism in the turbine gas temperature (TGT) indicator.

A knob on the indicator allows the pilot to set a 'bug' to a particular temperature. When the indicator pointer exceeds that setting, a pair of contacts in the indicator closes and provides asignalto the aircraft central warning system. The over-speed warning is provided by a pair of contacts in the engine control unit. In practice either one method or the other is used in one aircraft type,rather than a mix of methods.

In many modern aircraft the simple throttle signaling system is retained, but with the replacement of rods and levers by electrical signaling from the throttle levers. This reduces friction and eliminates the possibility of jamming in the control rod circuit. An example of a system with electrical throttle signaling is illustrated in Figure 2.9. The removal of any mechanical links between the pilot and the engine means that the control unit has full authority control.

There is nothing the pilot can do to correct an engine malfunction other than to shut down the engine. Because of this the throttle signaling circuit (like the rest of the control system) is designed with great care to ensure that all failures are detected and taken care of by the control system. For example, additional windings on the Tornado throttle position transducer enable the control system to detect open circuits and short circuits and to take corrective action.

EngineStarting

To start the engines a sequence of events is required to allow fuel flow, to rotate the engine and to provide ignition energy. For a particular type of aircraft this sequence is unvarying, and canbe performed manually with the pilot referring to a manual to ensure correct operation,or automatically bythe enginecontrol unit.Beforedescribingatypical sequenceof events,anexplanation ofsome of the controls will be given.

FuelControl

Fuel from the tanks to the engine feed line is interrupted by two shut-off cocks. The first is in the low pressure feed lines, at which fuel pressure is determined by the fuel boost pumps (see Chapter 3 – Fuel Systems). The valve, known as the LP cock or firewall shut-off cock, is situated close to the engine firewall. Its primary purpose is to isolate the engine in the event of a fire. It is usually a motor-driven valve controlled by a switch in the cockpit and, once opened, cannot be shut except by means of the switch. The switch is usually covered by a guard so that two actions are needed to select the switch to either open or close the cock.

This helps to prevent inadvertent actions that may lead toaccidental engine shutdown. The second valveisinthehigh-pressurefuelline,inwhichthefuelpressureisdeterminedbyanengine-driven pump. The function of this valve is to open and close the fuel feed close to the engine inlet at the fuel control unit. It is opened manually by the pilot, or automatically by the engine control unit at an appropriate stage in the engine startcycle. The location of these valves is shown in Figure

IgnitionControl

The ignition system consists of a high energy ignitor which is switched on for a period during the start cycle. The ignitors initiate combustion of the fuel vapor in the combustion chamber. An ignitor plug is supplied with electrical energy by an ignition exciter that produces stored energy from 1 to 6 joules depending on the type required. High energy systems are used for starting, and low energy systems can be provided to maintain engine ignition during aircraft operations in heavy rain, slushy runways or icing conditions. A typical ignition circuit is shown in Figure 2.19 and some examples of typical ignition equipment are shown in Figure.

EngineRotation

During the starting cycle the engine needs to be rotated until the fuel has ignited and thetemperature of combustion is sufficient for the engine to rotate without assistance. At this point the engine is said to be self-sustaining. A number of methods are in current use for providing assistance by means of air, electrical energy or chemical energy. The most common method in modern use is to use an external air source or an internal auxiliary power unit to start the first engine and to cross drive starts the remaining engines. Some smaller engines and the More-Electric B787 use electrical engine start. Air at high pressure canbe provided by anexternal aircompressor trolley connected tothe engine by ground crew, or by air supplied by an onboard

Auxiliary Power Unit (APU). This is a small gas turbine that is started prior to engine start. It has the advantage of making the aircraft independent of ground support and is useful at remote airfields. It is also used to provide electrical and hydraulicenergy for other aircraftservices. Anexample APUis shown in Figure 2.21, this has its own intake concealed beneath an opening hatch and its own exhaust positioned so as not to present a hot gas hazard to ground crew.

ThrottleLevers

The throttle lever assembly is often designed to incorporate HP cock switches so that the pilot has instinctive control of the fuel supply to the engine. Microswitches are located in the throttle box so that the throttle levers actuate the switches to shut the valves when the levers are at their aft end of travel. Pushing the levers forward automatically operates the switches to open the fuel cocks, which remain open during the normal operating range of the levers. Two distinct actions are required to actuate the switchesagain.Thethrottlelevermustbe pulledback toitsaftpositionanda mechanicallatchoperated to allow the lever to travel further and shut off the fuel valve.

StartingSequence

Atypicalstartsequenceis:
- OpenLPcocks
- Rotateengine
- Supplyignitionenergy
- Setthrottleleverstoidle–openHPcocks

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• Whenself-sustaining–switchoffignition
• Switchoffordisconnectrotationpowersource

Together with status and warning lights to indicate 'start in progress', 'failed start' and 'engine fire' the pilot is provided with information on indicators of engine speeds, temperatures and pressures that he can use to monitor the engine start cycle.

In many modern aircraft the start cycle is automated so that the pilot has only to select START for the complete sequence to be conducted with no further intervention. This may be performed by an aircraft system such as Vehicle Management, or by the FADEC control unit. In future this sequence may be initiated by an automated pre-flight check list.

Engine Indications

Despite the factthatengine control systems have become very comprehensive in maintaining operating conditions at the most economic or highest performance, depending on the application, there is still a need to provide the pilot with an indication of certain engine parameters.
Under normal conditions the pilot is interested in engine condition only at the startandwhen something goes wrong. The engine control system, with its monitoring and warning capability, should inform the pilot when something untoward does happen. However, there may be circumstances when human intuition wins the day.

During engine start the pilot monitors (and checks with his co-pilot in a multi-crew aircraft) that start progresses satisfactorily with no observed sluggish accelerations, no low oil pressures or over-temperatures. Much of this monitoring involves pilot familiarity with the aircraft type and engine type, incurred over many starts. The crew may accept certain criteria that an automatic system would not. During normal operation the control system should provide sufficient high integrity observation by self-monitoring and by checking certain parameters against preset values. In this way the systemcan monitor accelerations, rates of change, value exceedance and changes of state and issue the necessary warning.

Control systems are good at detecting sudden changes of level or state. However, slow, gradual but persistent drift and transient or intermittent changes of state are a designer's nightmare. The first may be due to degradation in performance of a component, e.g. a component becoming temperature sensitive, a gradually blocking filter or the partial occlusion of a pipe or duct.

The second may be due to a loose connection some where in the system. The pilot can observe the effectsof thesecircumstances.Inafour-engineaircraft,for example,oneindicator readingdifferentlyto three others can be easily seen because the indicators are grouped withjustsuch a purpose inmind.
Until recently all aircraft had at least one panel dedicated to engine instruments. These were in view at all times and took the form of circular pointer instruments, or occasionally vertical strip scales, reading such parameters as:

• Enginespeed–NHandNL
• Enginetemperature
• Pressureratio

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• Enginevibration
• Thrust(ortorque)

In modern aircraft cockpits the individual indicator has largely given way to the Multi-Function Display Unit (MFDU). With a MFDU any information can be shown in any format, in full color, at any time. This facility is often exploited to ensure that the pilot is only given the information that is essential for a particular phase of flight. This means that engine displays may occur on a single screen or page that is automatically presented to the pilot at certain times, say starting, take-off and landing, but is hidden at all other times. Provisionis made for the pilotto selectany page so thathe can check from time to time, and an engine warning may automatically trigger the engine page to appear.

Engine indications are obtained from the same type of sensors and transducers that provide the inputs to the control system, as described earlier. However, for integrity reasons at least two sources of signal are required – one (or more) for control, another for the indicator. For example the engine rpm signal will be obtained from two separate coils of a speed sensor. These guards against acommon mode failure thatwouldotherwise affect both the control system and the indication system.

Such systems are the Engine Indication and Crew Alerting System (EICAS) used on Boeing and other aircraft and the Electronic Crew Alerting andMonitoring (ECAM) on Airbus aircraft.
Some examples of engine synopticdisplays are shownin Figure 2.24and the Trent800indication circuit is shown in Figure 2.25.

EngineOfftakes

The engine is the prime mover for the majorityof sources of power on the aircraft. An accessory gearbox enables accessories to be connected to the engine HP shaft and allows a starter connection so that the engine can bestartedfrom an externalsupply or from the Auxiliary PowerUnit(APU). Itis alsoa convenient place to obtain measurement of engine rotational speed by measuring the speed of rotation of the gearbox using a tachometer or pulse probe. An example accessory gearbox is shown in Figure 2.27.
Typicalservices,showninFigure2.28,include:
• Electricalpowerfromgenerators
• Hydraulicpowerfromhydraulicpumps
• Cabinandequipmentconditioningsystemairfromenginebleed
• Pneumaticpower
• Antiand/orde-icingsystemair
Itcanbeseenthatmanyofthedrivesoffthe accessorygearboxarefortheuse of the engine:
• LPandHPfuelpumps
• Oilscavengepumps;oilisusedtocool theelectricalgeneratoraswellas lubricate the engine
• PMAstosupply28VDCpowerforthedualchannelFADEC
• Oil breather
Interfaceswiththeaircraftinclude:
• Supplyofthree-phase115VAC,400Hzelectricalpower–ratedinthe range from 40 to 90kVA per channel on most civil transport aircraft; 120 kVA per

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channelonB777andB767-400
• Supplyof3000psihydraulicpower
• Enginetachometerandotherengineindications

Input ofbleedairfroma suitableairsourceto start theengine.Thiscan bea groundpowercart, the APU or air from the other engine if that has already been started.

Reverse Thrust

A mechanism is provided on most engines to assist in decelerating the aircraft. On a turbo-prop engine this mechanism is to apply reverse pitch to the propeller blades. On a turbo-fan engine the usual mechanism istodeployspoilersorbucketsinto theexhaustgasstream. Both of thesemethods have the effect of reversing the thrust provided by the engines to assist the brakes and shorten the landing distance.

Reverse thrust is commanded by the crew by a mechanism in the throttle levers, usually by pulling the levers back to idle, selecting reverse thrust and then increasing the throttle lever position towards maximum to achieve the required braking effect. The effect is often combined with lift dumping, in whichair brakes and spoilers are deployed atthe same time to provide acombined deceleration effect.

The thrust reverser circuit must be designed to prevent inadvertent operation in the air, and usually combined interlocks between throttle position, reverser selection and main wheel

EngineControlonModernCivilAircraft

Most commercial aircraft engines are twin shaft engines with LP and HP shafts. Some Rolls-Royce engines such as the RB211 and Trent family are triple shaft engine with LP, IP and HP shafts. A high proportion of air by-passes the engine core on a modern gas turbine engine; the ratio of bypass air to engine core air is called the by-pass ratio. The by-pass ratio for most civil engines is in the ratio of 4:1 to 5:1. The Rolls-Royce Trent engine is shown in Figure 2.30 as an example of a modern high bypass ratio engine for the modern generation of commercial airliners. Further views of the engine are shown in Figures 2.31 and 2.32. Most modern civil engines use a Full Authority Digital Engine Control System (FADEC), mounted on the fan casing to perform all the functions of powerplant management andcontrol. Thekeyareasofmonitoringandcontrolare:
• Variousspeedprobes(N1,N2);temperatureandpressuresensors(P2/T2,
P2.5/T2.5, and T3); Exhaust Gas Temperature (EGT) and oil temperature
and pressure sensors are shown
• Theturbinecasecoolingloops–HighPressure(HP)andLowPressure(LP)
• Enginestart
• Fuelcontrolforcontrolofenginespeedand,therefore,thrust

The engine Permanent Magnet Alternators (PMAs) are small dedicated generators that supply primary power on the engine for critical control functions

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• Variousturbinebladecooling,InletGuideVanes(IGVs),VariableStator
Vanes (VSVs) and bleed air controls

Characteristicsof FuelSystems

The purpose of an aircraft fuel system is primarily to provide a reliable supply of fuel to the engines. Without the motive power provided by them the aircraft is unable to sustain flight. Therefore the fuel system is an essential element in the overall suite of systems required to assure safe flight. Modern aircraft fuels are hydrocarbon fuels similar to those used in the automobile. Piston engine aircraft use a higher octane fuel called AVGAS in aviation parlance.
Jet engines use a cruder fuel with a wider distillation cutand with a lower flashpoint. AVTAG and AVTUR are typical jet engine fuels. The specific gravity of aviation fuels is around 0.8, that is about eight-tenths of the density of water. Thereforefuel may bequantified by reference to either volume (gallons or liters) or weight (pounds or kilograms). As the density of fuel varies according to temperature both may be used. The volume of an aircraft fuel tank age is fixed and therefore it will not be ableto accommodate the same weight of fuel at high temperature when the fuel density is lower. For most practical purposes a gallon of fuel may be assumed to weigh around 8 lb (as opposed to10 lb for a gallon of water).
The essential characteristics of a modern aircraft fuel management system may embrace some or all of the following modes of operation:
• Fuelpressurization
• Engine feed
• Fueltransfer
• Refuel/defuel

FuelSystems

• Fuel storage – there are many issues related to the storage and assured supply of fuel during aircraft flight; these issues vary from aircraft to aircraft and form the kernel of the overall aircraft fuel system requirements
• Ventsystems
• Useoffuelasheatsink
• Fuel jettison
• In-flightrefueling
Before describing the operation of these typical modes of operation it is worth examining one and outlining the primary components that comprise such a system. It should also be stated that this represents the briefest introduction of issues addressed in acompanion volume dedicated to aircraft fuel systems.

DescriptionofFuelSystemComponents

FuelTransferPumps
Fuel transfer pumps perform the task of transferring fuel between the aircraft fuel tanks to ensure that the engine fuel feed requirement is satisfied. On most aircraft this will require the supply of fuel to collector tanks which carry out the obvious task of collecting or consolidating fuel before engine feed; thereby assuring aguaranteed (short-term) supply to eachengine. Transferpumps may alsobe required

to transfer fuel around the aircraft to maintain pitch or lateral trim. In the case of pitch trim this requirement is becoming more critical for unstable control configured aircraft where the task of active CG control may be placed upon the fuel management system.

On civil aircraft there is a requirement to transfer fuel from the fuselage centre wing tanks to tanks where fuel may typically be consolidated before engine feed. However there are FAR/JAR regulations which require independent engine feed systems. On more recent civil aircraft such as the Airbus A340 the horizontal stabilizer may contain up to 7 tons of fuel which has to be transferred to maintain the aircraftCG within acceptable limits during the cruise phase. Typically this schedule will be invoked when the aircraft has exceeded an altitude of FL250.

Older aircraft such as the Vickers VC10 also contain fuel in the empennage, in this case the fin, to increase fuel capacity. In these cases pumps are also required to transfer fuel forward to a centre tank for consolidation. A typical aircraft system will have a number of transfer pumps for the purposes of redundancy, as will be seen in the examples given laterin this chapter.

An example of a fuel transfer pump is shown in Figure 3.3, this particular example being used on the Anglo-FrenchJaguarfighter. Thisisafuel lubricated pump;a featureshared bymost aircraft fuel pumps. The pump has the capability of safely running dry in the event that no fuel should remain in the tank for any reason. Thermal protection is also incorporated to prevent over-heating. This particular pump is designed to supply in the region of 400 lb/minute at a pressure of 10 psi.

Fuel BoosterPumps

Fuel booster pumps, sometimes called engine feed pumps, are used to boost the fuel flow from the aircraft fuel system to the engine. One of the reasons for this is to prevent aeration (i.e. air in the fuel lines that could cause an engine 'flameout' with consequent loss of power). Another reason in the case of military aircraft is to prevent 'cavitations' at high altitudes. Cavitations is a process in which the combination of high altitude, relatively high fuel temperature and high engine demand produce a set of circumstances where the fuel is inclined to vaporize. Vaporization is a result of the combination of low fuel vapor pressure and high temperature. The effect is drastically to reduce the flow of fuel to the engine that can cause a flameout in the same way as aeration (as may be caused by air in the fuel). An aircraftsystem will possess a number oftransfer pumps as will be illustrated later inthe chapter.

The engine manufacturer usually imposes a requirement that fuel feed pressure must remain at least 5 psi above true vapor pressure at all times. Booster pumps are usually electrically driven; for smaller aircraft such as the BAE Systems Jet Provost and the Harrier the pump is driven from the aircraft 28 VDC system with delivery pressures in the range 10–15 psi and flow rates up to 2.5 kg/sec of fuel. The higher fuel consumption of larger, high performance aircraft booster pumps are powered by three-phase AC motors; in the case of Tornado delivering 5 kg/sec. Booster pumps are cooled and lubricated by the fuel in which they are located in a similar way to transfer pumps, and may be specified to run for several hours in a 'dry' environment. Fuel pumps can also be hydraulically driven or, in certain cases, ram air turbine driven, such as the VC10 tanker in-flight refueling pump. While most of the larger aircraft use electric motor-driven pumps, ejector pumps are in common use for both fuel feed and transfer in some applications.

FuelTransferValves

A variety of fuel valves will typically be utilized in an aircraft fuel system. Shut-off valves perform the obviousfunctionofshuttingofffuelflowwhenrequired.Thismightinvolvestemmingtheflowoffuelto an engine, or it may involve the prevention of fuel transfer from one tank to another. Refuel/defuel valves are used during aircraft fuel replenishment to allow flow from the refueling gallery to the fuel tanks. These valves will be controlled so that they shut off once the desired fuel load has been taken on board. Similarly, during defueling the valves will be used so that the load may be reduced to the desired level – almost entirely used for maintenance purpose. Cross-feed valves are used when the fuel is required to be fed from one side of the aircraft to the other.

Fuel dump valves perform the critical function of dumping excess fuel from the aircraft tanks in an emergency. These valves are critical in operation in the sense that they are required to operate and dump fuel to reduce the fuel contents to the required levels during an in-flight emergency. Conversely, the valves are notrequired to operate and inadvertently dump fuel during normal flight.

Themajorityof thefunctions describedareperformed bymotorized valvesthatare drivenfromposition to position by small electric motors. Other valves with a discrete on/off function may be switched by electrically operated solenoids. Figure 3.5 shows an example of a transfer valve driven by a DC

Non-ReturnValves(NRVs)

Avarietyofnon-return valvesor check valvesarerequiredinanaircraft fuel system to preservethe fluid logic of the system. Non-return valves as the name suggests prevent the flow of fuel in thereverse sense. The use of non-returnvalves together with the various transfer and shutoff valves utilised around the system ensure correct system operation in the system modes listed above and which will be described in more detail later in the chapter

LevelSensors

Level sensors measure the fuel level in a particular tank and thereby influence fuel management system decisions. Level sensors are used to prevent fuel tank overfill during refueling. Level sensors are alsoused for the critical low level sensing and display function to ensure that fuel levels do not drop below flight critical levels where the aircraft has insufficient fuel to return to a suitable airfield. Level sensors may be one of a number of types: Float operated; optical; sound or zener diodes – two of which are described below.

FloatLevelSensors

Float level sensors act in a similar way to a domestic toilet cistern connected to thewater supply shut-off valve that is closed as the float rises. The refueling valve, operating in the same way, is a simple but effective way of measuring the fuel level butithas the disadvantage that,having moving parts,the float arm may stick or jam.

ZenerDiodeLevelSensors

By using simple solid state techniques it is possible to determine fluid levels accurately. The principle is based upon a positive temperature coefficient directly heated Zener diode. The response time when sensing from air to liquid is less than 2 seconds (refueling valve) and from liquid toair less than 7 seconds(low level warning). Fluidlevel maybe sensedtoan accuracy ofabout plus/minus2mm andthe power required is around 27 mA per channel at 28 V DC. The sensor operates in conjunction with an amplifier within a control unit and can accommodate multi-channel requirements. A typical fluid sensor ofthis typeis shownin Figure3.7.Theadvantage of thismethodof level sensingisaccuracy and the fact thatthere are no moving parts. In more recenttimes this technique is disfavored for safety reasons.

CapacitanceSensors

Capacitancesensorswereused on A340and A380 for sensing fuel level. Theadvantageisthatthereisa measurable signal from the sensor under both states.

UltrasonicSensors

Ultrasonicpointsensorsarebecomingfavoredaspointlevelsensorswithinthefuelsensingsystem.

FuelGaugingProbes

Manyoftheaircraftfunctionsrelatingtofuelareconcernedwiththemeasurement of fuel quantity on board the aircraft. For example, the attainment of a particular fuel level could result in a number of differing actions depending upon the circumstances: opening or closing fuel valves or turningon/offfuelpumps inorder to achievethe desiredsystemstate.Quantitymeasurementisusually accomplished by a number of probes based upon the principle of fuel capacitance measurement at various locations throughout the tanks.

Air and fuel have different dielectric values and by measuring the capacitance of a probe the fuel level may be inferred. The locations of the fuel probes are carefully chosen such that the effects of aircraft pitch and roll attitude changes are minimized as far as quantity measurement is concerned. Additional probes may cater for differences in fuel density and permittivity when uplifting fuel at differing airfields around the world as well as for fuel at different temperatures.

Fuel gauging,or Fuel Quantity Indication Systems (FQIS) as they are sometimes known,are therefore an essential element in providing the flight and ground crews with adequate information relating to the amount of fuel contained within the aircraft tanks.

FuelQuantityMeasurementBasics

The underlying difficulties in accurately measuring aircraft fuel contents; also referred to as Fuel On Board (FOB) lie in the very nature of the agility and mobility of the air vehicle. The most obvious factors are:

- Thedifficultyinmeasuringafluidlevelwithinabodyinmotion
- Thefactthataircrafttanksarevirtuallyneverregularshapes
- The fact that aircraft fuel demonstrates diverse properties and has different composition when uplifted in different locations Fuel quantity may be expressed as kilograms (1000 kilogram=a metric tonne), pounds (lb), or gallons – either Imperial or US gallons.

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A US gallonis 0.8×an Imperial gallon (1Imperial gallon=8×20=160fluid ounces). The Specific Gravity (SG) of fuel is around 0.8,therefore an Imperial gallon is roughly equivalentto 160/16 or 10 lbs whereas a US gallon equates to around 8 lbs. Since the contents of aircraft tanks are characterised by tank volume the amount of energy contained within a fuel load is therefore determined by the weight (mass) of the FOB; itself a function of fuel density and fuel temperature.

FluidMotion

Measuring fuel level in flight is analogous to trying to run while carrying a bucket of water; the fluid appears to take on a mind of its own and the 'inertia' of the fluid has to be anticipated both when starting out and when stopping. This fluid can be ameliorated to a degree by natural boundaries such as wing ribs or fuselage frames that may protrude into the tank. The insertion of baffles may also prevent undue 'sloshing' of the fuel. This sloshing action can be modeled using 3D computer aided design tools together with fluid dynamic modeling tools such as Flow master. This enables a simulation of the fuel system, in whole or in part, to be modeled and subjected to aircraft maneuversto observe the effectsonthe fuel.Bafflescan then be insertedinto the model to allowobservationof theireffectonfuel slosh, and to optimize their location in a tank

TankShapes

Aircraft tank shapes vary greatly and are difficult to determine, particularly at an early stage in the aircraft design. Large, regular volumes are at a premium within an aircraft and the volumes available to thefuel systemdesignerareusuallythoseremainingwhenthe structuresand propulsiondesignershave had their day. Therefore not only are the tank shapes irregular but their boundaries may not be fixed until fairly late in the design.

Once the tank boundaries are frozen, the tank designer has to characterize the volumetric shape of the tankto understand whatthefluidlevelmeansforavarietyoftankattitudes.The problemmaybebetter understood by referring to Figure 3.8. This is a representation of a simple rectangular tank that might approximate to the centre tank on many typical civil aircraft. While the shape is regular the tank will be rotating as the aircraft pitch and roll attitude alter.

Aircraftaccelerations will alsooccur as speed changes are made. The fluid contents of this tank,or more correctly, the fluid level may be determined by placing quantity probes in each corner of the tank. This may be acceptable for a basicconfiguration butto permitnecessary levels of accuracy following a probe failure, additional probes may need to be added. In a sophisticated long range aircraft the probes may need to be replicated to provide dual redundant sensing.

Forward

Pitch

Roll

AdditionalEffects:

–WingSweep

–WingDihedral

–WingFlexure

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FuelSystemOperatingModes

The modes of operation described in the following paragraphs are typical of many aircraft fuel systems. Each is described as an example in a particular fuel system. Any system may exhibit many but probably not all of these modes. In an aircraft the fuel tanks and components have to compete with other systems, notably structure and engines for the useful volume contained within the aircraft profile. Therefore fuel tanks are irregular shapes and the layman would be surprised by how many tanks there are, particularly within the fuselage where competitionfor usable volume is more intense.
The proliferation of tanks increases the complexity of the interconnecting pipes and certainly does not ease the task of accurate fuel measurement. As an example of a typical fighter aircraft fuel tank configuration see Figure 3.14 that shows the internal fuel tank configuration for EAP. This is a simplified diagramshowing only the main fuel transfer lines;refuelingand ventlines havebeen omitted for clarity. Whereas the wing fuel tanks are fairly straightforward in shape, the fuselage tanks are more numerous and of more complex geometry than might be supposed.
The segregation of fuel tanks into smaller tanks longitudinally (fore and aft) is due to the need to avoid aircraft structural members. The shape of most of the fuselage tanks also shows clearly the impositions caused by the engine intakes. Furthermore as an experimental aircraft EAP was not equipped for in-flight refuelling nor was any external under-wing or ventral tanks fitted. It can be seen that a fully operational fighterwould have acorrespondingly morecomplicated fuel system than the one shown.

Pressurization

Fuel pressurization is sometimes required to assist in forcing the fuel under relatively low pressure from certain tanks to others that are more strategically placed within the system. On some aircraft there may be no need for a pressurization system at all; it may be sufficient to gravity feed the fuel or rely on transfer pumps to move it around the system. On other aircraft ram air pressure may beutilized to givea low but positive pressure differential. Some fighter aircraft have a dedicated pressurization system using high pressure air derived from the engine bleed system.
The engine bleed air pressure in this case would be reduced bymeans ofpressure reducing valves (PRVs) to a more acceptable level. For a combataircraftwhich may have a number of external fuel tanks fitted the relative regulating pressure settings of the PRVs may be used to effectively sequence the transfer of fuel from the external and internal tanks in the desired manner. For example, on an aircraft fitted with under-wing and under-fuselage (ventral) tanks it may be required to feed from under-wing, then the ventral and finally the internal wing/fuselage tanks. The PRVs may be set to ensure that this sequence is preserved,by applying a higher differential pressure to those tanks required to transfer fuel first.
In some aircraft such as the F-22, inert gas is used to pressurize the fuel tanks. Inert gas for this purpose can be obtained from an On-Board Inert Gas Generating System (OBIGGS).

EngineFeed

The supply of fuel to the engines is by far the most critical element of the fuel system. Fuel is usually collected or consolidated before being fed into the engine feed lines. The example in Figure 3.15 showsa typical combat aircraft, the fuel is consolidated intwocollector tanks; one for each engine.

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Introduction:

The modern turbofan engine is very effective for generating gas use of engine bleed air for a number of aircraft systems, either for heating of various equipments, provision of air for cabin air conditioning andpressurization. Bleedairisextractedfrom the engine compressorandafter cooling and pressure reduction/regulation it is used for avariety of functions. Inthe engine, high pressure bleed airis used as the motive power – sometimes called 'muscle power' which is used for actuation of many valves associated with the bleed air extraction function. Medium-pressure bleed air is used to start the engine in many cases, either using air from a ground power unit, APU or cross bled from another engine on the aircraft which is already running. Bleed air is also used to provide anti-ice protection by heating the engine intake cowling and it is also used as the motive power for the engine thrust reversers. Bleed air is also used for aircraft pressurizing hydraulic reservoirs, providing hot air for rain dispersal from the aircraft windscreen, pressurizing the water and waste system and so on. In some aircraft Air Driven Pumps (ADPs) are used as additional means of providing aircraft hydraulic power. In Pitot static systems to air is used forair data computer and other parts of this system for safe aircraftflight.

UseofBleedAir

Modern engines 'bypass' a significantportion of the mass flow past the engine and increasingly a small portion of the mass flow passes through the engine core or gas generation section**. The ratio of bypass air to engine core air is called the bypass ratio** and this can easily exceed 10:1 for transport civil aircraftengines. The characteristics of a modern turbofan engine are shown in Figure . This figure shows the **pressure (in psi) and the temperature** (in degrees centigrade) at various points throughout the engine for three engine conditions: ground idle, take-off power and in the cruise condition.

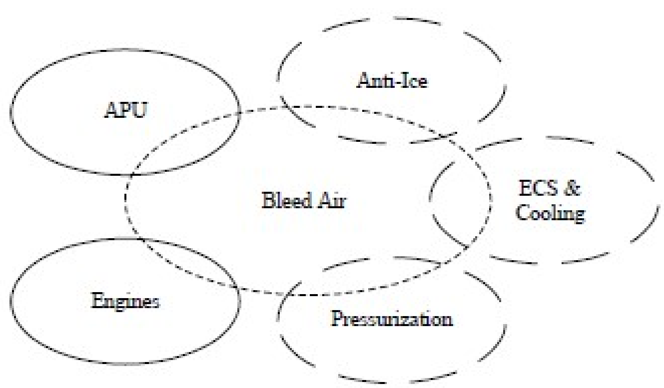

Figure4.1:UsesofBleedAir

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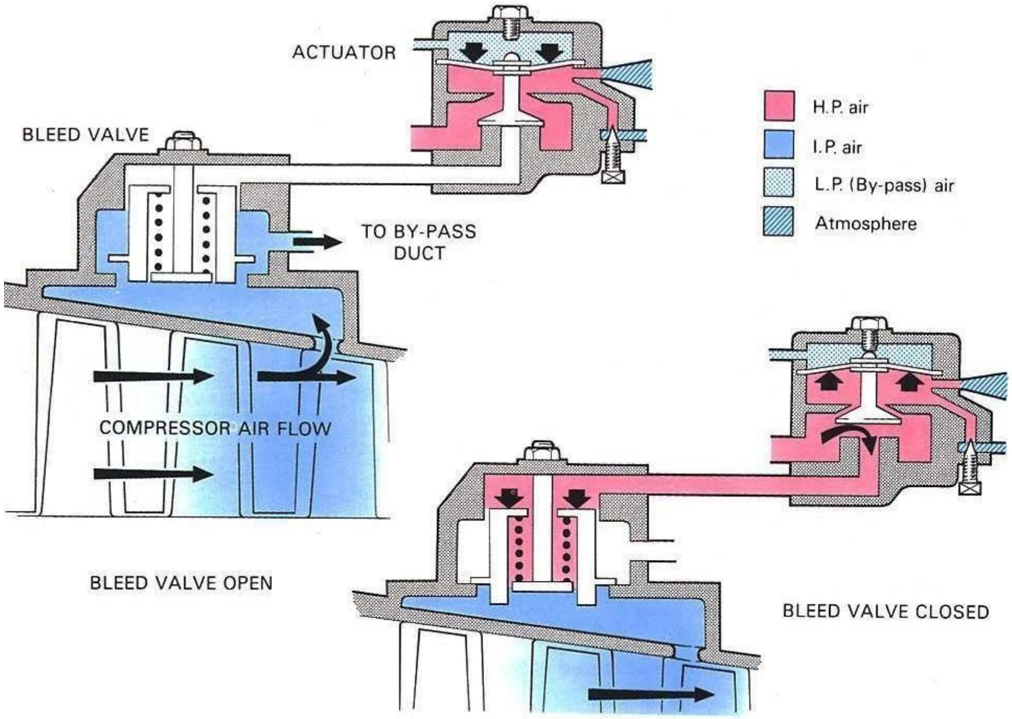

Figure4.2:Relationbetweenairbleedandotheraircraftdemandedsystems

ThemainaircraftenginesandAuxiliaryPowerUnit(APU)isalsoasourceofhighpressurebleedair.The APU is in itself a small turbojet engine, designed more from the viewpoint of an energy and power generator than a thrust provider like main engines.

APU The APU is primarily designed to provide **electrical and pneumatic power** by a shaft driven generator and compressor. The APU is therefore able to provide an independent source of electrical power and compressed air while the aircraft is on the ground, although it can be used as a backup provider of power while airborne. Some aircraft designs are actively considering the use of in-flight operable APUs to assist in in-flight engine re-lighting. The figure shows supply of air bleed to various services.

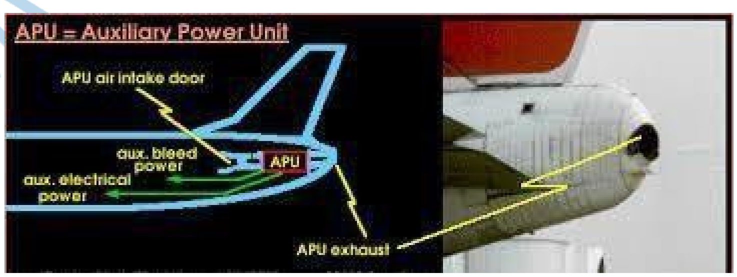

Figure4.3:APU

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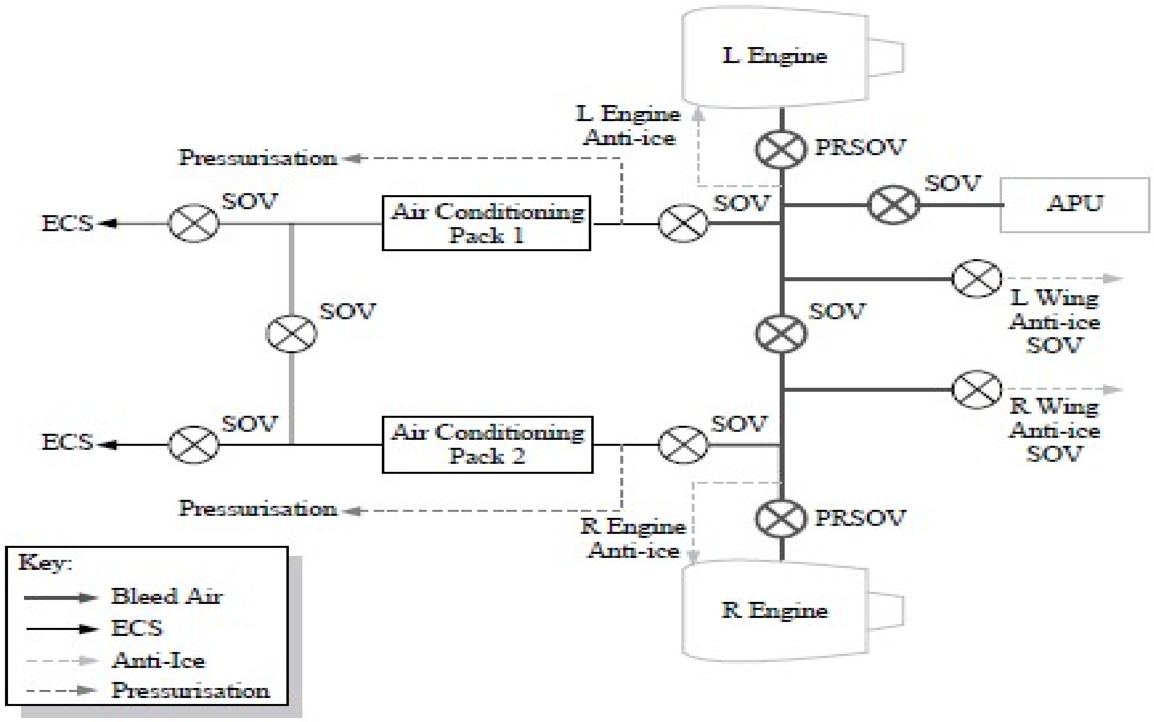

Figure4.4:AirBleedOperation

Airbleed Operation

The above figure shows the air bleed from the two engines is passed through a Pressure-Reducing Shut-Off Valve (PRSOV) which serves the function of controlling and, when required, shutting off the engine bleed air supply. Air downstream of the PRSOV may be used in a number ofways:

• BymeansofacrossflowShut-OffValve(SOV)thesystemmaysupplyairto

theoppositesideof theaircraftduring enginestartorif theoppositeengineisinoperativeforany reason.

• ASOVfromtheAPU maybeused toisolatetheAPU airsupply •SOVsprovideisolation as appropriate to the left and right airconditioning packs and pressurization systems.

• AdditionalSOVsprovidethemeansbywhichthesupplytoleftandrightwinganti-icingsystemsmay be shut off in the event that these functions are not required.

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Engineairbleedusers

Thefollowingareloadsofairbleed:-

1. **Airconditioning**
2. **Cargocompartmentheating**
3. **Wingandengineanti-iceprotection.**
4. **Enginestart**
5. **Thrust reversal actuation**
6. **Hydraulicreservoirpressurization**
7. **Rainrepellentnozzles–aircraftwindscreen**
8. **Watertankpressurizationandtoiletwaste**
9. **Airdrivenhydraulicpump(ADP)**
10. **HydraulicSystem.**
11. **Fuelsystempressurizationandventsystem**

Engineairbleedcomponents

PressureReducingShutoffValve(PRSOV)

Atypical PRSOVisshown in Figure isan exampleof asolenoid controlledand pneumatically operated and which controls temperature, flow and pressure is shown in Figure.

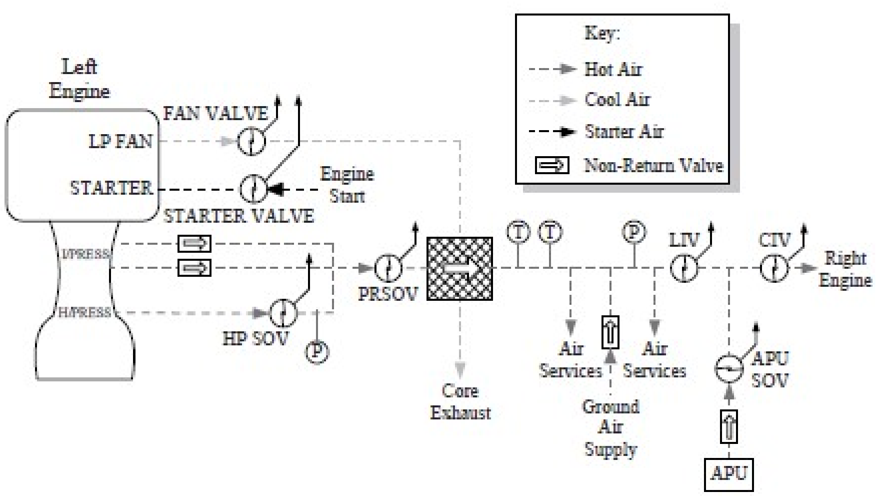

Figure4.5:PressureReducingShutoffValve

FunctionofPRSOV

• On/offcontroloftheenginebleedsystem

• Pressureregulationoftheenginesupplyairbymeansofabutterflyvalveactuatedbypneumatic pressure

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• Enginebleedairtemperatureprotectionandreverseflowprotection.

• Abilitytobeselectedduringmaintenanceoperationsinordertotestreversethrust operation.

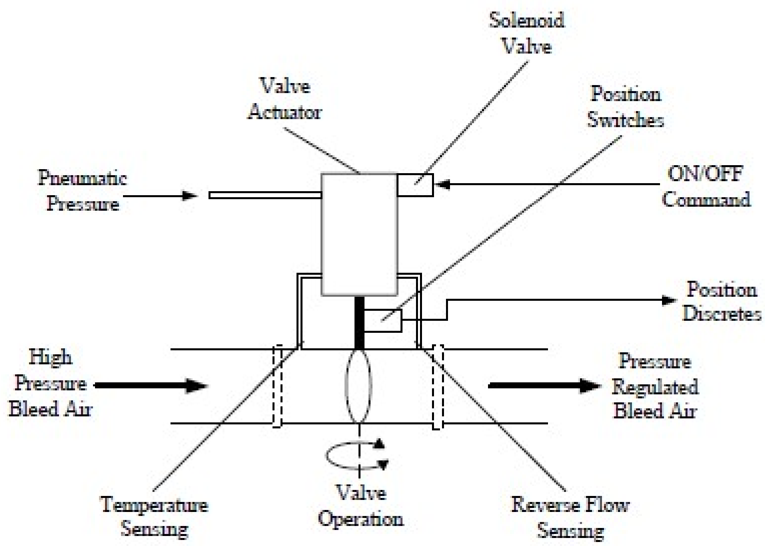

Figure4.6:WorkingPrincipleofPSROV

WorkingPrinciple:-

ThePRSOVispneumaticallyoperatedand electricallycontrolled.Operationof thesolenoidvalve from the appropriate controller enables the valve to control the downstream pressure pneumatically to approximately 40 psi within predetermined limits. The valve position is signaled by means of discrete signals to the bleed air controller and pressure switches provide over and under-pressure warnings. The various pressure, flow and discrete signals enable the bleed air controller Built-In Test (BIT) to confirm the correct operation of the PRSOV and fan control valve combination. This ensures that medium pressure air (40 psi) of the correct pressure and temperature is delivered to the pre-cooler and thence downstream to the pneumatic and air distribution system.

WindShieldHeating

Ice that accumulates on the aircraft windscreens are kept clear of ice by the use of window heating so that the flight crew has an unimpeded view ahead. The prevention of ice build-up on the windscreen is achieved by means ofelectric heating elements embedded in the glass panels.

Wing,TailUnitandEngineairintake&IGVAnti-Icing

The protection of theaircraft from theeffects of aircraft icing represents one of the greatest and flight critical challenges which confront the aircraft. Wing leading edges and engine intake cowlings need to be kept free of ice accumulation at all times.

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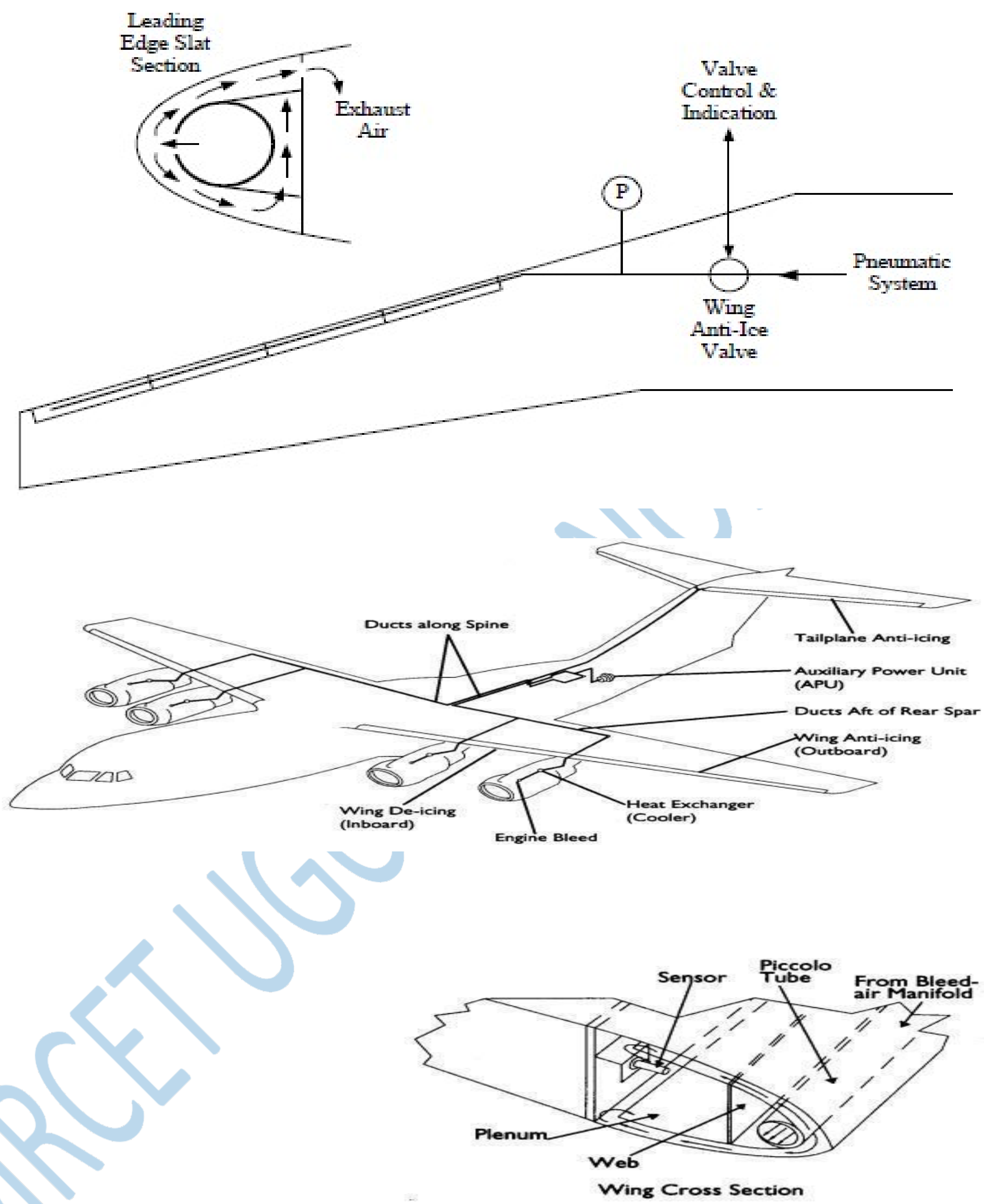

Figure4.7:Wing,TailUnitandEngineairintake&IGVAnti-Icing

In the case of the wings, the gathering of ice can degrade the aerodynamic performance of the wing, leading to an increased stalling speed with the accompanying hazard of possible loss of aircraft control.

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Ice that accumulates on the engine intake and then breaks free entering the engine can cause substantial engine damage with similar catastrophic results. Finally, the aircraft air data sensors are heated to ensure that they do notice up and result in a total loss of air data information that could cause a hazardous situation or the aircraft to crash..

In the case of the wing and engine anti-icing the heating is provided by hot engine bleed air which prevents ice forming while the system is activated. The principles of wing anti-ice control are shown in Figure. The flow **of hot air to the outer wing leading edges is controlled** by the Wing Anti- Ice Valve. The air flow is modulated by the electrically enabled anti-icing controller; this allows air to pass down the leading edge heating duct. This duct can take the form of a **pipe withholes appropriately sized to allow a flow of air onto the inner surface of the leading edge**. The air is bled out into the leading edge slatsection to heat the structure before being dumped overboard.

Engineanti-icing

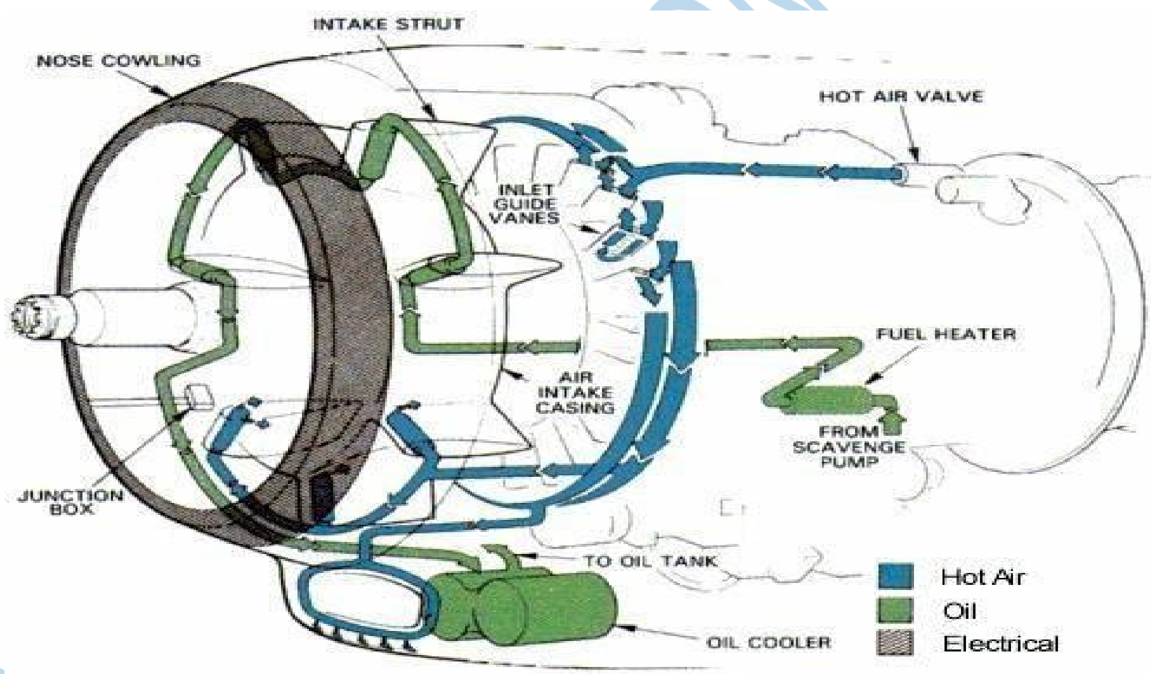


Figure4.8:AntiIcing

Engine anti-icing is similarly achieved by a valve fitted on the engine and Prevention of forming ice in the engine cowling is done by blowing hot air insidethe engine compartment. This activation of the engine anti-icing system is confirmed by the flightcrew by means of the closure of a pressure switch that provides an indication to the display system. The presence of hot air ducting throughout the airframein the engine nacelles and wing leading edges poses anadditional problem;thatis tosafeguard against the possibility of hot air duct leaks causing an overheat hazard. Accordingly, overheat detection loops are provided in sensitive areas to provide the crew with a warning in the event of a hot gas leak occurring. An overheatdetection system will have elements adjacent to the air conditioning packs,wing leading edge and engine nacelle areas to warn the crew of an overheat.

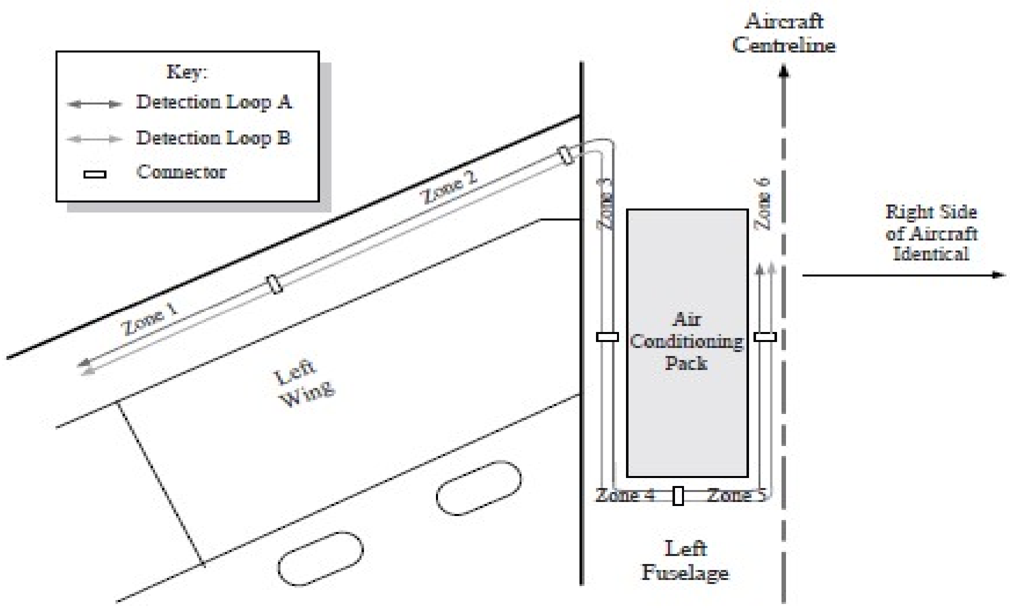
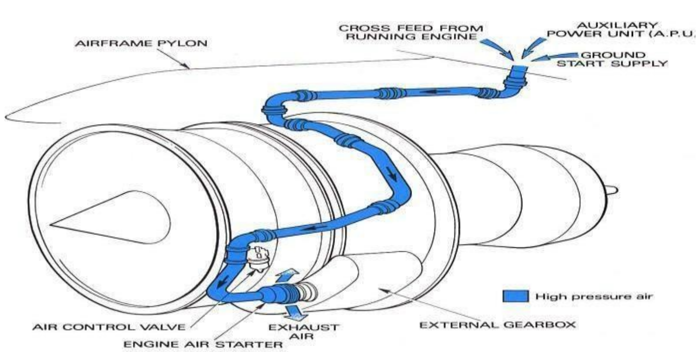


Figure4.9:AirConditioning

EngineStart

The availability of high pressure air throughout the bleed air system lends itself readily to the provisionof motive power to crank the engine during the engine start cycle. The start valve is activated to supply bleed air to the engine starter. On the groundthe engines may be started ina number of ways:

- **Byuseofagroundairsupplycart**
- **ByusingairfromtheAPU–probablythepreferredmeans**
- **Byusingairfromanotherenginewhichisalready running.**



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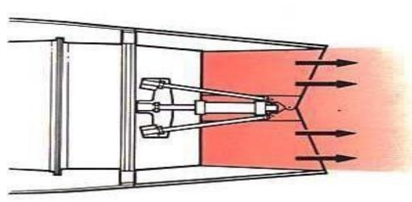
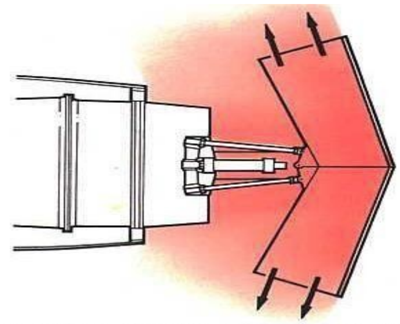
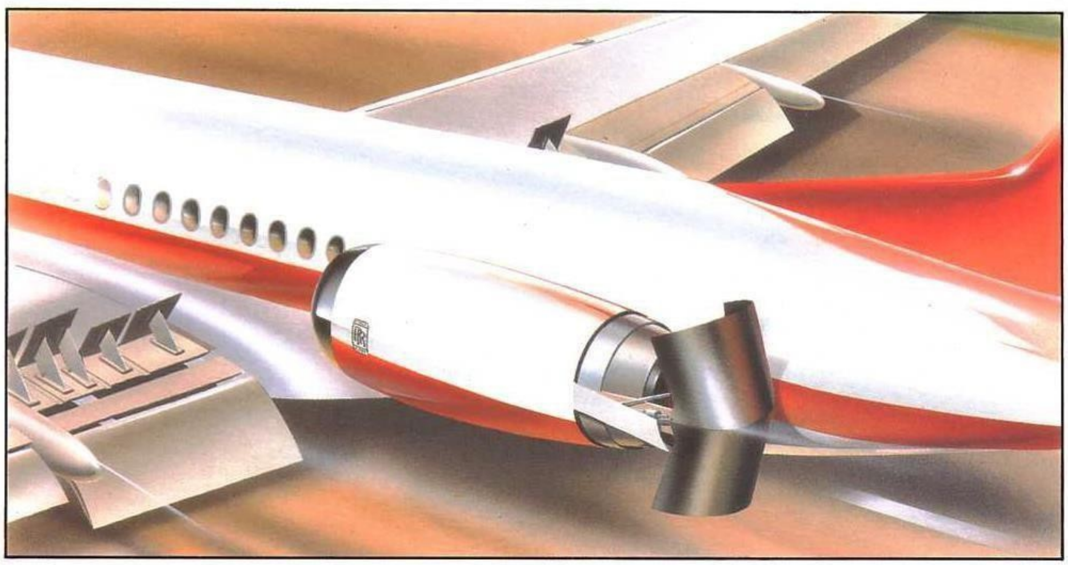
ThrustReversers



ACTUATOR EXTENDED AND BUCKET DOORS IN FORWARD THRUST POSITION



ACTUATOR AND BUCKET DOORS IN REVERSE THRUST POSITION



Engine thrust reversers are commonly used to deflect engine thrust forward during the landing roll-out to slow the aircraft and **preserve the brakes**. Thrust reversers are commonly used in conjunction with a lift dump function, whereby all the spoilers are simultaneously fully deployed, slowing the aircraft by providing additional aerodynamic drag while also dispensing lift. Thrust reversers deploy two buckets, one on each side of the engine, which are pneumatically operated by means of air turbine motor actuators to deflect the fan flow forward, thereby achieving the necessary braking effect when the aircraft has a 'weight-on-wheels' condition.

HydraulicSystems

The hydraulic reservoir is pressurized using regulated bleed air from the pneumatic/bleeds air system. Supply hydraulic fluid may be pressurized by the two alternate pumps:

• BymeansoftheACMPpoweredbythree-phase115VACelectricalpower.

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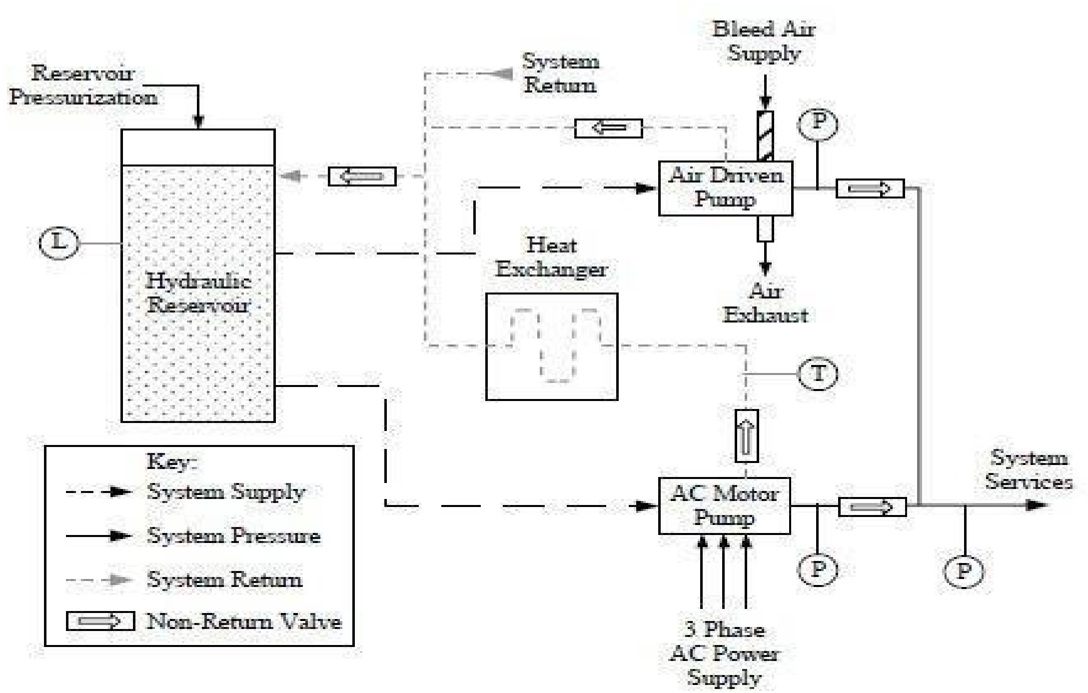
• BymeansoftheAirDrivenPump(ADP)usingpneumaticpowerasthesource.



PitotStaticSystems

Bycontrastwith the bleedairsystemalreadydescribedwhichprovidesenergyor powerfor a numberof diverse aircraft systems, the pitot static system is an instrumentation system used to sense air data parameters of the air through which the aircraft is flying. Without the reliable provision of air data the aircraft is unable safely continue flight. The pitot static system is therefore a high integrity system with high levels of redundancy. There are two key parameters which the pitot static system senses:

• Total pressure Pt is the sum of local static pressure and the pressure caused bythe forward flight of the aircraft (Dynamic pressure). The pressure related to the forward motion of the aircraft by the following formula:Pressure = ½ ρV^2Where _ isthe airdensity of the surrounding air andVis the velocity

• Staticpressure or Psisthelocalpressuresurroundingtheaircraftandvarieswithaltitude

Therefore total pressure, Pt=Ps+ ½ ρV^2

Theforwardspeedof theaircraftiscalculatedbytakingthedifferencebetweenPtandPsAnaircraftwill have three or more independent pitot and static sensors

Figure6.11showstheprincipleofoperationofpitotandsensors.

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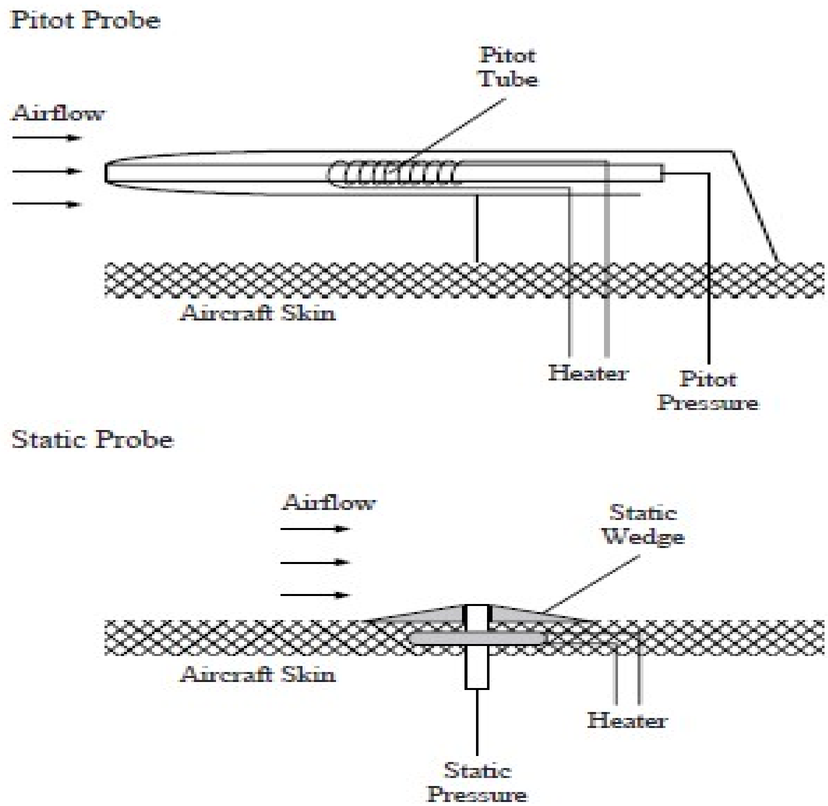
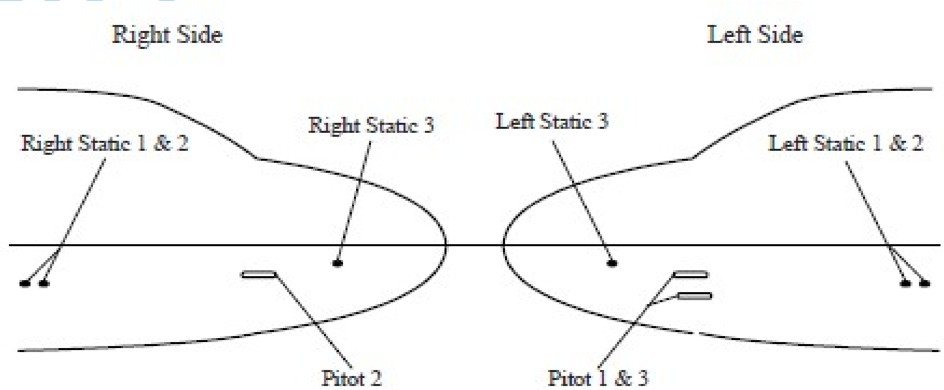


The static probe shown in the lower diagram is located perpendicular to the airflow and so is able to sense the static pressure surrounding the aircraft.Like the pitot probe thestatic probe is provided witha **heater element** that **continuously heats the sensor and prevents the formation of ice**. On some aircraft the pitot and static sensing functions are combined to give a pitot-static probe capable of measuring both dynamic and static pressures. A typical installation on a civil transport aircraftis depicted in Figure .



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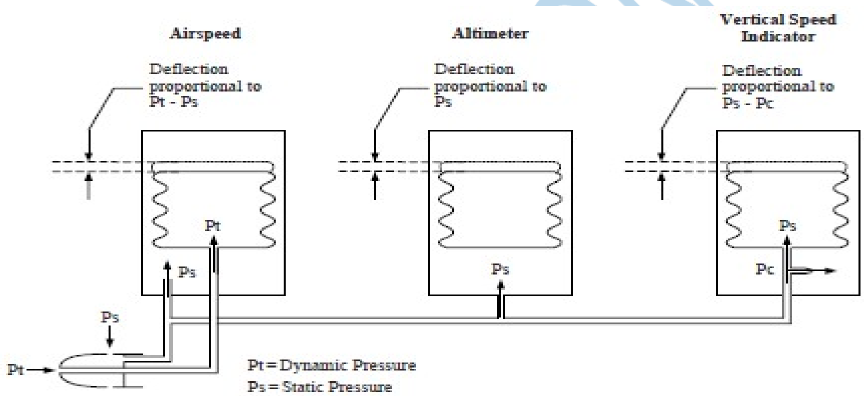
MeasurementofAirSpeed

Airspeed may be calculated from the deflection of needle in the instrument where Pt and Ps are differentially sensed. Airspeed is proportionate to Pt – Ps and therefore the mechanical deflection may be sensed and airspeed deduced. This may be converted into a meaningful display to the flight crew value in a mechanical instrument by the mechanical gearing between aneroid capsule and instrument dial.

• Altitude may be calculated by the deflection of the static capsule in the centre instrument. Again in a mechanical instrument the instrument linkage providesthe mechanical scaling to transform the data into a meaningful display.

• Vertical speed may be deduced in the right hand instrument where the capsule deflection is proportionalto therate of change of staticpressurewithreferencetoa casepressure,Pe.Therefore the vertical speed is zero when the carefully sized bleed orifice between capsule inlet and case allows these pressures to equalize.



NeedforControlledCabinEnvironment

In the early days of flight, pilots and passengers were prepared to brave the elements for the thrill of flying. However, as aircraft performance has improved and the operational role of both civil and military aircrafthas developed,requirements for Environmental Control Systems (ECS) have arisen. They provide a favorable environment for the instruments and equipment to operate accurately and efficiently, to enable the pilot and crew to work comfortably, and to provide safe and comfortable conditions for the fare-paying passengers . Providing sufficient heat for the aircraft air conditioning system is never a problem, since hot air can be bled from the engines to provide the source of conditioning air. The design requirement is to reduce the temperature of the air sufficiently to give adequate conditioning on a hot day.

PrincipleHeatSourcesintheAircraftwhichneedtobe addressedforcoolingproblem:

(a) ***KineticHeating*****($T_{rec}=T_{amb}(1+0.18M^2)$&$T_{ram}=T_{amb}(1+0.2\ M^2)$)**

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(b) ***SolarHeating*** **(**The combined effect of internal heating and direct solar radiation has an effect on the pilot, especially when wearing survival gear and anti-g trousers and vest which requires considerable cooling air in the cockpit).

(c) ***Airframe System Heat Loads*** (Heat is produced by hydraulic systems, electrical generators, engines and fuel systems components.This produce a radiation effectin the systems such as pumps or motors, or from heat rejected in cooling fluids such as oil. To maintain operating efficiency and to prevent chemical breakdown of fluids with resulting degradation in their performance it is essential to cool these fluids.)

(d) ***Avionics Heat Loads (***The avionic equipment is generally powered continuously from power up to power down and, hence, dissipates heat is continuous. The equipment is kept in the boxes in designated avionic equipment bays in small aircraft, or in equipment cabinets in largeraircraft.Airisducted to these areasfor the specificpurposeof coolingequipmentand is then re-circulated or dumped overboard. The system must be designed to protect the components of the equipment throughout the aircraft flight envelope, and in whatever climatic conditions the aircraft must operate.)

NeedforCabinConditioning

Design considerations for providing air conditioning in the cockpit of a high performance fighter are far more demanding than those for a subsonic civil airliner cruising between airports. The cockpit is affected by the sources of heat described above, but a high performance fighter is particularly affected by high skin temperatures and the effects of solar radiation through the large transparency.

However, in designing a cabin conditioning system for the fighter, consideration must also be taken of what the pilot is wearing. If, for example, he is flying on a mission over the sea, he could be wearingathickrubberimmersionsuitwhichgripsfirmlyatthe throatandwrists.Inaddition,the canopy and windscreen will have hot air blown over the inside surfaces to prevent misting which would affect the temperature of the cabin. Another important factor is pilot workload or high stress conditions such as may be caused by a failure, or by exposure to combat. All these factors make it very difficult to cool the pilot efficiently so that his body temperature is kept at a level that he can tolerate without appreciable loss of his functional efficiency.

Methodsofcooling

(a) Ramair:-

Ramaircoolingisthe process ofrejectingaircraftheat loadto theair flowinground the aircraft.This can be achieved by scooping air from theaircraft boundary layer orcloseto it. Theair is forced througha scoop which faces into the external air flow, through a heat exchanger matrix and then rejected overboard by the forward motion of the aircraft. The heat exchanger works just liketheradiator of a car. **This system has the disadvantage that it increases the aircraft drag because the resistance of the scoop**, pipe work and the heat exchanger matrix slowsdown the ram airflow.

The use of ram air as a cooling medium, at high altitude the air density becomes very low, reducing the ram air mass flow and hence its cooling capacity. In fact, when conditioning is required for systems which require coolingon the ground, thenramair coolingaloneis unsuitable.However, thissituation

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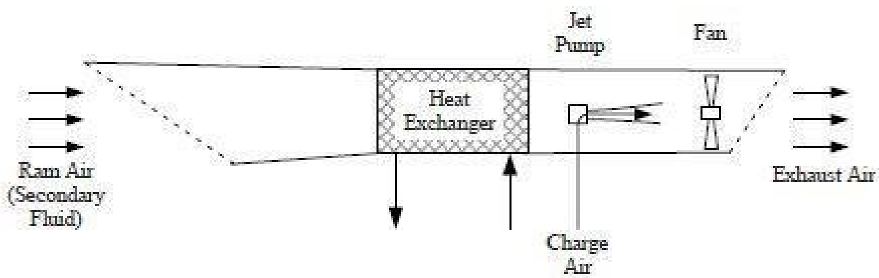
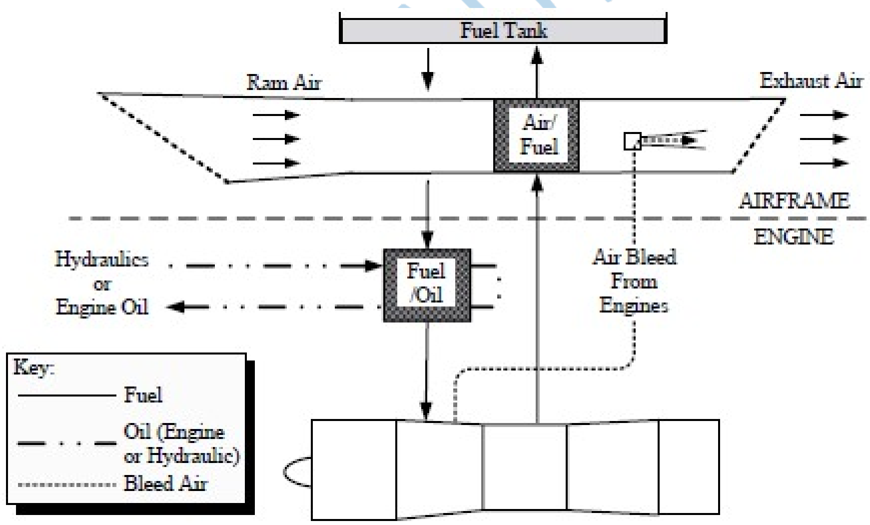
can be improved by the use of a cooling fan, such as used on a civil aircraft, or a jet pump, mainly used on military aircraft, to enhance ram air flow during taxi-ing or low speed flight. The jet pump enhances ram air cooling in the heat exchanger by providing moving jets of primary fluid bled from the engines to entrain a secondary fluid, the ram air, and move it downstream as shown in Figure



(b) FuelCooling:-

Fuelcoolingsystemshavelimitedapplicationsonaircraftfor thetransfer ofheatfroma heatsource into the aircraft fuel as fuel is much better than air as a cooling medium. Fuel has a higher heat capacity and a higher heat transfer coefficient. Fuel is typically used to cool engine oil, hydraulic oil and gearbox oil. Figure shows a typical fuel and oil cooling system.



(c) EngineBleed

The main source of conditioningair for both civil and military aircraft isengine bleed from the high pressure compressor. This provides a source whenever the engines are running. The conditioning air is also used to provide cabin pressurization. There are two types of bleed air system**: open loop and closedloop**.

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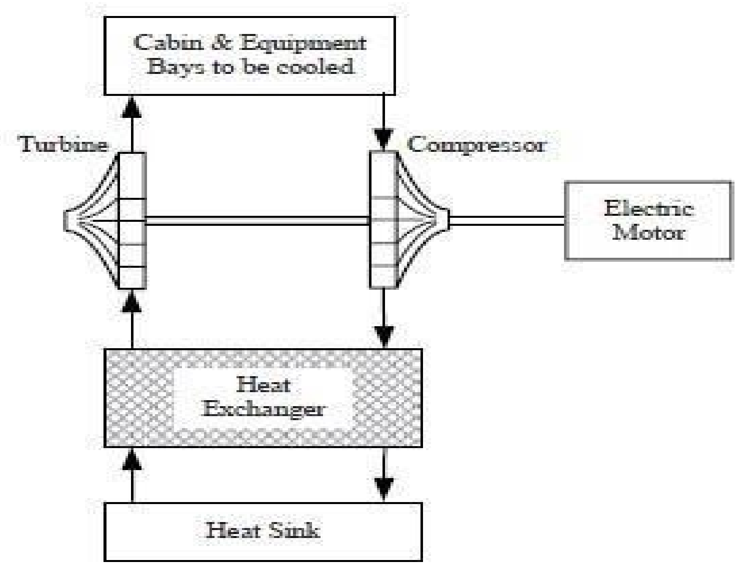
Open loop environmental control systems continually bleed large amounts of air from the engines, refrigerateitand then use ittocool the passengers and crew,as well as equipment,before dumping out in to the overboard.

Closed loop systems,as shown in Figure,collectthe air once ithas been used for cabin conditioning, refrigerate itand recycle it tobe usedagain. In this way bleed air is used only toprovide pressurization, a low venting air supply and sufficient flow to compensate for leaks in the closed loop system. This means that such a system uses considerably less engine bleed air than an open loop system ..



CoolingSystems

Therearetwomaintypesofrefrigerationsystemsinuse:

- Aircyclerefrigerationsystems
- Vaporcyclerefrigerationsystems

(a)AirCycleRefrigerationSystems

Air cycle refrigeration systems are used to cool engine bleed air down to temperatures required for cabin and equipment conditioning. Since engine bleed air is generally available, air cycle refrigeration is used because it is the simplest solution to the cooling problem, fulfilling both cooling and cabin pressurization requirements in an integrated system. This type is lighter and more compact.

TurbofanSystem

Thiswilltypicallybeusedinalow-speedcivilaircraftwhereramtemperatures will

never be very high as shown in figure below.

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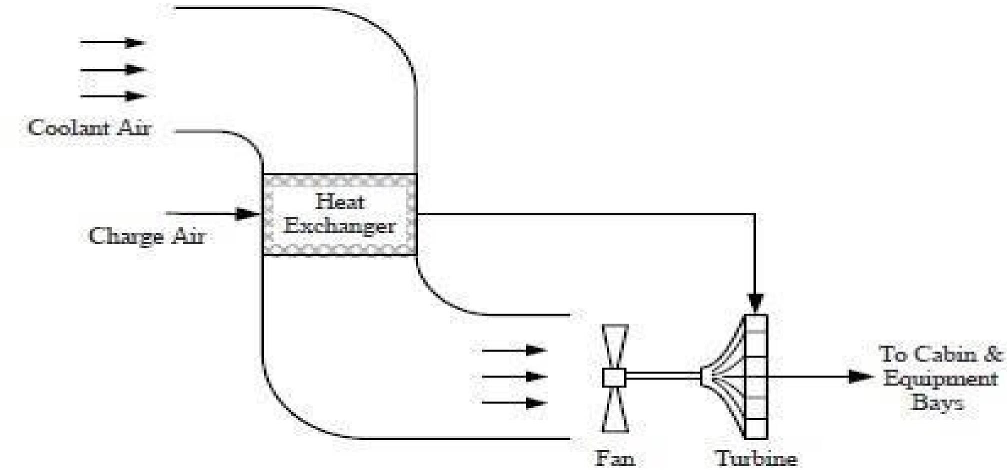

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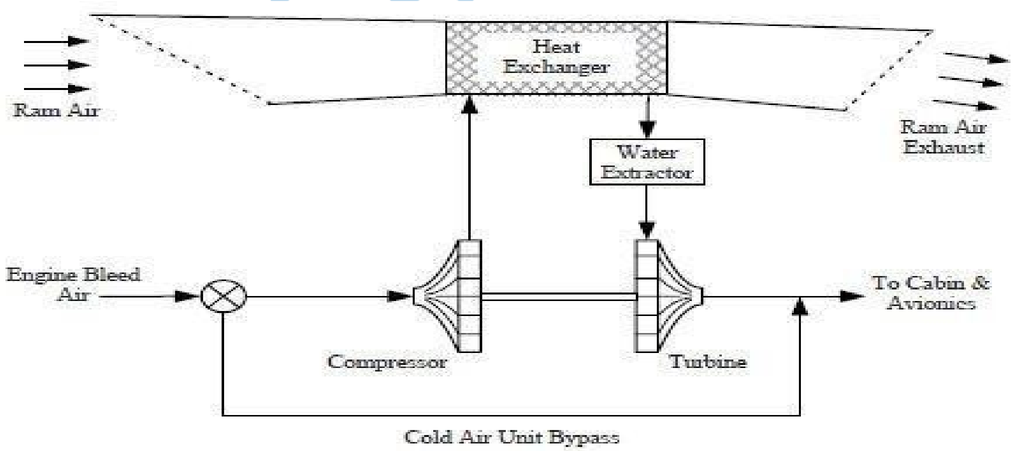
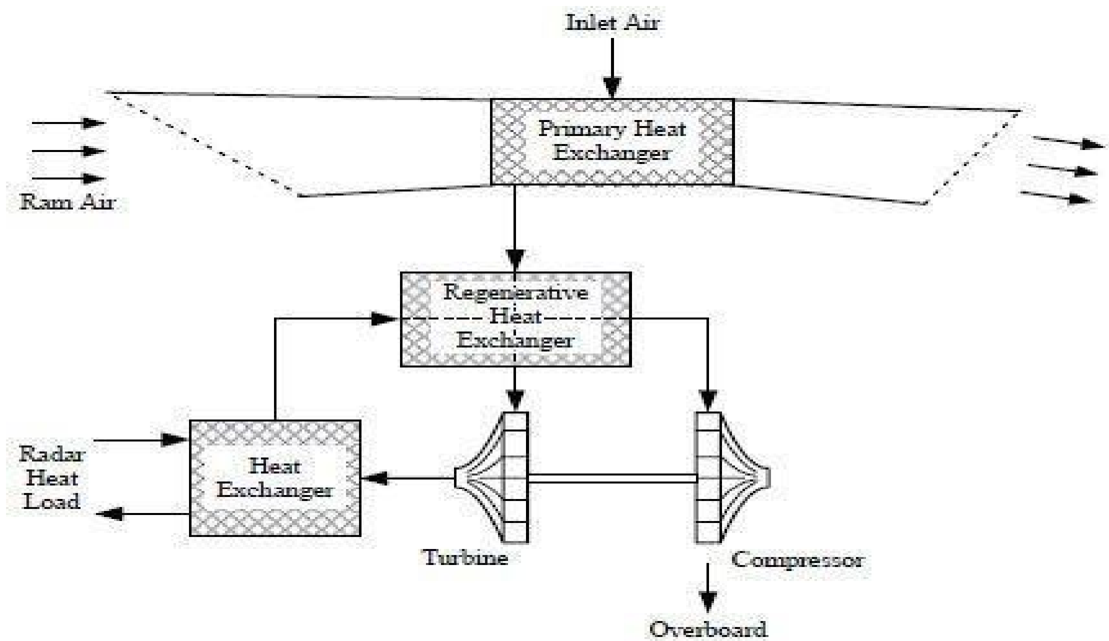
BootstrapRefrigerationSystem

Conventional bootstrap refrigeration is generally used to provide adequate cooling for high ram temperature conditions, for example a high performance fighter aircraft. The basic system consists of a **cold air unit** and a **heat exchanger** as shown in Figure .The turbine of the cold air unit drives a compressor. Both are mounted on a common shaft. Three-rotor cold air units or air cycle machines can be found on most recently designed large aircraft, incorporating a heat exchanger coolant fan on the same shaft as the compressor and turbine.



ReversedBootstrap

The reversed bootstrap system is so named because the charge air passesthrough the turbineof the cold air unit before the compressor. Following initial ram air cooling from a primary heat exchanger the air is cooled further in a regenerative heat exchanger and is then expanded across the turbine with a corresponding decrease in temperature. This air can then be used to cool an air or liquid closed-loop system, for radar transmitter cooling for example. The air then passes through the coolant sideoftheregenerativeheatexchangerbeforebeingcompressedbythecompressoranddumped overboard.



VaporCycle RefrigerationSystems

The vapor cycle system is a closed loop system where the heat load is absorbed by the evaporation of a liquid refrigerant such as Freon gas in an evaporator. The refrigerant then passes through a compressor with a corresponding increase in pressure and temperature, before being cooled inacondenserwhere theheat isrejected toa heat sink. Therefrigerantflowsback to theevaporator via an expansion valve as shown in the figure.

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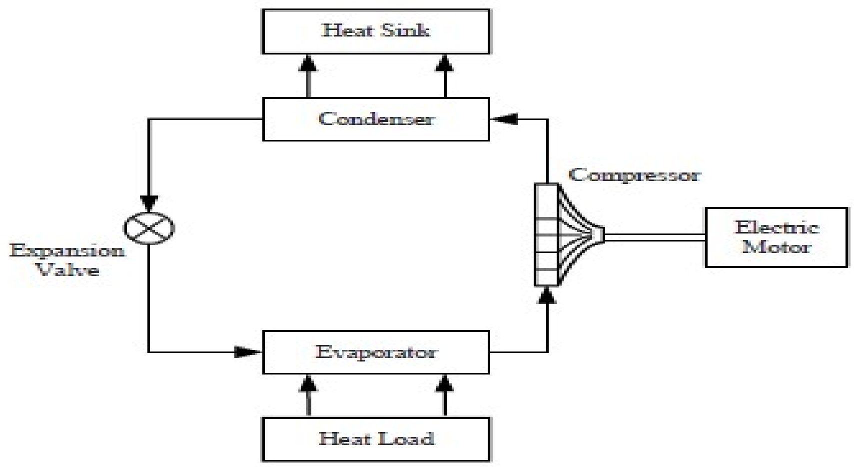

HumidityControl

Passengercomfortisachievednotonlybyovercomingtheproblemsofcoolingandcabin pressurization, but also by controlling humidity in the passenger

cabin. Without good humidity control this can result in a wet mist being supplied to thecabin. In addition to the aim of ensuring passenger comfort, humidity levels must be controlled to prevent damage to electrical and electronic equipment due to excessive condensation. Humidity control also reduces the need for windscreen and window de-misting and anti-misting systems. H***umidity is only a problem on the ground and at low altitudes, since the amount of moisture in the air decreases with increasing altitude***. Two types of water separator are in common use with air cycle refrigerationsystems:

a) Centrifugal device: In the centrifugal devices a turbine is commonly used to swirl the moist air. The relatively heavy water droplets are forced tothe sidesof a tube,where the water and a small amountof air is trapped and drained away, thus reducing the water content of the air downstream of a water separator.

b) Mechanical device: Which consists of a coalesce, a relief valve and a water collector, achieves the same result by forcing the moist air to flow through the coalescer where large droplets are formed and blown onto collector plates. The water runs down the plates and is then drained away The mechanical waterseparator,

AirDistributionSystems

Avionics Cooling: In civil aircraft the total avionics heat load is low when compared with the military aircraft. In civil aircraft it is often sufficient to draw cabin ambient air over the avionics equipmentracksusingfans.Thiswillhavetheeffectofincreasingtheoverallcabintemperaturebut,

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since the total avionics heat load is not massive, the environmental control system hassufficient capacity to maintain cabin temperatures at acceptable levels.

However, on a military aircraft with a high avionics heat load, only a few items of theavionicsequipment are located in the cabin. The majority are located in either conditioned or no conditioned equipment bays, an installation decision which is made by taking into consideration such criteria as the effect of temperature on equipment reliability or damage, and the amount of engine bleed available for air conditioning. Since the equipment can operate in ambient temperatures higher than humans can tolerate, the air used to condition it tends to be cabin exhaust air. There is usually very little space in equipment bays as they aretightly packed with equipment. There is little spaceleft for the installation of cooling air ducts. Therefore, the equipment racking and air distribution system must be carefully designed to ensure an even temperature distribution.

UnconditionedBays

Unconditioned bays may reach temperatures up to recovery temperature. However,air in these bays is not totally stagnant. The aircraft is usually designed to have a continuous venting flow through each equipment bay, only the pressure cabin is sealed. This ensures that there is no build up of differential pressure between bays, particularly during rapid climb and descent. The venting flow tends to be the conditioned bay outlet flow.

ConditionedBays

Equipmentcanbecooledbyavarietyofmethods,includingthefollowing;

• coolingbyconvectionairblownovertheoutsidewallsoftheequipment

boxes (external air wash)

• airblownthroughtheboxesandovertheprintedcircuitboards(directforcedair)

• Airblownthroughacoldwallheatexchangerinsidethebox(indirectforced air)

• FansinstalledintheboxtodrawasupplyofcoolingairfromtheboxSurroundings.

The first method of cooling is adequate for equipment with low heat loads. As the heat load increases it tends to become very inefficient, requiring a lot more cooling air than the other three methods to achieve the same degree of cooling. It is very difficult to design an avionics equipment box with a high heat load to enable the efficient dissipation of heat by convection via the box walls. Local ‘hot spots’ inside the box will lead to component unreliability. The other three methods of cooling are very much more efficient,butthe boxes musthave a good thermal design toensure precious conditioning air isnot wasted.

GroundCooling

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For aircraft with separate equipment bays fans are provided which are often located in the undercarriage bays. These are used to provide ambient cooling air flow for the avionics bays when the aircraftison the ground, and thereisonlyenoughbleedairflowfrom theenginesinthis casetoprovide cabinconditioning.

Thefanscanalsobeusedtocooltheequipmentiftheenvironmentalcontrolsystemfails.

CabinDistributionSystems

Cabin distribution systems on both civil and military aircraft are designed to provide as comfortable an environmentas possible. The aircrew and passenger's body temperature should be kept to acceptable levels without hot spots, cold spots or draughts. Civil aircraft are designed to maintain good comfort levels throughout the cabin since passengers are free to move about. On some aircraft each passenger has personal control of flow and direction of local air from an air vent above the head (often known as a 'punkah louvre'), although on modern large aircraft total air conditioning is provided. The personal air ventis no longer provided,partly because of the better performance of air conditioning systems, and also because the increased height of passenger cabins means that passengers areno longer able to reach the vent while seated. There are usually additional vents which blow air into the region of the passengers' feet so that there is no temperature gradient between the head and feet. Figure 7.21 shows an example of a Boeing B777 air conditioning pack and an illustration of the way in which air enters at the roof and

is extracted atfloor level in a typical cabin. Air flows predominantly down from the roof vents across the front of each passenger, and is extracted at floor level. A proportion of the exhaust air (up to 50%) is re-circulated by being first

CabinPressurization

Cabin pressurization is achieved by a cabin pressure control valve which is installed in the cabin wall to control cabin pressure to the required value depending on the aircraft altitude by regulating the flow of air from the cabin. For aircraft where oxygen is not used routinely, and where the crew and passengers are free to move around asin a long range passenger airliner, the cabin willbe pressurised so that a cabin altitude of about 8000 ft is never exceeded. This leads to a high differential pressure between the cabin and the external environment. Typically for an airliner cruising at 35 000 ft with a cabinaltitudeof 8000 ft there will beadifferentialpressureofabout 50 kpa (0.5atmosphere)across the cabin wall. The crew is able to select a desired cabin altitude from the cockpit and cabin pressurisation will begin when the aircraft reaches this altitude. This will be maintained until the maximumdesigncabin differential pressure is reached. This is also true for large military aircraft such as surveillance platforms or air-to-air refuelling tankers. For aircraft with the crew in fixed positions, using oxygen routinely as in a military aircraft, the pressurisation system is usually designed so that the cabin altitude does not exceed about 20 000 ft. Figure 7.22a showsa typical fighter aircraft automatic pressurisation

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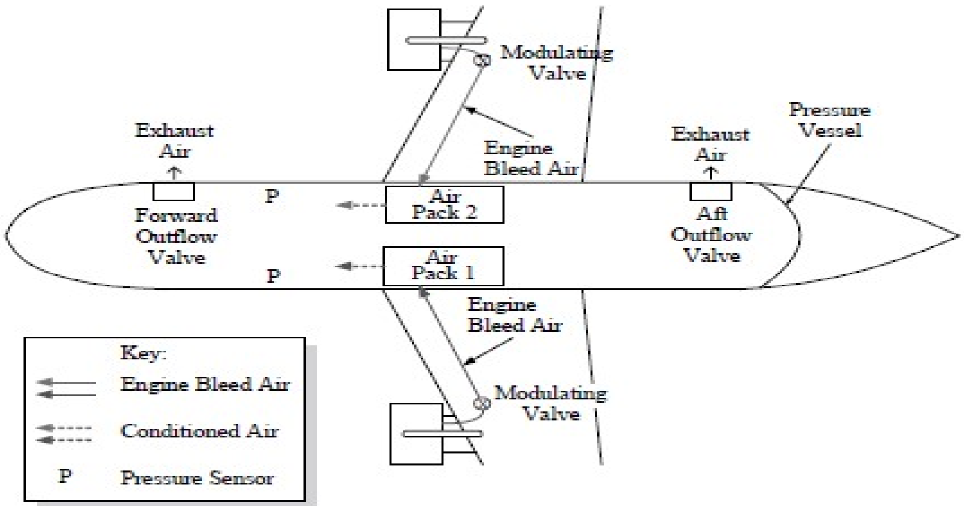
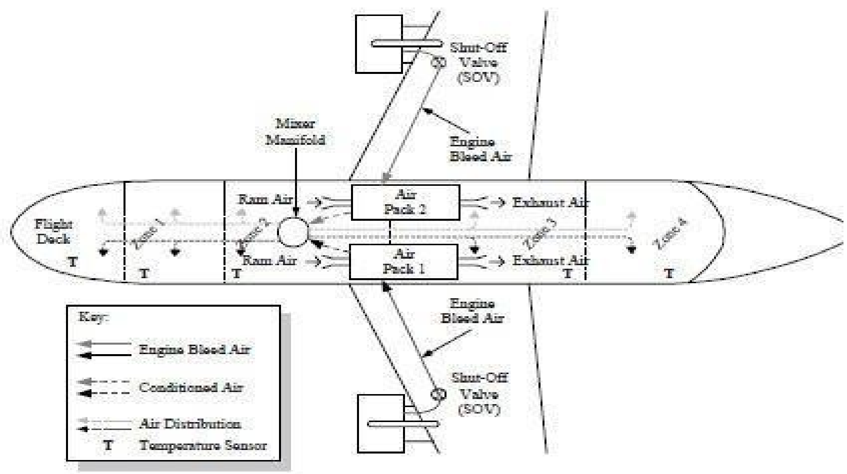
schedulewithtolerancesplottingCabinAltitude(y-axis)versusAircraftAltitude(x-axis).Thecabin pressurecontrol





MolecularSieveOxygenConcentrators

Until recently the only practical means of supplying oxygen during flight has been fromacylinder or a liquid oxygen bottle. This has several disadvantages, particularly for military aircraft.It limits sortie duration (fuel may not be the limiting factor if in-flight re-fuelling is used), the equipment is heavy and the Molecular Sieve Oxygen Concentrators (MSOC) are currently being developed for military applications. The MSOCs use air taken from the environmental control systems as their source of gas. Most of the gases in air have larger molecules than oxygen. These molecules are sieved out of the air mixture until mostly oxygen remains. This means that a continuous supply of oxygen can be made availablewithoutneedingtoreplenishthetraditionaloxygenstoragesystemaftereachflight.The

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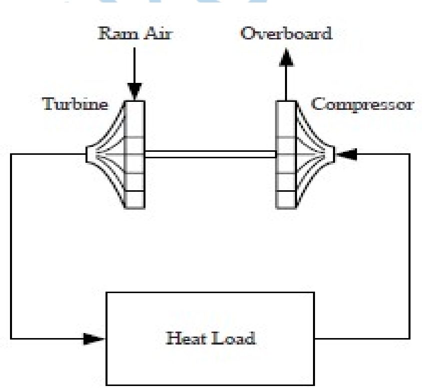
residual inert gases can be used for fuel tank pressurization and inerting. A system designed specifically forthe production of inertgasesisknownas On-Board InertGas GeneratingSystem(OBIGGS). However, MSOCs have a major disadvantage. If the environmental air supply from the engines stops then so does the supply of oxygen. Therefore, small backup oxygen systems are required for emergency situations to enable the pilot to descend to altitudes where oxygen levels are high enough for breathing. Developments of MSOCs are watched with interest, and further systems may be efficient enough to provide oxygen enriched air for civil aircraft cabins. In military aircraft which are typically designed to fly to altitudes in excess of 50 000 ft, both cabin pressurization and oxygen systems are employed to help alleviate the effects of hypoxia. In cases where aircrew are exposed to altitudes greater than 40 000 ft, either due to cabin de-pressurization or following escape from their aircraft, then additional protectionis required. In the event of cabin de-pressurization the pilot would normally initiate an emergency descent to a 'safe' altitude. However, short-term protection against the effects of high altitude is still required.

At altitudes up to 33 000 ft, the alveolar oxygen pressure can be increased up to its value at ground level by increasing the concentration of oxygen in the breathing gas. However, even when 100 per cent oxygen is breathed, the alveolar oxygen pressure begins to fall at altitudes above 33 000 ft. It is possible to overcome this problem by increasing the pressure in the lungs above the surrounding environmental pressure. This is called **positive pressure breathing**. At altitudes above 40 000 ft the rise in pressure in the lungs relative to the pressure external to the body seriously affects blood circulation roundthe body andmakesbreathingmore difficult. Partial pressure suitsaredesignedtoapply pressure to parts of the body to counter the problems of pressure breathingfor short durations above 40 000 ft.A partial pressure suit typically includes a pressure helmet and a bladder garment which covers the entire trunk and the upper part of the thighs. The pressure garments are inflated when required by air taken from the environmental control system and are used in conjunction with an inflatable bladder in anti-g trousers which are used primarily to increase the tolerance of the aircrew to the effects of g. Full pressure suits can be used to apply an increase in pressure over the entire surface of the body. This increases duration at altitude. For durations exceeding 10 minutes, however, other problems such as decompression sickness and the effects of exposure to the extremely low temperatures at altitude bottles need replenishing frequently.



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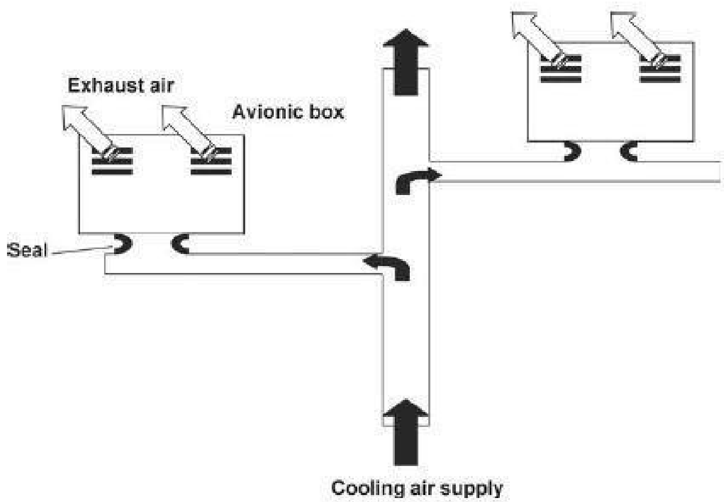

gTolerance

For aircraftwhich are likely to perform frequenthigh gmaneuvers such as Typhoon, a 'relaxed g protection' system is beneficial.

Thisconsistsof

- ***Increasedcoveragegtrousersand***
- ***pressurebreathingwithgandaltitudewhichrequiresabreathinggasregulator***
- ***mask capable of providing increased pressure gas, and a pressurized upper body garment to provide externalcounter pressure (a chest counter pressure garment).***

This enables the pilotto perform repeated high g maneuvers withoutthe need for g straining. It also provides altitude protection in the case of a cabin decompression in a manner similar to a full pressure suit. Engineers strive constantly to improve the agility and combat performance of military aircraft. Indeed technology is such that it is now man who is the limiting factor and not the machine. Accelerations occur whenever there is a change in velocity or a change in direction of a body at uniform velocity. For a centripetal acceleration, towards the centre of rotation, a resultant centrifugal force will act to make the body feel heavier than normal, as illustrated in Figure ..

Forcesdue to accelerationaremeasureding. 1 g is theaccelerationdue to gravity,i.e. 9.81m/s. Atypicalpilotiscapableof performingaircraftmaneuversupto 3 or 4g, i.e. until hefeelsabout threeor four times his normal body weight. At g levels above this the heart becomes unable to maintain an adequate supply of oxygenated blood to the brain, which will result in blackout. This is a very dangerous condition, particularly in low-flying aircraft. If the acceleration onset is gradual then the blood supply to the eyes is the first to reduce sufficiently to provide the symptoms of tunneling of vision,beforeblackout and loss ofconsciousnessoccurs.Anti-gtrousersare usedpartiallyto alleviate the effectsof

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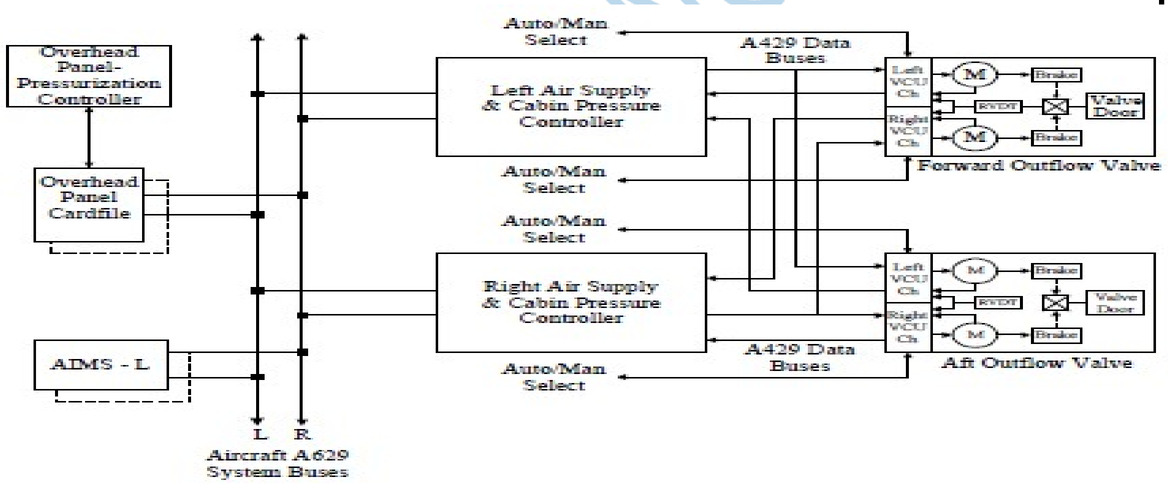
excessive g on the body. The trousers consist of inflatable air bladders retained beneath a non-stretch belt and leggings. The trousers are inflated using air from the

environmental control system.Inflation and deflationof the trousers is typically controlled by an inertial valve. The valve consists of a weight acting on a spring. At the onset of g, as the pilot is pushed down in his seat, the weight compresses the spring which acts to open the valve, thus allowing a supply of air to inflate the bladders in the trousers. The inflation action acts to restrict the flow of blood away from the brain. Using anti-g trousers a typical pilot can perform manoeuvres up to about 8 g. Positive pressure breathing also increases short term resistance to g. Another method of increasing g tolerance is to recline the pilot's seat. This increases the ability of the heart to provide an adequate supply of blood to the brain under high g conditions. However, in practice the seat can only be slightly reclined because of cockpit design problems, pilot visibility and the need to provide a safe ejection pathway to ensure injury free emergency exit from the cockpit.



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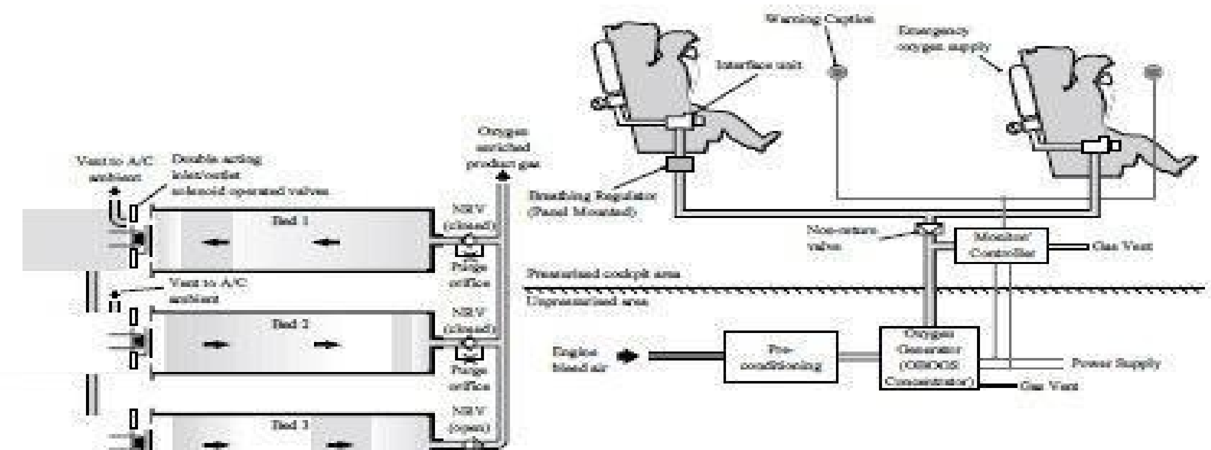


UNIT5-AIRCRAFT INSTRUMENTS

Flight Instruments

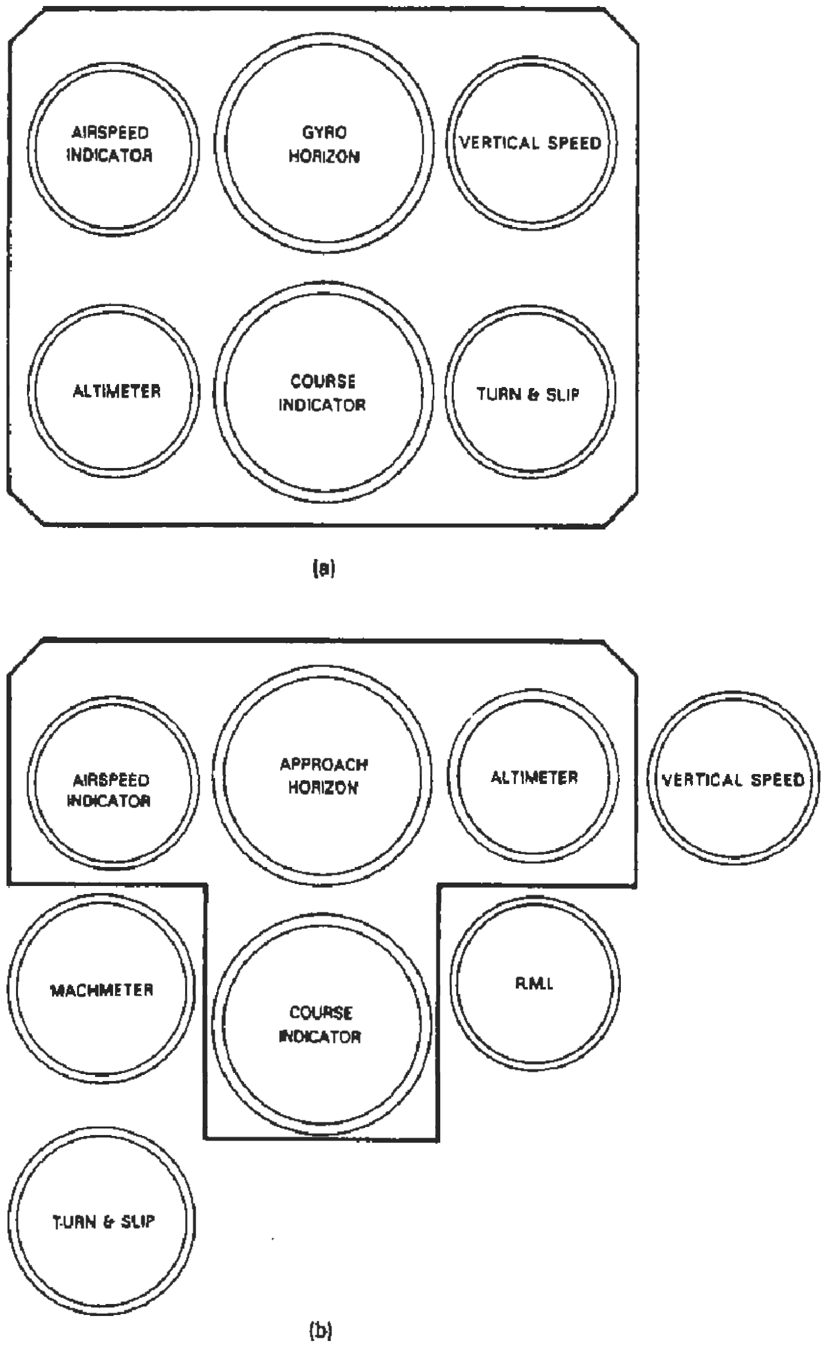
Basically there are six flight instruments whose indications are so co-ordinated as to create a 'picture' of an aircraft's flight condition and required control movements; they are, airspeed indicator, altimeter, gyro horizon, direction indicator, vertical speed indicator and turn-and-bank indicator. It is therefore most important for these instruments to be properly grouped to maintain co-ordination and to assist a pilot to observe them with the minimum of effort.

The first real attempt at establishing a standard method of grouping was the 'blind flying panel' or 'basic six' layout shown in Fig 3.18 (*a*). The gyro horizon occupies the top centre position, and since it provides positive and direct indications of attitude, and attitude changes in the pitching and rolling planes, it is utilized as the master instrument. As control of airspeed and altitude are directly related to attitude, the airspeed indicator, altimeter and vertical speed indicator flank the gyro horizon and support the interpretation of pitch attitude. Changes in direction are initiated by banking an aircraft, and the degree of heading change is obtained from the direction indicator; this instrument therefore supports the interpretation of roll attitude and is positioned directly below the gyro horizon. The turn-and-bank indicator serves as a secondary reference instrument for heading changes, so it too supports the interpretation of roll attitude.

With the development and introduction of new types of aircraft, flight instruments and integrated instrument systems, it became necessary to review the functions of certain instruments and their relative positions within the group. As a result a grouping known as the 'basic T' was introduced (Fig 3.18 (*b*)). The theory behind this method is that it constitutes a system by which various items of related flight information can be placed in certain standard locations in all instrument panels regardless of type or make of instrument used. In this manner, advantage can be taken of integrated instru ments which display more than one item of flight information.

It will be noted that there are now four 'key' instruments, airspeed indicator, pitch and roll attitude indicator, an altimeter forming the

Figure 3.18 Flight instrument grouping. (*a*) 'Basic six'; (*b*) 'basic T'.



horizontal bar of the 'T', and the direction indicator forming the vertical bar. As far as the positions flanking the direction indicator are concerned, they are taken by other but less specifically essential flight instruments, and there is a certain degree of freedom in the choice of function. From Fig 3.18 it can be seen, for example, that a Machmeter and a radio magnetic indicator can take precedence over a turn-and-bank indicator and a vertical-speed indicator.

Border lines are usually painted on the panel around the flight instrument groups. These are referred to as 'mental focus lines', their purpose being to assist pilots in focusing their attention on and mentally recording the position of instruments within the groups.

Navigation instruments

The need for integrating the functions and indications of certain flight and navigation instruments resulted in the main from the increasing number of specialized radio aids linking aircraft with ground stations. These were developed to meet the demands of safe en-route nagivation and to cope with increasing traffic congestion in the air space around the world's major airports.

The required information is processed by a multiplicity of 'black boxes' which can be stowed in electrical compartments and radio racks, but in order that the necessary precision flying may be executed, information must still be presented to the pilot. This requires more instruments and more instruments could mean more panel space. The method of easing the problem was to combine related instruments in the same case and to compound their indications so that a large proportion of intermediate mental processing on the part of the pilot could be bypassed and the indications more easily assimilated.

In some respects, integration of instruments is not new; for example, a combined pressure and temperature indicator was in use long before the present state of the art. Another early example and one of those around which most of today's fully integrated flight and navigation instrument systems have been built up is the *Radio Magnetic Indicator* (see page 196).

During that phase of a flight involving the approach to an airport runway, it is essential for a pilot to know, among other things, that he is maintaining the correct approach attitude. Such information can be obtained from the gyro horizon and from a special ILS indicator which responds to vertical and horizontal beam signals radiated by the transmitters of an *Instrument Landing System* located at the airport. It was therefore a logical step in the development of integration techniques in what are termed Flight Director Systems, to include the information from both the gyro horizon and ILS indicator. Furthermore, the RMI was developed to include the presentation of ILS information. The methods adopted for the integration of such information, and the manner in which it is presented vary between systems, but in basic form, they follow the pattern illustrated in Fig 15.1. A system normally comprises two

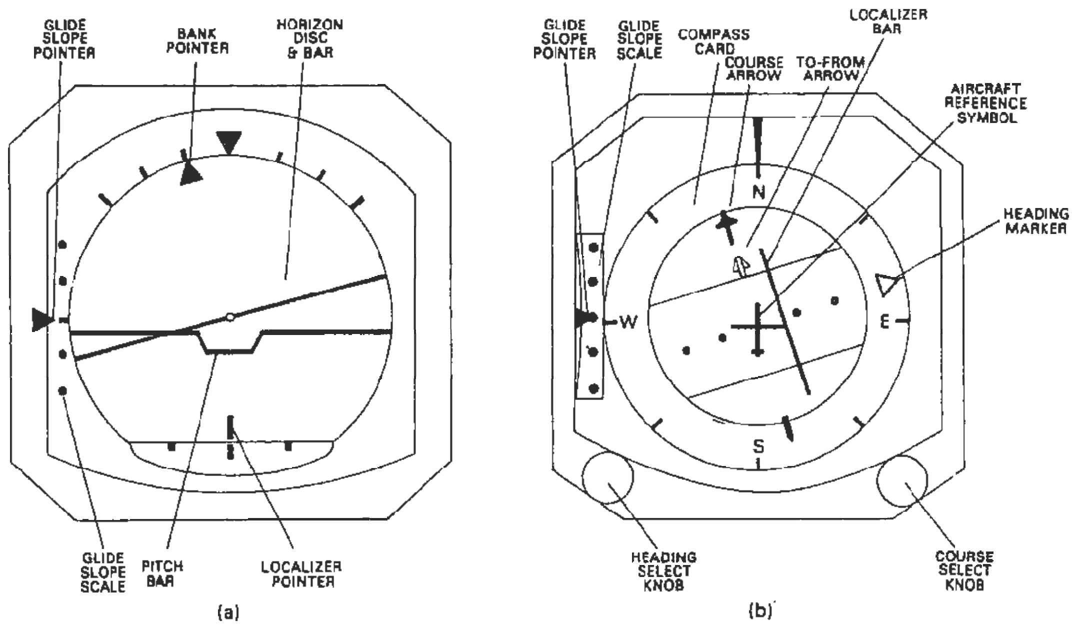


Figure 15.1 Basic presentations of flight director system indicators.

indicators: they are variously called (*a*) a flight director, an attitude flight director or an approach horizon, and (*b*) a course deviation indicator (CDI) or a horizontal situation indicator (HSI).

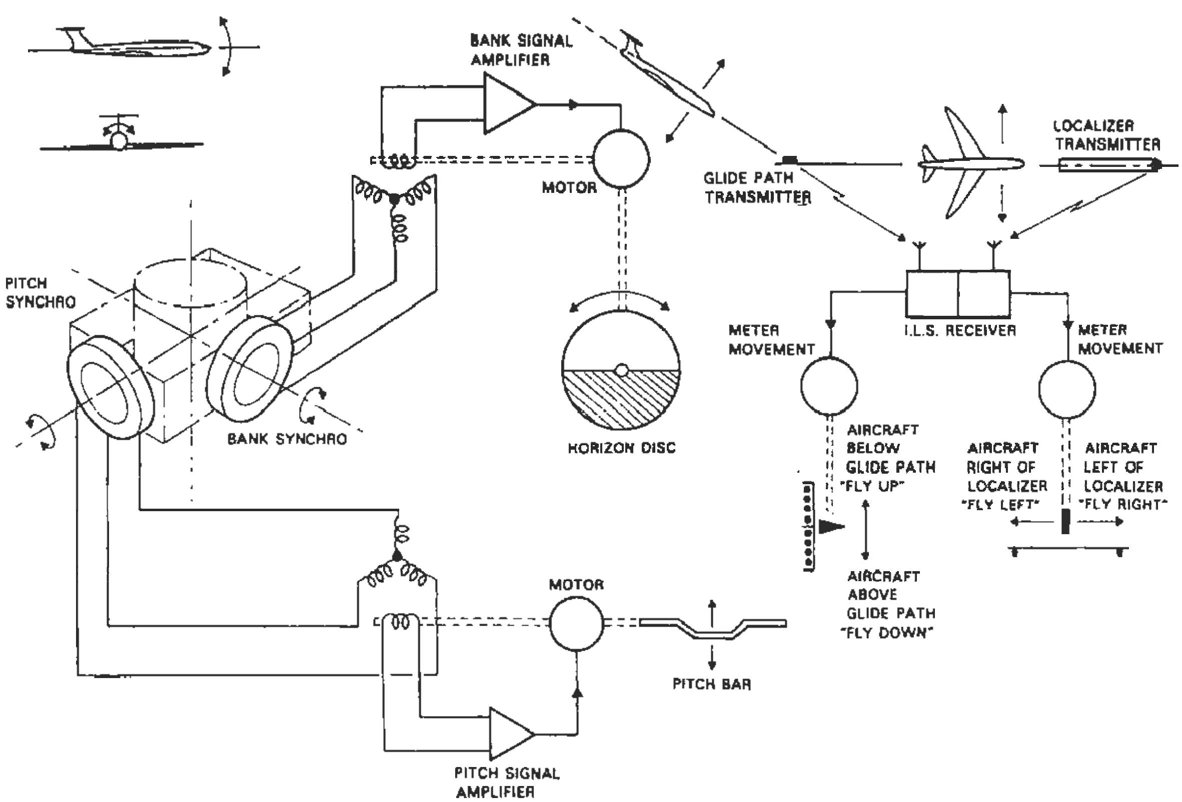
The flight director indicator has the appearance of a conventional gyro horizon, but unlike this instrument the pitch and roll indicating elements are electrically controlled from a remotely located vertical gyro unit. Furthermore, it employs a different method of referencing the elements. These features are common to all integrated instrument flight director systems. The horizon bar and roll scale are marked on the background disc which is monitored by roll command signals from the vertical gyroscope and rotates about the fore-and-aft axis. The pitch, or command bar, corresponds to the miniature aircraft symbol in a conventional gyro horizon, and is monitored by pitch command signals and moves in a vertical plane above and below the centre-line of the instrument.

The approach attitude of an aircraft with respect to its vertical-beam (glide-path) signals and horizontal-beam (localizer) signals is indicated by independent pointers monitored by the relevant ILS receiver channels. The glide slope pointer is referenced against a vertical scale and the pitch bar, and shows the displacement of the aircraft above or below the glide path. Displacement of the aircraft to the left or right of the localizer beam is indicated by deflections of the localizer pointer.

Electrical interconnection of the flight director indicator components primarily concerned with pitch and roll attitude information is shown in Fig 15.2. Whenever a change of aircraft attitude occurs, signals flow from pitch and roll synchros disposed about the relevant axes of the vertical gyroscope to the corresponding synchros within the indicator. Error signals are therefore induced in the rotors and after amplification are fed to the servomotors, which rotate to position the pitch bar and horizon disc to indicate the changing attitude of the aircraft. At the same time, the servomotors drive the synchro rotors to the 'null' position.

Figure 15.2 also shows the interconnection of the glide slope and localizer pointer with the ILS. During an ILS approach the receiver on board the aircraft detects the signals beamed from ground transmitters in vertical and horizontal planes. If the aircraft is above the glide path, signals are fed to the meter controlling the glide slope pointer causing it to be deflected downwards against the scale, thus directing the pilot to bring the aircraft down on to the glide path. An upward deflection of the pointer indicates flight below the glide path and therefore directs that the aircraft be brought up to the glide path. The pointer is also referenced against the pitch bar to indicate any pitch correction required to capture and hold the glide path. When this has been accomplished, the glide slope pointer and pitch bar are matched at the horizontal centre position.

Figure 15.2 Electrical interconnection of flight director indicator elements.



of flight either to or from a VOR station is indicated by an arrow-type element which is positioned by a meter. The course select and heading knobs permit the selection of a desired localizer or VOR radial, and desired magnetic heading respectively.

Description of a Representative System

The indicators of a Flight Director system which may be considered generally representative of those in current use are shown in Figs 15.4 and 15.5.

Flight Director Indicator

In the indicator illustrated, aircraft attitude and ILS information are presented in the form of a three-dimensional display. Attitude is displayed by the relationship of a stationary delta-shaped symbol representing the aircraft, with respect to bank and pitch commands displayed by two pointers, or command bars flanking the aircraft

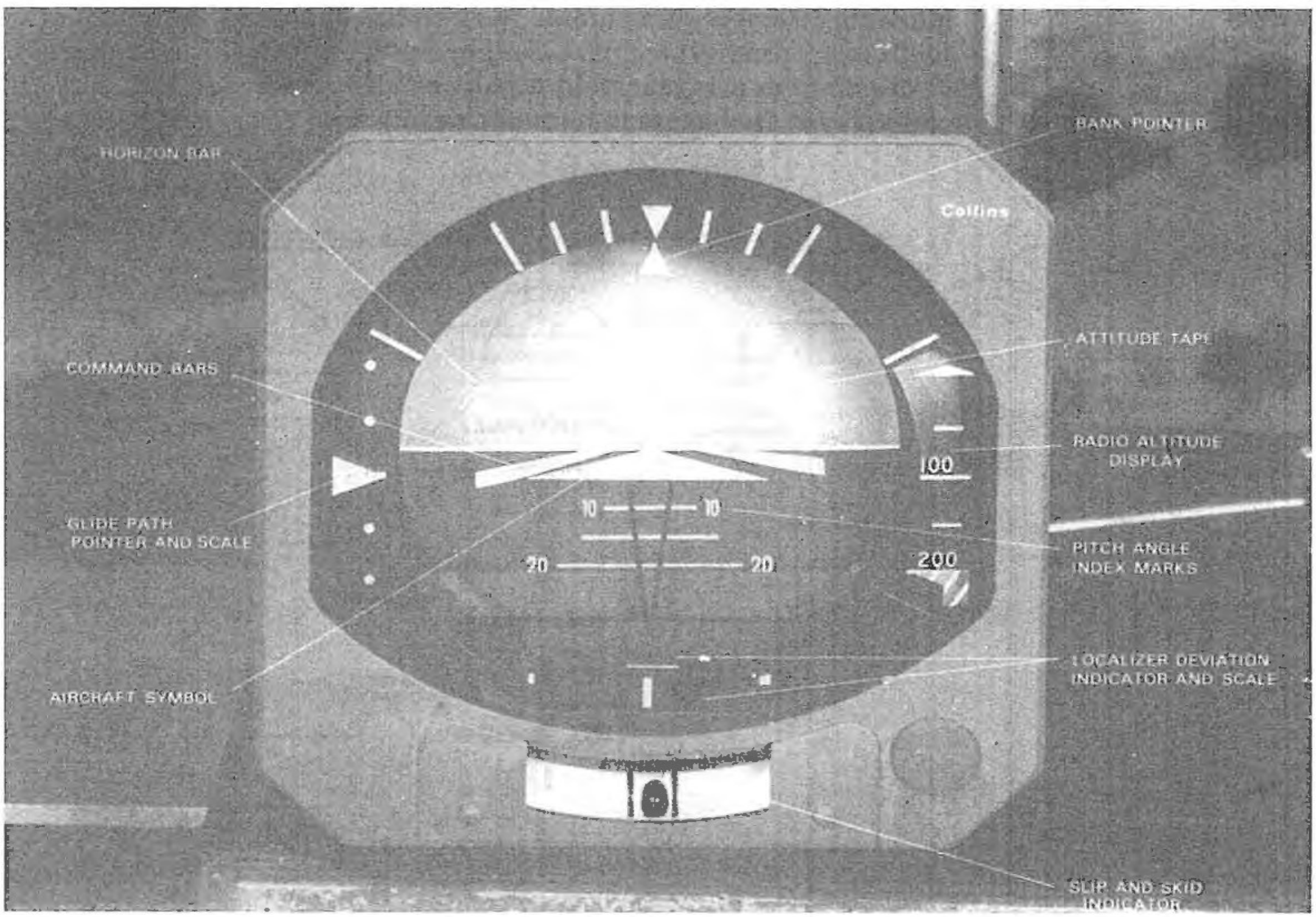


Figure 15.4 **Flight director indicator.**

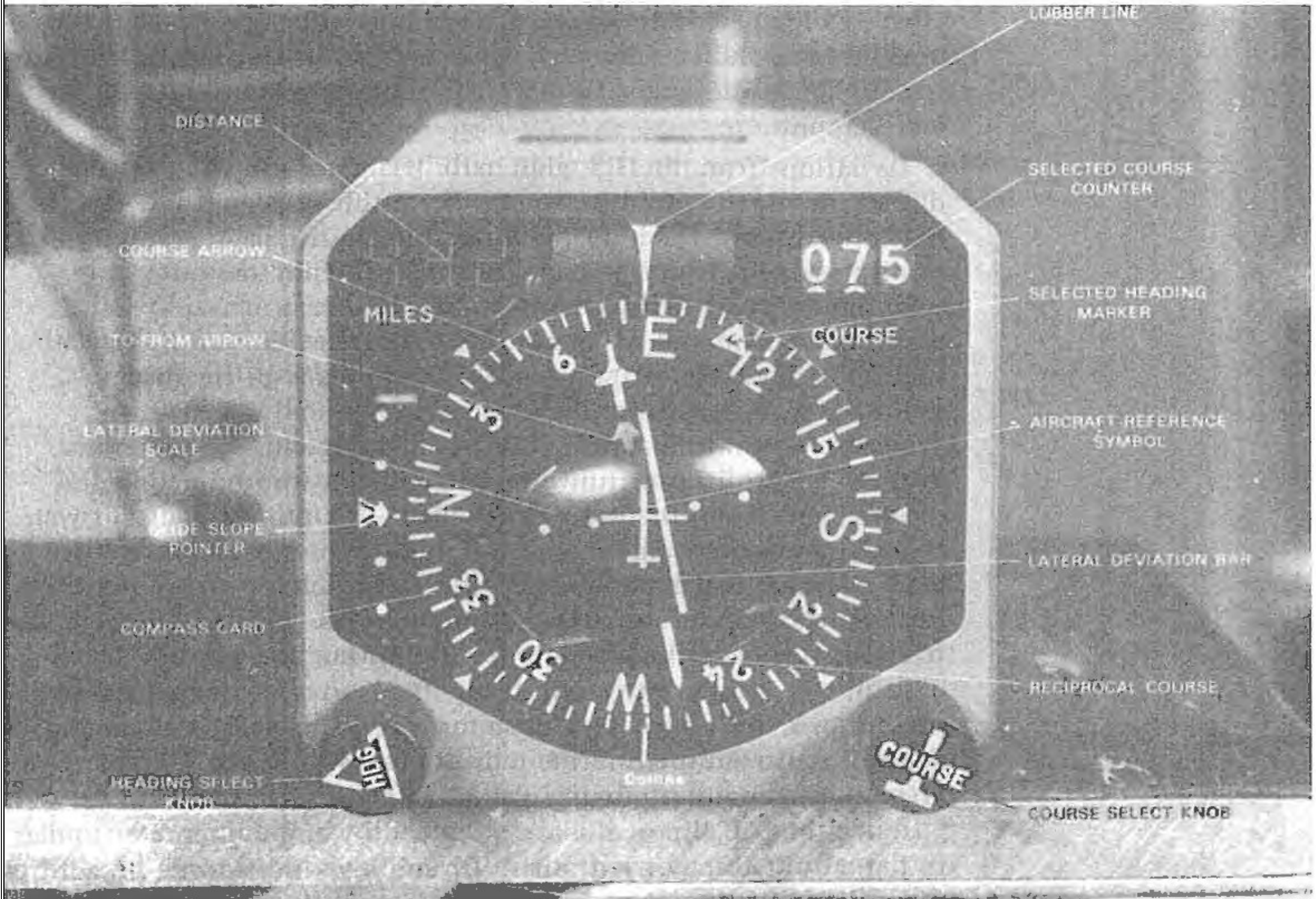


Figure 15.5 **Course deviation indicator.**

symbol and also by an horizon bar. The command bars form a shallow inverted 'V', and are driven by separate servomotors within the indicator such that they move up and down to command a change in pitch, and rotate clockwise and anticlockwise to command a change of bank attitude. The outputs of the two servos are combined mechanically so as to provide an integrated pitch and bank command. Sensing with respect to the aircraft symbol is such that the pilot is always directed to 'fly into the 'V''. When a command has been satisfied, the command bars are aligned with the edges of the aircraft symbol. The horizon bar is carried on a flexible tape which is also driven by separate pitch and roll servomotors within the indicator. Freedom of tape movement in pitch is ±90°, and 360° in roll. The upper and lower sections of the tape are coloured to represent the sky and ground respectively, and they also have index marks on them to indicate pitch angles. In some types of flight director, the lower section of the moving tape is also marked with lines converging on the centre of the indicator display thereby enhancing its 'forward view'

Accelerometers

The structure of an aircraft is designed to withstand certain stresses which may be imposed on it during flight, the magnitude of such stresses being dependent on the forces acting on the aircraft. All these forces may be resolved into components acting in the directions of the three mutually perpendicular axes of the aircraft, namely the longitudinal or roll axis, the lateral or pitch axis, and the vertical or yaw axis.

Force is the product of mass and acceleration, and since the mass of an aircraft may be considered constant, the forces acting on the aircraft in flight may be expressed in terms of the acceleration affecting it. During the manoeuvring of an aircraft, the largest changes in the accelerations to which it is subjected take place in the direction of the vertical axis. Consequently, the danger of exceeding allowable stresses and the possibility of failure of some part of the structure are greatest when excessive accelerations are applied through the vertical axis. Vertical components of acceleration are measured by ***accelerometers*** and ***fatigue meters***, either of which may be installed in an aircraft. They operate on the same basic principle, but whereas the accelerometer provides instantaneous indications of vertical acceleration, the fatigue meter is designed to count and record the number of times predetermined threshold values of vertical acceleration have been exceeded.

Basic Accelerometer Principle

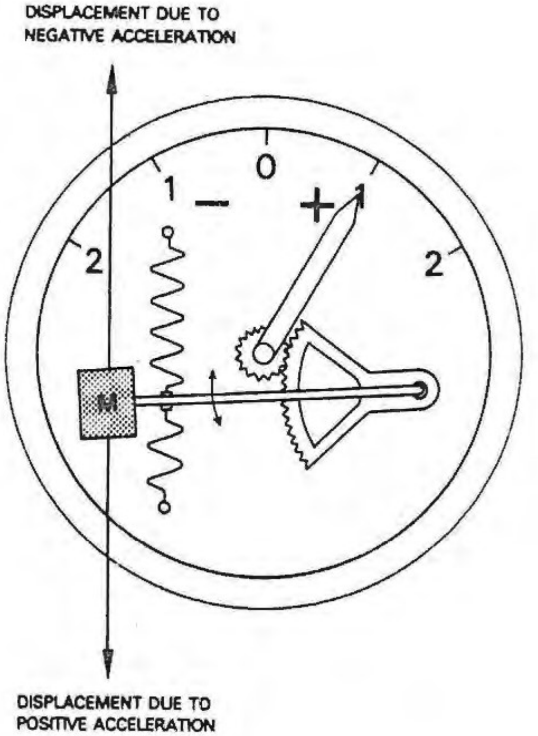
A basic mechanism is illustrated in Fig 16.1, from which it will be noted that the principal components are a mass and two calibrated springs tensioned to statically balance the weight of the mass. The position of the mechanism shown in the diagram is the one corresponding to normal straight and level flight.

In this condition, the force along the vertical axis is due to the aircraft's weight, and therefore the aircraft is subject to normal gravitational force, which produces an acceleration of $1g = 32$ ft/sec^2. Similarly, the force on the mass is due to its weight and so it too is subject to $1g$. The weight of the mass extends one spring and allows the other to contract. The pointer, which is actuated by the lever arm on which the weight is mounted, moves over a scale calibrated directly in g units, and for the level flight condition it is positioned at what may be termed the datum value of $1g$.

It will be noted from the diagram that the scale is calibrated in positive and negative values of g; these correspond respectively to upwards and downwards accelerations along the vertical axis. Thus, the load supported by the wings of an aircraft in any manoeuvre is the product of the aircraft's weight and the accelerometer indication.

Under vertical acceleration conditions brought about by manoeuvring of the aircraft, gusts or turbulent air, the mass will be displaced thus changing the tension of the springs until it balances the force

Figure 16.1 Basic accelerometer mechanism.

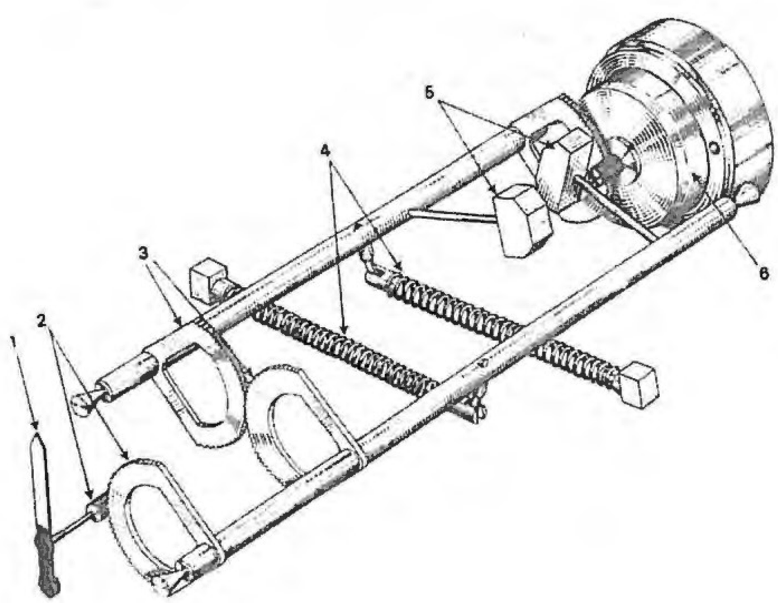


imposed and produces the corresponding change in indication. A positive acceleration moves the mass downwards and a negative acceleration moves it upwards.

The dial presentation and schematic arrangement of the mechanism of a typical accelerometer are shown in Fig 16.2.

The mechanism consists of two spring-controlled masses mounted on cantilever arms attached to two rocking shafts. A sector gear

Figure 16.2 Typical accelerometer. 1 Instantaneous *g* pointer, 2 pointer drive, 3 compensating gears, 4 control springs, 5 masses, 6 damping device.



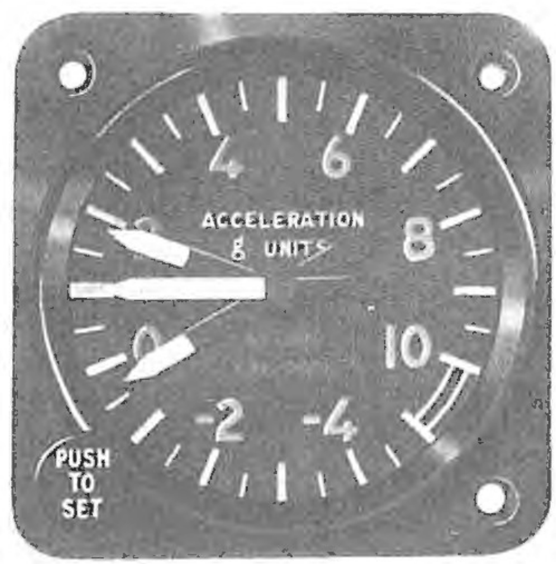


Figure 16.1 Basic accelerometer mechanism.

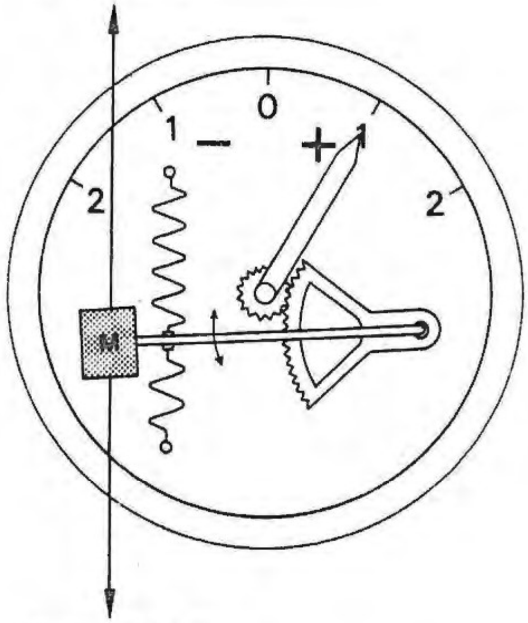


Figure 16.2 Typical accelerometer. 1 Instantaneous *g* pointer, 2 pointer drive, 3 compensating gears, 4 control springs, 5 masses, 6 damping device.

imposed and produces the corresponding change in indication. A positive acceleration moves the mass downwards and a negative acceleration moves it upwards.

The dial presentation and schematic arrangement of the mechanism of a typical accelerometer are shown in Fig 16.2.

The mechanism consists of two spring-controlled masses mounted on cantilever arms attached to two rocking shafts. A sector gear